Econometric Modelling of Infrastructure and Australia's Productivity

Internal Research Memorandum

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Preface

This Research Memorandum presents the results of econometric modelling of the relationship between infrastructure and productivity growth in Australia. The project was initiated as part of the stream of research on Australia's productivity performance in the Commission's supporting research program. It was an extension of the modelling exercise of Shanks and Zheng (2006), who undertook some preliminary analysis of infrastructure as part of their investigation of the effect of R&D capital on MFP.

The objective of this study was to improve on implausibly-large estimates of the productivity-enhancing effects of infrastructure found in previous studies. This study could take advantage of additional available data, improved infrastructure services measures and a wider range of estimation and testing procedures.

However, despite the advances in data and methods, the research was unable to generate robust results that were more credible. It represents a comprehensive demonstration that aggregate time series analysis still appears to have severe limitations for the examination of the infrastructure spillovers to productivity. The research has also identified some key modelling issues — such as incorporating spatial dimensions into more disaggregated analysis and incorporating utilisation/congestion — that may improve the quality of the results. The paper is being made available to assist other researchers in future work on this topic. However, Research Memoranda are internal working documents, designed to record the development and results of research conducted to support other activities of the Commission, and are not for quotation or citation without permission.

This paper was developed and written by Sid Shanks and Paula Barnes under the general direction of Dean Parham. Tony Kulys and Tracey Horsfall assisted in the preparation of the paper.

The Australian Bureau of Statistics provided vital assistance through the provision of unpublished data. In particular, Derek Burnell and Cedomir Pilipovic provided significant help with data. Helpful comments were received from Kevin Fox of the University of New South Wales, and Chris Sayers, Chris Chan and Jonathan Pincus of the Productivity Commission.

The views expressed in this paper are those of the authors and do not necessarily reflect those of the Productivity Commission.

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACCI	Australian Chamber of Commerce and Industry
ADF	Augmented Dicky-Fuller
AIC	Akaike’s information criterion
ANBERD	Analytical Business Enterprise Research and Development
ANZSIC	Australian and New Zealand Standard Industrial Classification
AR	autoregressive
ARDL	autoregressive distributed lag
ASIC	Australian Standard Industrial Classification
ASNA	Australian System of National Accounts
BLS	Bureau of Labor Statistics (US)
BRD	business research and development
BTE	Bureau of Transport Economics
CES	constant elasticity of substitution
CPI	consumer price index
CRS	constant returns to scale
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUSUM	cumulative sum
DOLS	Dynamic Ordinary Least Squares
DW	Durbin-Watson
ECM	Error Correction Method
ERA	effective rate of assistance
FMOLS	Fully Modified Ordinary Least Squares
GDP	gross domestic product
GFCF	gross fixed capital formation
GLS	Generalised Least Squares
GMM	generalised method of moments
GPC	government purpose classification

GRD	gross research and development
GST	Goods and Service Tax
GVA	gross value added
IC	Industry Commission
ICT	information and communication technology
IO	input-output
IPD	implicit price deflator
IT	information technology
ITT	information and telecommunications technology
IV	Instrumental Variables
JIT	just-in-time
lbcv	lower bound critical value
LP	labour productivity
LR	long run
MC	marginal cost
MFP	multifactor productivity
MP	marginal product
MR	marginal revenue
MRW	Mankiw, Romer and Weil
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
P&S	Pesaran and Shin
PC	Productivity Commission
PIM	perpetual inventory method
PKS	productive capital stock
QALI	quality-adjusted labour input
R&D	research and development
RBA	Reserve Bank of Australia
RIRS	restricted increasing returns to scale
SBC	Schwarz's Bayesian information criterion
SME	small and medium enterprises
SR	short run
SU	supply-use

TFP	total factor productivity
TVK	total vehicle kilometres
ubcv	upper bound critical value
USPTO	US Patent and Trademark Office
VA	value added
VAR	vector autoregressive
VECM	Vector Error Correction Model

1 Introduction and summary

Infrastructure is provided in many forms, including transport and communications networks, energy generation and distribution networks, and education and health systems. Infrastructure can raise productivity in the economy if the infrastructure industries provide their services more efficiently and if the provision of infrastructure services enables using firms and industries to improve their productivity. This paper is about the extent to which provision of selected forms of infrastructure lifts productivity performance in the Australian economy.

1.1 Background

Interest in the role of infrastructure in enabling growth in output and productivity is long-standing. For example, achievement of threshold levels of infrastructure is often seen in the development economics literature as a precursor to industrial development and economic growth in low-income countries.

Ownership of infrastructure assets is often in public hands. This can reflect historical constraints on finance, when it was easier for governments to organise the funding for large-scale infrastructure projects. But governments also get directly involved as a way of dealing with the natural monopoly characteristics of infrastructure provision — large sunk costs in installing assets, but low marginal costs in provision of services. Putting aside decision errors that governments might make, public ownership is viewed as one way of attempting to ensure appropriate investment in assets (avoiding underinvestment or wasteful duplication) and appropriate pricing (reflective of costs and not market power).

Issues in the empirical investigation of links to productivity

Aschauer (1989a) invigorated interest in the relationship between public infrastructure and productivity — in high-income, developed economies — through his empirical work. He posited, based on the finding of a strong positive link between public infrastructure and private-sector productivity, that a rundown in public spending on infrastructure contributed to the slowdown in US productivity growth from the mid-1970s. Aschauer's work stimulated a stream of further work in a number of countries, including Australia. (The literature is reviewed in the next chapter and in appendix A).

The Aschauer-type work has raised a number of empirical issues and has attracted some contention. In particular, it is common to find effects on productivity that imply very high — implausibly high — returns on infrastructure assets. The returns are higher than what might be implied by project evaluations and suggest the question, 'If the returns are so high, why do they not induce further investments in infrastructure, which would drive returns down?'

There are other issues, which may or may not contribute to the finding of high returns. One is the scope of the public infrastructure assets included in the empirical analysis. In many of these studies, infrastructure is defined (usually by default because of data limitations) to cover a wide range of public assets including schools and hospitals. However, some public assets, such as roads, can be expected to have more effect on current productivity performance than others, such as schools.

A further issue relates to public ownership. The scope of infrastructure hinges on innate characteristics of the assets and not on public ownership. A number of infrastructure businesses and attendant assets have been privatised and their operations have been subjected to government regulation. It is possible that privately-provided infrastructure services could still lift productivity performance in other industries through spillover benefits. (There has been empirical investigation of the effects of certain types of infrastructure assets, irrespective of ownership, and productivity — see next chapter.)

Several further issues can be illustrated with reference to the Australian experience. Casual observation does not provide support for a link between infrastructure and productivity in Australia over the past few decades. Dowrick (2001) observed that Australian public investment declined rather than increased between the mid-1980s and late 1990s, making it unlikely that an increase in public infrastructure could explain Australia's productivity surge in the mid- to late-1990s (see figure 1.1). Similarly, there has been very substantial growth in public investment in the early to mid-2000s, when productivity growth has fallen.

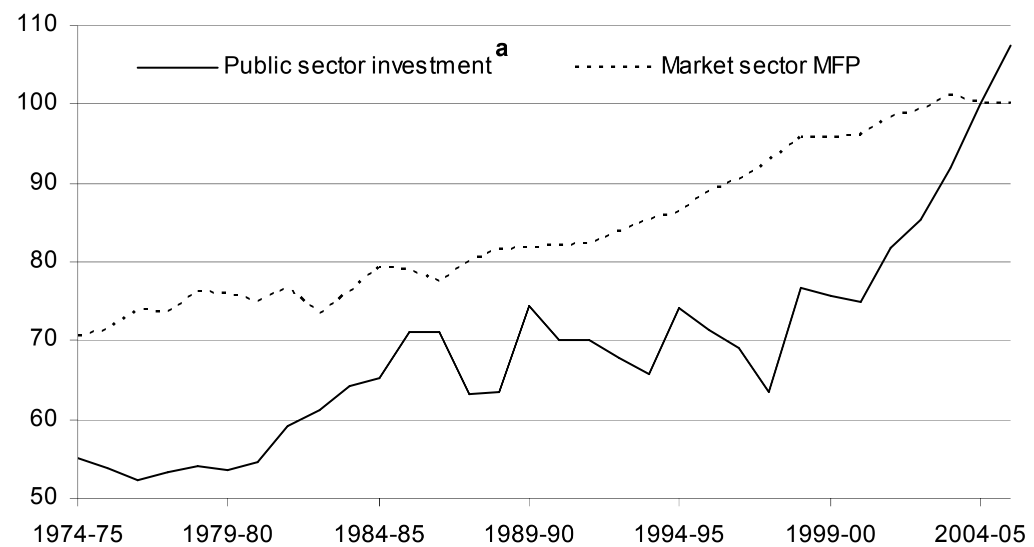
However, this evidence of a lack of positive correlation between infrastructure and productivity may not be as stark as it first seems. First, there are lags between expenditure and effect. Obviously, it is the stock of infrastructure assets, rather than the flow of investment, that matters. Even so, the translation of investment into the stock of (operational) assets may not be entirely smooth. Infrastructure assets are by nature large and may take a number of years of formation before they become fully operational. There may also be lags between the time that infrastructure becomes operational and when users are able to make use of the investments in productivity-enhancing ways.

Second, improvements in the efficiency of providing services could drive a distinction between spending on asset formation and the delivery of infrastructure services. Many of the government agencies that had a long history of providing infrastructure services in Australia were subjected to increased commercialisation and even privatisation through the 1980s and 1990s. Community service obligations were increasingly funded separately and explicitly by governments. Whilst growth in overall investment was more constrained, the allocation of investment was improved. It could be argued that the slowdown in growth in the provision of (effective) services was not as great as the slowdown in growth in spending.

Third, the bi-lateral comparison of infrastructure spending and productivity could be misleading because other factors at work during the 1990s and 2000s overshadow its positive relationship. This was Dowrick's (2001) point — not that there is no relationship between public infrastructure and productivity, but that the lack of positive correlation in the 1990s suggested that factors other than infrastructure spending account for the strong uplift in productivity growth over that period. (See Parham (2004) for a review of evidence on why productivity growth surged in the 1990s.)

Figure 1.1 **Real public sector investment and market sector multifactor productivity**

Index 2004-05 = 100



a Gross fixed capital formation of general government and public corporations (chain volume measure).

Data source: ABS (*Australian System of National Accounts, 2005-06*, Cat. no. 5204.0).

Finally, the links between infrastructure and productivity may be more apparent at a disaggregated level, in industry and spatial dimensions, than at an aggregated level. Parham (2004) noted that new infrastructure services or better utilisation of infrastructure may have provided spillover gains to particular Australian industries, such as agriculture, mining and distribution, which have had substantial productivity improvements. He suggested that improved communications and transport infrastructure may have facilitated geographic rationalisation of activity, reductions in transactions and coordination costs and improved the dissemination of knowledge and information.

1.2 Objectives and scope of the paper

There were two principal motivations for this project. The first was to analyse the role of infrastructure in Australia's productivity growth in the context of the Commission's ongoing program of research into factors that affect productivity performance. Even if infrastructure did not play a big role in the 1990s productivity surge, confirmation (or otherwise) of an underlying, long-term relationship would have policy relevance. The second motivation was to attempt to sort through the uncertainties of the above-mentioned empirical issues and to provide clearer and more credible estimates of the effects that infrastructure has on productivity.

Specific objectives of the paper are to:

- clarify — in at least qualitative fashion — the links between productivity and the provision of public and private infrastructure
- develop improved measures of infrastructure services for use in empirical analysis
- improve estimation of the effects of infrastructure on productivity by incorporating measurement and methodological enhancements into quantitative analysis.

Approach taken

The analytical approach in this study could be characterised, very broadly, as a modified and enhanced Aschauer framework. It is similar to the Aschauer framework in the sense that it is founded on time-series analysis of production relationships. However, while Aschauer-type studies have examined the effect of *publicly-provided* infrastructure on *private-sector* productivity, the analysis conducted in this study has taken a broader focus on the effect of economic infrastructure (publicly-owned, as a subset, but also the combination of publicly-and privately-owned infrastructure) on productivity generally (private- as well as public-sector activities within the market sector of the economy).

Although the analysis is broader in this sense, this approach actually narrows the scope of productivity gains that would enter the analysis (as explained below in section 1.3). It was considered that this approach may lead to more plausible estimates of the productivity returns to infrastructure provision.

Other features of the analysis, which depart from most other studies, are:

- improved measurement of infrastructure
  - the public infrastructure measure is confined to that which has more immediate effect on current production (economic infrastructure and not social infrastructure such as schools and hospitals)
  - measurement of the capital service flows from productive stocks of infrastructure assets (rather than wealth-based measures)
- investigation of different types of economic infrastructure
  - analysis of (public) roads and (public plus private) communications infrastructure
- investigation of lagged effects
- inclusion of control variables to quarantine the effect of other influences on productivity from the analysis of infrastructure and its effects
- investigation of effects at both aggregate and industry levels
- the use of a wide range of estimation techniques (including ones better suited to the characteristics of the data) and statistical tests to investigate thoroughly the relationship between infrastructure and productivity.

The expectation was that these numerous and substantial enhancements to the model specification, variable definitions and estimation methods would lead to more precise, credible and robust results.

That said, the implementation was also pragmatic. A limited number of observations available presented estimation challenges. Relationships, controls and lags could not be investigated as thoroughly or precisely as would have been preferred.

One specific example of pragmatism was to introduce independently-estimated observations of multifactor productivity (MFP) from ABS national accounts sources as the dependent variable to be explained. This had an advantage of conserving degrees of freedom, compared with estimation of a fully-specified production function. Consequently, the exercise can also be characterised as an attempt to explain the variation in the ABS estimates of MFP or, more specifically, as an attempt to test the influence of various infrastructure variables on ABS estimates of MFP, taking account of a number of other possible influences.[1]

What is out of scope

The analysis does not take into account improvements in the efficiency of delivery of infrastructure services. There have been very substantial improvements in efficiency in infrastructure industries since the early 1980s (PC 2005) which, in combination with the relatively large size of the industries, have contributed directly to improvements in average productivity in the economy. This is in the same way that efficiency gains in, say, wholesaling have contributed to improvements in average productivity. These types of gains are not the focus of the analysis undertaken here. The focus here is on what effect the flow of infrastructure services (and not the efficiency with which they are delivered) has on the productivity performance of other parts of the economy. Whilst it is also true that the effective flow of infrastructure services (for a given level of investment) will have improved as a result of better allocation of investment, this is not taken into account.

The analysis does not directly address the issue of the adequacy of infrastructure — an issue that has been prominent in recent years, with claims that infrastructure bottlenecks have constrained the ability of export industries to get increased product transported to booming overseas markets.[2] To the extent that producers have constrained production, because it cannot be physically delivered to market, the opportunities for productivity growth in these industries may have also been constrained. Only very general impressions on the adequacy of infrastructure can be drawn from this analysis. As indicated above, if high (and credible) returns to infrastructure were found, it would imply that further investment would in a general sense be worthwhile.

1.3 What the paper does and says

The next chapter outlines the nature of the links between infrastructure and productivity and reviews the empirical literature on how the links have been investigated and what has been found. The literature has focused on two mechanisms by which infrastructure can lead to productivity gains.

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[1] In fact the analysis is a carry-over from the modelling exercise of Shanks and Zheng (2006), who investigated the effect of R&D capital on MFP.

[2] See the Export and Infrastructure Taskforce (2005) for an investigation of this issue.

- A '*free input'* effect, which is the subject of Aschauer-type analysis. This is the effect on private-sector productivity that arises from the provision of public infrastructure at no charge to users. Where private producers use public infrastructure at no (or subsidised) cost, their measured productivity is enhanced.[3] By extension, provision of more free infrastructure can lead to more private-sector productivity gains.
- A *'production spillover'* effect. This is an improvement in productivity (which can be in the public sector, as well as the private sector) that arises because users of infrastructure are able to reorganise their production, access inputs or produce more or new products.[4] These spillovers can occur irrespective of public or private ownership of infrastructure assets. 'Network' effects from transport or communications infrastructure that enable producers to extent their markets and better coordinate their activities are examples.

Both these effects are spillovers, where a spillover is defined to be a benefit that is generated by a user of a good or service that is not offset by a charge to the user for the good or service. For convenience, however, they will be referred to respectively as 'the free input effect' and as 'production spillovers' in the rest of this paper.

Chapter 3 discusses the definitions and measurement of infrastructure variables, which are pivotal in determining the nature and interpretation of productivity gains captured in the quantitative analysis. The starting point is to analyse production and productivity in the market sector of the economy, as defined by the ABS. For productivity estimation purposes, the ABS includes public economic infrastructure in its capital input measures. Consequently, the use of public (economic) infrastructure is taken into full account in productivity measures and no 'free input' effect arises at the market-sector level. The investigation of productivity effects in this study is therefore confined to production spillovers or 'excess' returns (those in addition to returns to cover costs).

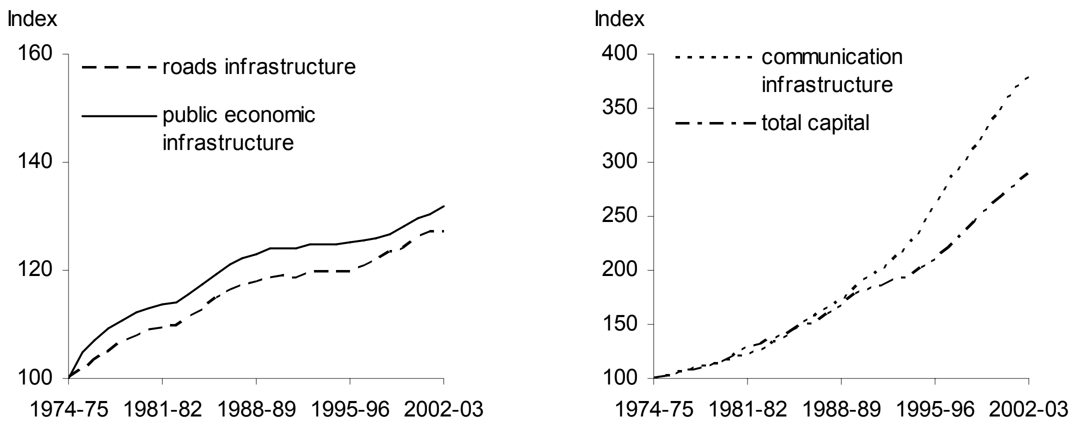
Three types of infrastructure are defined for the quantitative analysis — public (economic) infrastructure, the sub-category of public roads, and (both public and private) communications infrastructure. Both roads and, perhaps especially, communications infrastructure are considered to be potential sources of network spillovers — the additional gains to users that come from having more users join the network. The chapter describes the derivation of capital services measures for the

[3] Productivity is measured as the ratio of output to inputs. Irrespective of whether output is measured as gross output or value-added, provision of free infrastructure (which is not counted in the input measure) means producers are able to produce more measured output, without any increase in measured inputs.

[4] These spillovers can be clearly distinguished from free input effects as the benefit to users in excess of a market-determined user charge or an equivalent imputed charge.

infrastructure variables.[5] Figure 1.2 shows that communications infrastructure services have grown very rapidly, particularly from the mid-1990s, whereas there was a slowdown in growth in the two public infrastructure variables from the early 1990s.

Figure 1.2 **Trends in capital services from key infrastructure assets, market sector, 1974-75 to 2002-03**
Index 1974-75 = 100



Data source: Authors' estimates based on unpublished ABS data.

Allowance was also made for digitisation of the communications network, which increased the functionality of the network — allowing transmission of packets of data. Irrespective of whether users were fully charged for the additional functionality, network gains could have been enhanced.

While free input effects do not arise at the aggregate (market sector) level, they do arise in industry-level analysis. The ABS allocates types of public infrastructure to specific industries. Roads, for example, are allocated to the Transport & storage industry. For analytical purposes, other industries that use roads benefit from a free input effect.

Chapter 4 describes the framework for the quantitative analysis. As noted above, independently calculated ABS MFP indexes were regressed on a set of explanatory variables.

- Production spillovers from public infrastructure and communications infrastructure were investigated by re-entering these variables as explanators of productivity.

[5] Previous studies have used a net capital stock measure, based on asset values (in wealth terms). A capital services measure is based on a productive capital stock, where depreciation is measured in terms of loss of efficiency (due to physical wear and tear).

- The digitisation variable was included to allow for the additional functionality of the communication infrastructure.
- Other factors affecting productivity were included to reduce misspecification and omitted variable bias. These included education, R&D, scale effects and the business cycle.

The characteristics of the data influenced estimation methods. Co-integration analysis techniques based on bounds testing and Autoregressive Distributed Lag models were selected for the estimations — particularly because of the non-stationary characteristic of the data, lack of reliability of unit root tests, and the expected significance of dynamics.

Five criteria were established for selection of satisfactory model results:

1. evidence that the variables form a long-run co-integrating relationship
2. evidence that the direction of causation is in line with theoretical priors
3. other potentially important sources of growth are either controlled for or tested out of the regressions
4. acceptable statistical properties of models and coefficients
5. plausible economic magnitudes and signs.

However, the first criterion was difficult to apply strictly because of the small number of observations available for the modelling.

Despite all the methodological and measurement improvements, the results of the empirical analysis — presented in chapter 5 — remain somewhat unsatisfactory. There were some insights provided into factors affecting productivity. But, in general, models failed one or more of the acceptance criteria and, specifically, the estimated magnitudes of productivity returns to infrastructure remained generally high, if not implausible.

At the market sector level, the estimated effects of public economic infrastructure (and the sub-category of roads) on MFP are positive and large. But, while in line with the majority of other similar studies, these results are subject to the same concerns about implausible magnitudes. In most cases the industry models in this study did not pass the plausibility criteria and/or one or more of the statistical criteria.

A number of alternatives were therefore investigated at the market sector level — inclusion of scale effects, labour productivity models, differenced models and alternative infrastructure measures — but these did not produce smaller coefficients from acceptable models. Despite the improved infrastructure measures and the range of estimation and testing procedures employed in this study, there is enough contradictory evidence that there remains concerns that such large coefficients may in fact be spurious.

The estimated effects of communication infrastructure on MFP are positive and broadly in line with two similar studies. The results are also more plausible in size than those for road infrastructure in most cases. However, the effect of communication infrastructure is not estimated very precisely and the confidence interval around the estimates includes zero in many of the industry models. Alternative models suggest that MFP can be explained well without the inclusion of a spillover effect of communication infrastructure. Attempts to capture separately any effects of digitisation of the copper telecommunications network had mixed results. A separate digitisation effect could not be identified, but there is some evidence of a positive interaction between digitisation and IT capital.

1.4 Conclusions

Aggregate time series analysis still appears to have severe limitations for the examination of the infrastructure spillovers to productivity. The range of estimation and testing procedures and improved infrastructure measures employed in this study have not generated results that are more credible than the implausibly large results of other studies.

The extensive investigation has, however, identified some potential sources of estimation problems and key modelling issues for further examination.

- *Capacity utilisation and/or congestion*
  - There is relatively little variation in road capital services, making it difficult for statistical methods to identify relationships reliably. And changes in capacity utilisation or congestion of roads were not measured in this study (or previous Australian studies).
  - Incorporating capacity utilisation and congestion into the modelling of road infrastructure may remove bias from the estimates and assist in identification of a clear relationship.
- *Network threshold effects*
  - The elasticity of road infrastructure may have changed over time and there may be threshold effects.
  - Alternative modelling techniques that allow for this may produce more plausible results.

While the current analysis has been hampered by a number of factors (including limited degrees of freedom), it may also be true that alternatives to the aggregate time series approach are needed. One alternative approach that has been the subject of recent work is the use of spatial equilibrium models (see, for example, Haughwout 2002). Infrastructure can have localised benefits and network benefits. Localised infrastructure benefits may give rise to negative spillovers in other locations from which production and factors of production are drawn. But there may also be countervailing positive spillovers from network benefits of the infrastructure. A more disaggregated analysis, taking into account spatial dimensions, may make these links between infrastructure and productivity more apparent than in aggregate analysis. The extensive data requirements for such analysis, however, are likely to be a limiting factor.

Aggregate time series analysis has not provided evidence that is sufficiently clear to help guide formulation of specific policies (for example, an increase in spending on infrastructure of specific types would lead to increased productivity of a certain magnitude). This is not to say that infrastructure is not important to productivity or that increased spending will not increase productivity, just that the magnitude of the relationships remains unclear.

2 Links between infrastructure and growth

Infrastructure delivers joint products — input services to producers and final services to household consumers. However the way in which infrastructure affects producers is the focus of this paper. Producers rely on supporting infrastructure, such as transport, communications and power systems, to produce and distribute their goods and services. The services provided by this infrastructure enter directly and indirectly into the production process and therefore affect the productivity of producers.

This chapter examines the scope of infrastructure and the mechanisms by which infrastructure affects productivity. It also provides a brief overview of the empirical literature in this area.

2.1 What is infrastructure?

While the term infrastructure is commonly used, there is no universally accepted definition. The *Macmillan Dictionary of Modern Economics* defines it as:

> Those structural elements of an economy which facilitate the flow of goods and services between buyers and sellers. Examples of these structural elements are communications and transport (roads, railways, harbours, airports, telephones, etc), housing, sewerage, power systems etc. These facilities are usually, though not necessarily, provided by public authorities and may be regarded as a prerequisite for economic growth in an economy. (Pearce 1992, p. 206)

The *Essential Dictionary of Economics* provides a broader definition:

> Range of social capital assets or social overhead capital that make up the basic structural elements of an economy. Infrastructure includes assets such as sewerage, power system, dams, roads, ports, and communication facilities, as well as things such as health and education spending and the systems of regulation and supervision that allow any economy to operate. Infrastructure is necessary for development and growth to occur. It is often provided by governments but doesn't have to be, and many areas of infrastructure are currently being privatised. (Stanton and Launder 1998, p. 58)

Infrastructure is divided into a variety of sub-groups, depending on the issue of interest. One common division is between economic infrastructure and social infrastructure — economic infrastructure includes structures such as roads, railways, port facilities, power facilities and telecommunications networks, while social infrastructure includes facilities such as educational institutions, hospitals, justice facilities and community facilities. An alternative division common in the empirical literature is based on ownership — public infrastructure and private infrastructure — and particular infrastructure assets have moved between these groups over time with the privatisation of some government-owned infrastructure.[1]

The characteristics of infrastructure that have led to it being publicly-owned or, if in private ownership, subject to regulation, are that it may be a natural monopoly (or in less extreme cases, have a small numbers of viable producers) and it may have public good characteristics to some degree (see Otto and Voss 1995a for a detailed discussion).

- In the case of natural monopoly one firm can produce the required output at a lower cost than two or more firms. This arises from the 'lumpiness' of investment and economies of scale and is common in infrastructure industries where capital costs are large relative to variable costs.
- A public good is non-excludable (the producer is unable to prevent anyone from consuming it) and non-rival (one person's consumption does not reduce its availability to anyone else). While most infrastructure is not a pure public good, some infrastructure is a public good to some degree — for example, an uncongested urban road where the cost of toll collection is prohibitively expensive.

Economic infrastructure is often used to refer to a subset of infrastructure considered to be the element that is likely to contribute most directly to current growth and productivity.[2] And it is this type of infrastructure that is the primary focus of this paper. Reference is made to the ownership of economic infrastructure where relevant to the effect on productivity being discussed.

[1] Obviously these two groupings can be combined. For example, Aschauer (1989a), one of the early studies of public infrastructure, referred to economic infrastructure that is publicly owned as core infrastructure.

[2] This is not to suggest that social infrastructure has no effect. For example, education and health infrastructure may have long-term spillovers through the effect on the human capital of the labour force.

2.2 How infrastructure affects productivity

The *provision* of infrastructure services is a large part of economic activity. The efficiency of the provision of these infrastructure services therefore directly influences the overall productivity of the economy.[3] (See PC 2005, 2006a for a discussion of the efficiency of infrastructure provision.) And as noted above, economies of scale are often associated with infrastructure services and this means that changes in capacity utilisation also affect productivity. For example, additional road use can involve few additional resources (up to the point where congestion sets in) thereby increasing the productivity of provision. However, it is the effects of the *use* of infrastructure services on the productivity of the using industries/sector that are the main focus of this paper.

Leaving the above issues aside, the theoretical and empirical literature on the link between infrastructure, output and productivity suggests that infrastructure can have three main effects.

1. Public infrastructure that is not subject to user charges is an unaccounted for direct input into production and therefore provides a benefit that *directly* affects private-sector output and productivity, if it is not counted as an input. This is often referred to as the 'free input effect'.
2. Public or private infrastructure can facilitate product or process innovations and therefore lead to benefits that *indirectly* affect private-sector output and productivity — it can, for example, be an enabler for innovation, allowing firms to do what they do now in a better way or to do new things.
3. Public or private infrastructure can also affect the productivity of other inputs — it can be a complement to or substitute for these other inputs and affect their productivity. This is often referred to as the 'factor bias effect'.[4]

The first two effects are positive *spillovers* to private production. Positive spillovers occur whenever a producer obtains a good or service that is in excess of any charge for the good or service. The first effect is a spillover because there is no charge for use of the infrastructure services, leaving the full gain to users. The second effect is

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[3] Another possible effect, not examined in this paper, is that the provision of infrastructure may affect the output mix of the economy. If the provision of infrastructure facilitates a shift in production towards particular sectors that have above- or below-average measured productivity this will affect aggregate productivity of the economy.

[4] These induced changes in input mix may not affect multifactor productivity but only partial productivity measures, such as capital productivity. However, it is worth noting that any economically-efficient investment in infrastructure will, in itself, raise multifactor productivity; and excessive investment will lower it.

a spillover because, even if there were a charge, a market-determined charge would not be able to capture all the benefits that users generate.[5]

Freely-provided public infrastructure gives rise to the direct 'free' input effect and can also indirectly give rise to other production spillovers. Dowrick (1994, p. 16) states that by definition the benefits gained by private producers from the stock of public capital are spillovers to the extent that the services of the public capital are not marketed. If charges are levied for the use public infrastructure, the 'free' input effect can still arise to the extent that services are subsidised by government funding. However, unless the user charge also fully captures the value of any indirect benefits from product or process innovations enabled by the infrastructure, there will still be some production spillover effect from the use of the infrastructure.[6]

In the case of privately-owned infrastructure services that are marketed, there is no direct effect from a free input into production. If charges are determined in competitive markets they will reflect the balance between supply costs and the value that users place on the service (at the margin).

But there may be other production spillovers from the use of infrastructure through enabled innovations. They are spillovers because the provider of these services cannot capture these benefits through market prices.

While both these spillover effects arise from a difference between the value of and any charge for the use of the infrastructure services, in this paper the first effect will be referred to as the *free input effect* (in line with the public infrastructure literature) and the second effect will be referred to as *production spillovers*. Examples of these two types of spillover are provided below.

The three mechanisms by which infrastructure affects productivity are not explicitly examined in much of the literature. Romp and de Haan (2005, p. 44) note that:

> This issue [of *how* public capital affects economic growth] has received only scant attention in the literature on the relationship between public capital spending and economic growth. As Holtz-Eakin and Lovely (1996, p. 106) note, "A somewhat surprising feature of this literature is the noticeable absence of formal economic models of the productivity effects of infrastructure."

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5 This is generally because property rights cannot be well defined and easily enforced.

6 Many of these spillovers arise from what are described by Carlaw and Lipsey (2001, p. 7) as technological complementarities — where the innovation actions of one set of agents create opportunities for a second set of agents to make other innovations that incorporate, or rely on in some way, the initial innovation. These spillovers are therefore less direct, than those from the direct use of an initial innovation that is freely available, and may not be captured by conventional measures of externalities.

Individual analyses tend not to examine the three effects separately, either theoretically or empirically. The first and third effects are commonly examined in the public infrastructure literature (see, for example, Aschauer 1989b, Lynde and Richmond 1992, Nadiri and Mamuneas 1994, Conrad and Seitz 1994, and Pereira 2001). This literature started as an investigation into what became known as the 'public capital hypothesis' — that investment in public capital had both a direct and indirect effect on national output. The direct (or productivity) effect arises from the provision of unpriced direct inputs to the production process. The indirect (or factor-bias) effect is asserted to arise from public capital making private capital more productive (because the two kinds of capital are complements in the production process).[7]

The empirical literature on public infrastructure often characterises the 'free' input effect as a spillover but generally does not distinguish it from any production spillovers. However, these production spillovers are the focus of a small number of studies of privately-owned communications infrastructure, where there is no 'free' input effect (see, for example, Nadiri and Nandi 2001, 2003).

The focus of this paper is on spillovers effects — the following sections examine the two types of spillover effects in more detail.

Infrastructure as a free input

Infrastructure services are a direct input into the firm's production. The direct effect on production and costs of a private firm will depend on whether the infrastructure is publicly or privately provided and whether there are user charges.

Public infrastructure, which is not subject to user charges, is an unaccounted for or 'free' direct input into production and therefore directly affects private-sector productivity. Nadiri and Mamuneas (1996, p. 67) describe the direct effect of public infrastructure on private sector productivity as follows.

> The direct effect arises from the assumption that the marginal product of public capital is positive, i.e., an increase in public capital services decreases private sector production costs. This in turn leads to an increase in private sector output.

[7] From a macroeconomic perspective, there may also be two offsetting effects. The initial increase in public investment may crowd out private investment. But the rise in public investment may eventually provide an incentive for additional private investment if the additional public investment raises the marginal product of private capital. The net long-run effect of an increase in public investment will depend on the relative magnitude of these two effects. (Otto and Voss 1995a, p. 185)

For example, if a new public highway provides a more direct route to market, allowing deliveries in less time, driver costs will be lower and there will be less wear and tear on the truck. This will lower the total unit cost of production, thereby increasing productivity.

Where charges are levied for the use of the infrastructure, the ‘free’ input effect is eliminated or, if the infrastructure services are subsidised by government funding, reduced. For example, prior to privatisation/corporatisation of the electricity and gas industries, cross-subsidies between different classes of users meant that there was a partially-free input effect for some users.

Infrastructure as a source of production spillovers

Infrastructure can also give rise to production spillovers in non-infrastructure industries, in addition to their role as a direct input into production. These production spillovers have been characterised as facilitating innovations (in products and processes) in other sectors.

- Gillen (2001, pp. 41–2) suggests an ‘enabling’ role — both for doing new things and for doing the same thing better.

  > Some analysts say that public infrastructure has a facilitating role. It allows existing firms not only to do better what they do now but also to do new things. … This thesis is that transportation serves as an enabler for growth and productivity by creating opportunities to do things better by improvement or wholesale change; just as important is the opportunity to do different things.

- Garrison and Souleyrette (1996, p. 8) suggest that transport and communications function as connecting technologies that enable interactions of other sectors and improvements in these connections may ‘energise’ innovations in other sectors.

Communications infrastructure is also said to have an additional specific type of spillover — network externalities. Roller and Waverman (2001, p. 911) note that:

> Clearly, telecommunications infrastructure is intrinsically different from other types of infrastructure: information highways are different from transportation highways. One seemingly important characteristic of telecommunications technologies, which is not present in other types of infrastructure, is *network externalities:* the more users, the more value is derived by those users.[8]

[8] Roller and Waverman (2001) note that network externalities of the kind present for telecommunications infrastructure are not present for transport infrastructure because of congestion. However, it could be argued that there are some circumstances where there may also be congestion in communications technology. For example, where the capacity of the network to provide broadband services is limited and an additional user results in decreasing quality of service to other users.

The exact nature of the spillovers varies by type of infrastructure — for example, they can affect transactions and coordination costs, geographic rationalisation and the dissemination of knowledge and information. And the effect of the spillover may also differ depending on the industry using the infrastructure — for example, spillover benefits from communications infrastructure may increase with the information intensity of an industry (Roller and Waverman 2001).

Examples of spillovers, by type of infrastructure, are provided below.

Transport infrastructure

Examples of the spillovers from transport infrastructure include the following.

- Improved transport infrastructure may provide *innovation opportunities*, such as new products. This can be by allowing access to larger markets or making new resources available (Garrison and Souleyrette 1996).
  - The market area of a firm is enlarged when transport costs decrease as a result of better transport infrastructure. This can also result in the benefits of increased competition, increased specialisation and economies of scale. (Garrison and Souleyrette 1996; Prud’homme 2002)
  - Better transport infrastructure may improve access to inputs. For example, better transport networks may expand labour market catchments. A larger effective size of labour market increases the probability of both workers and firms finding what they want and therefore decreases qualification mismatch. (Aschauer 1992; Prud’homme 2002)
- Improvements in transport (jointly with improvements in telecommunications) have been linked to beneficial changes in *industry relocation and concentration and just–in–time (JIT) processes* (see for example, Prud’homme 2002).
  - Better transportation networks allow a decrease in the number of distribution depots and production sites. (Aschauer 1992)
  - By decreasing the costs of relocation and increasing factor mobility, improved transport infrastructure may facilitate industrial agglomeration with its benefits of geographical proximity to other firms. These benefits include improved operational efficiency from information spillovers and access to common input pools. (Berechman 2002)
  - JIT production methods depend on reliable and timely delivery, which needs an efficient transport network (Aschauer 1992; Gillen 2001). For example, a new freight terminal may enable intermodality between truck and rail, which improves JIT production and decreases inventory costs to producers (Berechman 2002). A number of case studies have linked transportation and

economic productivity through enabling manufacturers to adopt JIT production. (Aschauer 1992 lists a number of examples)

- Better transport infrastructure may allow *other organisational changes*.
  - Improved transportation networks give staff more flexibility in their work arrangements, which may lead to increased labour productivity and hence lower costs. (Otto and Voss 1997, p. 147, as cited in BTE 1999)

Communications infrastructure

Antonelli (1993) suggests that improved telecommunications infrastructure is the basis for a range of innovations.

> The availability of an advanced telecommunications infrastructure is essential to provide universal, reliable, high–quality and low–cost advanced information and communications services upon which a full array of technological and organizational innovations such as flexible manufacturing systems, just–in–time management systems, distributed data networks, advanced services and intra and intercorporate information flows are based. … High levels of investment in advanced telecommunications are thus likely to spread major pecuniary and technical externalities to downstream sectors — users of telecommunications services — and to potential adopters of those technological and organizational innovations based upon advanced telecommunications services. (p. 389)

Specific examples of the spillovers from communications infrastructure include the following.

- Improvements in telecommunications infrastructure may facilitate *product innovation*.
  - Advances in telecommunications infrastructure, particularly through digital technology, have facilitated new communications services, such as computer-communication services. (Globerman 2001; Cronin et al. 1993)
- Better communications systems can increase the *diffusion of technology*.
  - Canning (1999, p. 1) states that "… communication systems may increase the rate of diffusion of technology, as a pure externality, raising output but without necessarily raising the demand for infrastructure use". Nadiri and Nandi (2003, p. 6) and Madden and Savage (1998) also refer to communications capital increasing productivity by increasing the diffusion of knowledge and technology.
  - Nadiri and Nandi (2001, p. 92) also highlight network effects. "Investment in the communications infrastructure also facilitates economic growth by increasing the size and efficiency of the network, which in turn enhances the

transfer of information and knowledge to all participants, thereby increasing the quality and number of economic activities."

- Improved communication systems may allow *access to new customers* (together with improved transport systems that allow delivery to those customers in a timely and efficient manner).
  - For example, Batina (2001, p. 114) notes "… the so-called 'e-commerce' by 'e-tailers', who make sales via the Internet, requires an infrastructure capable of handling a large volume of deliveries".
  - Madden and Coble-Neal (2002, p. 352) suggest the impact on traditional markets of the emergence of WWW and e-commerce is expansion of the geographic scope of markets, a decrease in their concentration and prices better matching costs.
  - Better information flows, facilitated by improved communications infrastructure, allow the integration of domestic and international markets and increased competition and market efficiency (Madden and Savage 2000, p. 895).
- Better communications infrastructure can *lower transactions costs* associated with buying inputs.
  - Better communication systems (including larger networks) can lower the costs to telecommunications-using sectors of ordering, gathering information and searching for goods and services (see, for example, Leff 1984, Nadiri and Nandi 2003, Madden and Savage 1998, and Globerman 2001).
  - Madden and Coble-Neal (2002) also suggest that non-search transactions costs can be decreased by e-commerce (for example, the widespread adoption of standardised electronic contracts can lower the average cost of contracting, especially for business to business transactions).[9]
- Improved communications infrastructure can provide the basis for a range of *other organisational changes*.
  - Improvements in telecommunications have combined with those in transport to enable beneficial changes in industry relocation and concentration and JIT processes (Prud'homme 2002). Better communication with customers (for example, through e-commerce) may also have a role in facilitating centralisation of distribution sites.

[9] Madden and Coble-Neal (2002) provide a detailed review and assessment of the potential linkages between e-commerce and the industrial organisation of backbone infrastructure, transmission and service markets.

– Improved information flows and decision-making may be facilitated by better communications systems.

  ... Better communications systems allow better diffusion of information within a firm and consequently better and more timely decision making. According to Nadiri and Nandi (2001), modernisation of the communications network has increased the efficiency of managers' communications, helped the coordination of independent units and increased the transfer of information and knowledge.

  ... Madden and Savage (2000, p. 895) suggest that "The ability of managers to communicate efficiently over large distances reduces X-inefficiency and expands the stock of entrepreneurial talent".

2.3 Empirical literature

The empirical literature on the effects of infrastructure on output and productivity growth has a number of streams — the approach taken depends on the particular issues of interest. Initially the literature was dominated by the examination of public infrastructure as a 'free' input. More recently this has been extended to include production spillovers from private infrastructure (particularly communications infrastructure).

These bodies of literature are examined in turn, followed by a discussion of the extent to which these empirical approaches measure the three types of effects discussed in the previous section.

Public infrastructure

A stream of empirical literature on the effects of public infrastructure on productivity growth commenced in the 1990s. It was stimulated by the work of Aschauer (1989a), which attempted to explain the slowdown in US productivity growth during the 1970s in terms of the decline in public infrastructure investment.

Aschauer used a Cobb-Douglas production function, including public capital as well as private capital, with aggregate time series data (see box 2.1 for details). He estimated the elasticity of total factor productivity (TFP) with respect to public infrastructure for the aggregate US economy to be between 0.2 and 0.4. The rate of return to public infrastructure implied by this was considered to be implausibly large by many researchers (see, for example, Munnell 1992; Gramlich 1994).

Box 2.1 **Seminal empirical studies**

The study commonly referred to as starting the stream of empirical research into the effects of public infrastructure on productivity is Aschauer (1989a). Aschauer was prompted to investigate this issue by the slowdown in US productivity growth in the 1970s.

Aschauer's analysis centres on aggregate production technology in which it is assumed that public infrastructure capital is one of the direct inputs to production:

$$Y = A F(K, L, G) \tag{2.1}$$

where *Y* is real aggregate output of the private sector, *A* is a measure of total factor productivity, *K* is the aggregate private non-residential capital stock, *L* is aggregate employment of labour services and *G* is the stock of public infrastructure capital (it is assumed that the flow of services is assumed to be proportional to the stock and there are no user fees).

He assumed a generalised Cobb-Douglas form for the production technology yielding (in logs):

$$y = a + \alpha k + \beta l + \gamma g \tag{2.2}$$

where the coefficients are the output elasticities with respect to the input variables.

The associated equation for the level of private sector productivity depends on the assumptions regarding returns to scale. Aschauer suggests there are opposing arguments on the issue of scale.

> The argument for possible economies of scale resting behind the public provision of a significant share of the inputs to private production suggests that a reasonable specification of the private technology would involve assuming that *f( )* exhibits constant returns to scale over the private inputs … but increasing returns over all inputs, inclusive of government services … On the other hand, it may be argued that congestion effects are severe enough so as to render the assumption of increasing returns inappropriate, at least in the relevant range. (pp. 180–1)

He derives expressions for both cases. For *restricted increasing returns to scale*, RIRS, (increasing over all inputs but constant over private inputs), the expression for private sector productivity (in logs) is

$$p = y - s_l l - s_k k = a + \gamma g \tag{2.3}$$

where s_i is input *i*'s share of total output and assuming private inputs are paid their marginal factor productivity.

For *constant returns to scale*, CRS, (constant across all inputs), the expression for private sector productivity (in logs) becomes

$$p = a + \gamma(g - i) \tag{2.4}$$

where $i_t = s_l l_t - s_k k_t$ and assuming private factor shares are proportionally related to their respective true marginal productivities.

(continued on next page)

Box 2.1 **(continued)**

Aschauer estimated a number of equations, allowing for different scale assumptions, with the most general equation being:

$$p_t = b_0 + b_1 t + b_2 g_t - b_3 i_t + b_4 cu_t + e_t \qquad (2.5)$$

where *t* is a time trend, *cu* is a business cycle variable and *e* is the error term. Rejection of the restriction $b_3 = 0$ is evidence against the restricted increasing returns to scale specification; rejection of the restriction $b_2 = -b_3$ is evidence against the constant returns to scale specification.

Aschauer examined the United States over the period 1949 to 1985. He could not reject the restriction of CRS and found that the elasticity of total factor productivity with respect to total net non-military public capital was between 0.34 and 0.39, depending on specification. He also disaggregated public infrastructure into different components which produced varying elasticities — core infrastructure (roads, mass transit facilities, airports, electricity, gas and water facilities) 0.24, other buildings (including police and fire stations, courthouses and office buildings) 0.04, hospitals 0.06, conservation and development 0.02 and educational buildings -0.01. (He noted that from the perspective of the production technology with CRS the coefficients on the separate components should not depart significantly from the coefficient for the aggregate stock and this was the case.) However, the estimated elasticity was significant only for core infrastructure.

The Aschauer approach was first applied to Australian data by Otto and Voss, with similar results. Otto and Voss (1994a) examined Australia over the period 1966-67 to 1989-90 using a broad definition of infrastructure — gross general government capital stock (non-dwelling construction and equipment). For the total private sector their estimates were 0.45 (RIRS) and 0.38 (CRS) and they favoured the RIRS specification. Their sectoral estimates ranged from -0.24 to 2.04 (RIRS) and -0.26 to 1.55 (CRS) but were considered by the authors to be generally poor.

Sources: Aschauer (1989a); Otto and Voss (1994a).

A number of similar studies followed, for example Munnell (1990b) (see appendix A for details). These tended to produce similar elasticity estimates at the aggregate level but estimates at the state or region level were smaller — in the range 0.04 to 0.20 (Paul 2003). The large variation in estimates led to criticisms of the Aschauer approach, including the appropriateness of the restrictive approach based on a Cobb-Douglas production function and the possibilities of spurious correlation, reverse causation[10], and the effects of omitted variables (with most studies not including 'control' variables).[11]

[10] The possibility of reverse causation means it is not clear that the estimated parameters can be interpreted as output or productivity elasticities.

[11] However, it has also been suggested that disaggregated studies are capturing fewer spillovers than national studies and this may explain the lower estimates (Eberts 1999).

There were two main responses to these criticisms in subsequent empirical work. One response was to introduce more flexible function forms into the production function approach. An alternative response was to use a cost function approach, which was based on flexible cost functions.[12] Many studies, from both approaches, continued to find a positive relationship but of a smaller magnitude than the Aschauer study. However, some studies found no significant relationship.

These two competing approaches have persisted. Each approach is briefly outlined below (further details are provided in appendix A).

Production function approach

The production function approach assumes that public infrastructure capital is one of the direct inputs to production and regresses time series data of output (or productivity) on the usual input variables plus the stock of public infrastructure.

The adjusted production function is

$$Y = A\,F(K, L, G) \tag{2.6}$$

where Y is private output, A is TFP (purged of the influence of public infrastructure), K is private capital stock, L is labour input and G is the stock of public infrastructure capital.

In its simplest functional form[13], this is estimated (in logs) as

$$y = a + \alpha k + \beta l + \gamma g \tag{2.7}$$

where the coefficients are the output elasticities with respect to the input variables.

Some studies go on to derive the associated equation for the level of private sector productivity. In its simplest form[14] it is

$$p \equiv a + \gamma g \tag{2.8}$$

where γ is the productivity elasticity with respect to public infrastructure.

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[12] A small number of studies have used a profit function. This approach is not discussed here but the results of these studies are included in appendix A.

[13] Translog production functions have also been estimated (in logs):

$$y = a + \alpha_1 k + \beta_1 l + \gamma_1 g + \alpha_2 k^2 + \beta_2 l^2 + \gamma_2 g^2 + \psi_{kl} kl + \psi_{kg} kg + \psi_{lg} lg$$

See, for example, Wylie (1996), Charlot and Schmitt (1999) and Canning and Bennathan (2000).

[14] The effect of scale is discussed in box 2.1 and appendix A.

In equations (2.7) and (2.8), other control variables, such as the business cycle and R&D capital, may also be included. However, most empirical studies focused on public infrastructure go no further than including a cycle variable.

In general, the empirical evidence using the production function approach suggests that infrastructure contributes significantly to growth in output and productivity. However, there is no consensus about the magnitude of the effect of public infrastructure on productivity. Indeed, Eberts (1999, p. 7) notes that "The conclusion most supported by the literature is that there is no definitive estimate of the effect of infrastructure in general and transport infrastructure more specifically on output." There is considerable variation in estimates of the magnitude of this contribution, in part because of differences in methodology and data.[15]

The results of Australian studies are presented in table 2.1. The estimates of the elasticity of aggregate output or productivity with respect to public infrastructure range from 0.01 to 0.45. The industry elasticity results range from -0.75 to 2.04. A selection of studies of other countries are presented in appendix A, with estimates ranging from below 0 to more than 1.

15 These differences include the definition of infrastructure, industry coverage, geographic coverage, modelling methodology and econometric techniques.

Table 2.1 **Results of main production function studies including public infrastructure, Australia**

Author	*Specification/ method*	*Infrastructure variable/ dependent variable*	*Period*	*Elasticity*
Australian single-country studies				
Otto and Voss (1992, 1994a)	Cobb-Douglas	general govt capital stock[a]; private sector productivity[d]	1966-67 to 1989-90	Agg: 0.38 to 0.45 Ind: -0.14 to 1.55 (CRS); -0.24 to 2.04 (RIRS)[f]
Otto and Voss (1993)	Cobb-Douglas	investment in road infrastructure; private sector TFP[d]	1966-67 to 1991-92	Agg: 0.27
IC (1995)	Cobb-Douglas (incl. range of control variables)	general govt capital stock; MFP	1976-77 to 1990-91	Ind: 0.16 to 0.28
Otto and Voss (1996)	Cobb-Douglas (co-integration analysis)	general govt plus public enterprises capital stock; private output[g]	1959:3 to 1992:2	0.17 long run (CRS)
Otto and Voss (1998)	Cobb-Douglas and constant elasticity of substitution (CES) (co-integration; instr. variables)	see Otto and Voss (1994); private output[g]	1959:3 to 1992:2	0.06–0.07[c]
Chand et al. (1998)	Neoclassical growth model	general govt capital stock; growth in MFP	1968-69 to 1994-95	Food, beverage & tobacco -0.75 and Textiles, clothing & footwear 0.84; Manufacturing panel -0.26 (insignif.)
Kam (2001)	Error Correction Method (ECM) model (stochastic growth model)	general govt and public enterprises; Labour productivity	1931 to 1991	0.10 long run (output)
Song (2002)	CES	general govt capital stock plus a congestion term; private output	1976:1 to 2001:2	0.27 to 0.38[e]
Connolly and Fox (2006)	Cobb-Douglas (incl. range of control variables)	general govt capital stock; MFP	1966 to 2002	Manufacturing 0.15 (CRS) Wholesale & retail trade 0.71 (CRS) Not signif. for Ag. & Mining
Shanks and Zheng (2006)	Cobb-Douglas (incl. range of control variables)	Capital services index for general govt infra. assets; MFP	1974-75 to 2002-03	Mkt sector: 0.23 Ind: 0.5 to 1.07

(continued on next page)

Table 2.1 **(continued)**

Author	*Specification/ method*	*Infrastructure variable/ dependent variable*	*Period*	*Elasticity*
Multiple-country studies that include Australia				
Ford and Poret (1991)	Cobb-Douglas (log differences)	narrow (capital stock of govt services producers) or broad (narrow + EGW equipment & structures + Transport & communication structures); TFP	1967 to 1987, 11 OECD	Australia: narrow 0.18–0.27 (insignif.) broad 0.22–0.37 (insignif.)
Pereira (2001)	Vector autoregressive/ ECM models	broad (as above); private output and labour productivity	1965 to 1990, 12 OECD[d]	Australia: elasticities with respect to public invest. 0.017 (LR output); 0.097 (LR labour prod. growth)
Milbourne, Otto and Voss (2001)	Cobb-Douglas (CRS) within a Mankiw, Romer and Weil structural model of economic growth	public investment (agg.; 6 disagg. sectors); output per capita	1960 to 1985, panel, 74 countries	Aggregate: 0.19–0.24 (output with respect to public invest.) transition model, depending on country set. Insignif. in other models.
Kamps (2006)	Cobb-Douglas (first differences)	general government net capital stock (adjusted for international comparability); output	1960 to 2001, 22 indiv. countries and panel	Australia: 0.270 (insignif.) OECD panel av.: 0.223 (signif.).
Khan and Luintel (2006)	MFP regressions (various methods)	stock of public physical capital; MFP	1980 to 2002, panel, 16 OECD	Australia: 0.008 (insignif.)
Colletaz and Hurlin (2006)	Cobb-Douglas (panel smooth threshold regression)	general government net capital stock; capital productivity	1965 to 2001, panel, 21 OECD	Australia: 0.136 (CRS); 0.267 (RIRS).

[a] Results at aggregate level for alternative measure of public capital (general government plus government trading enterprises) not reported, except to state that they did not change basic finding of positive relationship between public capital and productivity. [b] RIRS is restricted increasing returns to scale (constant over all inputs but increasing for public capital) was preferred specification. [c] Lower than 1996 because different method (that is, hypothesis of efficient capital provision acts as a restriction on parameter estimation). [d] Private output. Otto and Voss define this as consisting of those industries in which production is predominantly performed by private enterprises (Agriculture, Mining, Manufacturing, Wholesale and retail trade, Recreation and personal services) [e] Private output with respect to public capital 0.27 (ABS data) to 0.386 (TRYM data). Private output with respect to public capital output ratio 0.4–0.6. [f] -0.24 to 2.04 for RIRS, -0.26 to 1.55 for CRS (elasticity with respect to public/private capital ratio) but ranking of industries not the same between RIRS and CRS specifications. [g] Uses a different definition of private output and different capital stock estimates to Otto and Voss (1994a). Data is separated by institutional sector as collected by ABS (that is, public and private) rather than mainly private industries being selected are the private sector.

Cost function approach

The cost function approach measures the productivity effects of public infrastructure in terms of cost savings. A cost function with a flexible functional form, in which public infrastructure is included as a fixed unpaid factor of production, is estimated. This approach is less restrictive in terms of the technology and allows input prices a role in the decision making process of the firm.

The basic cost function is

$$C = (p_L, p_K, Y, G, t) \tag{2.9}$$

where p_is are the factor prices, Y is output, G is the stock of public capital and t is technology.

For empirical implementation, a flexible functional form, generally a translog function or a generalised Leontief function, is used (see, for example, Paul 2003). From this function the productivity effect (measured on the cost side) is the elasticity of cost with respect to public infrastructure $\partial \ln C / \partial \ln G$.[16]

From the cost function approach, it is also possible to examine how individual input demand is affected by changes in public infrastructure. The input demand elasticity of public capital is made up of the elasticity of that input's cost share with respect to public capital (measuring the bias in input use induced by public capital) and the productivity effect (measuring the neutral effect of public capital on input demand).

In general, the empirical evidence using the cost function approach suggests that infrastructure is cost saving overall at the aggregate economy level but results for complementarities between public infrastructure and other inputs are mixed (although for labour a substitution relationship is often found). Surveys of the literature suggest that cost function studies, in general, find a relatively smaller contribution of infrastructure to output growth than production function estimates[17] (see, for example, the survey by Gillen 2001) — although the results from cost functions still cover a large range. Also, more recent studies (both cost and production function), using more sophisticated functional forms and econometric techniques, tend to find smaller contributions from public infrastructure than earlier studies (OECD 2004). Otto and Voss (1995a, p.61) note that the estimates of very

[16] This is the dual measure to the output (primal) productivity effect of public capital, $\partial \ln Y / \partial \ln G$, where the relationship between these two effects is $\partial \ln Y / \partial \ln G = -(\partial \ln C / \partial \ln G)/(\partial \ln C / \partial \ln Y)$. The measures are equivalent only under constant returns to scale (Paul 2003, pp. 448–9).

[17] Compared after deriving the output equivalent from the cost dual. The output equivalent is, however, not reported in many studies.

high elasticities of private output with respect to public capital (such as in Aschauer 1989a and Otto and Voss 1994a) have not proved robust to more sophisticated analysis of the time series. OECD (2004, p. 80) states that, based on literature reviews, estimated results are largely dependent on econometric formulation.

The cost function approach appears to have been applied to Australian data in only two studies (see table 2.2). The estimates of the elasticity of cost with respect to public infrastructure at the aggregate level are -0.41 to -1.09. Only the second study (Paul 2003) includes sectoral analysis, with a range of estimates from -0.48 to -1.27.

These cost function results are not directly comparable with the production function results — but the output (primal) productivity effect of public capital can be calculated from the dual (cost) measure. Only Paul (2003) provides the output equivalent to his results — 1.19 for the aggregate and 0.67 to 1.27 for the sectoral analysis. Contrary to the trend in overseas studies, these results from the cost-function approach are actually higher than many of those using the production-function approach.

A selection of studies of other countries are presented in appendix A. For those cases where the cost elasticity was reported, the estimates range from -0.31 to 0.

Table 2.2 **Results of main cost function studies including public infrastructure, Australia**

	Description			*Direct effect*	*Indirect effects*	
Author	*Coverage*	*Specific-ation*	*Infrastructure variable*	*Cost elasticity*	*Labour demand elasticity*	*Capital demand elasticity*
Song (2002)	1968–2001 aggregate	translog cost shares	general govt capital stock	-0.413 to -0.367[c]	-0.78 to -0.98 (substitute)[a]	0.36 to 0.84 (compl.)[a]
Paul (2003)	1969–96 aggregate[b], industry	translog cost	general govt capital stock (agg; ind. estimates adjusted for usage)	agg: cost -1.09 (output 1.19) ind: cost -0.48 to -1.27 (output 0.67 to 1.27)	agg: -1.4 (substitute) ind: -0.56 to -1.74 (substitute)	agg: -0.5 (substitute) ind: -1.22 to 0.83 (sub./compl.)

[a] Restricted estimates of the cost function model (imposing price homogeneity, constant returns to scale over three inputs and symmetry). Test statistics indicate restriction of CRS is valid. [b] Private output. Follows the Otto and Voss (1994a) definition of those industries in which production is predominantly performed by private enterprises (ASIC industries of Agriculture, Manufacturing, Mining, Wholesale and retail trade, and Recreation, personal and other services) plus those classed by Otto and Voss as 'mixed' industries (Construction, and Transport, storage and communication). [c] Imputed as 'cost share' of public capital from ABS and TRYM data, not estimated in regressions.

Private infrastructure

While infrastructure systems can be owned either by the public or private sector, the majority of infrastructure studies have focused on publicly-owned infrastructure. Communication infrastructure[18], which is the privately-owned infrastructure[19] of particular interest in this paper, is the subject of many empirical studies but most do not explicitly examine spillovers to productivity. For example, there are many studies that focus on the relationship between output growth and growth in the number of phone lines in developing countries (see appendix A). There are also numerous studies that examine the combined effect of information and communications technology (ICT) equipment growth on output.

However, Nadiri and Nandi (2001) suggest that, while there are differences in the effects of public and private infrastructure, it is possible to examine the spillovers of privately-owned infrastructure on the productivity of other industries using a similar approach to that used for public infrastructure.

> For publicly funded infrastructure capital, the government either provides them "free" or charges a small user fee. … The sources of funding for this type of capital are taxes and long term government debt, which eventually will be paid by future taxes. Therefore, in the industry production function the services of this type of infrastructure capital are treated as "unpaid" factors of production.
>
> For privately financed infrastructure capital such as the communication infrastructure capital, the source of finance is the communications firms themselves, and they recoup their expenses by charging their customers for the services rendered. That is, each industry incurs some expenses for telecommunications services. These expenses are included as part of the material cost. However, in addition, each industry in the private sector receives the externality benefits in terms of added efficiency gains from the expansion and modernization of the total communications infrastructure network for which they do not pay any direct fees. … Therefore, similar to services provided by public infrastructure capital, the privately funded communications infrastructure capital can also be treated as an unpaid input in the private industry production process. (p. 92)

Nadiri and Nandi (2001) examined United States data using an approach similar to the cost function approach for public infrastructure. They estimated a translog cost function for each *industry* based on

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18 There is some overlap between communications infrastructure and ICT capital. ICT capital as a potential source of equipment spillovers has been considered elsewhere by the Commission (see, for example, Parham, Roberts and Sun 2001; Gretton, Gali and Parham 2002) and will not be discussed in this chapter. However, IT capital has also been included amongst the control variables in the modelling presented in chapter 5.

19 In Australia, telecommunications infrastructure has moved from the public sector to the private sector over the time period examined in this paper. Its classification by the ABS in capital estimates is discussed in appendix B.

$$C=C(q, Y, S1, S2, T) \quad (2.10)$$

where q is a vector of input prices for labour, private capital and materials; Y is output; T is a time trend for disembodied technological change; $S1$ is the flow of communication infrastructure services; and $S2$ is the flow of public infrastructure services.[20]

From this function they estimated a cost elasticity with respect to communication infrastructure capital $(\partial C/\partial S1).(S1/C)$.[21] They found that a 1 per cent increase in communication capital would reduce costs by between 0.0084 to 0.0125 per cent, depending on the industry. The elasticities tended to be larger for information intensive industries. They aggregated the industry level estimates to obtain an economy level elasticity of -0.0136.

This approach does not appear to have been applied in other empirical studies. Nadiri and Nandi noted in a more recent conference paper (Nadiri and Nandi 2003) that they know of no other econometric studies of the externality effects of communications infrastructure. They acknowledge a number of studies of communications infrastructure based on simple statistical or regression analyses or input-output frameworks but note that these do not consider the externality effects (further details are provided in appendix A).

Canning (1999) used an output-side approach and panel data for a cross-section of developed and developing countries to examine spillovers from telecommunications networks. His production function included a normal total capital stock measure (inclusive of telecommunication infrastructure capital) but also included the number of telephones[22] to test for spillovers from telecommunications infrastructure. He found an elasticity of output with respect to the telephone stock of 0.14 for the full sample of countries and 0.26 for high-income countries. (Although in a later paper, Canning and Bennathan (2000), these productivity effects were considered to be implausibly large and the number of telephones was excluded from the estimations).

A number of Australian productivity studies have examined communications capital as part of ICT capital — for example, Madden and Savage (1998),

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20 In both cases, the flow of services is measured as capital stock adjusted for industry capacity utilisation.

21 The indirect or 'factor bias effect' is measured by the impact of communications infrastructure on private sector input demand functions (although these are not discussed in their paper).

22 It is noted that the use of physical measurements, such as the number of telephones, does not reflect quality differences in infrastructure across countries and over time.

Valadkhani (2003), Diewert and Lawrence (2005)[23] and Connolly and Fox (2006) (see appendix A for details). However, again, these studies did not focus on the spillovers from communications infrastructure. Madden and Savage and Valadkhani examined labour productivity and this does not allow specific consideration of spillovers because labour productivity growth can be due to capital accumulation. Also, Valadkhani, Diewert and Lawrence, and Connolly and Fox used measures of ICT that focused on communications equipment (and in combination with IT capital) rather the communications network infrastructure. Madden and Savage also noted that the number of phone lines, which they used as a proxy for information and telecommunications technology infrastructure, does not take account of expansions beyond basic telephony (such as the rollout of broadband networks). In addition, Madden and Savage (2001) and Barker et al. (2006) specifically examined the effect of digitisation of telecommunications infrastructure in cross-country studies that included Australia. Madden and Savage found a negative relationship with productivity growth of the telecommunications industry, which they attributed to short-run adjustment costs, while Barker et al. found that digitisation enhanced the impact of computer penetration on aggregate labour productivity (see appendix D).

Summary

The different streams of empirical literature focus on different issues and therefore measure different aspects of the effect of infrastructure. Table 2.3 summarises the extent to which the different approaches allow the separate identification of the three effects of infrastructure on productivity outlined in section 2.2. The empirical studies have two common features — where there is a free input effect and production spillovers they are not separately identified; and complementarity is generally only examined using the cost function approach.

[23] This paper is part of a Department of Communications, Information Technology and the Arts series of reports examining the link between ICT and productivity (see DCITA 2007 for a summary of these reports).

Table 2.3 **Summary of empirical approaches**

Type of infrastructure	Method	Effect examined: Free input	Complementarity	Production spillovers
Public infrastructure	Production function	✓	b	✓ a
	Cost function	✓	✓	✓ a
Communications infrastructure	Cost function	na	✓	✓
	Production function	na	b	✓

na not applicable. [a] Cannot be separately identified from free input effect. [b] Most studies use a Cobb-Douglas production functions in which complementarity cannot be identified. However, use of a translog production function does allow complementarity or substitution to be identified.

In the simplest production function approach, all effects of public infrastructure are captured by the coefficient on the single public infrastructure variable. These studies have generally been motivated by an interest in the 'free' input effect. However, this empirical approach cannot distinguish between the 'free' input effect and any production spillovers that would flow from infrastructure. Also, simple log linear production functions are based on the assumption that inputs are substitutes and do not identify the extent of any complementarity with other inputs.[24] However, as Dowrick (1994, p. 18) notes, translog production functions are capable of picking up substitution or complementarity between factors.

In the cost function approach, based on flexible cost functions, it is possible to distinguish between the direct effect and the effect due to complementarity. Gillen (2001, p. 10) notes that the direct effect is measured by the size of the cost decrease due to increase in level of public capital. The indirect effect is provided by cost savings from increased productivity from other factors complementary to public capital. As is the case for the production approach, it is not possible to distinguish between the free input effect and any production spillovers.

However, both these approaches are based on modelling *private* productivity not multifactor productivity (MFP) of the market sector (the calculation of which takes into account part of the stock of public capital). The latter case rules out the 'free' input effect at the aggregate (market sector) level and these approaches would then allow the separate identification of the effect of any production spillovers. Issues

24 The results of Aschauer (and later researchers) based on Cobb-Douglas production functions only measured the direct effect of public capital (because in a Cobb-Douglas function the elasticity of substitution between public capital and other factors is defined to equal one).

related to the interpretation of regression coefficients in this case are discussed in more detail in chapter 4.

In the case of privately-owned infrastructure, there is also no 'free' input effect to be modelled. The cost function approach used by Nadiri and Nandi captures the production spillovers through the inclusion of a communications infrastructure variable in addition to the priced communication services. Complementarity between communications infrastructure and other variables can be examined using the interaction terms in the translog functional form. The production function approach can also capture production spillovers through the inclusion of a communications infrastructure variable (and a digitisation variable) in addition to its inclusion in the normal capital stock.

The Aschauer-type empirical literature has raised a number of empirical issues and attracted some contention. The estimated effects of infrastructure cover a wide range and in many cases imply implausibly high returns on infrastructure assets. There are several factors that may complicate the identification of the relationship between infrastructure and productivity in empirical studies:

- the scope of infrastructure included often covers a wide range of public assets but excludes privately-owned infrastructure
- there may be considerable lags between expenditure on infrastructure and users being able to use it in productivity-enhancing ways
- the efficiency of provision of infrastructure services may have changed over time
- other factors will also affect productivity and need to be taken into account
- some links may be more apparent at a disaggregated level (in industry and spatial dimensions) than at an aggregate level.

3 Infrastructure measurement and trends

To examine the relationship between infrastructure services and conventionally measured multifactor productivity (MFP), it is necessary to derive infrastructure measures consistent with MFP for the market sector and individual industries. In doing this the extent to which the mechanisms identified in chapter 2 can be separately examined needs to be considered against the practical considerations of data availability.

The purpose of this chapter is therefore to:

- outline the sectoral coverage and scope of the analysis (section 3.1) so that it is clear how infrastructure is being defined and what effects are being investigated
- detail the ABS treatment of infrastructure in the *Australian System of National Accounts* (ASNA) to clarify the extent to which the infrastructure components already accounted for market sector MFP estimates by the ABS, and equivalent industry estimates by the Commission (section 3.2)
- outline the methodology used to construct new specific infrastructure services measures (section 3.3)
- provide some background on the trends in infrastructure and productivity variables used in the modelling for this paper (section 3.4).

3.1 Sectoral coverage and scope of the analysis

There are two main differences in focus between most other empirical studies of the effect of infrastructure (as discussed in chapter 2) and the modelling exercise in this paper — the sector of the economy being examined, and the scope of the infrastructure that is of interest.

Both these factors affect model specification and the interpretation of coefficients because of the way the ABS incorporates infrastructure into standard MFP estimates.

Sectoral coverage corresponds to the ABS's market sector

For this modelling exercise, the objective is to explain the determinants of measured *market sector* MFP (as well as MFP of individual industries).[1] The industries that make up the market sector are listed in table 3.1.

This focus on the market sector is different to most of the empirical studies discussed in chapter 2, which focused on 'private sector' productivity. Otto and Voss (1994a) constructed variables for what was as close as possible to an Australian private sector to examine the effect of public capital on *private* productivity.[2]

Table 3.1 **Industries included in the market sector[a]**

Industry	*Abbreviation used in this paper*
Agriculture, forestry & fishing	AG
Mining	MIN
Manufacturing	MAN
Electricity, gas & water	EGW
Construction	CON
Wholesale trade	WT
Retail trade	RT
Accommodation, cafes & restaurants	ACR
Transport & storage	TS
Communication services	COM
Finance & insurance	FIN
Cultural & recreational services	CRS

a The industries excluded are Property & business services, Government administration & defence, Education, Health & community services, and Personal & other services.

Scope of infrastructure

Economic infrastructure (regardless of ownership) has potentially significant spillovers not already accounted for in the measurement of market sector MFP — and it is therefore this infrastructure that is the focus of this paper and the modelling

1 MFP estimates are not available for the total economy, only for the market sector (which is the subset of industries for which outputs can be measured independently of inputs). See ABS Cat. no. 5204.0 for details.

2 The private sector has been variously defined in the empirical literature. This is because data limitations do not generally allow differentiation between private and public sector for all required variables. The private sector as defined in these studies generally does not coincide with the market sector. For example, Otto and Voss (1994a) define the private sector as including those ABS ASIC industry sectors they consider to be *predominantly* private: Agriculture, Mining, Manufacturing, Wholesale and retail trade, and Recreation, personal and other services.

exercise. In particular, it is public economic infrastructure owned by the general government sector (especially road infrastructure) and communications infrastructure[3] that have been chosen for examination.[4]

Infrastructure variables can be defined with varying scope and can be measured in different ways. However, Sturm et al. (1996, pp. 21–2) notes that few authors deal carefully with the concept of infrastructure (narrow versus broad) and the way it is constructed, and few authors experiment with different definitions (and that those who do find divergent outcomes).

The concept of economic infrastructure is commonly used to refer to a subset of infrastructure considered to be the element that is likely to contribute most to current growth and productivity. This subset of infrastructure commonly includes transport infrastructure, electricity, gas and water facilities, and communications infrastructure. This is not to suggest that social infrastructure has no effect. For example, education and health infrastructure may have long-term effects on the human capital of the labour force (see, for example, PC 2006a).

Empirical studies of Australia (particularly in the early 1990s) have tended to focus on public infrastructure owned by general government (see, for example, Otto and Voss 1994a and Paul 2003). However, with increasing corporatisation and privatisation, the ownership of economic infrastructure (and, therefore, its allocation in statistical collections) has changed over time. In some cases this has also changed whether it is provided without charge or on a user pays basis. Economic infrastructure is spread across general government (for example, roads), public corporations (for example, some electricity infrastructure) and private corporations (for example, some communications infrastructure).

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[3] The term communications infrastructure, in this paper, is the communications network infrastructure of the Communication services industry. It does not include communications equipment owned and used by other industries.

[4] This is not to suggest that public economic infrastructure and communications infrastructure are the only sources of possible spillovers. For example, electricity, gas and water infrastructure is of interest, in principle, as a source of possible spillovers. (Much of Electricity, gas and water infrastructure is owned by the private sector or public corporations and not covered by the general government sector.) There may be some spatial effects, from the extension of distribution networks, that affect business location. The interconnection of electricity and gas between states may have increased quality/reliability of supply, affecting business productivity. However, these spillovers are not expected to be as significant as those from communications infrastructure and are not discussed further here.

Asset types in scope

An additional aspect to the scope of infrastructure is the capital asset types considered to be infrastructure. A related issue is whether certain asset types are of particular interest, in their own right, and need to be separated from both public and private capital.

For this modelling exercise the asset coverage is varied from other studies in two ways (see table 3.2).

- For both public economic infrastructure and communications infrastructure, computer hardware and software are excluded to allow separate identification of IT capital. Alternative scopes of infrastructure, including IT capital, were also tested. In addition, public road infrastructure, which is part of public economic infrastructure, is considered separately in some models.[5]
- The subset of assets allocated to communications infrastructure is narrowed further by excluding road vehicles and other transport equipment. The remaining assets are more directly related to the provision of communication services with potential spillovers.[6]

Table 3.2 **Scope of infrastructure**

	Description
Public economic infrastructure	General government capital allocated by the ABS to market sector industries (selected asset types: non-dwelling construction plus all machinery and equipment less computer hardware)
Public road infrastructure	General government road capital (subset of asset type non-dwelling construction)
Communications infrastructure	Communication services industry capital (selected asset types: non-dwelling construction plus all machinery and equipment less computer hardware less road vehicles less other transport equipment)

There is no consensus about which asset types constitute infrastructure. While traditionally infrastructure consisted primarily of construction (or structures), the

5 Does not include private road infrastructure — for example, roads owned by mining companies are part of the Mining industry capital stock; and private toll roads would be part of the Transport and storage industry capital stock.

6 The ANZSIC industry Communications services includes postal and courier services, which are likely to account for a large share of the road vehicles and other transport equipment assets of the industry. However, it is the telecommunications part of this industry that is the most likely source of spillovers.

nature of modern economies and technological change has led to an expanded definition that also includes machinery and equipment contained within or attached to the construction (Swimmer 2001).

The ABS does not have an 'infrastructure category' of capital but does have a number of asset types, among which are 'Other buildings and structures'[7] (non-dwelling construction) and 'Machinery and equipment'[8].[9] Australian studies, such as Otto and Voss (1994a) and Paul (2003), include machinery and equipment with non-dwelling construction in their measures of public infrastructure. Similarly, Aschauer (1989a) and many of the subsequent studies of the US and other countries include machinery and equipment, although Aschauer (1989a, p. 191) separately examined the stock of structures and the stock of equipment and found that the stock of structures was more significant.

3.2 ABS treatment of infrastructure in MFP estimates

Given this scope, there are two main questions.

- Where does economic infrastructure appear in the ABS capital estimates?
- How does the level of aggregation affect the extent to which it is then included in the estimation of market sector MFP by the ABS and industry MFP by the Commission?

Where infrastructure appears in the capital estimates

The ABS industry capital estimates (and therefore the aggregate capital for the market sector) already include the economic infrastructure discussed in section 3.1. Communications infrastructure forms part of the capital stock of the Communications services industry — this includes that infrastructure owned by private and public corporations (see appendix B). Other public infrastructure

[7] Other buildings and structures includes '… industrial, commercial, and non-dwelling residential buildings; water and sewerage installations; lifts, heating, ventilating and similar equipment forming an integral part of buildings and structures; land development; roads; bridges; wharves; harbours; railway lines; pipelines; and power and telephone lines. This category also includes expenditures that lead to major improvements in the quantity, quality or productivity of land, or prevent its deterioration' (ABS 2000, section 15.16)

[8] Subcategories of Machinery & equipment: Computer hardware; Electrical & electronic equipment; Industrial machinery & equipment; Road vehicles; Other transport equipment; and Other plant & equipment.

[9] The other asset types are dwellings, software, artistic originals (for Cultural and recreational services), mineral exploration (for Mining), livestock (for Agriculture), land and inventories.

(economic and social) is allocated across a number of ABS ANZSIC industries, with public economic infrastructure being allocated to industries in the market sector.

Publicly-owned capital is first allocated to the two subsectors of the public sector — general government and public corporations.[10] These subsectors are treated differently by the ABS in the compilation of industry capital estimates.

The ABS basically treats public corporations in the same way as private corporations — they are allocated to ANZSIC industry on the basis of their primary activity[11] and this is where their capital will appear. This means that the infrastructure capital of public corporations is already included in the 'usual' capital estimates for ANZSIC industries. And the capital stock of public corporations is no longer separately identified from private capital.[12]

The capital of general government, however, is collected by purpose category and then mapped across to ANZSIC industry division on an approximate basis (see appendix B for details of this industry mapping and measurement issues arising from the approximations used). While some proportion of the capital of general government is allocated to the non-market sector industry of Government administration & defence (22 per cent of general government net capital stock in 2002-03), the remainder is distributed across several other non-market sector industries and a few market sector industries.

In broad terms, the principle behind the industry mapping of general government capital is that it is all allocated to the main industry that is directly using the capital. For example, public road infrastructure is included in the capital of the market sector industry of Transport and storage (not distributed across all industries using roads), and educational buildings are allocated to the non-market sector industry of Education. Details of the allocation of specific types of public economic infrastructure to ANZSIC divisions in the market sector are provided in table B.2 of appendix B.

[10] Over time, corporatisations have led to some public infrastructure moving from general government to public corporations.

[11] Some businesses will be made up of a number of establishments which have different primary activities and may be allocated to different industries.

[12] The reason for this is the extent of privatisations and statistical difficulties in dealing with them (see appendix B for details). It should be noted that the distinction between private and public corporations is still maintained in ABS series for investment (rather than capital stock). These series are affected by the change of classification of Telstra, from a public sector corporation to a private sector corporation, from March quarter 2007. This is beyond the period examined in this paper but would need to be accounted for in future empirical work.

Level of industry aggregation

In its estimation of market sector MFP, the ABS uses the aggregate of the industry capital estimates for the 12 ANZSIC industry divisions that make up the market sector (see table 3.1). The Commission estimates MFP for the 12 ANZSIC industry divisions, using the same ABS industry capital estimates.

The level of aggregation will obviously affect the extent to which public economic infrastructure and communications infrastructure are included in the capital estimates used in the calculation of MFP.

Public infrastructure

This aggregation issue was noted by Otto and Voss in their study of the relationship between public infrastructure and private sector productivity in Australia.

> … standard measures of total factor productivity generally involve aggregate measures of inputs and production. As long as this aggregation is suitable, then these standard measures of total factor productivity do account for the contribution of public capital as well as all other resources used in the public sector. (Otto and Voss 1994a, p. 124)

For the market sector, the 'usual' ABS capital measure includes public economic infrastructure (part of which is public road infrastructure). The 'free' input effect of this public infrastructure is therefore already accounted for in the estimation of MFP. However, there may be production spillovers, beyond those from the direct use of a 'free' input, such as improvements in the organisation of production facilitated by better public infrastructure, that are not captured.

At the industry level it is more complicated. For an industry, the 'usual' capital of that industry can include some public infrastructure (this varies across industries). The 'usual' capital therefore already accounts for the 'free' input effect of that part of public infrastructure, but not any production spillovers from it. None of the effects of public infrastructure allocated to the capital of *other* industries are captured. One example is roads, which are allocated by the ABS to Transport and storage but are also used by other industries.

Communications infrastructure

In the same way as for public infrastructure, communications infrastructure is already counted in the usual capital stock of market sector. For an individual industry other than Communication services, it is not part of the 'usual' capital stock but there is no 'free' input effect. Communication services are an intermediate input that are paid for and are included in the calculation of industry MFP. But this does not account for any production spillover benefits, such as network externalities, beyond those benefits for which the industry pays direct fees.

3.3 Construction of the infrastructure variables

Stock or flow?

Having determined the scope of infrastructure to be included, an appropriate measure must be chosen to reflect the services provided by infrastructure.

Although data limitations often result in the use of a stock measure, it is generally recognised that the flow of capital services from the infrastructure is the relevant measure for examining the effect of infrastructure on output (see, for example, Aschauer 1989a, Nadiri and Mamuneas 1994, Conrad and Seitz 1994, Otto and Voss 1995a, Fraumeni 1999, Paul 2003).

Three factors should be considered in selecting a measure of the flow of services for examining the effect of infrastructure on output — capital capacity, capital usage and efficiency of usage.

- The productive capacity of the capital generally declines in efficiency due to ‘wear and tear’ associated with age. The way in which capital measures take account of such changes is therefore important. Gross capital stock takes no account of the age of the assets and net capital stock accounts for depreciation. However, productive capital stock writes down each asset in accordance with its decline in efficiency due to age and is the basis of capital service indexes recently incorporated into ABS measures of productivity.[13]
- Usage of capital can vary (and therefore so can the magnitude of potential spillovers). Paul (2003, p. 448) notes that there are significant swings in the intensity with which public infrastructure is used (for example, variation in rates of road utilisation). He also notes that while a firm may have no influence on the size of the stock of public infrastructure provided by the government, it can vary its usage (for example, by choice of routes). Public capital may be subject to congestion so the amount used by an industry may be less than the total amount supplied (Nadiri and Mamuneas 1994, p. 24).

[13] Fraumeni (1999, pp. 33–4) lists the use of wealth capital stocks instead of productive capital stock in public capital studies as a major shortcoming. Sturm et al. (1996, p. 22) also note that most empirical research implicitly assumes that services can be proxied by stock or level of investment and this may not be true.

- Efficiency of use of infrastructure is also variable. Otto and Voss (1995a, p. 187) note that a stock measure does not capture changes in the efficiency of use of existing infrastructure (due, for example, to the use of more appropriate pricing for infrastructure services). They note that as a consequence it would be possible to observe a decline in the public investment to output ratio without any implications for future growth. This factor does not appear to have been incorporated into many of the empirical studies of public infrastructure.[14]

Empirical studies have used a range of measures (see box 3.1 and appendix A for details of capital variables used in selected studies).

However, as noted above, due to data limitations, most empirical studies at the aggregate level have used the net stock of infrastructure capital (in constant prices) and assume that the flow of capital services is proportional. At the industry/sector level, some studies have made an adjustment to the stock measure for the degree of usage. Paul (2003) suggests that, while the amount of services a firm receives from public infrastructure is not observable, the degree of usage is dependent on the level of a firm's activities. He used the industry's or sector's share of total national output as a proxy and applied this to the stock of public infrastructure. Other studies have used intermediate usage data from input-output (IO) tables to construct more specific usage measures (for example, Cronin et al. 1993). It could be argued that network spillovers, for example, may be more closely related to an industry's use of communications services as an input rather than simply its output.

For this paper, it has been possible to cover, to some extent, the first two of the three factors outlined. The flow of capital services has been estimated using capital services indexes, with the inclusion of an adjustment for industry/sector usage of infrastructure. The details of these estimations are discussed below. The third factor, efficiency of usage of the infrastructure, has not been measured.

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14 Hulten (1996) confirms this. He notes that the effectiveness with which infrastructure is used involves many dimensions and is not easily modelled. However, he does include an infrastructure effectiveness variable in a growth model of *low and middle income* countries. The effectiveness measure used is an aggregate index based on electricity system loss (electricity generation losses as a per cent of total system output), road conditions (percentage of paved roads in good condition), telephone faults (mainline faults per 100 telephone calls) and locomotive availability (as a percentage of total). It is applied to the infrastructure stock variable in the production function. He finds a 'growth penalty' for inefficient infrastructure use.

For high income countries, it would be expected that these broad measures would show much less variation over time and be less useful.

Box 3.1 **Infrastructure measures in selected studies**

While a stock variable is the most commonly used measure of infrastructure in empirical studies, there are different ways in which the stock can be quantified. Value measures are the most common, but in some cases physical stock measures have been used. A few examples are provided here.

Value of stock measures

Public infrastructure studies

- A measure of general government capital stock is generally used.
  - Aschauer (1989a) used net public capital stock. He examined core (public economic) infrastructure and other (social) infrastructure. He separately examined the stock of structures and the stock of equipment and found that the stock of structures was more significant.
  - Otto and Voss (1994a) and Paul (2003) in studies of Australia used gross stock of general government capital (non-dwelling construction and equipment) for the aggregate level and the same for the industry level. As a variation, Otto and Voss (1994a) added in the gross capital stock of public trading enterprises (a measure which is no longer available).
  - The Industry Commission's R&D Inquiry (IC 1995) used the general government stock of net public capital (non-dwelling construction and equipment) as the public infrastructure variable in estimating industry productivity. For aggregate estimation, infrastructure was not separated from total capital stock.
- In some cases, a utilisation adjustment is made.
  - Conrad and Seitz (1994) and Nadiri and Mamuneas (1991) multiplied the stock of public infrastructure capital by the industry specific capacity utilisation rate to yield a proxy for the flow of public services provided by the stock of capital. Paul (2003) made an adjustment using industry share of national output, noting that capacity utilisation data were not available for Australia.
  - Fernald (1999) used the stock of vehicles to capture the utilisation of the stock of roads.

'Private' infrastructure studies

- Nadiri and Nandi (2001) used the net capital stock (structures and equipment) of the communications industry in their examination of the effect of communications infrastructure on output and productivity in other industries. The stock was adjusted by industry capacity utilisation rates.
- Cronin et al. (1993) in calculating resource savings from changes in communications technology used input-output data on usage of communications services.

(continued on next page)

Box 3.1 **(continued)**

Physical stock measures

Other studies (not necessarily focused on explaining productivity) have used a range of physical stock measures.

- Madden and Savage (1998) used the number of phone lines as a proxy for information technology and telecommunications capital. Roller and Waverman (2001) used the penetration rate of telephone lines and Datta and Agarwal (2004) used access lines per 100 inhabitants. Greenstein and Spiller (1995) used miles of optic fibre cables.
- Canning (1999), in examining developing countries, used more specific infrastructure quantity measures — number of telephones, electricity generating capacity and kilometres of transportation routes.

Other measures

It has also been argued that infrastructure services are produced using more than capital. Luskin (1996) suggests that other inputs required to produce infrastructure services (labour, fuel, etc) are neglected in studies which use only public capital. He notes that when modelling private production, Otto and Voss (1994a) also included government consumption expenditure, to allow for non-capital infrastructure inputs, but found it to be insignificant.

Capital services methodology

Capital services indexes have been constructed for the scope of public infrastructure and communications infrastructure defined in table 3.2, to reflect the flow of capital services from these types of infrastructure. This has been done using unpublished ABS national accounts data and ABS methodology, but with the inclusion of an adjustment factor to reflect changes in the usage of infrastructure by the market sector and by individual industries (discussed below).

The details of the estimation process are described in appendix C. In brief, the productive capital stock of each asset type in each institutional sector (government, corporate and unincorporated) within each industry is weighted and summed to form an index for aggregate capital services. The *productive capital stock* of an asset over time is the volume of capital, adjusted for efficiency losses related to age. The weights are based on *rental prices*, which can be thought of as estimates of the rates each asset type would attract if the assets were leased in a commercial arrangement.

For the total capital services index for the market sector, the ABS includes all market sector industries, all asset types and all institutional sectors. For the construction of capital services indexes for public infrastructure and communications infrastructure for this paper, the relevant industries, asset types and institutional sectors have been varied. The productive capital stock and rental prices used to construct these indexes are unpublished ABS national accounts data.

For public economic infrastructure, only the general government institutional sector is included. The ABS allocates general government capital across a number of industries but only those in the market sector are included to arrive at public economic infrastructure for the market sector for this paper. The subset of assets included is non-dwelling construction and five of the six types of machinery and equipment (electrical and electronic equipment, industrial machinery and equipment, other plant and equipment, road vehicles and other transport equipment). Computer hardware is excluded. Public road infrastructure includes general government sector road capital (which is part of the non-dwelling construction asset type).

For communications infrastructure, the only relevant industry is Communication services and the corporate and unincorporated institutional sectors are included.[15] The subset of assets included is non-dwelling construction and three of the six types of machinery and equipment (electrical and electronic equipment, industrial machinery and equipment, and other plant and equipment). Computer hardware, road vehicles and other transport equipment are excluded.

In order to allow the separate examination of IT capital in the modelling, public infrastructure and communications infrastructure have been estimated without the inclusion of any relevant IT capital. The alternative of including the relevant IT in these infrastructure variables has also been examined in sensitivity testing of results.

Digitisation of the communications network

The capital services index for communication infrastructure may not fully reflect the additional functionality of the copper network that has arisen from digitisation. Capital expenditure on digitising exchanges would be included in the capital services index. However, the additional functionality provided represents an unmeasured shift in the service flow from the copper network.

No adjustment has been made to the capital services index to account for this change. However, a separate variable that measures the extent of digitisation of the network over time has been used to attempt to capture this unmeasured shift in

[15] There is no general government allocation to Communications services so there is no overlap with public infrastructure.

services. The available measure is the share of standard analogue lines connected directly to digital exchanges (see appendix D).

Alternatives methods for incorporating this variable into the modelling are discussed in appendix E. They include:

- the inclusion of the digitisation variable separately
- the interaction of the digitisation variable and the communications variable
- using a term that allows the estimated elasticity on communication infrastructure to shift at 1990 (the first observation for the 'digital' variable).

In addition, the digitisation variable has also been used to examine complementarities between digitisation of the communications network and other forms of capital (IT capital and other private capital). Digitisation may have enhanced the impact of IT on productivity, for example, in its role in facilitating information flows within firms and across firms. However, in this case the available measure of digitisation is only a partial measure of the possible digitisation effects — complementarities would not be restricted to digitisation of the copper network but would include other elements of digitisation such as optic fibre.

Usage adjustment factor

Usage of infrastructure can vary (and therefore so can the magnitude of potential spillovers). While the overall stock of public infrastructure is determined by government, a firm can vary its usage of that stock.

For this paper, the main adjustment factor used for the market sector is the market sector's share of total value added. Similarly, for each of the industries examined the adjustment factor is the industry's share of total value added. This adjustment is a crude approximation of actual usage (other alternatives discussed in box 3.1 were not readily available for Australia).[16]

For communications infrastructure, an alternative adjustment factor was also tested. This was based on the share of intermediate usage of communications services by

[16] The amount of services an industry/sector receives from public infrastructure is not directly observable. The usage adjustment factor is a crude proxy based on the assumption that each industry/sector utilises the available public infrastructure services in proportion to its contribution to total output in the economy. It does not account for changes in the overall intensity of utilisation of a given level of infrastructure (for example, an increase in the use of underutilised infrastructure). An alternative measure used in some studies, industry capacity utilisation rates, is not readily available for Australia.

the market sector or an individual industry, which may be more closely related to the source of the potential spillovers.

The details of the construction of the adjustment factors, and examination of alternatives, are in appendix C.

The adjustment factors were applied to the productive capital stocks used in the calculation of the capital services indexes rather than included as separate variables. This was to preserve degrees of freedom in the regressions.

Definition of the infrastructure variables used in the models

The definition of each infrastructure variable used in modelling is summarised in table 3.3.

Table 3.3 **Infrastructure variables**[a,b]

Explanatory variable	*Description*
Public economic infrastructure (I3, I3ug2, I3ug2s)[c]	Capital services index for selected general government capital assets (non-dwelling construction plus all machinery and equipment except computer hardware) allocated by the ABS to the market sector (I3). Usage adjusted by market sector/industry$_i$ share of value added (VA) (I3ug2) or smoothed share of value added (I3ug2s).
Public road infrastructure (roads, roadug2, roadug2s)	Capital services index for road assets of general government sector (roads). Usage adjusted by market sector/industry$_i$ share of value added (roadug2) or smoothed share of value added (roadug2s).
Communications infrastructure (ci5, ci5ioug, ci5iougs, ci5vaug)[d]	Capital services index for selected capital assets (non-dwelling construction plus all machinery and equipment except computer hardware, road vehicles and other transport equipment) of Communication services industry. Not usage adjusted (ci5) or adjusted by either of market sector (including Communication services industry) or industry$_i$ share of value added (ci5vaug) or market sector (excluding Communication services industry)/industry$_i$ share of intermediate usage of communications services (ci5ioug) or smoothed intermediate usage share (ci5iougs).
Digitisation (digi)	Share of standard analogue lines connected directly to digital exchanges (switches).

[a] All data are authors' estimates based on published and unpublished ABS national accounts data, except for digitisation from OECD Telecommunications database 2003. [b] Capital services indexes for non-infrastructure capital components, for example IT capital, are defined in appendix E for the market sector and appendix F for industries. [c] Some sensitivity testing was undertaken extending the selected assets to include general government computer hardware and software (I8 and I8ug2). [d] Some sensitivity testing was undertaken extending the selected assets to include computer hardware and software of the Communication services industry (ci8, ci8ioug and ci8vaug).

3.4 Patterns in the infrastructure and productivity variables

The patterns in the main variables discussed above are examined below.

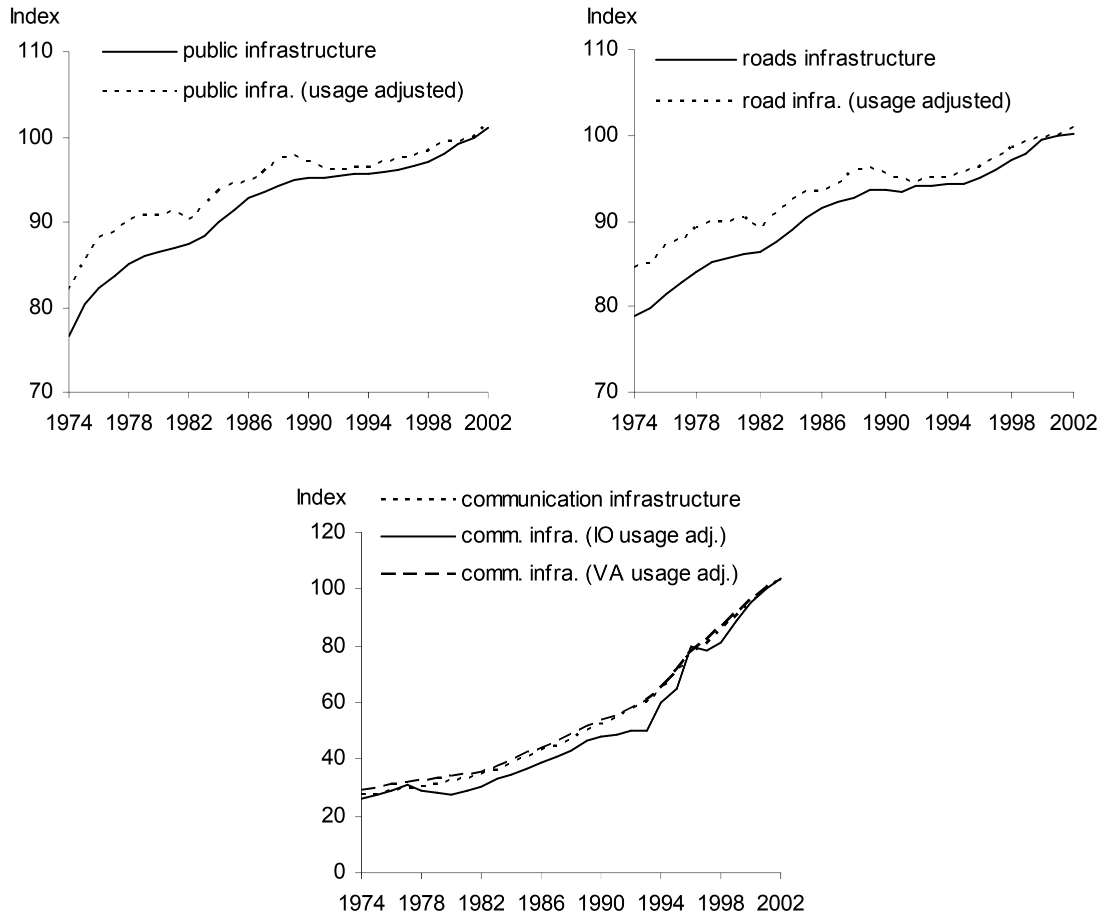
Trends in infrastructure services

The trends in capital services indexes for the main infrastructure variables for the market sector are shown in figure 3.1. The equivalent usage-adjusted capital services indexes for the individual industries are shown in figure 3.2 (the unadjusted indexes are the same as for the market sector).

Growth in public economic infrastructure and road infrastructure has declined since the mid-1970s. Communications infrastructure has trended upwards over the period at a higher rate than public infrastructure. The usage-adjusted measures are all more volatile than the unadjusted measures, reflecting greater fluctuations in the usage adjustment factors than in infrastructure growth.

Figure 3.1 **Trends in capital services from key infrastructure assets[a], market sector, 1974-75 to 2002-03**

Index 2001-02 = 100



Financial years beginning 1 July of year specified. [a] Specific variable definitions provided in table 3.3. Public infrastructure variables are ‘I3’ and ‘I3ug2’; road infrastructure variables are ‘roads’ and ‘roadug2’; and communication infrastructure variables are ‘ci5ioug’, ci5vaug’ and ‘ci5’.

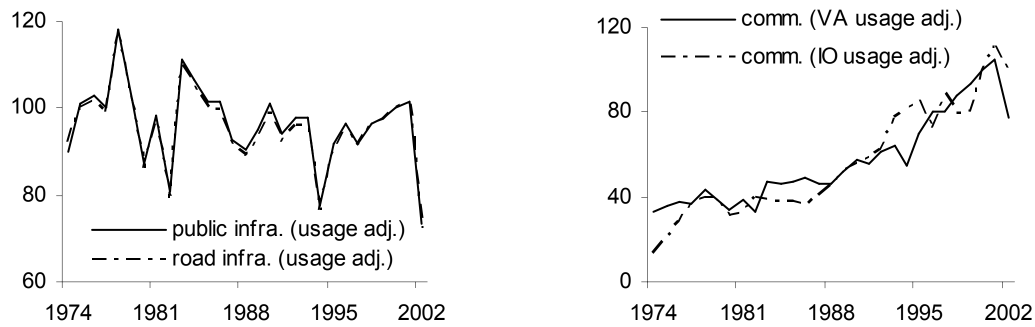
Data source: Authors’ estimates based on unpublished ABS data.

Selected usage-adjusted infrastructure measures by industry are presented in figure 3.2 (other measures are presented in appendix F). The differences across industries reflect differences in the usage adjustment factors across industries. Agriculture, Construction, Wholesale trade and Retail trade show more volatility in these usage adjustments than the other industries. Of the usage adjustment factors applied to communications infrastructure those based on input-output intermediate usage are generally more volatile than the valued-added adjustment factors.

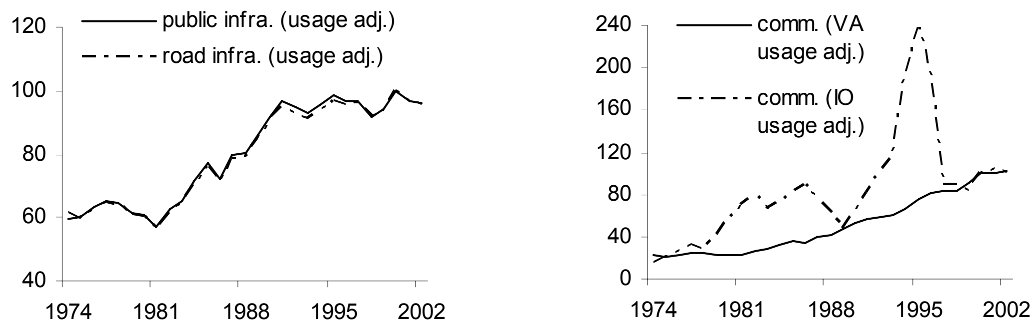
Figure 3.2 **Key infrastructure capital services, by industry, 1974-75 to 2002-03**

Index 2000-01 = 100

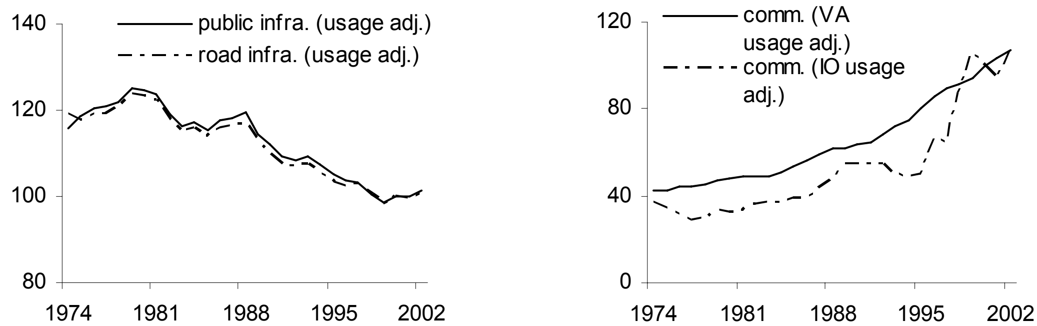
Agriculture



Mining



Manufacturing



Electricity, gas & water

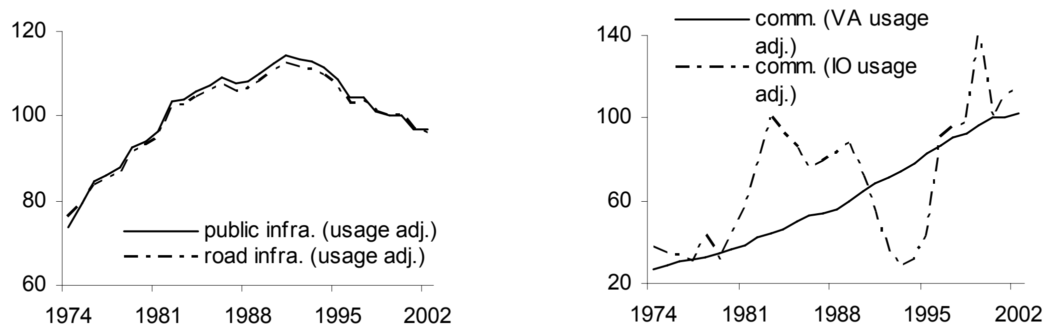


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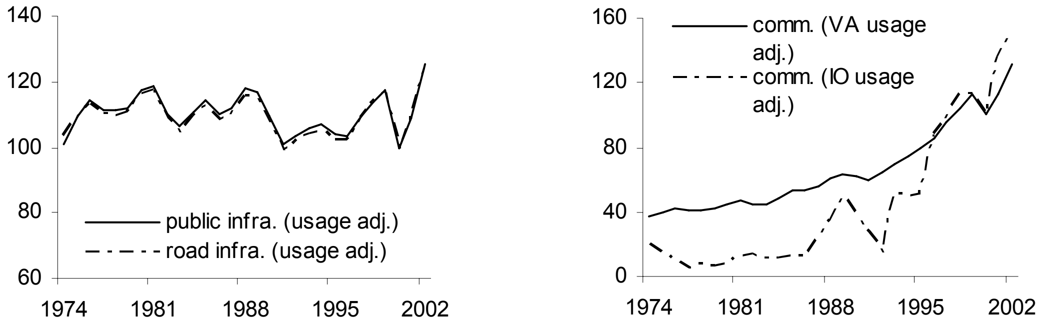
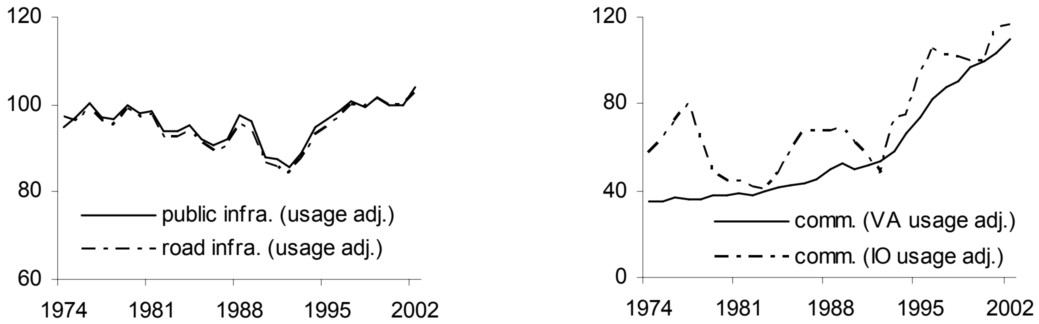
Figure 3.2 **(continued)**

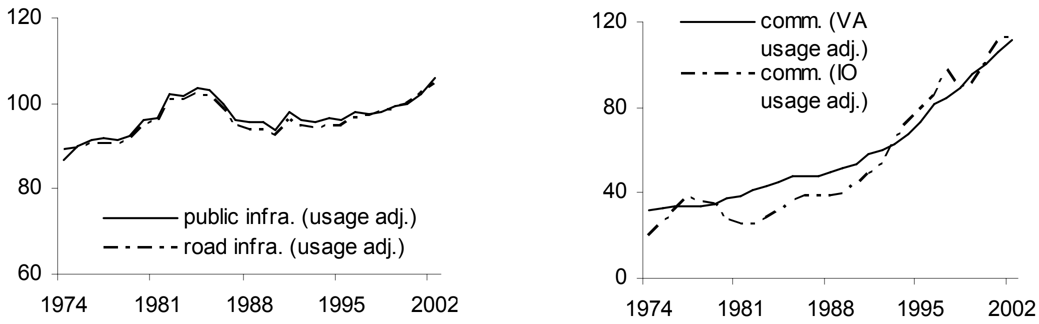
Construction



Wholesale trade



Retail trade



Transport & storage

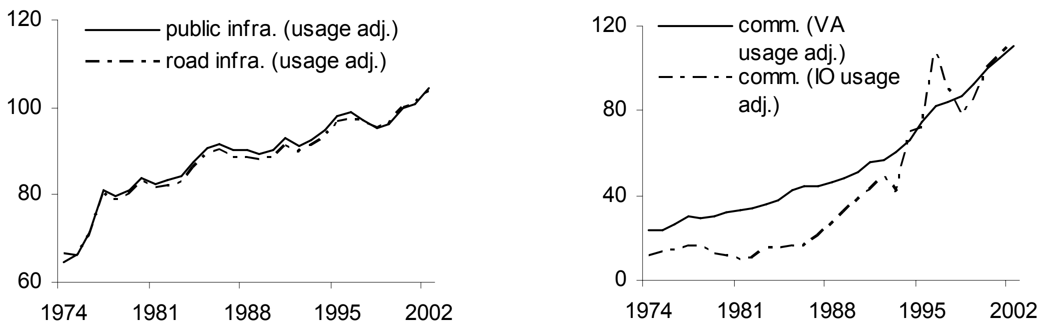


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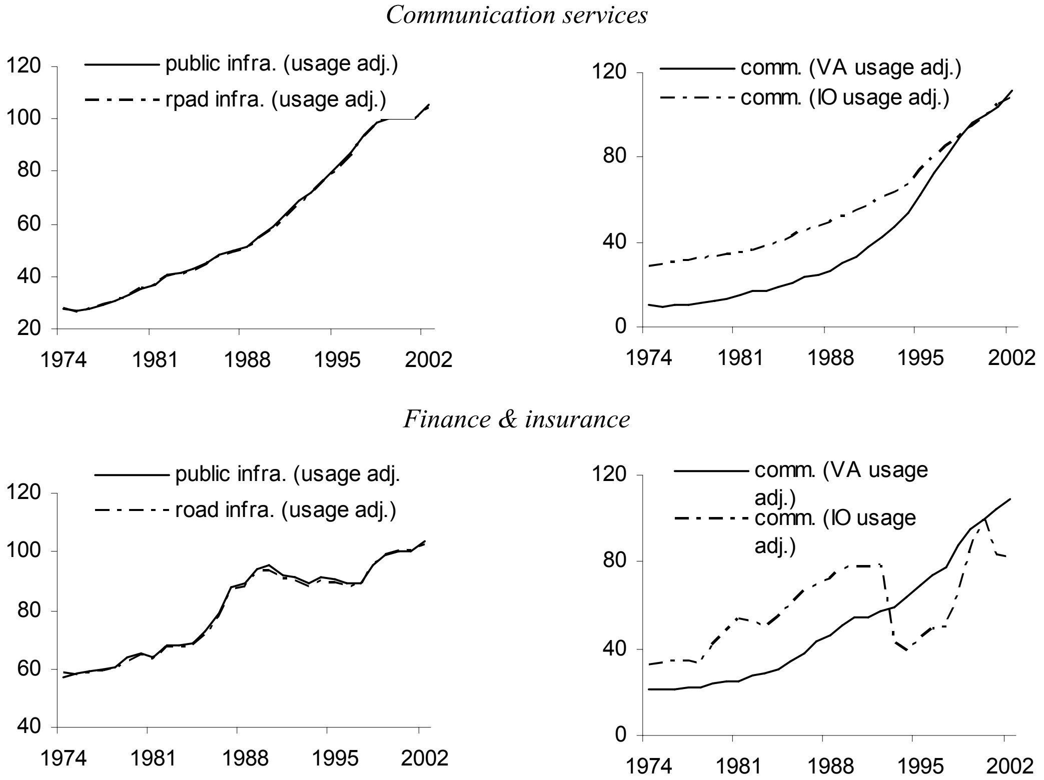
Figure 3.2 **(continued)**



Financial years beginning 1 July of year specified.

Data source: Authors' estimates based on unpublished ABS data.

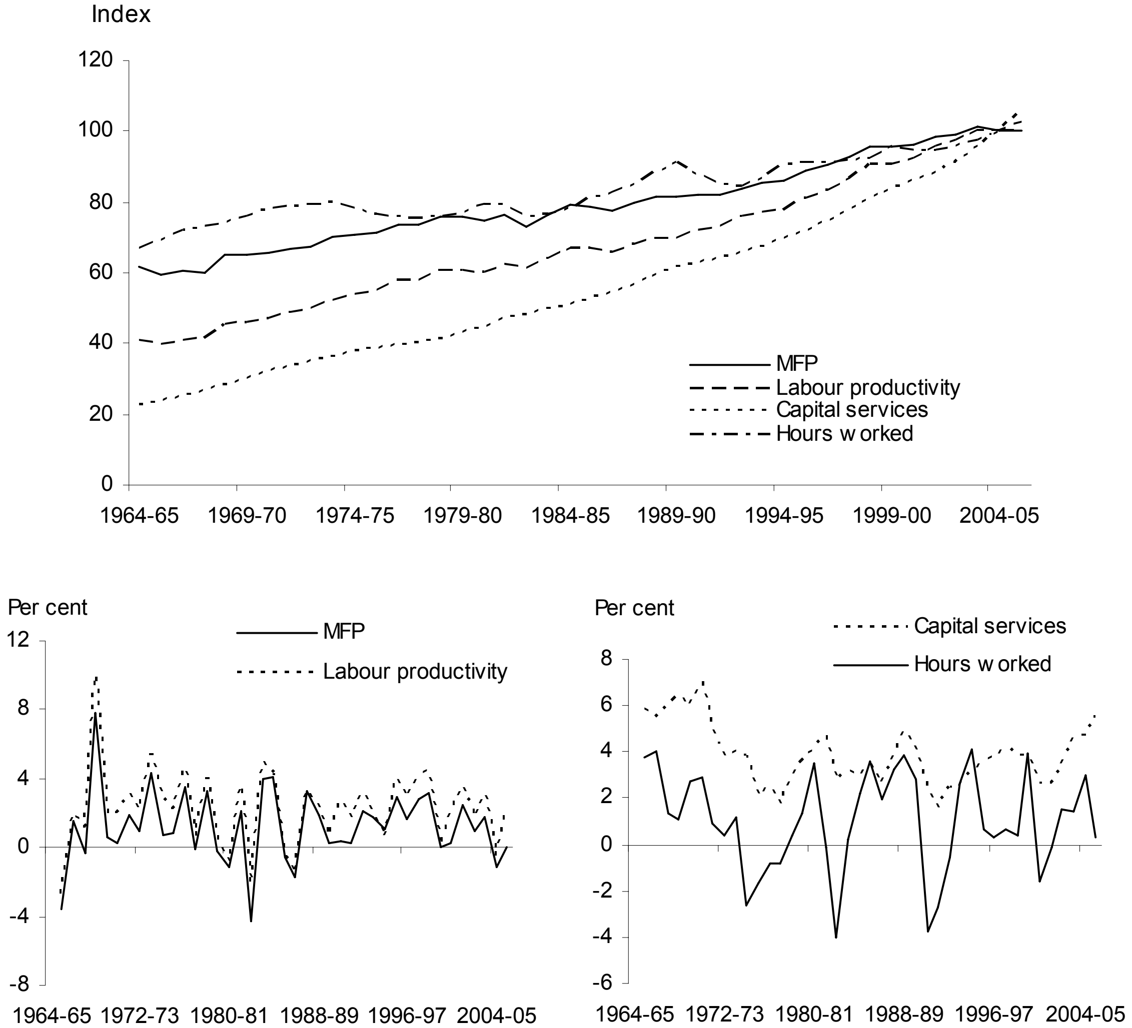
Trends in MFP and labour productivity

Most models in this paper seek to explain the observed pattern of growth in MFP from the mid-1970s to 2002-03. Some market sector models seek to explain labour productivity growth. Of particular interest is the role of economic infrastructure in determining productivity trends.

MFP, labour productivity, total capital services and hours worked have all increased since the mid-1960s (figure 3.3, upper panel). Annual growth rates in labour productivity and MFP follow the same pattern, especially prior to the mid-1990s (lower left panel). The average growth rate in market sector capital services is substantially higher than the average growth rate in hours worked (lower right panel).

Figure 3.3 **Trends in productivity and conventional input services indexes, 1964-65 to 2005-06**

Index 2004-05 = 100; Growth per cent per year

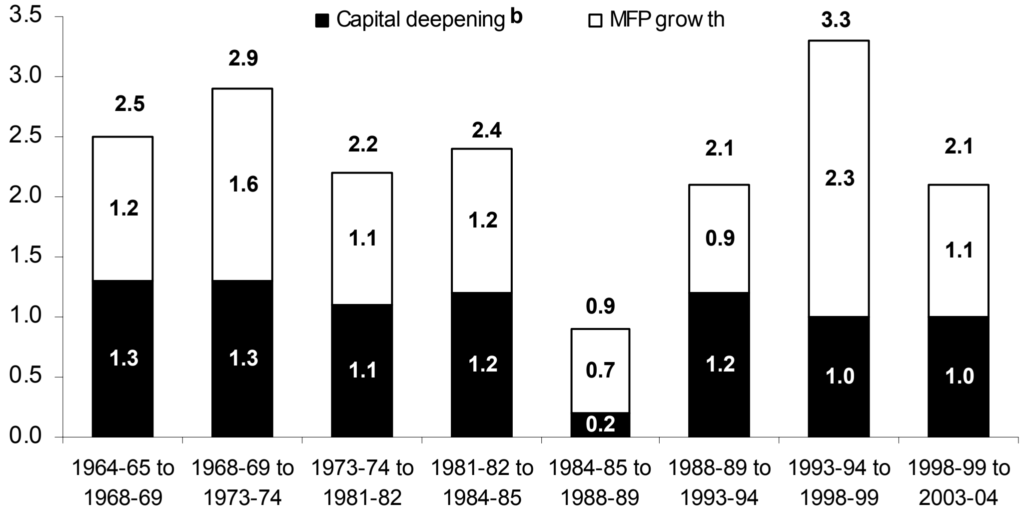


Data source: ABS (*Australian System of National Accounts, 2005-06,* Cat. no. 5204.0).

As is well known, Australia experienced a productivity resurgence in the 1990s. Productivity growth was historically slow in the 1980s, but surged to record highs in the 1990s (figure 3.4). It was especially high, and consistently so, between 1993-94 and 1998-99.

Figure 3.4 **Labour productivity growth[a] in Australia's market sector, 1964-65 to 2003-04**

Per cent per year



[a] Components may not add to total due to rounding. 1998-99 to 2003-04 is the last complete productivity cycle. [b] Capital deepening is the growth in the capital to labour ratio multiplied by the average capital income share for the period.

Data sources: ABS (*Australian System of National Accounts, 2005-06,* Cat. no. 5204.0); Commission estimates.

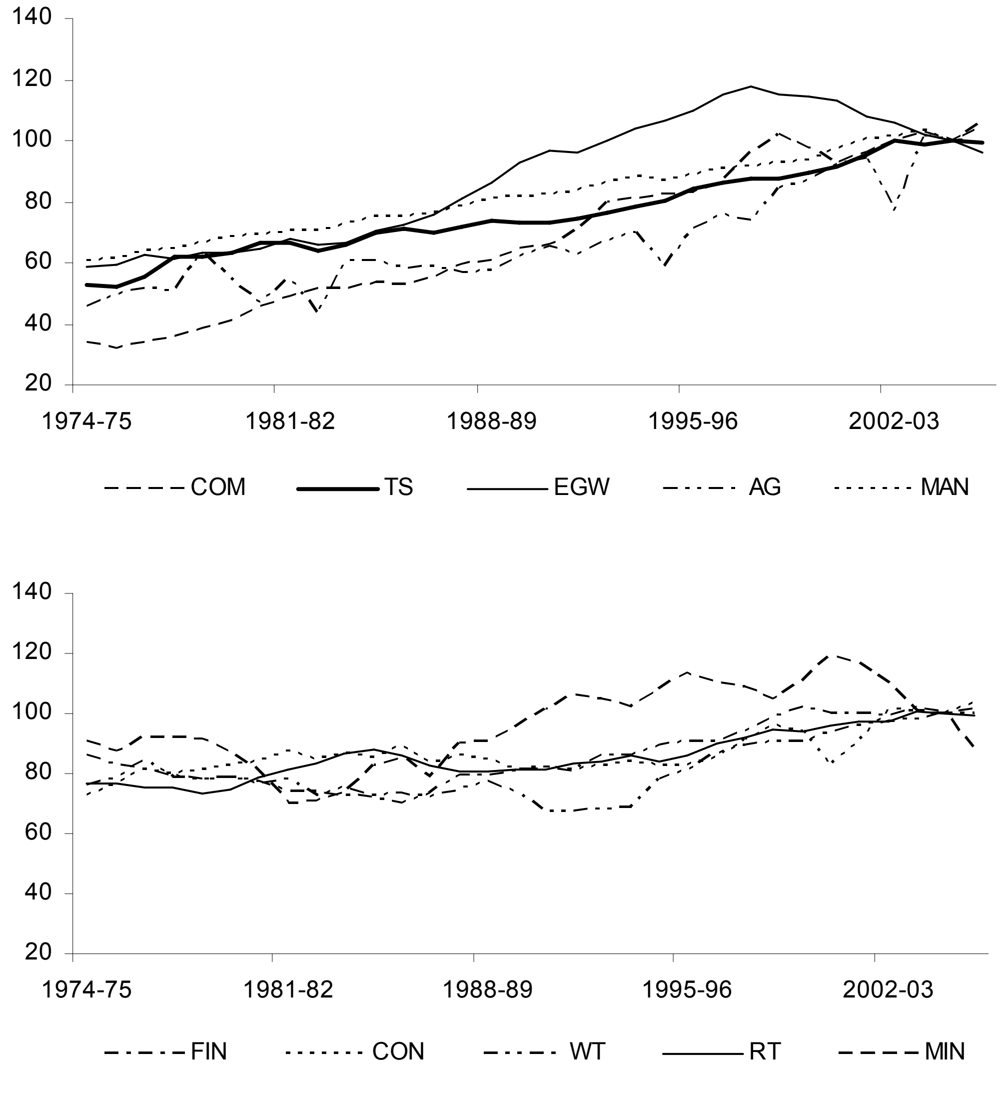
Since the late 1990s, productivity growth has slipped towards the long-term average. The slowdown appears to be a combination of a drop in underlying productivity growth from previous record highs, and a number of short-term one-off factors that have held average productivity growth below the 'true' underlying rate (Parham 2005). In the last couple of years Mining has dragged down average productivity (PC 2007a).

At the industry level[17], average productivity growth over the period 1974-75 to 2005-06 was strongest in Communication services (figure 3.5, left panel). The other industries in the upper left panel of figure 3.5 (Transport & storage, Electricity, gas & water, Agriculture, Manufacturing) also had relatively strong growth on average over the entire period. The right panel shows industries that had weaker growth on average (Construction, Wholesale trade, Retail trade, Finance & insurance) or contracted on average (Mining).

[17] It should be noted that productivity estimates are less accurate at the industry level than at the aggregate level. In particular, the allocation of aggregate inputs and outputs across industries is subject to more uncertainty than at the market sector level (see Cobbold 2003).

The 1990s productivity acceleration was greatest in Wholesale trade, followed by Communication services. Agriculture also showed a significant acceleration over this period but was more volatile over the entire period than most other industries. Mining showed relatively little overall productivity growth from the mid to late 1990s.

Figure 3.5 **MFP growth by industry, 1974-75 to 2005-06[a]**
Index 2004-05 = 100



[a] Commission estimates as at 18 December 2006, based on unpublished ABS data from 2005-06 national accounts.

Data source: Commission estimates.

The correlations between productivity growth and growth in infrastructure services are examined in appendix I.

4 Framework for quantitative analysis

This chapter details the empirical methodology used — the empirical specifications adopted (section 4.1) and the estimation issues and strategies used (section 4.2).

4.1 Framework specification

The effects of infrastructure are modelled within the production function framework at both the level of the market sector and for individual industries.

Market sector models

The first step is to specify a production function that identifies public infrastructure, communications infrastructure separately from other capital

$$Y_t = A(t)F(L_t, G_t, C_t, K_t) \tag{4.1}$$

where Y is output, $A(t)$ is a measure of multifactor productivity (where t is time), G is public infrastructure, C is communication infrastructure, K is other capital, and L is labour inputs measured as hours worked.

Assuming a Cobb-Douglas form, equation (4.1) can be rewritten as

$$y_t = a + \lambda t + \beta_1 k_t + \beta_2 l_t + \beta_3 g_t + \beta_4 c_t \tag{4.2}$$

where lower case variables represent logarithms of the corresponding upper case variables. The βs are the output elasticities with respect to the input variables.

Most empirical specifications for this paper are based on a two step approach, where multifactor productivity (MFP) is first calculated independently in a growth accounting framework. The standard approach, as adopted by the ABS, is to assume competitive markets in which factors are rewarded according to their marginal products — so that the output elasticities can be represented by factor shares in total factor income — and constant returns to scale — so that factor shares sum to unity.

Then

$$mfp_t = y_t - s_1 k_t - s_2 l_t - s_3 g_t - s_4 c_t \quad (4.3)$$

Substituting (4.3) into (4.2) gives

$$mfp_t = a + \lambda t \quad (4.4a)$$

The second step is to regress the MFP index on a set of explanatory variables. This approach conserves degrees of freedom relative to estimating equation (4.2), and it may also reduce estimation problems arising from collinearity between inputs.

This exercise can be characterised as an attempt to explain the variation in the ABS estimates of MFP or, more specifically, as an attempt to test the influence of various infrastructure variables on ABS estimates of MFP, taking account of a number of other possible influences.[1]

There are a number of factors that may explain part of productivity (a), which are not reflected under the assumptions made in the calculation of the ABS MFP estimates — infrastructure spillovers; other factors affecting productivity; violation of constant returns to scale (CRS); and capacity utilisation shocks.

There may be external effects or spillovers from public and communications infrastructure and this is allowed for by re-entering these variables as explanators of productivity.

$$mfp_t = a + \lambda t + \gamma g_t + \alpha c_t \quad (4.4b)$$

Also, other factors affecting productivity are generally included to reduce misspecification and omitted variable bias (see, for example, the discussion of this in Connolly and Fox 2006). Equation (4.4b) can be augmented to become

$$mfp_t = a + \lambda t + \gamma g_t + \alpha c_t + \theta_i x_{it} \quad (4.4c)$$

where x_{it} is a vector of other factors affecting measured productivity.

It is also possible to allow for an error in the CRS assumption. As indicated earlier, the official MFP index produced by the ABS for the market sector incorporates public and communication infrastructure in the capital services measure used to construct MFP in a way that assumes CRS. To the extent that this assumption is violated γ and α will capture infrastructure-related scale effects in addition to spillovers. Although the CRS assumption is unlikely to be statistically rejected at

[1] In fact the analysis is a carry-over from the modelling exercise of Shanks and Zheng (2006), who investigated the effect of R&D capital on MFP.

the level of the market sector (see appendix H), this assumption has been tested in this paper. The estimating equation becomes

$$mfp_t = a + \lambda t + \gamma g_t + \alpha c_t + \theta_i x_{it} + (\varepsilon - 1)s_t \tag{4.4d}$$

where s_t represents a scale control variable. (The coefficient of which will be negative/positive if the true scale technology is decreasing/increasing returns — see appendix H for further details).

The construction of the capital service indexes and labour input index also does not recognise business cycle or shock effects on the capacity utilisation of the inputs. (The pro-cyclical characteristic of MFP and controlling for the effects of the business cycle are discussed in appendix H). Adding a cycle term and a stochastic error term results in the estimating equation

$$mfp_t = a + \lambda t + \gamma g_t + \alpha c_t + \theta_i x_{it} + (\varepsilon - 1)s_t + \pi m_t + \mu_t \tag{4.4e}$$

where m_t is the control for the business cycle and μ_t is the error term.

If hypothesis testing of the estimated parameters γ and α cannot reject a zero coefficient with a reasonable degree of confidence, then this indicates that the excess effects of infrastructure are zero. The excess effect is a net effect. It may capture a number of the different possible effects of infrastructure, some of which may be offsetting. If the coefficients are positive and statistically significant, then there is evidence of positive net excess effects.

At the level of the market sector, the determinants of labour productivity are also investigated. The capital-to-labour ratio is added to the regressions, most variables are expressed in terms of per hours worked and no scale restrictions are imposed

$$lp_t = a + \lambda t + \gamma g_t + \alpha c_t + \theta_i x_{it} + \pi m_t + \beta_1 k + \mu_t \tag{4.5}$$

where lp is gross value added per hour worked, and, in this case, k represents the capital-to-labour ratio. The scope of infrastructure and capital included in the capital-to-labour ratio has an influence on interpretation of the public and communication infrastructure estimated coefficients. If infrastructure is included in k, then the coefficients are interpreted as excess effects; otherwise, the coefficients are interpreted as representing both the direct and excess effects. Both strategies to estimating the effects of infrastructure on labour productivity are employed.

It may also be thought that the effect of a particular form of infrastructure or other capital varies over time conditional on some other factor or characteristic of the economy. Two such examples, for which limited testing has been undertaken, are:

- the effect of road infrastructure may have varied with congestion to the extent that congestion is not reflected in the constructed road infrastructure services measures; and
- the effect of communication infrastructure and/or IT capital may have varied over time in relationship to the digitisation of the telecommunication network.

Summary of the types of effects captured

At the level of the market sector, estimated parameters from the MFP regressions in this study capture only the excess effect including technological, system or network spillovers, and do not capture the direct free input effect (table 4.1).

Table 4.1 **Effects that are captured in market sector regressions**

	Effect measured/Interpretation	
Infrastructure variable	*Free input*	*Production spillovers*
MFP regressions		
Public economic infrastructure[a]	**na**	✓
Communications infrastructure[b,c]	**na**	✓
Labour productivity regressions		
Public economic infrastructure[d]	✓	✓
Communications infrastructure[d]	✓	✓

na not applicable because already included in usual capital used in estimation of MFP. **a** Infrastructure owned by public corporations could also have spillovers but no data are available to separately identify the capital of public corporations. **b** Some communications infrastructure is owned by public corporations and the communications infrastructure variable will include that infrastructure. **c** No overlap with general government because there is no general government component of Communications services industry. **d** Both the free input effect and other effects are captured in estimated parameters if the capital-to-labour ratio is adjusted to exclude infrastructure.

Estimated parameters from labour productivity regressions can also capture the free input effect depending on whether the capital-to-labour ratio has been adjusted to exclude infrastructure.

Industry models

The infrastructure effects captured in industry regressions differ for some industries, and in comparison with the market sector. Differences result because of the way infrastructure measures are or are not included in the construction of MFP.

The effects of infrastructure at the industry level are investigated using very similar empirical specifications to those above. A number of minor adjustments are required resulting from the extent to which infrastructure capital is included in the 'usual' capital of the industry[2]

$$mfp_t = a + \lambda t + (\beta_3 + \gamma)g_t + \alpha c_t + \theta_i x_{it} + (\varepsilon - 1)s_t + \pi m_t + \mu_t \quad (4.6)$$

where ε now only captures errors in the CRS assumption across non-infrastructure capital k and labour l. The estimated parameter $(\beta_3 + \gamma)$ captures both the 'free' input effect of any public economic infrastructure *not* allocated by the ABS to the capital stock of that industry and excess effects of *all* public economic infrastructure.[3] The estimated parameter α captures only the excess effects of communication infrastructure. MFP is based on a gross value added (GVA) concept, where GVA is gross output less intermediate inputs consumed in production and payments for communication infrastructure services will be recorded as intermediate inputs.[4] There is no 'free' input effect of communications infrastructure.

A complication in interpreting results for public infrastructure is the degree to which it is a 'free' input for any industry. For some public infrastructure (such as roads) there may also be charges. However, these charges may not fully reflect the input cost. Road charges tend to be indirect in the form of, for example, registration fees and fuel taxes. These charges vary approximately with distance travelled and vehicle mass but not location.[5] Overall, there may not be a strong nexus between an industry's road usage and payments for road usage, so that economically significant free input effects may exist for some industries. For example, PC (2006b) states that the current heavy vehicle arrangements generate pervasive cross-subsidies as a result of averaging across the network and across truck classes. It also finds some evidence of cross-subsidies between road users over time.

Summary of effects captured in industry regressions

Table 4.2 summarises the effects that are captured and tested by the inclusion of each type of infrastructure variable in the industry regressions.

[2] The ABS allocation of public infrastructure to the *main* industry that uses it may result in an overallocation to the capital stock of that industry — reducing its level of productivity. The extent of this is not examined in this paper.

[3] These effects are not separated because the public economic infrastructure allocated to different industries has not been separately identified.

[4] For the industry Communication services, the communications infrastructure will obviously be part of the usual capital stock.

[5] According to McInerney, Nadarajah and Perkins (2007) the amount paid by heavy vehicles varies very approximately with the distance travelled (roughly proxied by fuel taxes) and mass of heavy vehicles (roughly proxied by registration) but not with their location.

Table 4.2 **Effects that are captured in an industry MFP regression**

	Effect measured/Interpretation	
Infrastructure variable	*Free input*	*Production spillovers*[a]
Public economic infrastructure	✓ (from part *not* allocated to this industry)	✓ (from all public economic infrastructure)
Communications infrastructure	**na**	✓

na not applicable because already taken account of as an intermediate input in the estimation of MFP (or, in the case of Communication services, included in usual capital used in estimation of MFP). [a] Technological or system/network spillovers.

4.2 Estimation issues and strategy

While the empirical specifications are relatively straightforward there is a number of estimation challenges. These issues and the approach to dealing with them are outlined below — the details of the estimation strategy are provided in appendix J.

Selection of estimation technique

Several issues militated against using simple ordinary least squares (OLS) estimation techniques — particularly the non-stationarity of the data, lack of reliable unit root tests, and the expected significance of dynamics.

Non-stationary or trending economic variables is a common problem in time series econometrics. If two variables are trending over time, standard regression techniques could show a relationship even if the two variables are totally unrelated. This is the spurious regression problem.

Tests of the main market sector data series used in this study, including MFP and the infrastructure measures, generally indicated that the data were non-stationary, with most variables stationary in growth rates — integrated of order one I(1) (appendix G). However, tests did vary depending on, for example, whether breaks were included.

One of the criticisms made of other studies of the relationship between infrastructure and output is that the estimates could be the result of reverse causation — that is, they may represent changes in the stock of infrastructure in response to changes in output rather than the reverse. For example, as output grows so do tax revenues and this provides a source of financing additional infrastructure projects.

Given these estimation issues, co-integration analysis techniques based on bounds testing and Autoregressive Distributed Lag (ARDL) models were selected for the estimations. (This was based on the Pesaran and Shin (1999) method — further details are provided in appendix J.) The ARDL models explain current MFP in terms of past values of MFP and past and present values of the infrastructure and control variables.

This approach has a number of advantages. Co-integration analysis of this type provides confidence that the estimated effects are not purely the outcome of trending data giving the impression of a relationship between variables, when in fact there is only statistical correlation. This approach also allows testing for reverse causality. And it incorporates dynamics in a systematic way without the need for prior specification of the lag structure. Infrastructure is an area in which lagged effects are likely, but the shape of the lag structure is unknown. These advantages are diminished to some extent in the context of a small number of observations.

Estimation process

A two step approach is used to estimate the market sector and industry models. Step one tests for the existence of a long-run co-integrating relationship using the bounds and long-run forcing tests procedures described in appendix J.

The long-run parameters are obtained in step two by estimating the following general ARDL(p,m) model

$$mfp_t = \alpha_0 + \lambda_t + \sum_{i=1}^{p} \phi_i mfp_{t-i} + \sum_{i=0}^{m} \delta_i x_{t-i} + u_t \tag{4.7}$$

where p is the maximum number of lags of the dependent variable and m is the maximum number of lags of the explanatory variables. The maximum choice of the number of lags is constrained by the number of available observations and the number of explanatory variables.

This model is estimated for every possible combination of p and m. For example, if the model contains 6 explanatory variables and 2 is the maximum lag then $(2+1)^6=729$ regressions are computed. From these estimated models those with the best fit are chosen using, in most cases, the Schwarz Bayesian Criterion (see table E.2). This criterion takes account of how well the model explains the dependent variables given the number of explanators used.

For the selected model — that is, the model with the best fitting lag structure — the long-run coefficient for explanatory variable x_1 is calculated as the sum of the coefficients on it and its lags divided by one minus the sum of the coefficients on the lagged dependent variable.

$$\alpha_1 = \frac{\sum_{i=0}^{m} \delta_i x_1}{(1 - \sum_{i=1}^{p} \phi_i)}$$

Dealing with limited observations

The available time series for the variables in this study is 29 observations. This is relatively limited when there are several infrastructure variables of interest and a number of other influences on productivity that should be controlled for in the regressions. Tradeoffs therefore had to be made in the choice of the initial set of explanatory variables before it was possible to implement the estimation process described above.

Ideally, the variables included in a model would be the result of a procedure that systematically tested alternative selections, starting with the inclusion of *all* possible control variables and interactions between variables. However, the limited time series means that tradeoffs must be made between: the prime interest in the infrastructure variables; a desire to control for other influences on productivity; a possible need to include controls for the business cycle and a linear time trend; and a desire to specify as general a specification as possible including the incorporation of lagged effects.

A tightly specified general-to-specific test down procedure is used to manage these tradeoffs. This means that the tests seek to control for what is believed to be other large influences on productivity based on the findings of other studies (for example, business R&D and education). Additional tests of the key variables are undertaken within specifications that contain fewer control variables but allow for a richer specification of lagged effects.

Criteria for model acceptance

Having used these estimation techniques, the results need to be assessed to see if they are satisfactory. A number of criteria need to be met:

1. evidence that the variables form a long-run co-integrating relationship
2. evidence that the direction of causation is in line with theoretical priors

3. other potentially important sources of growth are either controlled for or tested out of the regressions
4. acceptable statistical properties of models and coefficients
5. plausible economic magnitudes and signs.

The estimation process as described above includes assessment against the first four criteria. The first two criteria were tested by the bounds tests and long-run forcing tests, respectively. (Although the first criterion was difficult to apply strictly because of the small number of observations available for the modelling.) The general-to-specific test down procedure employed managed the process of controlling for other sources of growth (criteria 3). The standard suite of statistical tests for model robustness (as described in table E.2) also formed part of the estimation process (criteria 4).

The remaining criteria, the plausibility of the economic magnitudes of the coefficients on the variables of interest and the direction of effects, was assessed by comparing the results with other studies and theory.

Selection of the preferred models presented in chapter 5 and appendixes E and F was on the basis of these five criteria. Where a model failed to meet all of these criteria, this was indicated and alternative models were tested. In some cases, despite extensive testing, no model that satisfied all criteria was found.

For the market sector, the sensitivity of the preferred models was also tested using alternative infrastructure measures. This testing focused on two aspects of the measures — the scope of the infrastructure included (for example, all general government infrastructure not just roads) and the type of usage adjustment factor used (for example, a factor based on the share actual intermediate usage of communication services rather than value added).

5 Results and interpretation

This chapter summarises the results of this study — it is an overview of the main messages from the detailed results reported in appendix E (market sector) and appendix F (industries). The results are preliminary, in the sense that many of them have identified key modelling issues that require further examination.

5.1 The context for the results

A considerable body of empirical research exists on the effects of public infrastructure on output and productivity — although the number of Australian studies is more limited (chapter 2 and appendix A). This analysis extends or differs from previous Australian studies in a number of ways.

- It focuses on explaining conventionally measured multifactor productivity (MFP) for the market sector (and industries) rather than a constructed 'private' sector.
  - The 'free input' effect of some public infrastructure does not arise in conventionally measured MFP for the market sector. This shifts the focus from a 'free input' effect to production spillovers from infrastructure.
- It broadens the scope of infrastructure to include the communications network infrastructure not just public (general government) infrastructure.
  - Potential spillovers related to infrastructure facilitating innovation and organisational change are not restricted to publicly-owned infrastructure.
- It models the influence of infrastructure in the context of a range of other determinants of productivity.
  - By controlling for other determinants, the infrastructure effect should be better estimated.
- It uses improved measures of infrastructure services.
  - The capital services indexes that have been constructed for this study measure the flow of infrastructure services from a productive capital stock, rather than a wealth-based net capital stock. The service flow is generally recognised as the relevant measure but data limitations have previously led to the use of stocks.

- Alternative definitions of public infrastructure are compared. The emphasis is on road infrastructure because the theoretical basis for expecting possible spillovers is stronger. Road infrastructure is also a very large share of general government infrastructure.
- Alternative methods of proxying actual usage of total infrastructure services by the market sector or individual industries are examined for communication infrastructure.

- It includes a more extensive industry analysis than some studies.
- It uses estimation techniques more suited to the characteristics of the data than many studies that use similar data and the production function approach.

5.2 Empirical results and implications

The main messages of the empirical analysis presented in this section are based on the detailed results in appendix E (market sector) and appendix F (industries). While these results need to be considered within the context and constraints of the available data and methods adopted, they represent a detailed exploration of the relationship between various types of infrastructure and productivity at the market sector and industry levels.

Preferred models were selected from the range of models tested as part of the general to specific test down procedure employed and on the basis of the criteria for model acceptance outlined in chapter 4 (four criteria covering statistical/econometric properties and the last criteria relating to economic plausibility). However, in general the results were less than fully satisfactory against these criteria, failing one or more of the criteria. Most of the industry models failed the plausibility criteria and/or one or more of the statistical criteria. The preferred market sector models generally passed the statistical criteria but failed the economic plausibility criteria (for road infrastructure) or were very imprecisely estimated (for communication infrastructure).

Therefore, the magnitudes of the elasticities and implied rates of return have not been reported in detail in this chapter (tables of results are provided at the end of appendix E for the market sector and the end of appendix F for industries). The discussion of results in this chapter is aimed at: highlighting at a broad level where these results of this study fit within the range of results from other studies of this kind; the methods used to attempt to improve the results; and potential sources of estimation problems.

In most cases, robust estimates of the effect of road infrastructure and communication infrastructure on MFP could not be obtained within the same model. The results are therefore examined by infrastructure type.

Public economic infrastructure

Market sector results

The preferred MFP level models for the market sector produced road elasticities (effect on MFP of a 1 per cent increase in road services) of 0.31 to 0.43 and elasticities for the broader measure of public infrastructure (closer to that used in most other studies[1]) of 0.39 to 0.49. The lower ends of these ranges are the usage-adjusted infrastructure variables and the upper ends are the unadjusted variables. This shows the sensitivity of the results to the construction of the infrastructure measure.

These estimates are statistically significant and are from models that pass most of the criteria established for model acceptance. However, the economic magnitude of the coefficients is very large — particularly considering they are capturing spillovers other than a free input effect. (Public infrastructure is already included in the capital service measure used by the ABS to construct their market sector MFP index).

A number of alternatives were therefore investigated.

- Since MFP is constructed assuming constant returns to scale, the existence of increasing returns to scale could bias the estimates upwards. But tests suggested this was not the problem.
- Labour productivity regressions were used to test whether the measured effects held in the absence of the assumptions used to construct MFP. But labour productivity models including roads did not meet the criteria for model acceptance.
- The estimation method used for the level models is based on the assumption of the existence of a co-integrating relationship between the variables. Additional confidence can be obtained from differenced regressions if the results are roughly similar to those in the levels models. But in most differenced models the roads variable tested out of the model. Where it was retained it was of similar economic magnitude (0.37), but estimated very imprecisely.

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1 This public infrastructure measure is still narrower than that used in other studies because it excludes social public infrastructure such as schools and hospitals.

Industry level results

The industry results in this study suggest broadly similar relationships to those found at the market sector (although the extent of the relationship varied by industry). The estimates capture both a free input effect and production spillovers. But the models are subject to more acute estimation difficulties.[2] For most industries there is no preferred model — while a number of plausible models can be generated, in most cases the models fail one or more econometric tests for robustness.

On the basis of the most reliable (least unreliable) industry estimates, the range of elasticity estimates is 0.5 to 2.3 (for those industries where the road infrastructure variable was statistically significant). Manufacturing, Wholesale trade and Retail trade are at the lower end of this range, Transport & storage, Agriculture and Mining are mid range and Electricity, gas & water is at the top of the range. But in all cases, except Manufacturing, the road variable is usage adjusted and this drove the significance of the variable. When the unadjusted variable was used, the road variable became insignificant.

Many different strategies were employed in the industry tests. While varying by industry, the strategies included:

- tests of alternative controls for scale
- tests of parameter breaks due to, for example, structural reform of an industry or one-off shocks, such as the Sydney Olympics
- shifts in the effect of IT capital with an increasing effect expected
- different controls for the business cycle and shocks, such as terms of trade or variations in the cost of capital and holding inventories
- alternative estimation techniques.

Comparison with other studies

While comparisons with other studies are not straightforward because of differences in infrastructure coverage and time periods, the range of estimates for public infrastructure elasticities is very wide. In most cases rates of return are not reported in other studies (limited comparisons of rates of return are therefore provided in appendix sections E.9 and F.11).

[2] As noted earlier, industry MFP data used in the models are also less accurate than at the aggregate level.

For Australian aggregate studies that produce output-side elasticities[3], the range is 0.008 to 1.19 — although the majority of studies fall in the 0.2 to 0.5 range (appendix A). The 'preferred' market sector models in this paper are in line with the majority of other studies and are also subject to the same concerns about the large magnitudes.

For Australian industry studies, the range of elasticity estimates for public infrastructure is even wider — -0.26 to 3.50 across all industries — and the authors generally considered their industry results less reliable than their aggregate ones (appendix A). The range for most individual industries is similarly wide and there is no clear pattern in terms of which industries have the largest/smallest effects. The industry results in this study fit within the range of those in other studies (at the positive end) and are subject to similar concerns about reliability.

Implications

Overall, in this study the estimated effects of public economic infrastructure on MFP are positive and large. But, while in line with the majority of other studies, these results are subject to the same concerns about implausible magnitudes — that they are too high to be credible in absolute terms (over 100 per cent in many cases) and relative to private capital (several times private returns in many cases).[4]

The elasticities in this study imply implausibly large rates of return on infrastructure[5] and are also imprecisely estimated, as figure 5.1 illustrates for the market sector. And while similar in magnitude to other studies there are two differences in approach in this study that might have been expected to make them smaller. At the market sector level the estimates do not include the 'free' input effect captured in other studies. And other influences on productivity are controlled for in the models, unlike many other studies.

At the industry level, the results are largely driven by the usage adjustment to the infrastructure variable. The adjustment factor is based on valued added and is a relatively crude proxy for actual usage. It also introduces some interdependence between the measurement of inputs and outputs. This weakens the interpretation of

[3] Production function studies, or cost function studies in which the output-side equivalent is derived and reported.

[4] For further discussion of the implausibility of returns in infrastructure studies see Gramlich (1994) and Munnell (1992).

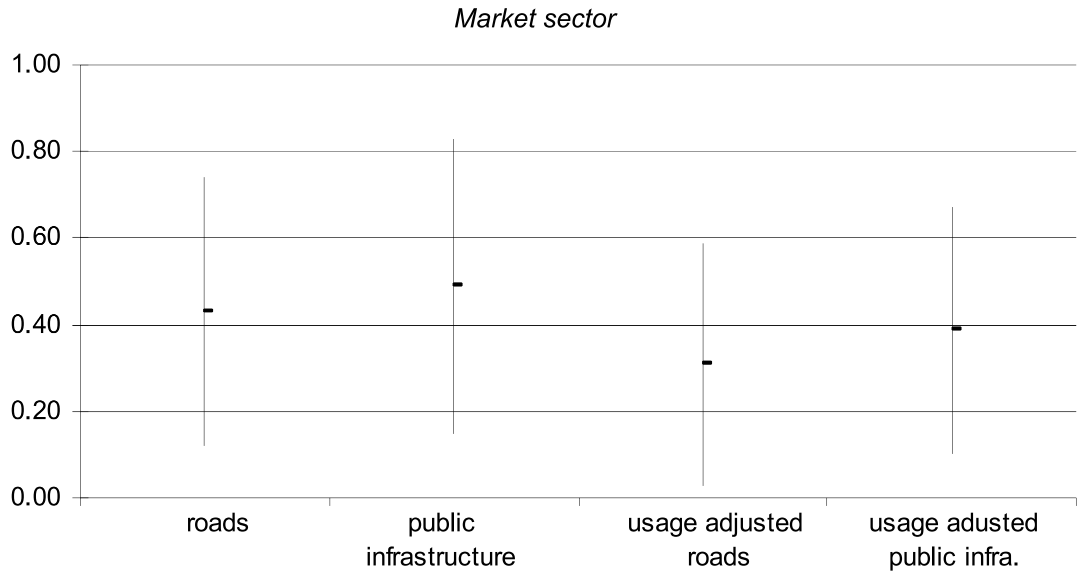
[5] The rates of return are calculated by multiplying the estimated MFP elasticity with respect to infrastructure by the ratio of output to the average productive capital stock of infrastructure. This calculation is based on the assumption that the MFP elasticities are close approximations of the output elasticities from which rates of return are usually calculated (see appendix E).

the results (in this and previous studies using similar usage adjustments) as changes in infrastructure causing productivity growth.

Despite the improved infrastructure measures and the range of estimation and testing procedures employed, there is enough contradictory evidence that there remains concerns that such large coefficients may in fact be spurious. The very large estimates for road infrastructure from the MFP level models are not corroborated by the differenced models or labour productivity models at the market sector level. And in most cases the industry models did not pass the criteria for model acceptance.

Figure 5.1 **Implausibly large and imprecisely estimated public economic infrastructure elasticities**

Point estimate and confidence interval based on plus or minus two standard errors



Results are from appendix E models RI5, RI5(1), RI6 and RI5(2), respectively.

Data source: Authors' estimates.

This study therefore adds to the doubt about the 'stratospheric' returns to public infrastructure produced in earlier studies — but it does not provide alternative, robust and more plausible estimates. However, it has identified some potential sources of estimation problems and areas for further examination.

Potential sources of the problems in modelling roads

Given these implausible results, consideration was given to some potential sources of the problems in modelling roads (section E.7).

- There is relatively little variation in road capital services and this could affect the ability of statistical methods to reliably identify relationships. Estimation based on a panel of industries may help increase variation, but not without introducing other problems. For example, as there is only a single road capital services measure available for all of Australia, one method for achieving an increase in variation involves allowing the effect of roads on industry MFP to vary by the intensity of vehicle use (see Fernald 1999). Initial testing of that model on Australian data did not produce encouraging results.
- Changes in capacity utilisation or congestion of roads, which were not measured in this study[6] (nor in previous Australian studies), may have led to an upward bias in the estimated effect of roads on MFP.
  - Total vehicle kilometres travelled has consistently grown faster than measured road capital services, suggesting that average capacity utilisation has increased significantly over the period.
  - It is possible that estimates of the effect of road infrastructure are biased upward by ignoring the apparent long-term upward trend in capacity utilisation.
- The elasticity of road infrastructure may have changed over time if network threshold effects are strong. Simple structural break tests did not indicate a break in the effect of roads, but this may be because the effect of roads is imprecisely measured. A more formal approach to investigating these issues was undertaken by Colletaz and Hurlin (2006).
  - The authors applied a 'panel smooth threshold regression' model to investigate the effects of public capital in a cross-country panel context and found more plausible elasticities on public capital — 0.066 for the United States and 0.136 for Australia.[7]
  - They interpreted their results as indicating that the relationship between output and the public capital stock is non-linear and exhibits strong threshold effects. At low levels of infrastructure, the return to public capital is not dissimilar to private capital (investment levels are too low to capture potential network effects). At mid-range levels, the return to public capital is significantly above the return to private capital. At high levels of public capital, where infrastructure networks are largely complete, the return to additional investment is again roughly equal to that of private capital.

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6 The usage-adjusted infrastructure measures used in this paper only capture changes in relative usage between sectors and not underutilisation or congestion.

7 Colletaz and Hurlin (2006) did not report the implied rates of return for Australia. However, as this elasticity is less than half that of other studies the rate of return would also be more than halved.

Communications infrastructure

Market sector results

Initial models including both communication infrastructure (adjusted by sector's share of intermediate usage) and IT capital and a range of other explanatory variables produced statistically significant estimates of around 0.06 for the communication elasticity and -0.02 for the IT capital elasticity. A negative effect of IT may be plausible if the wide diffusion of IT capital has entailed substantial disruptive effects and adjustment costs. However, tests suggested that the results could not be interpreted as intended — that is, that a change in communication infrastructure or IT capital would *result* in a change in MFP — because they left open the possibility of reverse causation. Attempts to improve these models by using different business cycle controls, lag structures and sets of control variables did not produce a model that was satisfactory overall.

Additional models were therefore examined. One factor not incorporated into the initial models was the digitisation of the copper telecommunications network. The capital services index for communication infrastructure may not fully reflect the additional functionality of the copper network that has arisen from digitisation. Attempts to separately capture this effect did not produce a significant estimate — but some models that incorporated an interaction between digitisation and IT capital passed the model acceptance criteria. The 'preferred' model produced a communication elasticity of 0.05 and a coefficient on the interaction between digitisation and IT capital of around 0.01. This provided some evidence of positive spillovers from communication infrastructure and digitisation of the copper network enhancing the effect of IT capital on productivity.

However, the direct effect of communication infrastructure in these models was not estimated very precisely. Alternative specifications were therefore tested.

- Market sector MFP was also explained well by models that did not include a direct excess effect of communication infrastructure.
- Differenced regressions did not support an effect different from zero.
- Sensitivity testing of the usage adjustment showed that an alternative (value-added) usage adjustment factor or no adjustment did not improve the precision of the estimates. These alternatives led to much larger estimates that were estimated with less precision.

Industry level results

The preferred industry models containing communication infrastructure provide some support for the market sector results. However, the results for particular infrastructure variables vary considerably across industries. This would be expected as a result of industry specific effects but may also be due to measurement issues and the significant difficulties in modelling industry MFP. The modelling of MFP at the industry level has highlighted the value of current ABS efforts to improve the quality and availability of industry level data.

Communication infrastructure had a positive effect on industry MFP (for those industries where it survived the test down procedure). Preferred model results range from 0.03 to 0.10 (with the market sector results about mid-range at 0.05). The communication infrastructure elasticity was statistically significant for Transport & storage (0.10), Wholesale trade (0.07), Manufacturing (0.08) and Electricity, gas & water (0.03) (see appendix F). Some acceptable models of Finance & insurance, other than the preferred model, also had a positive effect (0.3–0.13). However, the imprecision of the preferred model estimates also mean that the confidence interval for these estimates included zero (or no effect) for Electricity, gas & water and for Wholesale trade.

The industry models also provide some support for the market sector results of the effect of digitisation. For five of the seven industries for which the preferred model included this variable, digitisation enhances the effect of IT capital on MFP. The positive industry results were considerably larger than those for the market sector — with an industry range of 0.027 to 0.201 compared with around 0.01 for the market sector. The exceptions are Mining and Manufacturing, for which the effect was around -0.04 (suggesting disruption effects). The largest positive effects were for Wholesale trade and Transport & storage.

Comparison with other studies

There are few directly comparable studies available. Australian studies have generally focused on the impact of IT or ICTs on productivity, rather than on communication network infrastructure. However, one US study (Nadiri and Nandi 2001) examined communication infrastructure in a similar way to public infrastructure studies and this study. Differences in methodology make magnitude comparisons difficult. But, given a number of assumptions, the US estimate appears smaller than the results in the preferred market sector models in this paper (0.014 compared with 0.05) (see appendix E for details). This might be expected if Australia lags the United States in the completion of major networks or the significant upgrading of those networks, as the potential gains from upgrading may have been more fully exploited in the United States.

Similar comparisons of magnitudes are not possible at the industry level but industry patterns can be compared. Nadiri and Nandi (2001) found positive spillovers for all industries and relatively larger spillovers in the service industries (such as Wholesale & retail trade and Finance & insurance). They suggest this is a reflection of the high information intensities of these industries. This industry pattern is not as apparent in the preferred models in this paper — for Retail trade and Finance & insurance, for example, communication infrastructure was not statistically significant. However, communication infrastructure was statistically significant for Wholesale trade and in some acceptable models of Finance & insurance (other than the preferred model).

For the effect of digitisation there are also few direct comparisons available. However, the generally positive estimates for the interaction between digitisation and IT capital found in this paper accord with the results of Barker et al. (2006) — that digitisation of telecommunications infrastructure improved the productivity impact of increases in the penetration of personal computers.

Implications

Overall, in this study the estimated effects of communication infrastructure on MFP are positive and broadly in line with similar studies. The results are also more plausible in size than those for road infrastructure in most cases. However, they are still less than definitive.

The effect of communication infrastructure is not estimated very precisely and the confidence interval around the estimates includes zero in many of the industry models. Alternative models suggest that MFP can be explained well without the inclusion of a direct excess effect of communication infrastructure. And alternative specifications, such as labour productivity models and differenced regressions, are also less supportive of this positive spillover effect.

Attempts to capture separately any effects of digitisation of the copper telecommunications network yielded mixed results. A separate digitisation effect could not be identified but there is some evidence of a positive interaction between digitisation and IT capital. But if it is the case that the process of digitisation of telecommunication infrastructure is essentially complete, then these effects could be expected to diminish. Further increases in transmission capacities of the digitised network are unlikely to bring the same sort of social return that it appears resulted from the initial digitisation of the network.

5.3 Further work

At the level of the market sector, the preferred results for the effects of road infrastructure, communication infrastructure and digitisation are from models that are statistically acceptable. The models include a good range of control variables that have effects that are signed as expected and are measured well.

The results are from general-to-specific test down procedures, with the sensitivity of results to various tests documented in the supporting appendixes. The estimation methods employed are suitable for the data at hand (subject to the limitations of a small number of observations).

A transparent approach to which models 'did not work' was taken, giving additional confidence to the measured effects, and clearly demonstrating the limitations of current data and methods in identifying the magnitudes of effects.

That said, the results of the econometric analysis in this study have not provided robust and more plausible estimates for the effects of public infrastructure in most cases. The extensive investigation has identified some key modelling issues for further examination.

There are three key issues.

- Changes in capacity utilisation and/or congestion are not accounted for in the road capital services measure used in the modelling.
- There may be threshold effects that are not allowed for in the modelling techniques used in this study.
- There may be spatial dimensions to the infrastructure spillovers that are not allowed for in the aggregate level modelling in this study.

Some preliminary investigation of the issue of utilisation/congestion of roads was undertaken but the further work required is beyond the scope of this paper. The application of more complex modelling techniques to aggregate time series analysis may assist in the identification of the link between infrastructure and productivity. But their application is severely limited by the small number of data observations that are currently available. Alternative types of disaggregated analysis (such as spatial equilibrium models) may provide more insight into this link — although these approaches may also be limited by data availability.

A Overview of empirical literature

This appendix surveys the main empirical literature of the links between public infrastructure and communications infrastructure and productivity.

The literature on the effects of infrastructure on output and productivity was initially dominated by examination of public infrastructure. The following literature review therefore starts with public infrastructure before broadening out to examine communications infrastructure.

This appendix focuses on broad methodology and results, rather than details of econometric and data specifications. It is not intended to be exhaustive but rather to provide an overview of the main types of empirical analyses in this subject area.

A.1 Public infrastructure

A stream of empirical literature on the effects of public infrastructure on productivity commenced in the 1990s. It was stimulated by the work of Aschauer (1989a), which attempted to explain the slowdown in US productivity growth during the 1970s in terms of the decline in public infrastructure investment.[1]

Using a Cobb-Douglas production function with aggregate time series data, Aschauer estimated the (private sector) total factor productivity (TFP) elasticity with respect to public infrastructure for the aggregate US economy to be between 0.34 and 0.39. This implied a very large rate of return to public infrastructure (60–146 per cent per year), and was considered to be implausibly large by many researchers (see, for example, Munnell 1992; Gramlich 1994).

This led to a number of similar studies (for example, Munnell 1990b, Garcia-Mila and McGuire 1992) that produced similar elasticity estimates at the aggregate level

[1] Conrad and Seitz (1994, p. 303) note that "The fundamental idea of this so–called 'public capital hypothesis' [that public capital raise the productivity of private capital] is not new, because this aspect has been examined both theoretically and empirically especially in the urban and regional economics literature in the past … What is new in the ongoing debate, besides bringing this aspect to the level of the national economy, is the identification of the neglect of public investment as an explanation for the slowdown of productivity observed throughout most industrialized countries."

but smaller estimates at the state or region level[2] — in the range 0.04 to 0.20 according to Paul (2003). The large variation in estimates led to questions about the Aschauer approach, including the appropriateness of the restrictive approach based on a Cobb-Douglas production function.

There were two responses to these criticisms in subsequent empirical work. One stream of work introduced more flexible function forms, such as translog functions, into the production function approach. An alternative stream of research was based on flexible cost functions. The estimates of studies from both these approaches tended to be smaller, although some studies found no significant relationship.

There remain two competing lines of research into the contribution of public infrastructure to economic growth — the production function approach and the cost function approach. The details of these approaches are outlined in turn.

Production function approach

The production function approach assumes that public infrastructure capital is one of the direct inputs to production and regresses time series data of productivity on the usual input variables plus the stock of public infrastructure. The production function

$Y = \tilde{A}\,F(K, L)$ is redefined as

$Y = A\,F(K, L, G)$ where

where Y is private sector output; $\tilde{A}$ is the level of total factor productivity; A is total factor productivity purged of the influence of the public infrastructure capital stock; L is the quantity of labour input; K is the stock of private capital; and G is the stock of public infrastructure capital.

Initially, the commonly–used specification was the Cobb-Douglas production function.

$$Y = A\,K^{\alpha} L^{\beta} G^{\gamma}$$

2 It has also been suggested that disaggregated studies are capturing fewer spillovers than national studies and this may explain the lower estimates (Eberts 1999). Kahn (1993, p. 2) noted that the decline in the output elasticities (by about half) when state level data are used is generally attributed to neighbourhood spillover effects that are not captured at the state level but are included in national data.

The estimated equation was typically

$$\ln Y = \ln A + \alpha \ln K + \beta \ln L + \gamma \ln G \text{ or } y = a + \alpha k + \beta l + \gamma g$$

where γ is the elasticity of output with respect to public infrastructure capital.

Most studies do not directly estimate the relationship between infrastructure and productivity but instead use the elasticity of output with respect to public infrastructure to represent the effect. However, a few studies are more explicit. For example, Aschauer (1989a) and Otto and Voss (1994a) derive an equation for private sector productivity.[3] They have two alternative specifications depending on the assumptions about returns to scale:

1. *Restricted increasing returns to scale*, where returns are increasing over all inputs but constant over private inputs. In log terms the expression for private productivity is

   $p \equiv a + \gamma g$ where γ is the output elasticity with respect to public infrastructure and assuming private inputs are paid their marginal factor productivity.

2. *Constant returns to scale,* where returns are constant across all inputs. In log terms the expression for private productivity becomes

   $p = a + \gamma\,(g – s_l l – s_k k)$ where s_i is input i's share of total output.

There are a number of criticisms of the production function approach. The use of the Cobb-Douglas production function in particular raises questions about returns to scale in such estimations. Hakfoort (1996, pp. 63–5) notes

> The usual questions about the returns to scale over all three factors and the influence of the public capital stock on factor demands are interesting when interpreting the empirical results. …The restrictions of the functional form are apparent from the fact that the substitution–elasticities between the various inputs are constant and equal to unity. This implies that any additional investment raises *by assumption* the average and marginal productivity of the other inputs. The possibility that public and private capital stock are complementary is not allowed for in this setting.

3 Otto and Voss (1994a) define the private sector as agriculture, mining, manufacturing, wholesale and retail trade, and recreation (an alternative definition also includes construction and transport, storage and communication). They note that the standard measure of TFP generally involves aggregate measures of inputs and production and so long as this aggregation is suitable, then those standard measures do account for the contribution of public capital as well as all other resources used in the public sector. But their definition of private sector does not do this.

Gramlich (1994, p. 1185) notes that

> Because government capital is not paid for its services, interpretation of the production elasticities, *a ,b,* and *c* [where *a*=α, *b*=β and *c*=γ], is tricky. If one assumes that private capital and labor are paid their marginal products and finds *a* to be positive*,* $a + b = 1$ and $a + b + c > 1$, so that returns to scale are increasing. If one assumes returns to scale are constant and finds *c* to be positive, $a + b + c = 1$ and $a + b < 1$, so that labor and capital are paid more than their marginal products.

More general criticisms of the production function approach, particularly as applied in early studies, such as Aschauer (1989a), include the following.

- The estimated elasticities imply implausibly large returns on public capital, exceeding the returns on private capital by several times. However, as noted above, disaggregated data and different functional forms do reduce the size of the estimates.
- The estimates may not reflect a causal relationship but may represent spurious correlation, with productivity and public infrastructure moving together due to other forces.
- Reverse causation may be present between public infrastructure capital and productivity. The estimates may represent the effect of productivity on infrastructure capital rather than the reverse.
- The effects of omitted variables may be attributed to public capital.

Aschauer (1992) provides a fuller discussion of the criticisms of this approach and econometric techniques that may address these criticisms.

Results

The literature largely focused on the US economy initially. However, from the mid-1990s studies of a number of countries, including Australia, were undertaken. Because studies differ in their definition of infrastructure, industry coverage, geographic coverage, modelling methodology and econometric techniques, comparisons of results are problematic. However, there are a small number of papers that examine multiple OECD countries and allow international comparisons (for example, Ford and Poret 1991, Demetriades and Mamuneas 2000, Pereira 2001).

Table A.1 presents the estimates for the output or productivity elasticity of public capital in the main production function studies for countries other than Australia and table A.2 reports on studies of, or including, Australia. Across the full range of studies, the estimates range from below zero to more than one. For Australia, the estimates range from 0.02 to 0.4 The wide range may be, in part, the result of differences in the study methodology. This wide range of estimates, however, is one of the reasons for the criticisms of this approach.[4]

The literature on this topic is voluminous and the coverage in this paper is not exhaustive. Additional details can be found in survey articles that focus of particular subsets of the literature. Romp and de Haan (2005) provides a summary of focused on recent studies (1997-2004), mainly regional and cross-country studies. They report a range of elasticities from 0.05 to 0.65. However, the estimates tend to be concentrated at the lower end of this range and the authors note that the elasticities reported in recent studies are substantially less than suggested in earlier studies. Sturm et al. (1996) also provides a summary that includes additional US state studies and studies of other countries (prior to 1997) and report a range of elasticities of -0.11 to 0.73.

4 The sensitivity of Aschauer's results to data revisions has also been noted by several authors (for example, Luskin 1996; Kinhill 1994).

Table A.1 **Results of main production function studies including infrastructure, other countries**

Author	*Specification of functional form (method)*	*Data*	*Elasticity*[a]	*Comments*
Aschauer (1989a)	Cobb-Douglas production function and TFP regressions	time series 1949-85, US private business economy	0.36 to 0.39 (output) 0.34 to 0.39 (TFP) (0.24 for core infrastructure)	CRS in all inputs (incl. public capital)[c]
Aschauer (1989b)	Labour productivity regressions	time series 1967-85, G7 countries	0.34 to 0.73 (LP with respect to ratio of public investment to GDP)	
Eberts (1988)	Translog production function	cross-section, manufacturing, 1958-78, 38 US metropolitan areas	0.04	CRS[c], public and private capital are substitutes, public capital and labour complements
Munnell (1990a)	Cobb-Douglas production function (reproduces Aschauer)	time series 1948-87, US private non-farm sector	0.34 to 0.41	CRS in all inputs[c]
Munnell (1990b)	Cobb-Douglas production function	cross-section of 48 US states, time series 1970-86	0.15	Increasing returns to scale
Munnell (1991)	Cobb-Douglas production function	cross-section, average, 1970-86; US states by level of eco. development (12 high, 26 mid, 10 low)	0.14 0.11 0.22	Increasing returns to scale
Tatom (1991)	Cobb-Douglas production function including energy price, with first differences	time series 1974-87, US business sector	0.146 insignificant	CRS[c]
Ford and Poret (1991)	TFP regressions based on Cobb-Douglas production function	time series and country cross-section, US and 11 OECD countries (various periods 1957-88)	-0.55 to 1.11 (TFP) narrow infrastructure -0.77 to 1.39 (TFP) broad infrastructure (insignificant for half of countries)	mixed support of Aschauer results
Hulten and Schwab (1991)	TFP regressions	cross-section, time series, US regional study of snow-sun belt, 1970-86, gross output value added	public capital insignificant in all regressions	

(continued on next page)

Table A.1 **(continued)**

Author	*Specification of functional form (method)*	*Data*	*Elasticity*[a]	*Comments*
Garcia-Mila and McGuire (1992)	Cobb-Douglas production function	cross-section, time series, 14 annual observations of 48 US states; gross state production, capital expenditures on education and highways	highways: 0.045-0.044 education: 0.16-0.072	Cannot reject increasing returns to scale
Canning, Fay and Perotti (1994)	Output growth	panel, 1960-85, 98 countries (cross-section and panel analysis)	numerous results; telephones and electricity significant; roads and railways unclear because of statistical problems	physical infrastructure measures; relationship between infrastructure level and output growth
Holtz-Eakin (1994)	State production functions using various methods including instrumental variables	panel, 1969-86, 48 US states	-0.1 to 0.02 but insignificant in most cases	Account for state-specific effects
Garcia-Mila, et al. (1996)	Cobb-Douglas production function	cross-section, time series, 1970-83, 48 US states	highways: -0.058 water & sewers: -0.029 other public capital: -0.022 (all insignificant)	Preferred specification of first differences with fixed state effects
Wylie (1996)	Cobb-Douglas and translog production functions	time series 1946-91, Canadian goods sector	For Cobb-Douglas, 0.407-0.436 (labour productivity) For translog production function, MP of infrastructure 0.248	For translog function, infrastructure measured as complementary to both labour and private capital
Lau and Sin (1997)	Multivariate stochastic co-integration method	1925-89, US	0.11 (output)	
Vijverberg et al. (1997)	Cobb-Douglas & semi-translog production function	time series 1976-85, US	labour productivity elasticity -4.03 to 2.84 depending on model and type of infrastructure	wide range of models with different assumptions and infrastructure definitions

(continued on next page)

Table A.1 **(continued)**

Author	*Specification of functional form (method)*	*Data*	*Elasticity*[a]	*Comments*
Charlot and Schmitt (1999)	Cobb-Douglas and translog production functions	Panel, 22 French regions, 1982-93	Cobb-Douglas CRS 0.07 to 0.32; Cobb-Douglas IRS 0.16 to 0.32 Translog OLS -0.25 to -0.64; Translog fixed effect 0.12 to 0.51	Fixed effects model preferred
Fernald (1999)	Translog production function	time series 1953-89, US agg and industry groups. Focus on roads infrastructure	0.35 to 0.38 for agg (elasticity not reported for industry groups)	Includes congestion (road services as a road use and road stock)
Pereira and Flores de Frutos (1999)	Vector auto-regressive framework	time series 1956-89, US private output	0.63 (long run)	Includes dynamic feedbacks
Canning and Bennathan (2000)	Variant of translog production function	Panel 1960-90 for 62 countries. Physical measures of infrastructure (length roads, Kw electricity generation capacity); Output	0.09 (roads) 0.09 (electricity)	CRS imposed. Compl. with other types of capital
Pereira (2000)	Vector auto-regressive framework	time series 1956-97, US private output, public investment not stock of infrastructure	Long term (output)[d] 0.006 roads 0.021 (electricity & gas, other transport) 0.009 (water & sewerage) 0.04 (aggregate)	Includes dynamic feedbacks
Wang (2002)	Dynamic 2 sector model	time series 1979-98, for 7 East-Asian countries, private production	0.2-1.5 (long run)	some evidence of reverse causation

[a] Elasticity refers to the percentage increase in some variable (output unless specified) that will arise from a 1 per cent increase in the level of infrastructure capital. For example, Aschauer estimates that a 1 per cent increase infrastructure leads to an increase of 0.36 to 0.39 percent in aggregate private sector output. Estimates are 'significant' (in a statistical sense, significantly different from zero) unless otherwise stated. [c] CRS is constant returns to scale. [d] Total percentage point change in output for each long-term accumulated percentage point change in public investment once all dynamic feedback effects among different variables are considered.

Source: Updated from Gillen (2001).

Table A.2 **Results of main production function studies including infrastructure, Australia**

Author	*Specification of functional form (methodology)*	*Infrastructure variable/ Dependent variable*	*Data*	*Elasticity*
Australian single-country studies				
Otto and Voss (1992, 1994a)	Cobb-Douglas	**public capital** (gross capital stock of general govt non–dwelling construction & equipment)[a] **private output/productivity**[d]	time series 1966-67 to 1989-90	Aggregate: 0.38 to 0.45 (productivity) Sectoral: -0.14 to 1.55 for CRS; -0.24 to 2.04 for RIRS (productivity)[bg]
Otto and Voss (1993)	Cobb-Douglas	**road infrastructure** (investment) **private output/productivity**[d]	time series 1966-67 to 1991-92	Aggregate: 0.27
IC (1995)	Cobb-Douglas (included range of control variables)	**public capital** (general government stock of net public capital non-dwelling construction & equipment) **MFP**	1976-77 to 1990-91	Sectoral: 0.16-0.28
Otto and Voss (1996)	Cobb-Douglas (co-integration analysis)	**public capital** (as above plus public enterprises) **private output**[h]	quarterly time series 1959:3 to 1992:2	LR 0.17 (output) CRS across all 3 inputs
Otto and Voss (1998)	Cobb-Douglas; CES (co-integration analysis; instrumental variables)	**public capital** (as for Otto and Voss 1994a) **private output**[h]	time series 1959:3 to 1992:2	0.06–0.07[c] (output)
Madden and Savage (1998)	ECM model (co-integration analysis)	**ITT capital** (telephones) **labour productivity**	time series 1950 to 1994	LR 0.183; SR 0.264 (labour productivity)
Chand et al. (1998)	Neoclassical growth model	**net general government capital stock** **growth in MFP**	Mfg industries time series 1968-69 to 1994-95 and panel	FBT -0.75 and TCF 0.84; manufacturing panel -0.26 (insignif)
Kam (2001)	ECM model (stochastic growth model)	**net public capital stock** (plant&equip + railways of general government and public enterprises) **labour productivity**	time series 1931 to 1991	LR 0.10 (output)

(continued on next page)

Table A.2 **(continued)**

Author	*Specification of functional form (methodology)*	*Infrastructure variable/ Dependent variable*	*Data*	*Elasticity*
Song (2002)	CES	**public capital** (capital stock of general govt) plus a congestion term **private output**	quarterly time series 1976:1 to 2001:2	0.27–0.38[e] (output) CRS imposed over 3 inputs.
Connolly and Fox (2006)	Cobb-Douglas	**general government net capital stock; private output/mfp**	time series 1966 to 2002 Industry sectors Mfg, WART, Mining, Ag.	Mfg 0.15 (mfp) WART 0.71 (mfp) Not significant for other industries. CRS across all inputs imposed.
Shanks and Zheng (2006)	Cobb-Douglas (included range of control variables)	**Capital services index for public infrastructure assets** **MFP**	1974-75 to 2002-03	Market sector: 0.23 Sectors: 0.5 to 1.07
Multiple-country studies that include Australia				
Ford and Poret (1991)	TFP regressions based on Cobb-Douglas (log differences)	**narrow infrastructure** (capital stock of producers of govt services); **broad infrastructure** (narrow + equip&structures in EGW + structures in T&C) **TFP**	time series 1967 to 1987, 11 OECD incl Aust	Australia: narrow 0.18–0.27 (insignificant); broad 0.22–0.37 (insignificant); (TFP)
Pereira (2001)	VAR/ECM models	**broad public capital** (public investment in capital stock of producers of govt services, infrastructure in transport & comms and equipment & structures in EGW); **private output**	1965 to 1990, 12 OECD incl Aust[d]	Australia: elasticities with respect to public investment 0.017 (LR output); 0.097 (LR labour productivity growth) Public investment substitute for both private investment and labour.
Milbourne, Otto and Voss (2001)	Cobb-Douglas (CRS) within a Mankiw, Romer and Weil structural model of economic growth	**govt capital investment** (aggregate and disaggregated into 6 sectors) **output per capita**	cross section, 74 countries incl Aust; 1960 to 1985	0.19–0.24 (output with respect to public investment) for transition model, depending on set of countries. Insignificant in other models.

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Table A.2 **(continued)**

Author	*Specification of functional form (methodology)*	*Infrastructure variable/ Dependent variable*	*Data*	*Elasticity*
Kamps (2006)	Cobb-Douglas (first differences)	**General government net capital stock** (adjusted for international comparability; **output**	1960 to 2001, 22 indiv. countries and panel	Australia: 0.27 (insignif) OECD panel av.: 0.223 (signif).
Khan and Luintel (2006)	MFP regressions (range of methods incl static OLS and IV; AR OLS and IV; GMM single equation and system)	**Stock of public physical capital** **MFP** (R&D focus and includes a number of control variables)	Panel 16 OECD countries, 1980 to 2002	Australia: 0.008 (GMM system) but insignificant. Other countries: +ive effect on 7 and –ive effect on 8 other countries. Panel: -0.01 for AR; -0.1 for static; insignif on own for GMM but effect in interaction terms with domestic R&D is +ive and with high tech import share is –ive
Colletaz and Hurlin (2006)	Cobb-Douglas (panel smooth threshold regression)	**Public net capital stock (general government sector)** (from Kamps 2004) **capital productivity**	Panel 21 OECD countries, 1965 to 2001	Australia: 0.136 (CRS); 0.267 (RIRS).

[a] Results at aggregate level for alternative measure of public capital (general government plus government trading enterprises) not reported, except to state that they did not change basic finding of positive relationship between public capital and productivity. [b] RIRS is restricted increasing returns to scale (constant over all inputs but increasing for public capital) was preferred specification. [c] Lower than 1996 because different method (that is, hypothesis of efficient capital provision acts as a restriction on parameter estimation). [d] Private output. Otto and Voss define this as consisting of those industries in which production is predominantly performed by private enterprises (Agriculture, Manufacturing, Mining, Wholesale & retail trade, Recreation & Personal services) [e] Private output with respect to public capital 0.27 (ABS data) to 0.386 (TRYM data). Private output with respect to public capital output ratio 0.4–0.6. [g] -0.24 to 2.04 for RIRS, -0.26 to 1.55 for CRS (elasticity with respect to public/private capital ratio) but ranking of industries not the same between RIRS and CRS specifications. [h] Uses a different definition of private output and different capital stock estimates to Otto and Voss (1994a). Data is separated by institutional sector as collected by ABS (ie public and private) rather than mainly private industries being selected are the private sector.

Table A.3 provides further details from Australian industry productivity regressions.

Table A.3 **Results for public infrastructure variables in Australian industry productivity regressions**

Public infrastructure elasticity

Author	*AG*	*MIN*	*MAN*	*CON*	*WRT*	*TSC*	*RPS*	*AGG*
Otto and Voss (1994a)[abl] — 1966-67 to 1989-90; dep. variable =ln(KP)[m]								
• CRS	1.30	1.55	0.15	-0.26	-0.15	0.15	-0.14	0.45
• RIRS	0.41	2.04	0.27	0.43	0.24	-0.24	0.29	0.38
IC (1995)[d] — 1976-77 to 1990-91; dep. variable =ln(MFP)	0.28[j]	[e]	0.27		0.16			
Chand et al. (1998)[d] — 1968-69 to 1994-95; dep. variable = Δ ln(MFP)			(FBT) -0.75 (TCF) 0.84 (panel[k]) -0.26					
Mahadevan (2002)[o] — 1968-69 to 1994-95; dep. variable =TFP growth			2 digit [p] 0.18-0.31					
Paul (2003)[abn] — 1967-68 to 1995-96; dep. variable =ln(cost) (output-side equivalent reported here)								
• translog, with usage adjustment[c]	0.94	1.27	0.68	0.82	1.15	1.23	0.99	1.19
• translog, without usage adjustment	1.72	1.79	1.39	2.05	2.85	3.50	0.09	1.60
• Cobb-Douglas, with usage adjustment								0.47

(continued on next page)

Table A.3 **(continued)**

Author	*AG*	*MIN*	*MAN*	*CON*	*WRT*	*TSC*	*RPS*	*AGG*
Connolly and Fox (2006)[dg] — 1966 to 2002; dep. variable =ln(MFP)	[e]	[e]	0.15		0.71			
Shanks and Zheng (2006)[fgh] — 1974-75 to 2002-03; dep. var. =ln(MFP)	1.03[i]	1.07	0.50		0.86			0.23

AG=Agriculture, forestry & fishing; MIN=Mining; MAN=Manufacturing; CON=Construction; WRT=Wholesale & retail trade; TSC=Transport, storage & communication; RPS=Recreation and personal services. FBT=Food, beverages & tobacco; TCF=Textiles, clothing, footwear & leather. [a] Public infrastructure is gross general government capital stock (non-dwelling construction and equipment). [b] AGG is the 'private sector' made up of AG, Min, Man, WRT and RPS. [c] Adjusted by industry share of output. [d] Public infrastructure is net general government capital stock. [e] Not reported because insignificant. [f] Core public infrastructure is capital services index of general government infrastructure allocated to the market sector by the ABS, adjusted by industry value-added share. [g] AGG is the market sector. [h] Specifications preferred by authors from an R&D perspective. [i] Δlog (MFP) is dependent variable. [j] Broadacre agriculture only. [k] Not significant. Other 2 digit industries also not significant but ranged from -0.96 to 0.73. [l] The authors note that these estimates at the industry level are generally poor. They note that this may be due, in part, to the public capital variable not being tailored to each industry and structural changes making the Cobb-Douglas specification inappropriate. [m] Results are for capital productivity — MFP results were discussed in paper but not presented. [n] Output-side results are significantly higher than cost-saving estimates in sectors with scale economies — AG, MIN, WRT (1980-81 to 1995-96) and TSC (1990-91 to 1995-96). Constant returns to scale found for MAN, CON, RPS and at aggregate level. [o] Stochastic frontier model. [p] None of the coefficients were significant.

Cost function approach

The cost function approach measures the productivity effects of public infrastructure in terms of cost savings. A cost function with a flexible functional form, in which public infrastructure is included as a fixed unpaid factor of production (or a fixed external input), is estimated. This approach is less restrictive in terms of the technology and allows input prices a role in the decision making process of the firm.

The cost function incorporating public infrastructure is

$$C = C(Q, P, t, G)$$
$$where$$
$$C = PX$$

and Q is output; P is a vector of prices of private inputs; t is a time trend representing technology; G is public infrastructure services; X is a vector of quantities of inputs.

For empirical implementation, a flexible functional form, generally a translog function or a generalised Leontief function, is used. According to Paul (2003), from this function two productivity effects can be derived:

$\partial \ln C / \partial \ln G$ a cost side productivity effect of public capital or the shadow price of public capital; and

$\partial \ln Q / \partial \ln G$ an output side productivity effect of public capital.

The relationship between these two effects is

$$\partial \ln Q / \partial \ln G = -(\partial \ln C / \partial \ln G)/(\partial \ln C / \partial \ln Q)$$

Paul (2003, pp. 448–9) notes

> Both the measures are equivalent only under constant returns to scale and instantaneous adjustment when they are evaluated at the same point. Under non–constant returns to scale, the output side (primal) measure of productivity effects can be obtained from the cost function approach. But it is not always possible to obtain accurate values of the cost side measure from the production function approach.

Hakfoort (1996, p. 68) notes that an increase in public capital is always cost saving (has a negative shadow price) if labour and private capital are both substitutes of public capital. If one factor is complementary to the public capital the effect depends on whether the substitutive effects outweigh the complementary effect. He finds that most studies that use a flexible functional form find that private and public capital are complementary rather than substitutable (p. 71). However, Nadiri and Mamuneas (1996) suggests the literature generally shows that public infrastructure is a substitute for labour, while the effect on private capital, and therefore total private inputs, is unclear.

Results

Table A.4 gives the reported estimates for the cost elasticity of public capital in the main cost function studies for countries other than Australia, and table A.5 reports studies of, or including, Australia.[5] Across the full range of studies, the estimates range from 0 to -1.09 (for the aggregate economy). For Australia, few cost studies were found and only one explicitly reported the cost elasticity of public capital (-1.09 aggregate; -0.48 to -1.27 sectoral). In most cases the equivalent output elasticities are not reported so direct comparisons with the results from production function studies are not possible. Nadiri (1993) notes that even the direct magnitude of productivity effect in terms of elasticity of cost with respect to public infrastructure is unfortunately not reported in many studies.

Again, Romp and de Haan (2005) provides a summary of recent cost function studies, particularly regional studies, but for most no elasticity is reported. They also review VAR/VECM studies, which do not impose causal links among the variables under investigation, and generally find positive output effects of public capital.

5 A few studies use a profit function rather than a cost function and some results are also included in the tables.

Table A.4 **Results of main cost function studies, other countries**

	Description			Direct Effect (cost elasticity with respect to public capital)	Indirect Effect (input demand elasticities with respect to public capital)	
Author	*Geographic Unit of Analysis*	*Cost-Function Specification*	*Definition of Public Capital*	*Cost Changes*	*Labour*	*Capital*
Deno (1988)	USA: 36 SMSA manufacturing industries[a], 1970-78, pooled	profit truncated translog	highway, water, & sewer; adjusted by the % population employed by sector	profit increase elasticity = 0.08 to 0.5	gross complements; elasticity = 0.1 to 0.4	gross complements; elasticity = 0.11 to 0.4
Keeler and Ying (1988)	USA trucking industry, 1960-88 regional, pooled	cost translog	highway stock	cost savings	not reported	not reported
Berndt and Hansson (1991)	Sweden: private sector, 1960-88	labour-input requirement fn (generalised Leontief cost fn)	core public capital	cost savings	short-run complements	not reported
Morrison and Schwartz (1991)	USA: manufacturing by state, 1971-87, pooled by region; state-specific effects	variable cost, generalized, Leontief P=MC, [b,c]	core	cost savings elasticity = -0.10 to -0.27	not reported	not reported
Nadiri and Mamuneas (1991)	USA: manufacturing, 12 2-digit industries, 1995-86 pooled industry-specific effects	cost translog CRS for private inputs[c]	total stock adjusted with capacity utilization rate Also includes public R&D capital	cost savings elasticity = 0 to -0.21	substitutes; elasticity = -0 to -1.4	substitutes; elasticity = -0.02 to-1.4

(continued on next page)

Table A.4 **(continued)**

	Description			Direct Effect (cost elasticity with respect to public capital)	Indirect Effect (input demand elasticities with respect to public capital)	
Author	*Geographic Unit of Analysis*	*Cost-Function Specification*	*Definition of Public Capital*	*Cost Changes*	*Labour*	*Capital*
Lynde and Richmond (1992)	USA: non-financial corporate business sector, 1958-89 times series	cost translog P = MC, and CRS[b,c]	total federal and state	cost savings	substitutes; elasticity = -0.45 to -0.49	complements; elasticity = 0.71 to 0.90
Shah (1992)	Mexico: manufacturing sector, 26 3-digit industries pooled	variable cost translog	total adjusted by industries' output %	cost saving	complements; elasticity = 0.006	substitutes; elasticity = -0.002
Seitz (1993)	West Germany: 31 2-digit industries 1970-89, pooled industry-specific effects	cost generalized Leontief	public roads, length of motorway system	cost saving	substitutes; elasticity = -0.0004	complements; elasticity = 0.03 to 0.04
Lynde and Richmond (1993)	UK: manufacturing sector, 1966: Q1-1992: Q2 value-added	cost translog	total	cost savings	not reported	substitutes
Conrad and Seitz (1994)	West Germany: manufacturing, construction, trade and transport, 1961-88 time series	cost translog and MR=MC[b]	total, adjusted with capacity utilization rate	cost savings	substitutes	complements

(continued on next page)

Table A.4 **(continued)**

	Description			Direct Effect (cost elasticity with respect to public capital)	Indirect Effect (input demand elasticities with respect to public capital)	
Author	*Geographic Unit of Analysis*	*Cost-Function Specification*	*Definition of Public Capital*	*Cost Changes*	*Labour*	*Capital*
Seitz (1994)	West Germany: 31 2-digit industries 1970-89, pooled industry-specific effects	cost generalized Leontief	total core	cost saving	substitutes; elasticity = -0.15 to -0.13	complements; elasticity = 0.34 to 0.86
Nadiri and Mamuneas (1996)	US: 35 2 digit industries 1950 to 1989; pooled cross-section	Normalised symmetric MacFadden functional form	highway capital stock	agg: -0.04 (cost) (0.04 to 0.06 output)	substitute	complement
Khanam (1996)	Canada: 1961-94, aggregate and provincial-level data	translog	total core and highway	cost savings	substitutes	complements
Vijverberg et al. (1997)	US 1976-85	translog cost, translog profit	net stock (non-military) equipment and structures (all levels government)	Contribution of change in net stock to change in labour productivity (%pts) 0.05 to 1.07 cost fn -0.23 to 1.19 profit fn (depending on definition of infra. and model specification)	not reported	not reported

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Table A.4 **(continued)**

Author	Description			Direct Effect (cost elasticity with respect to public capital)	Indirect Effect (input demand elasticities with respect to public capital)	
	Geographic Unit of Analysis	*Cost-Function Specification*	*Definition of Public Capital*	*Cost Changes*	*Labour*	*Capital*
Gillen (1998)	Canada: 1961-96, aggregate and provincial-level data	log-linear and translog	total core and highway	cost savings	substitutes; elasticity = -0.16	complements, substitutes; elasticity = -0.17
Nadiri and Mamuneas (1998)	US: 35 2 digit industries 1950 to 1991; pooled cross-section	translog cost	highway capital stock; other infrastructure capital	agg: -0.08 (cost) (0.08 output)	substitute	complement
Sturm (2001)	Netherlands 1952-93	modified; symmetric generalised Mcfadden cost function	net stock of public grounds, roads & waterways (used PIM)	-0.308	substitutes; elasticity = -0.243 (but not consistent over time)	substitutes; elasticity = -0.526

[a] SMSA = standard metropolitan statistical area. [b] MR = marginal return; MC = marginal cost. [c] P = prices; CRS = constant returns to scale.

Source: Updated from Gillen (2001).

Table A.5 **Results of main cost function studies including infrastructure, Australia**

	Description			Direct Effect (cost elasticity wrt public capital)	Indirect Effect (input demand elasticities wrt public capital)	
Author	*Coverage*	*Function Specification*	*Definition of Public Capital*	*Cost Changes*	*Labour*	*Capital*
Individual country studies						
Song (2002)	1968–2001; Aust., aggregate	translog cost shares	**public capital** (capital stock of general govt sector)	-0.413 to -0.367[b]	-0.78 to -0.98 (substitute)[a]	0.36 to 0.84 (complement)[a]
Paul (2003)	1969–96; Aust., aggregate[c], sectoral	translog cost	**aggregate general govt capital stock**; **sectoral stock estimate** (adjusted for usage)	aggregate: cost -1.09 (output 1.18) sectoral: cost -0.48 to -1.27 (output 0.67 to 1.27)	aggregate: -1.4 (substitute) sectoral: -0.56 to -1.74 (substitute)	aggregate: -0.5 (substitute) sectoral: -1.22 to 0.83 (substitute/ complement)
Multiple country studies						
Demetriades & Mamuneas (2000)	1972–91; 12 OECD countries including Aust.; aggregate (panel estimation)	flexible profit	**public capital** (stock of producers of govt services)	Australia: (output 1.80 SR; 1.78 LR)	Australia: 2.00 SR; 1.96 LR (complement)	Australia: 0.03 SR; 0.41 LR (complement)

[a] Restricted estimates of the cost function model (imposing price homogeneity, constant returns to scale over three inputs and symmetry). Test statistics indicate restriction of CRS is valid. [b] Imputed as 'cost share' of public capital from ABS and TRYM data, not estimated in regressions. [c] Private output. Follows the Otto and Voss (1994a) definition of those industries in which production is predominantly performed by private enterprises (ASIC industries of Agriculture, Manufacturing, Construction, Mining, Wholesale and retail trade, Transport, storage and communication, and Recreation, personal and other services).

Comparing the estimates of the production function and cost function approaches

Nadiri (1993, p. 23) notes that comparisons between production function and cost function estimates are difficult, not only because of the diversity of data and assumptions, but because of the information provided by the authors. The elasticity of cost with respect to public infrastructure is not reported in many studies. To compare the cost elasticity with the output elasticity with respect to public infrastructure, the elasticity of cost with respect to output also needs to be known. The public capital output elasticity is equivalent to the negative of the ratio of the elasticity of cost with respect to public capital over the cost elasticity of output (this is dependent on the assumption of constant returns to scale).

To some extent, the range of results is due to the differences in assumptions and coverage of studies. That said, even studies that apply the different approaches to the same data find very different estimates across approaches (see, for example, Vijverberg et al. (1997, p. 267) who suggest '… it will be hard to ever settle the debate about the effect of public capital on private productivity').

The conclusion most often drawn about the differences between the approaches is that cost-function studies tend to find a smaller contribution from public infrastructure to output growth than production-function analyses (see, for example, the survey by Gillen (2001, p. 48)) — although this is not the case when comparing the Australian results of Otto and Voss (1996) with those of Paul (2003). Also, more recent studies of both types, using more sophisticated functional forms and econometric techniques, tend to find smaller contributions from public infrastructure than earlier studies (OECD 2004, p. 77).[6]

Overall, there is a wide range of results from both types of studies. Eberts (1999, p. 7) notes that 'The conclusion most supported by the literature is that there is no definitive estimate of the effect of infrastructure in general and transport infrastructure more specifically on output.' However, many authors note that they expect to find a positive effect of infrastructure on productivity on theoretical grounds (see, for example, Khan and Luintel 2006). Sturm, et al. (1996, p. 21) note that a review of the literature only allows them to arrive at very modest conclusions

[6] Otto and Voss (1995b, p. 61) note that the estimates of very high elasticities of private output with respect to public capital (such as in Aschauer 1989a and Otto and Voss 1994a) have not proved robust to more sophisticated analysis of the time series. OECD (2004, p. 80) states that, based on literature reviews, estimated results are largely dependent on econometric formulation.

> First, public capital probably enhances economic growth, a conclusion that most economists intuitively would ascribe to. Second, we are less certain about the magnitude of the effect and this is a disappointing outcome, given the enormous amount of research in this field.

A.2 Communications infrastructure

While infrastructure systems can be owned either by the public or private sector, the majority of infrastructure studies appear to have been focused on publicly–owned infrastructure. Nadiri and Nandi (2003, p. 2) suggest that this is because public financing is more common than private financing, since investments in infrastructure systems are highly risky.

Communications infrastructure is one type of infrastructure that has generally been excluded from the studies of public infrastructure (particularly as it has a long history of private ownership in the US). However, a few studies have examined the spillover effects of (privately owned) communications infrastructure. The most relevant article is Nadiri and Nandi (2001).

The difference between examining public and private infrastructure is well summarised by Nadiri and Nandi (2001, p. 92) in their description of their modelling approach.

> For publicly funded infrastructure capital, the government either provides them "free" or charges a small user fee. … Therefore, in the industry production function the services of this type of infrastructure capital are treated as "unpaid" factors of production.
>
> For privately financed infrastructure capital such as the communication infrastructure capital, the source of finance is the communications firms themselves, and they recoup their expenses by charging their customers for the services rendered. That is, each industry incurs some expenses for telecommunications services. These expenses are included as part of the material cost. However, in addition, each industry in the private sector receives the externality benefits in terms of added efficiency gains from the expansion and modernization of the total communications infrastructure network for which they do not pay any direct fees. … Therefore, similar to services provided by public infrastructure capital, the privately funded communications infrastructure capital can also be treated as an unpaid input in the private industry production process.

Nadiri and Nandi (2001) examine the contribution of communications infrastructure in the US to productivity (industry and aggregate) by estimating a shadow price of communications infrastructure, which captures the externality benefits. This is interpreted as a willingness to pay by each industry for communications infrastructure capital services over and above their direct payments for these services (which are included in materials cost).

Nadiri and Nandi (2001) estimate a translog cost function for each industry based on

C=C(q, Y, S1, S2, T)

where q is a vector of input prices for labour, private capital and materials; Y is output; T is a time trend for disembodied technological change; $S1$ is the flow of communication infrastructure services[7]; and $S2$ is the flow of public infrastructure services.

From this function they produce two estimates.

- Cost elasticity with respect to communication infrastructure capital is $(\partial C/\partial S1).(S1/C)$. This is said to represent the direct productivity effect and ranges (across industries) from –0.0084 to –0.0125 (all negative indicating cost savings). The indirect or 'factor bias effect' is measured by the impact of communications infrastructure on private sector input demand functions.
- The cost elasticity is converted into a marginal benefit $-(\partial C/\partial S1)$. This measures the willingness to pay for an additional unit of communications infrastructure capital services exclusive of direct payments for those services and ranges from 0.0003 to 0.0184 (all positive indicating benefits).[8] The wide range is said to reflect the information intensity of industries, with low benefits for mining and high benefits for finance and insurance, for example.
- Both sets of industry estimates can be aggregated to get an economywide benefit (In 1987 it was –0.0136 cost elasticity and 0.328 marginal benefit).

Other articles of this type have not been found. Nadiri and Nandi (2001) and a more recent conference paper (Nadiri and Nandi 2003) note that while a number of other studies have examined the effect of communications infrastructure on productivity, these studies are based on simple statistical or regression analyses and do not consider the externality effects (see for example, Loveman 1994; Wildman 1992; Gera et al. 1998; Kahn 1993; Hardy 1980; Cronin et al. 1991, 1993; Dholakia and Harlam 1994).

Nadiri and Nandi (2001) note that they know of no other econometric studies of the externality effects of telecommunications infrastructure. However, they refer to a number of studies which have attempted to capture the indirect effects of

7 In their estimation, they use the net capital stock of the communications industry to measure their communication infrastructure variable.

8 The small magnitudes of the benefits are partly due to the relatively large size of communications infrastructure capital stock corresponding to total costs in each industry.

telecommunications service improvements in using industries by use of an input–output framework (Cronin et al. 1991, 1993, 1997).

The input–output based studies calculate a total benefit in resource savings from advancements in telecommunications sector by (according to Nadiri and Nandi 2003) first solving the input-output (IO) system to obtain the input requirements at current relative prices and telecommunications technology and then resolving under the assumption that the relative price and telecommunications technology had remained at its initial level (hypothetical economy). The focus is on cost savings from direct input use rather than externalities.

Canning (1999) used an output-side approach and panel data, for a cross-section of developed and developing countries from 1960 to 1990, to examine spillovers from telecommunications networks. Telecommunications infrastructure was part of the normal physical capital stock included in the production function but the telephone stock[9] was also included to test for spillovers. He found an elasticity of labour productivity with respect to the telephone stock of 0.14 for the full sample of countries and 0.26 for high-income countries. (Although in a later paper, Canning and Bennathan (2000), these productivity effects were considered to be implausibly large and the number of telephones was excluded from the estimations).

Other studies also take a production function approach but do not separate out any spillover effect.

- Roller and Waverman (2001) jointly estimate a micromodel of demand and supply for telecommunications investments with a macro production function for 21 OECD countries. The aggregate production function has separate variables for telecommunications infrastructure stock (proxied by phone lines per person) and other capital stock. They find a causal relationship between telecommunications infrastructure and aggregate output (0.045 per cent increase in economic growth for a one per cent increase in the telecommunications infrastructure variable). While they state that they do not directly measure network externalities they find some non–linearities (increasing returns to telecommunications investment) in the relationship between telecommunications infrastructure investment and growth, which they believe are suggestive of network externalities.
- Madden and Savage (2000) used a supply-side growth model to examine the cross-country relationship between telecommunications capital and economic growth. Using teledensity and the share of telecommunications investment in national income as telecommunications capital proxies they found a significant

9 It is noted that the use of physical measurements, such as the number of telephones, do not reflect quality differences in infrastructure across countries and over time.

positive relationship between telecommunications capital and economic growth using data for 43 countries (0.162 to 0.181 output elasticity).

A number of Australian productivity studies have examined communications capital as part of ICT capital (see table A.6). However, again, these studies do not focus on the spillovers from communications infrastructure. Madden and Savage and Valadkhani examine labour productivity and this does not allow specific consideration of spillovers because labour productivity growth can be due to capital accumulation. Valadkhani and Connolly and Fox also use measures of ICT that focus on communications equipment (and in combination with IT capital) rather the communications network infrastructure. A series of reports examining links between ICT (in a broad sense) and productivity have also been published by the Department of Communications, Information Technology and the Arts (see, for example, Diewert and Lawrence 2005 and, for a summary of the series, DCITA 2007).

In addition, Madden and Savage (2001) and Barker et al. (2006) incorporate the effect of digitisation of telecommunications infrastructure in cross-country studies that include Australia (see appendix D). Madden and Savage find a negative relationship with productivity growth of the telecommunications industry, which they attribute to short-run adjustment costs, while Barker et al. find that the impact of computer penetration on aggregate labour productivity was enhanced by the digitisation of the telecommunications infrastructure.

Table A.6 **Results of main production function studies including ICT capital, Australia**

Author	*Specification of functional form (methodology)*	*Infrastructure variable/ Dependent variable*	*Data*	*Elasticity*
Madden and Savage (1998)	ECM model (co-integration analysis)	ITT capital (telephones) labour productivity	time series 1950–94	LR 0.183; SR 0.264 (labour productivity)
Connolly and Fox (2006)	Cobb-Douglas	High tech capital share of total capital (net capital stocks of electronic, electrical machinery and communications equipment, computers and software) MFP	time series 1966-2002. Agg and ind.	Mkt: 3.046 Ind: -29.25 to 30.573
Valadkhani (2003)	Cobb-Douglas (included range of control variables)	ITT capital (net capital stock of computers, electronic equipment and computer software) Labour productivity	time series 1970 to 2000	Aggregate: 0.077

B Treatment of public infrastructure in ABS estimates of MFP

The treatment of public infrastructure in ABS capital estimates, and therefore in multifactor productivity (MFP) estimation, affects the relevance and interpretation of any infrastructure variables included in models of the determinants of MFP.

In principle, public economic infrastructure (part of which is public road infrastructure) is included in the capital stock of the market sector and elements of it are included in the capital stocks of some industries. However, there are some broad approximations used by the ABS when incorporating public infrastructure into industry capital stocks.

This appendix outlines the process the ABS uses to allocate public infrastructure to the capital stock of Australian and New Zealand Standard Industrial Classification (ANZSIC) industries, the approximations used in this process and the implications for MFP estimates.[1]

B.1 Construction of ABS capital stock estimates by ANZSIC industry

The capital stock owned by various institutional sectors of the economy is treated in different ways.

For the *private sector*, it is relatively straightforward. Private sector firms are allocated to ANZSIC industry classifications according to their predominant activity and their capital stock is allocated accordingly.

One potential complication is the use of leases. The ABS treats leases differently depending on whether they are financial or operating leases. Financial leasing is an alternative to lending as a method of financing the acquisition of assets. Capital leased under a financial lease is therefore allocated to the using industry rather than the owning industry.

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[1] Capital services indexes are used in the calculation of MFP. These indexes are based on capital stocks, and it is the construction of the stock measure that is discussed in this appendix.

> Assets which are purchased under a financial lease arrangement are treated as involving an effective change of ownership, and are therefore recorded as gross fixed capital formation by the lessee, not the lessor. (ABS Cat. no. 5216.0, para 15.46).

Operating leases are leases that provide for renting of assets for specified periods of time that are substantially shorter than the total expected service lives of the assets. Rentals are treated as payment for total service provided (usually including maintenance) and are included in intermediate consumption of producers (ABS Cat. no. 5216.0, para 4.29). Capital leased under an operating lease is therefore allocated to the owning industry.

The *public sector* is made up of public corporations and general government. While gross fixed capital formation (GFCF) estimates are separately compiled for private and public corporations, separate capital stock estimates are no longer compiled. The reason for this is the extent of privatisations and statistical difficulties in dealing with them (ABS Cat. no. 5204.0, 1997-98, p. 14).[2] Public corporations are therefore treated in the same way as those in the private sector in the allocation of their capital stock to ANZSIC industry.

Capital expenditure by general government, however, is collected by government purpose category. The government purpose classification (GPC) is used to classify revenues, expenses, and net acquisition of non-financial assets of the public sector in terms of the purposes for which the transactions are made. There are four main categories (ABS Cat. no. 5514.0.55.001).

- *General services* are those government activities that cannot be associated with services to persons or to business. They are collective services that cannot be allocated to particular groups of beneficiaries. They include the major groups of general public services, defence, and public order and safety.
- *Community and social services* are services supplied directly to the community, and to households and persons. They include the major groups of education, health, social security and welfare, housing and community amenities, and recreation and culture. Housing and community amenities includes water supply and sewerage (para 2.203).
- *Economic services* are government activities associated with the regulation and more efficient operation of business. These services include the major groups of fuel and energy, agriculture, forestry, fishing, hunting, mining and mineral resources, manufacturing, construction, transport, communications, and other economic affairs. Fuel and energy includes electricity and gas (para 2.205).

[2] Capital stock estimates are constructed using the perpetual inventory method so when a public corporation is privatised all previous GFCF would need to be reallocated for this separation in the statistics to be maintained.

Transport includes road construction and road maintenance; water, rail, air and multi-mode urban transport; and pipelines (para 2.208).

- *Other purposes* includes public debt transactions, general purpose inter-government transactions and natural disaster relief.

For national accounts purposes, general government capital stock estimates are then mapped across to the ANZSIC industry classification on an approximate basis.[3]

> Estimates of general government capital stock and consumption of fixed capital are calculated using the PIM [perpetual inventory method] by government purpose category. Estimates by purpose are then transformed into industries to obtain general government capital stock and consumption of fixed capital by industry. As the relationship between the government purpose classification and the ANZSIC is complex, this can only be done on an approximate basis. (ABS 2000, para 16.41)

The capital stock of roads is separately allocated to Transport & storage. The remainder of the general government capital stock is allocated according to the concordance in table B.1. The government purpose categories to which the concordance is applied are the column headings.[4] The row headings are the ANZSIC divisions to which the data is allocated. This ABS mapping is done at the ANZSIC division level only[5] and the weights are not changed over time (and were established in the late 1980s).

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3 General government capital stock is not simply allocated in total to ANZSIC division ‘Government administration & defence’. (The national accounts capital stock figures for general government are many times larger than the capital stock of ANZSIC division Government administration & defence).

4 These do not correspond exactly to the four main categories of the GPC outlined above but are groupings of the major GPC groups, in some cases across main categories. Further details are in the notes to table B.1.

5 There are no capital stock estimates of any kind at the 2 digit industry level.

Table B.1 **General purpose classification to ANZSIC industry concordance**

Percentage share

	General purpose category						
ANZSIC industry	*Economic services*[a]	*Education*	*General public service*	*Health*	*Public order and safety*	*Social security*	*Other*[b]
Market sector							
Ag., forestry & fishing	10[c]						
Mining							
Manufacturing	2[d]	1	5	1	1	1	
Electricity, gas & water	2[e]						
Construction	5[f]		5				2
Wholesale trade			1				
Retail trade							
Accom., cafes & rest.							
Transport & storage	15[g]		2				
Comm. services							
Finance & insurance							
Cultural & rec. services							5[h]
Market sector	*34*	*1*	*13*	*1*	*1*	*1*	*7*
Non-market sector							
Property & bus services		1	3		2		
Govt admin. & defence	60	1	75	10	44	57	8
Education	3	97	5			4	40
Health & com. serv.	3		4	87		38	30
Personal & other serv.				2	53		15
Non-market sector	*66*	*99*	*87*	*99*	*99*	*99*	*93*
Total	100	100	100	100	100	100	100

[a] Economic services includes Fuel and energy; Agriculture, forestry and fishing; Mining and mineral resources, other than fuels; Manufacturing and construction; Transport and communications; Other economic affairs. [b] Other includes Housing and community amenities; Recreation and culture; Other purposes. [c] Includes capital related to general government activities associated with, for example, agriculture including land management, water resources management, support schemes; and research and extension services; and forestry including commercial forest operations and fishing including hatcheries. [d] Includes capital related to general government activities associated with, for example, marketing schemes, factory inspections and industrial R&D support. [e] Includes capital related to general government activities associated with, for example, price control, research, construction of dams to provide electricity and conservation. [f] Includes capital related to general government activities associated with, for example, enforcing building standards and research into construction methods. [g] The allocation for roads is done separately and is not included in this percentage. Other transport capital includes, for example, bridges, harbour facilities, railway facilities, air transport facilities and pipelines. [h] Includes capital related to general government activities associated with, for example, provision of national parks, public recreational facilities and public cultural facilities.

Source: ABS unpublished data.

Table B.1 shows that most of the categories of general government capital are allocated to industries outside the market sector. The main exception is ‘economic services’, of which around one-third is allocated to market sector industries (including a total of 17 per cent, excluding roads, to Transport & storage and Electricity, gas & water). In many cases the small allocations to market sector industries may reflect ownership of public infrastructure by public corporations (which are not part of this allocation process).

There is no allocation of general government capital to the ANZSIC industry Communication services. This may be because all relevant infrastructure is owned by public corporations, like Telstra, or private corporations.[6]

In principle, water and sewerage capital owned by government would be allocated under the GPC to ‘Housing and community amenities’ (within the ‘Community and social services’ category of the GPC), which is included under ‘other’ in table B.1. However, there is no allocation from the ‘other’ column to Electricity, gas & water. This may reflect, a movement in ownership of this capital (for example, to the private sector or public corporations). The ABS Classification Manual for Government Financial Statistics also notes that

> Some of the services in “Housing and community amenities” … might be more appropriately classified as economic services. For example, water supply serves both homes and businesses but it is taken that the main thrust of such expenditures is towards the satisfaction of the needs of households. (ABS Cat. no. 1217.0, 1989, p. 16)

From a broader perspective, table B.2 provides a summary of where the *main* types of economic infrastructure (regardless of ownership) are, in principle, included in capital stocks by ANZSIC division.

6 Broadcasting is part of Cultural and recreational services not Communication services. Telstra was a public corporation before the allocation weights were established. It should be noted that the distinction between private and public corporations is still maintained in ABS series for investment (rather than capital stock). These series are affected by the change of classification of Telstra, from a public sector corporation to a private sector corporation, from March quarter 2007. This is beyond the period examined in this paper but would need to be accounted for in future empirical work.

Table B.2 **Economic infrastructure[a] by ANZSIC industry**

	ANZSIC industry		
Infrastructure type[b]	*Electricity, gas & water*	*Transport & storage*	*Communications services*
Roads		*x*	
Bridges		*x*	
Airports		*x*	
Railways		*x*	
Harbours		*x*	
Water storage & supply	*x*		
Sewerage & drainage	*x*		
Electricity generation, transmission & distribution	*x*		
Gas production, storage & distribution	*x*		
Pipelines		*x*	
Telecommunications[c]			*x*

a Other 'non-economic' (or social) infrastructure, including educational buildings, hospitals, police and fire stations, etc, are not included here because they are allocated to non-market sector industries. **b** These groups of economic infrastructure are based on the categories of non-dwelling construction for which statistics are collected. **c** Includes towers, lines and cables.

To provide an indication of the importance of public infrastructure in the capital stock of each industry, table B.3 shows the allocation of general government infrastructure capital to each market sector industry. (As discussed in chapter 3, infrastructure is a subset of capital assets — in this case, it is assumed to be non-dwelling construction plus machinery and equipment excluding computer hardware.) Transport & storage is the industry with the most significant allocation (the majority of which is roads), followed by Construction and Cultural & recreational services.

Table B.3 **Net capital stock[a], by industry, 2002-03**

	General government infrastructure allocation	
Industry	*$m*	*% of industry capital stock*
Agriculture, forestry & fishing	3062	2.4
Mining	0	0.0
Manufacturing	2582	2.5
Electricity, gas & water	612	0.5
Construction	3663	13.8
Wholesale trade	225	0.6
Retail trade	0	0.0
Accommodation, cafes & rest.	0	0.0
Transport & storage	77896	45.9
Communication services	0	0.0
Finance & insurance	0	0.0
Cultural & recreational services	2522	11.4
Market sector	90561	7.4

[a] Productive capital stocks are used in capital services indexes but cannot be added across asset types. These net capital stock numbers are therefore only indicative of the stocks used in the calculation of capital services indexes.

Source: ABS unpublished national accounts data.

B.2 Implications for MFP estimates

Approximations aside, capital stock estimates by ANZSIC industry include all capital directly used by an industry, whether it is owned by the private firms in that industry, subject to a financial lease, or publicly owned. Therefore, while unpriced public infrastructure is a 'free' input to the firm in its production function, in the ABS MFP estimates for the market sector it is accounted for in the capital stock and is not an unmeasured input. For an industry, only the public infrastructure allocated to the capital stock of that industry will be included so there may be a 'free' input effect from other public infrastructure. At the industry and aggregate levels there may also be production spillovers that are not captured, such as organisational improvements facilitated by better public infrastructure.

C Calculation of capital services indexes

Capital services indexes have been calculated for public economic infrastructure and communications infrastructure, both at the market sector level and the industry level.[1] This appendix outlines the methodology used and presents estimates for a range of infrastructure variables used in the modelling.

C.1 Methodology

Capital services indexes have been constructed for public infrastructure and communications infrastructure to reflect the flow of capital services from these types of infrastructure. This has been done using unpublished ABS national accounts data and ABS methodology, but with the inclusion of an adjustment factor to reflect changes in the usage of infrastructure by the market sector and by individual industries. Alternative proxies for usage have been examined.

Construction of standard capital services indexes

Capital services reflects the amount of 'service' an asset provides during a period (which is proportional to an asset's productive value in the period). Aggregate capital services indexes are formed by using the productive capital stock of each asset type and its rental price.

The *productive capital stock* of an asset over time is the volume of capital, adjusted for efficiency losses related to age (according to the relevant age-efficiency profile). The productive capital stock of each asset type is weighted and summed to form an aggregate capital services measure.

The weights used in the summation are based on the *rental prices* for the different asset types. Rental prices can be thought of as estimates of the rates each asset type would attract if the assets were leased in a commercial arrangement. They cover: the opportunity cost of investing elsewhere, represented by the interest rate; the loss

[1] The industry coverage is restricted to ten of the industries included in the ABS's market sector (see appendix F).

in market value of the good due to ageing; and the capital gains or losses due to asset price inflation/deflation; and adjustments for tax made to correct for distortions in rental prices due to differential tax treatment across capital items.

The use of rental prices as weights assumes that the rental price reflects the marginal product of an asset and so more productive assets are given a higher weight in forming the capital services measure.

Aggregate estimates are formed by using estimates of productive capital stock and rental prices for each asset type, j, for each institutional sector (general government, other corporate, unincorporated)[2] within each industry, i, to form a Tornqvist index[3] for industry capital services. Thus the capital service flow index from period t-1 to period t is:

$$c_{it} = c_{it-1} * \exp\left[\sum_j \left(\ln\left(K_{ijt} / K_{ijt-1}\right) * w_{ijt}\right)\right] \tag{C.1}$$

where K_{ijt} are the real productive capital stocks and w_{ijt} are the capital stock weights

$$w_{ijt} = 0.5 * \left(\frac{r_{ijt} . K_{ijt}}{\sum_j r_{ijt} . K_{ijt}} + \frac{r_{ijt-1} . K_{ijt-1}}{\sum_j r_{ijt-1} . K_{ijt-1}} \right) \tag{C.2}$$

and where r_{ijt} are the rental prices. (See ABS 2000, chapter 27 for further details).

Similarly, this can be done at the market sector level by including the assets of all market sector industries.

To form capital services indexes for particular types of capital, such as selected infrastructure, the relevant industries, asset types and institutional sectors that are included will vary. For the total capital services index for the market sector, the ABS includes all market sector industries, all asset types and all institutional sectors. But only a subset of this capital is included for public infrastructure,

2 For its aggregate capital services indexes the ABS uses two institutional sectors — corporate and unincorporated. For this paper, the ABS provided unpublished data in which it split the productive capital stock of the corporate sector, by main asset type, into general government and other corporate. Separate rental prices are not available for these two sub-sectors, so the rental prices for the corporate sector in total have been used for both general government and other corporate. Also, separate rental prices are only available for the main asset types (such as non-dwelling construction) and not for more disaggregated categories (such as roads).

3 A Tornqvist index is the weighted geometric mean of the component growth rates.

communications infrastructure, and a number of other capital asset subgroups (for example, IT capital and the 'remainder' capital after other specific capital types have been deducted from total capital).

For public infrastructure, only the general government institutional sector is included. There is a general government allocation to a number of industries (see appendix B) and only those in the market sector are included to arrive at public economic infrastructure (I3).[4] Only a subset of assets is included in this definition of infrastructure — non-dwelling construction and five of the six types of machinery and equipment[5] (computer hardware is excluded to allow the separate examination of IT). An alternative definition of public infrastructure (I8) also includes computer hardware and software in the subset of assets. Public road infrastructure (roads) includes only part of the non-dwelling construction asset type (all of which is allocated to the market sector via its allocation to Transport & storage).[6]

For communications infrastructure (ci5), the only relevant industry is Communication services and all institutional sectors are included (although the general government allocation to Communication services is zero, as discussed in appendix B). The subset of assets included is non-dwelling construction and three of the six types of machinery and equipment (computer hardware, road vehicles and other transport equipment are excluded). The additional exclusions are made so that the infrastructure measure is closer to one that includes only those infrastructure assets that are directly related to the provision of communication services. An alternative definition of communication infrastructure (ci8) also includes computer hardware and software in the subset of assets.

Details of the asset groups include for other non-infrastructure capital services indexes is provided in the variable definition tables in appendixes E and F.

Usage adjustment factors

In constructing an index to reflect the usage of infrastructure by the market sector of the economy or an individual industry, an adjustment factor reflecting this usage is incorporated into the calculation of the capital services index.

4 See chapter 3 for variable definitions.

5 The machinery and equipment asset types included are electrical and electronic equipment, industrial machinery and equipment, other plant and equipment, road vehicles and other transport equipment.

6 No weighting (rental price) is required in this case since there is no aggregation across asset types.

The basic method of making the adjustment is to multiply the productive capital stock by the chosen usage factor for that industry. (The alternative usage factors are discussed below.)

In equation (C.1) K_{ijt} is replaced with $u_{xt}K_{ijt}$, where u_{xt} is the usage factor of industry/sector x in period t. The usage factor for industry/sector x can be varied across assets if required.

Different alternative usage factors are available for public infrastructure and communications infrastructure.

Public infrastructure

As discussed in chapter 3, some studies (for example, Paul 2003) have applied an industry's share of output to the public infrastructure stock.[7]

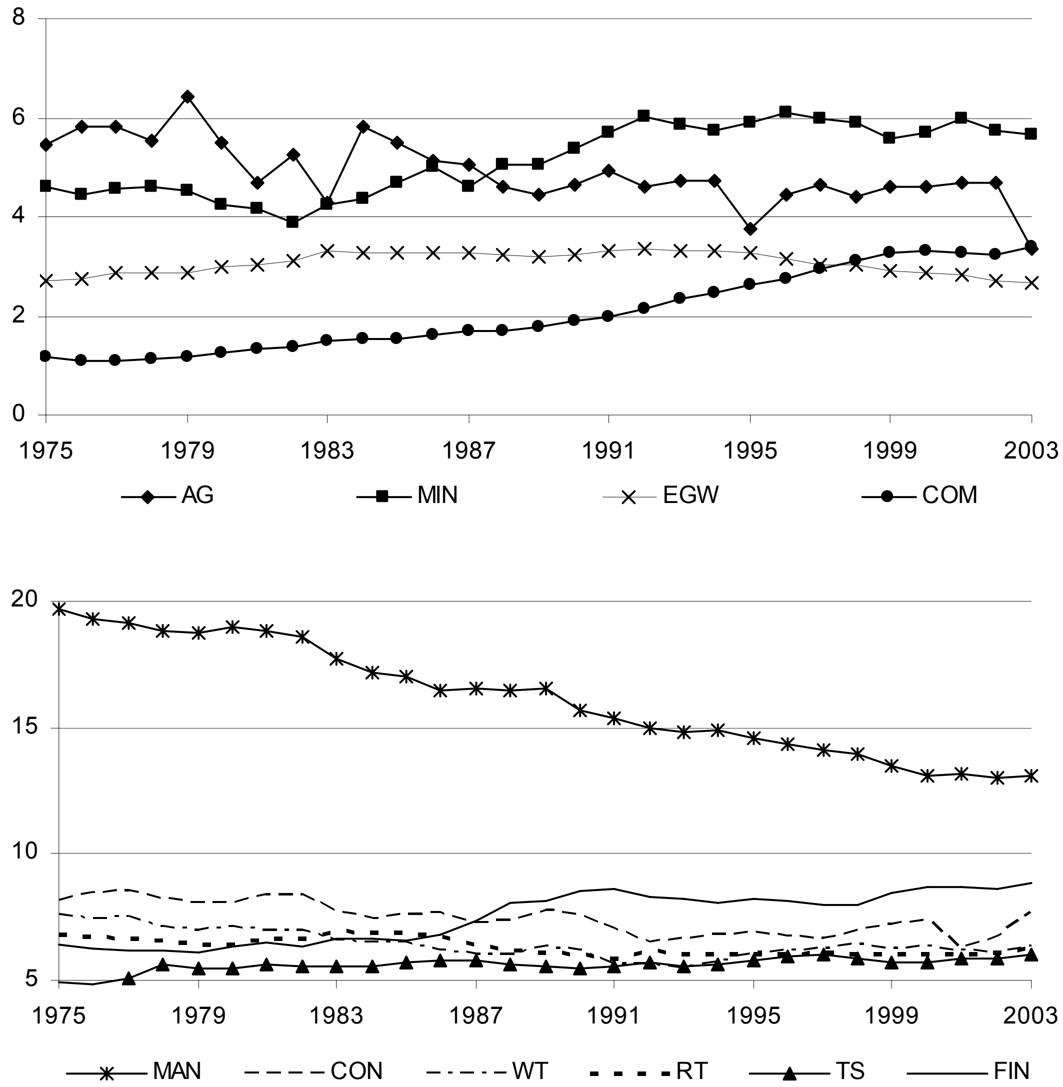
Industry gross value added (VA) data are available from the ABS (Cat. no. 5204.0) and have been used to calculate industry output shares of the kind used by Paul (2003).[8] The calculated industry shares are shown in figure C.1.

[7] The industry's capacity utilisation rate is an alternative adjustment factor, which has been used in studies of public and private infrastructure in other countries (see, for example, Conrad and Seitz (1994), Nadiri and Mamuneas (1991), Nadiri and Nandi (2001)). Paul (2003) notes that capacity utilisation data are not available for the Australian private sector.

[8] Paul (2003, p. 455) tests alternative indexes of usage, with $U(\theta)=U^{\theta}$, where $\theta=1.1$ (usage rate of infrastructure services increases more than proportionately with the increase in its share in national output, $\theta=1$ (proportionate), $\theta=0.9$ (less than proportionate), $\theta=0$ (services equal to stock). He found no difference in the sign of the effect of infrastructure on output or cost but his preferred model was the inclusion of a proportionate usage index ($\theta=1$). Nadiri and Mamuneas (1994) also found no difference in the sign of cost savings from public infrastructure when including a capacity utilisation measure.

Figure C.1 **Share of output, by industry[a], 1974-75 to 2002-03**

Per cent



[a] See table 3.1 for industry abbreviations.

Data source: Based on industry gross value added data from ABS (*Australian National Accounts*, Cat. no. 5204.0).

For each industry/sector the relevant output share is applied to the public economic infrastructure of the market sector (I3ug2) or public road infrastructure (roadug2). A smoothed adjustment factor series (3-period moving average) was also used in some cases (I3ug2s, roadug2s). This was done because it is the long term trend that is of interest and endogeneity problems were encountered in the modelling. Sensitivity tests using unadjusted infrastructure measures were also undertaken because of concerns about the lack of independence of the adjusted infrastructure measures and the output measures used in the modelling (see appendix E).

Communications infrastructure

Rather than simply using output shares, alternative adjustment factors for communications infrastructure have been calculated and compared. There are two main alternatives:

1. industry/market sector output share (based on published ABS data for gross value added)
2. industry/market sector shares of intermediate usage of communication services (based on published ABS input-output tables and unpublished ABS supply-use tables).

The relevant industry output shares are the same as those used for public infrastructure. The rationale for the second of these measures is that network spillovers in particular may be more closely related to an industry's use of communications infrastructure as an input rather than simply the industry's output. This second option is discussed in the following section.

Intermediate usage shares

ABS input-output (IO) tables and, for later years, ABS supply-use (SU) tables, provide intermediate usage of communication services across commodities, which can be aggregated to industry groups and the market sector. A series for communication services usage has been compiled from these tables and aggregated by industry. Published IO tables (ABS Cat. no. 5209.0) are available for 1974-75, 1977-78 to 1983-84, 1986-87, 1989-90, 1992-93.[9] Unpublished ABS supply-use data are available annually from 1994-95 to 2002-03.

Industry usage shares have been calculated for all available years as:

$$\frac{\text{Intermediate usage of communication services by industry I}}{\text{Total intermediate usage} - \text{Communication services industry own usage}}$$

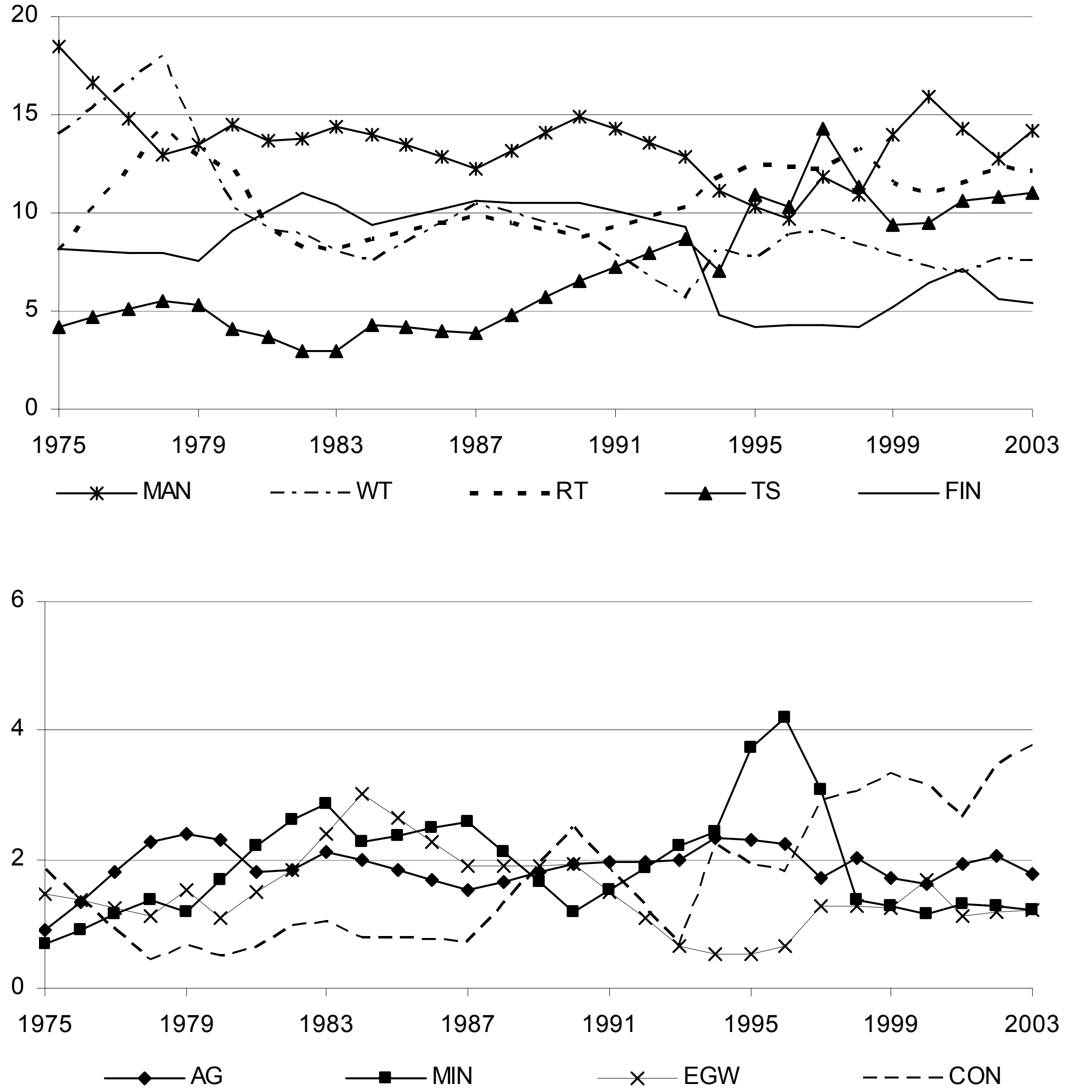
Missing years have been interpolated, using the observations immediately before and after the gaps. This has been done using the percentage shares, not the absolute numbers for intermediate usage by industry.

The calculated industry usage shares are shown in figure C.2.

[9] The IO table series has been adjusted to reflect changes in classifications over time, including adjustment to reallocate the dummy commodity 'business expenses' that appeared in IO tables prior to 1977-78.

Figure C.2 **Share of total intermediate usage[a] of Communication services, by industry[b], 1974-75 to 2002-03**

Per cent



[a] Does not include Communication services usage of own services. [b] See table 3.1 for industry abbreviations.

Data source: Based on ABS (*Australian National Accounts: Input-Output Tables*, Cat. no. 5209.0, table 2) and unpublished ABS supply-use table data.

Comparison of adjustment factors for communication infrastructure usage

Figure C.3 compares indexes of the two adjustment alternatives discussed above. Table C.1 shows the absolute values of these adjustment factors for 1974-75 and 2002-03. However, for the adjustment to the capital services indexes it is the differences in growth rates that are important. Table C.2 shows the difference in the average growth of these adjustment factors over the same period. There is obviously considerable difference between the growth paths of these adjustment factors. The ranking of industries according to value added share is very different to that for the intermediate usage share. For example, Finance & insurance has the fastest growth in value added share but is towards the bottom of the ranking on the other measure. The opposite is the case for Agriculture, forestry & fishing, which is ranked four for intermediate usage share but at the bottom of the value added shares.

The intermediate usage shares are theoretically more appealing because, as noted above, they are more closely linked to the source of potential spillovers. However, they are subject to some data consistency corrections over the time series and are very volatile for some industries. While the intermediate usage shares are used as the main adjustment factor in the modelling in this paper, some of the results are tested for sensitivity to these alternative adjustment factors (see appendix E).

Figure C.3 **Alternative industry adjustment factors, 1974-75 to 2002-03**
Indexes 2001-02 = 100

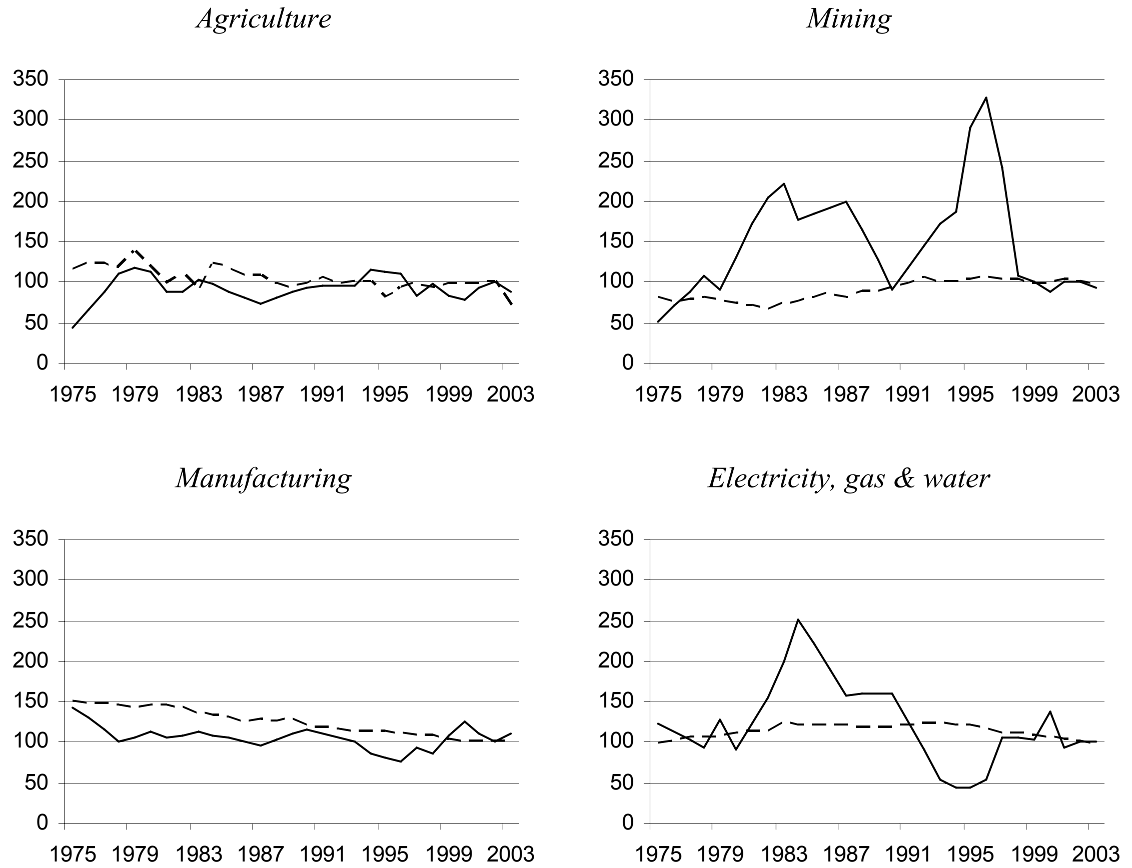


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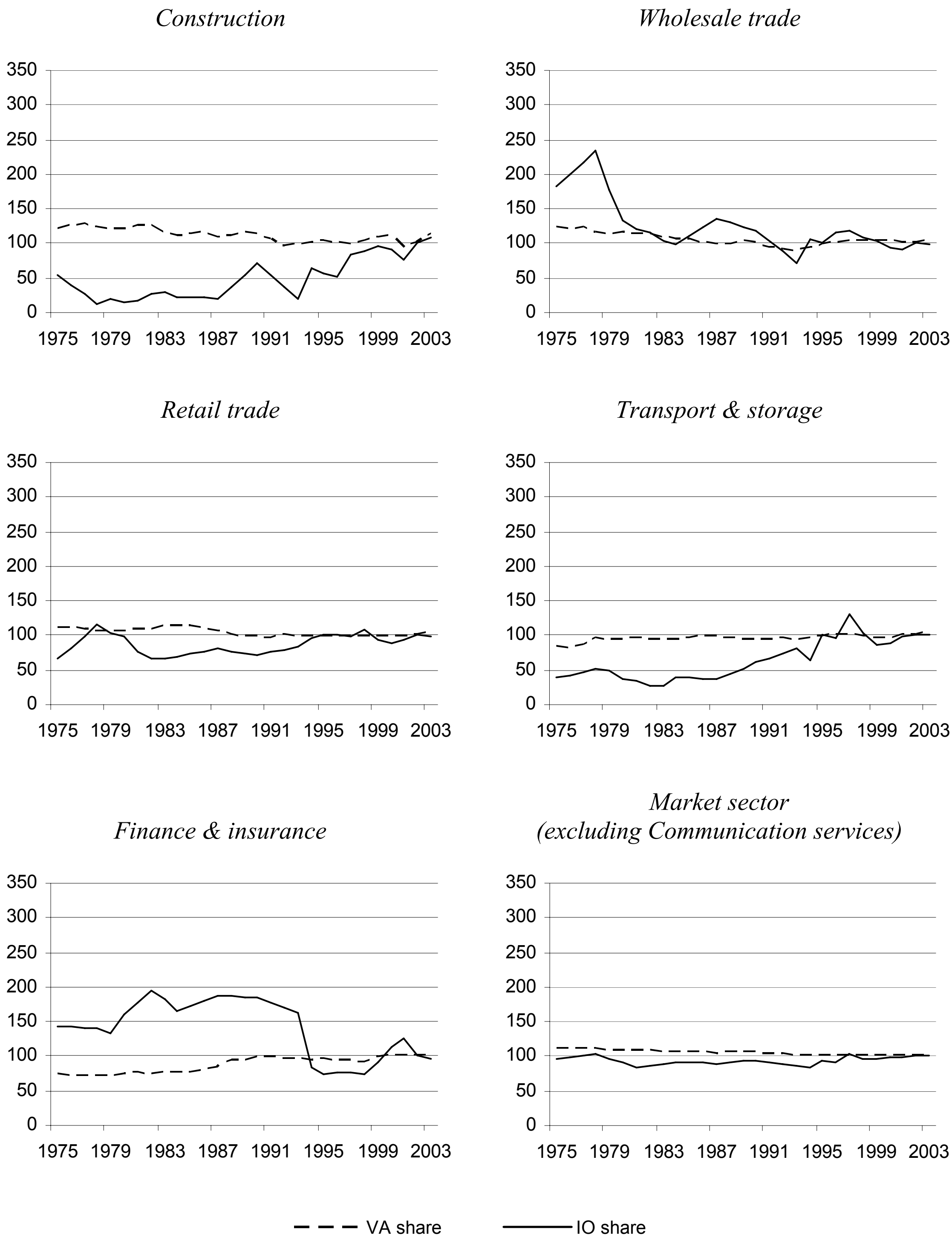
Figure C.3 **(continued)**



Data source: Authors' estimates based on ABS data.

Table C.1 **Comparisons of adjustment factors, 1974-75 and 2002-03**

	Value added share[a]		*Intermediate usage share*[b]	
	1974-75	*2002-03*	*1974-75*	*2002-03*
	per cent		per cent	
Agriculture, forestry & fishing	5.45	3.36	0.89	1.78
Mining	4.61	5.64	0.67	1.21
Manufacturing	19.71	13.11	18.43	14.17
Electricity, gas & water	2.70	2.68	1.47	1.20
Construction	8.12	7.64	1.83	3.76
Wholesale trade	7.58	6.30	13.95	7.55
Retail trade	6.78	6.26	8.08	12.16
Transport & storage	4.92	6.04	4.23	11.02
Finance & insurance	6.39	8.82	8.13	5.41
Market sector (excluding Communication services)	71.12	64.42	63.18	67.05

[a] Industry gross value added as a share of total value added. [b] Industry intermediate usage of communication services as a share of total intermediate usage (excluding Communication services industry own use) of communication services.

Source: Authors' estimates based on ABS national accounts data.

Table C.2 **Comparisons of average growth in usage adjustment factors, 1974-75 to 2002-03**

Per cent per year

	Value added share		*Intermediate usage share*	
	Growth	*Rank*	*Growth*	*Rank*
Agriculture, forestry & fishing	-1.72	11	2.50	4
Mining	0.72	3	2.12	5
Manufacturing	-1.44	10	-0.93	8
Electricity, gas & water	-0.02	5	-0.73	7
Construction	-0.22	6	2.60	3
Wholesale trade	-0.66	9	-2.17	11
Retail trade	-0.28	7	1.47	6
Transport & storage	0.73	**2**	3.48	**1**
Finance & insurance	1.15	**1**	-1.44	10
Market sector (excluding Communication services)	-0.35		0.21	

Source: Authors' estimates based on ABS national accounts data.

C.2 Estimates

The estimated capital services indexes for public infrastructure and communications infrastructure (for alternative definitions of infrastructure and alternative adjustment factors) are shown in tables C.3 to C.4 for the market sector and, where they differ by industry, tables C.5 to C.14 at the industry level. (Variable definitions are provided in table 3.3.)

Table C.3 **Capital services indexes for public infrastructure variables, market sector**

Index 2001-02 =100

Year	*roads*	*roadug2*	*roadug2s*	*I3*	*I3ug2*	*I3ug2s*	*I8*	*I8ug2*	*I8ug2s*
1974-75	78.8	84.4	84.1	76.6	82.1	81.7	67.6	72.4	72.1
1975-76	79.9	85.1	85.2	80.3	85.5	85.6	71.1	75.7	75.8
1976-77	81.3	87.2	86.5	82.1	88.0	87.4	72.7	77.9	77.3
1977-78	82.8	87.9	87.9	83.6	88.8	88.8	74.1	78.7	78.7
1978-79	84.1	89.2	88.8	85.0	90.1	89.8	75.4	79.9	79.6
1979-80	85.1	89.8	89.6	85.9	90.7	90.4	76.3	80.5	80.3
1980-81	85.7	90.0	89.9	86.5	90.8	90.7	77.0	80.8	80.8
1981-82	86.1	90.4	89.6	87.0	91.3	90.5	77.6	81.5	80.8
1982-83	86.4	89.2	89.7	87.5	90.3	90.8	78.3	80.9	81.3
1983-84	87.4	90.8	90.5	88.5	91.9	91.5	79.4	82.5	82.1
1984-85	88.9	92.4	91.9	89.9	93.5	93.0	80.9	84.2	83.7
1985-86	90.4	93.3	92.9	91.5	94.4	94.0	82.6	85.3	85.0
1986-87	91.6	93.5	93.7	92.8	94.7	94.9	84.1	85.8	86.0
1987-88	92.3	94.4	94.4	93.6	95.8	95.7	85.1	87.2	87.1
1988-89	92.7	95.8	95.1	94.2	97.3	96.6	86.2	89.0	88.4
1989-90	93.6	96.2	95.8	95.0	97.7	97.3	87.6	90.1	89.7
1990-91	93.7	95.5	95.3	95.2	97.0	96.8	88.3	90.1	89.9
1991-92	93.5	94.7	94.4	95.1	96.3	96.0	88.9	90.0	89.7
1992-93	94.2	94.6	94.8	95.5	95.9	96.1	90.0	90.4	90.5
1993-94	94.2	95.0	94.6	95.6	96.5	96.0	90.7	91.5	91.1
1994-95	94.2	95.0	95.0	95.7	96.4	96.4	91.6	92.3	92.3
1995-96	94.4	95.7	95.2	95.8	97.1	96.6	92.4	93.6	93.1
1996-97	95.1	96.2	96.1	96.1	97.2	97.1	93.3	94.4	94.3
1997-98	96.1	97.3	97.0	96.5	97.7	97.5	94.1	95.3	95.0
1998-99	97.2	98.5	98.3	97.0	98.3	98.1	95.3	96.5	96.3
1999-00	97.9	99.3	98.7	98.1	99.5	98.8	96.9	98.3	97.6
2000-01	99.4	99.7	99.7	99.2	99.4	99.5	98.7	99.0	99.0
2001-02	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2002-03	100.3	100.8	100.3	101.0	101.5	101.0	101.8	102.3	101.9

Source: Authors' estimates based on published and unpublished ABS national accounts data.

Table C.4 **Capital services indexes for communications infrastructure variables, market sector**

Index 2001-02 =100

Year	*ci5*	*ci5vaug*	*ci5oug*	*ci5iougs*	*ci8*	*ci8vaug*	*ci8ioug*
1974-75	27.2	29.1	26.0	27.6	15.5	16.6	14.8
1975-76	27.9	29.7	27.4	28.9	16.0	17.0	15.7
1976-77	28.9	30.9	29.2	30.8	16.6	17.8	16.8
1977-78	29.6	31.5	30.8	31.3	17.1	18.2	17.8
1978-79	30.3	32.2	28.9	31.0	17.6	18.7	16.8
1979-80	31.2	33.0	28.5	29.8	18.4	19.4	16.8
1980-81	32.2	33.8	27.3	29.8	19.4	20.3	16.5
1981-82	33.2	34.8	29.0	30.4	20.4	21.4	17.8
1982-83	34.4	35.5	30.3	32.3	21.5	22.2	18.9
1983-84	36.1	37.5	33.0	34.3	23.0	23.9	21.0
1984-85	37.8	39.3	34.4	36.3	24.7	25.7	22.4
1985-86	40.9	42.2	36.9	39.0	27.7	28.5	25.0
1986-87	43.0	43.9	38.5	41.0	30.0	30.6	26.8
1987-88	44.8	45.8	40.8	43.0	32.0	32.8	29.1
1988-89	46.8	48.4	43.3	45.7	34.3	35.4	31.7
1989-90	49.8	51.2	46.8	48.7	37.5	38.6	35.3
1990-91	52.4	53.4	47.9	50.5	40.4	41.2	36.9
1991-92	54.5	55.2	48.5	51.1	42.8	43.4	38.1
1992-93	57.7	57.9	49.8	52.5	46.6	46.8	40.3
1993-94	60.3	60.9	50.3	55.7	49.3	49.7	41.1
1994-95	64.5	65.0	59.9	60.9	53.3	53.7	49.5
1995-96	70.4	71.4	64.9	71.5	59.1	59.9	54.5
1996-97	77.0	77.9	79.7	79.1	65.8	66.6	68.1
1997-98	80.8	81.9	78.0	84.0	69.9	70.8	67.5
1998-99	85.3	86.4	81.5	87.0	75.1	76.1	71.7
1999-00	90.7	92.0	88.8	93.5	84.7	85.9	82.9
2000-01	95.6	95.8	95.3	100.0	93.7	93.9	93.4
2001-02	100.0	100.0	100.0	105.8	100.0	100.0	100.0
2002-03	102.8	103.3	104.1	109.3	104.9	105.4	106.2

Source: Authors’ estimates based on published and unpublished ABS national accounts data.

Table C.5 **Capital services indexes for infrastructure variables, Agriculture, forestry & fishing**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	92.5	94.9	90.1	92.4	13.3
1975-76	100.2	98.2	101.0	98.9	20.6
1976-77	101.7	100.6	102.9	101.8	28.5
1977-78	98.8	106.0	100.1	107.4	36.6
1978-79	116.7	105.8	118.2	107.2	39.5
1979-80	100.9	101.8	102.1	103.0	39.4
1980-81	86.3	95.2	87.2	96.2	31.6
1981-82	97.2	87.9	98.5	89.0	33.0
1982-83	79.5	95.4	80.6	96.8	40.0
1983-84	109.7	98.2	111.2	99.5	39.2
1984-85	105.4	105.4	106.8	106.8	37.8
1985-86	100.2	102.3	101.6	103.7	37.4
1986-87	99.9	97.6	101.4	99.1	35.6
1987-88	91.3	93.7	92.8	95.3	40.4
1988-89	89.0	91.3	90.6	92.9	45.7
1989-90	93.3	94.3	94.9	96.0	52.3
1990-91	99.4	95.4	101.2	97.1	55.5
1991-92	92.5	96.0	94.3	97.8	58.3
1992-93	96.2	95.4	97.7	96.9	62.3
1993-94	96.0	89.7	97.6	91.3	77.2
1994-95	76.4	87.8	77.7	89.4	81.2
1995-96	90.5	87.4	92.0	88.8	86.2
1996-97	95.1	92.5	96.3	93.7	71.6
1997-98	91.4	94.5	92.0	95.2	88.7
1998-99	96.6	95.5	96.7	95.5	79.7
1999-00	97.3	98.0	97.7	98.4	80.4
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	101.1	91.6	101.4	91.8	111.2
2002-03	72.5	82.3	73.2	83.1	100.0

Source: Authors' estimates based on published and unpublished ABS national accounts data.

Table C.6 **Capital services indexes for infrastructure variables, Mining**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	61.2	62.3	59.6	60.7	14.7
1975-76	59.7	63.0	60.1	63.4	20.4
1976-77	62.9	64.2	63.6	65.0	26.6
1977-78	64.5	65.7	65.3	66.6	32.9
1978-79	63.9	65.1	64.8	65.9	28.7
1979-80	60.9	63.6	61.7	64.3	42.5
1980-81	60.0	60.9	60.7	61.6	57.3
1981-82	56.3	61.1	57.0	61.9	69.9
1982-83	61.7	62.5	62.6	63.4	78.9
1983-84	64.5	67.4	65.4	68.3	65.9
1984-85	70.5	72.4	71.4	73.4	72.1
1985-86	76.1	74.9	77.2	75.9	81.3
1986-87	71.2	77.7	72.3	78.9	88.9
1987-88	78.7	78.6	80.0	79.9	75.9
1988-89	79.0	83.1	80.4	84.6	61.9
1989-90	84.7	87.4	86.2	88.9	47.4
1990-91	90.2	92.8	91.8	94.5	64.2
1991-92	95.1	95.3	96.9	97.1	81.8
1992-93	93.2	96.2	94.7	97.8	102.5
1993-94	91.3	95.5	92.9	97.1	116.8
1994-95	93.8	96.8	95.4	98.5	192.9
1995-96	96.9	98.1	98.5	99.7	237.9
1996-97	95.6	98.9	96.9	100.2	190.8
1997-98	95.8	97.1	96.4	97.8	89.4
1998-99	91.6	96.7	91.7	96.7	88.1
1999-00	93.8	97.7	94.1	98.1	83.5
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	96.8	100.4	97.0	100.6	103.1
2002-03	95.3	98.7	96.2	99.6	99.9

Source: Authors’ estimates based on published and unpublished ABS national accounts data.

Table C.7 **Capital services indexes for infrastructure variables, Manufacturing**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	118.9	118.5	115.8	115.4	36.8
1975-76	117.7	118.9	118.5	119.8	34.0
1976-77	119.2	119.3	120.6	120.7	31.3
1977-78	119.2	120.2	120.8	121.8	28.2
1978-79	120.4	121.9	122.0	123.4	29.9
1979-80	123.8	123.3	125.3	124.8	33.3
1980-81	123.3	123.9	124.6	125.3	32.3
1981-82	122.4	121.6	123.9	123.1	33.5
1982-83	117.4	118.5	119.2	120.2	36.3
1983-84	114.8	116.4	116.4	118.0	37.1
1984-85	115.7	115.3	117.3	116.9	37.3
1985-86	113.8	115.9	115.4	117.5	38.7
1986-87	115.9	116.1	117.6	117.8	38.9
1987-88	116.2	117.1	118.1	119.1	43.3
1988-89	117.4	115.8	119.5	117.8	48.3
1989-90	112.4	114.1	114.4	116.1	54.6
1990-91	110.0	110.5	112.0	112.5	54.8
1991-92	107.3	108.2	109.3	110.3	54.3
1992-93	106.8	108.0	108.5	109.7	54.6
1993-94	107.4	107.0	109.2	108.8	49.4
1994-95	105.4	105.9	107.2	107.7	49.0
1995-96	103.4	104.0	105.1	105.8	50.2
1996-97	102.4	103.2	103.8	104.5	67.1
1997-98	102.6	102.2	103.3	102.9	64.8
1998-99	100.5	101.1	100.5	101.1	87.7
1999-00	98.2	99.8	98.6	100.2	106.2
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	99.6	100.7	99.8	100.9	94.0
2002-03	100.6	100.8	101.5	101.8	107.0

Source: Authors’ estimates based on published and unpublished ABS national accounts data.

Table C.8 **Capital services indexes for infrastructure variables, Electricity, gas & water**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	75.9	77.1	73.9	75.1	37.1
1975-76	78.7	79.8	79.3	80.4	35.0
1976-77	83.4	83.0	84.4	84.0	33.1
1977-78	84.8	85.7	85.9	86.8	30.7
1978-79	86.7	88.4	87.8	89.6	43.2
1979-80	91.4	91.2	92.5	92.3	31.2
1980-81	93.1	94.0	94.1	95.1	44.3
1981-82	95.0	97.5	96.2	98.7	56.6
1982-83	102.1	100.4	103.6	101.9	75.8
1983-84	102.5	103.7	103.9	105.1	100.4
1984-85	104.4	105.1	105.8	106.5	92.4
1985-86	105.9	106.9	107.4	108.3	86.0
1986-87	107.3	107.5	108.9	109.1	75.7
1987-88	106.0	107.4	107.8	109.2	78.9
1988-89	106.1	107.5	108.0	109.4	82.7
1989-90	108.1	109.3	110.0	111.2	88.2
1990-91	110.4	111.2	112.4	113.3	72.5
1991-92	112.3	111.9	114.4	114.1	54.4
1992-93	111.4	112.8	113.3	114.6	35.3
1993-94	111.1	111.6	113.0	113.5	29.2
1994-95	109.7	110.0	111.6	111.9	31.2
1995-96	106.7	107.2	108.5	109.0	42.8
1996-97	103.2	105.3	104.5	106.6	90.9
1997-98	103.6	103.4	104.3	104.1	95.3
1998-99	101.1	102.6	101.2	102.6	97.1
1999-00	100.0	101.0	100.4	101.3	139.7
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	96.8	98.5	97.0	98.7	110.7
2002-03	96.0	97.1	96.9	98.0	114.2

Source: Authors’ estimates based on published and unpublished ABS national accounts data.

Table C.9 **Capital services indexes for infrastructure variables, Construction**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	103.5	96.3	100.8	93.8	19.7
1975-76	108.9	99.4	109.7	100.1	15.1
1976-77	112.8	101.6	114.2	102.8	10.4
1977-78	110.0	101.9	111.4	103.2	5.3
1978-79	109.8	101.3	111.2	102.6	7.7
1979-80	110.7	103.2	112.1	104.4	6.3
1980-81	115.9	105.4	117.2	106.6	7.9
1981-82	117.2	104.6	118.6	105.9	12.6
1982-83	108.6	101.0	110.2	102.5	14.1
1983-84	104.9	98.7	106.3	100.0	11.3
1984-85	109.2	100.0	110.8	101.4	11.4
1985-86	112.8	101.3	114.4	102.7	11.9
1986-87	108.4	101.6	110.0	103.2	12.1
1987-88	110.0	102.4	111.8	104.1	23.1
1988-89	115.8	104.1	117.9	106.0	35.2
1989-90	114.8	103.7	116.8	105.6	49.2
1990-91	107.3	98.4	109.3	100.1	38.9
1991-92	98.8	94.0	100.7	95.8	27.1
1992-93	101.7	93.5	103.4	95.1	14.5
1993-94	104.2	95.2	106.0	96.9	52.6
1994-95	105.2	95.4	107.0	97.1	49.4
1995-96	102.4	94.6	104.1	96.2	50.5
1996-97	101.9	95.8	103.2	97.0	88.3
1997-98	108.8	99.2	109.5	99.9	97.8
1998-99	113.7	104.1	113.8	104.1	112.7
1999-00	117.0	101.1	117.4	101.5	112.5
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	108.6	101.9	108.8	102.1	136.0
2002-03	123.9	109.2	125.1	110.2	152.7

Source: Authors' estimates based on published and unpublished ABS national accounts data.

Table C.10 **Capital services indexes for infrastructure variables, Wholesale trade**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	97.3	96.0	94.7	93.5	57.1
1975-76	96.2	96.8	96.9	97.6	64.1
1976-77	99.2	96.7	100.3	97.8	72.3
1977-78	96.0	96.4	97.3	97.7	80.2
1978-79	95.5	96.4	96.7	97.6	62.3
1979-80	98.9	96.7	100.1	97.9	48.5
1980-81	97.0	97.3	98.1	98.4	44.6
1981-82	97.4	95.1	98.6	96.3	44.3
1982-83	92.4	93.4	93.8	94.8	41.5
1983-84	92.7	92.3	94.0	93.6	40.9
1984-85	93.8	91.9	95.1	93.2	48.3
1985-86	91.0	91.0	92.2	92.2	58.2
1986-87	89.2	89.9	90.6	91.3	67.4
1987-88	90.4	91.3	91.9	92.8	67.1
1988-89	95.6	92.9	97.3	94.6	67.0
1989-90	94.5	91.9	96.2	93.5	67.9
1990-91	86.4	88.5	88.0	90.1	62.2
1991-92	85.7	84.7	87.3	86.3	55.2
1992-93	84.2	85.5	85.6	86.9	48.3
1993-94	87.3	87.7	88.8	89.2	74.1
1994-95	93.1	91.3	94.8	92.9	74.4
1995-96	94.9	94.4	96.5	96.0	94.6
1996-97	97.2	96.7	98.4	98.0	104.9
1997-98	100.0	98.2	100.7	98.9	102.2
1998-99	99.4	99.8	99.4	99.8	101.4
1999-00	101.1	99.4	101.5	99.8	99.3
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	99.7	100.4	99.9	100.6	115.5
2002-03	102.8	101.3	103.8	102.2	116.7

Source: Authors’ estimates based on published and unpublished ABS national accounts data.

Table C.11 **Capital services indexes for infrastructure variables, Retail trade**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	89.2	88.4	86.9	86.1	20.0
1975-76	89.5	88.9	90.2	89.6	25.7
1976-77	90.2	89.6	91.3	90.6	32.0
1977-78	90.5	89.9	91.7	91.1	38.4
1978-79	90.5	90.3	91.6	91.5	35.4
1979-80	91.4	91.8	92.5	92.9	34.7
1980-81	94.9	93.5	96.0	94.5	27.1
1981-82	95.5	96.4	96.7	97.6	24.9
1982-83	100.6	98.0	102.1	99.5	25.4
1983-84	100.6	100.4	101.9	101.7	28.3
1984-85	102.2	100.8	103.6	102.2	31.2
1985-86	101.6	100.2	103.0	101.6	35.3
1986-87	98.2	97.8	99.7	99.3	38.8
1987-88	94.7	95.1	96.3	96.6	38.8
1988-89	93.8	93.5	95.5	95.1	38.9
1989-90	93.9	93.0	95.5	94.6	39.6
1990-91	92.2	93.6	93.9	95.2	44.0
1991-92	96.0	93.4	97.9	95.2	48.4
1992-93	94.6	94.6	96.2	96.1	53.9
1993-94	94.0	93.9	95.6	95.5	64.8
1994-95	94.9	93.9	96.5	95.5	72.9
1995-96	94.6	94.6	96.2	96.2	79.1
1996-97	96.5	95.3	97.8	96.6	85.7
1997-98	96.8	96.5	97.5	97.1	97.4
1998-99	98.0	97.5	98.0	97.5	89.2
1999-00	99.0	98.2	99.4	98.5	91.2
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	102.0	101.7	102.3	102.0	111.9
2002-03	104.8	103.3	105.7	104.2	113.5

Source: Authors' estimates based on published and unpublished ABS national accounts data.

Table C.12 **Capital services indexes for infrastructure variables, Transport & storage**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	66.4	66.5	64.6	64.8	11.3
1975-76	66.1	68.1	66.5	68.6	12.8
1976-77	70.7	72.8	71.6	73.7	14.4
1977-78	80.0	77.2	81.0	78.2	16.1
1978-79	78.8	80.4	79.9	81.5	15.8
1979-80	80.0	81.4	81.0	82.4	12.5
1980-81	82.9	82.3	83.8	83.2	11.7
1981-82	81.5	82.9	82.5	83.9	9.5
1982-83	82.1	82.7	83.3	83.9	10.1
1983-84	83.1	84.4	84.2	85.5	15.1
1984-85	86.1	86.9	87.3	88.1	15.4
1985-86	89.4	89.4	90.6	90.6	16.2
1986-87	90.1	90.3	91.5	91.7	16.5
1987-88	88.6	89.9	90.1	91.4	21.1
1988-89	88.6	89.0	90.2	90.6	26.2
1989-90	87.7	89.3	89.3	90.8	32.2
1990-91	88.6	90.1	90.2	91.7	37.5
1991-92	91.3	90.3	93.0	92.1	42.8
1992-93	89.7	91.8	91.2	93.3	49.2
1993-94	91.2	92.0	92.7	93.6	41.8
1994-95	93.0	94.3	94.6	96.0	69.5
1995-96	96.5	96.4	98.2	98.0	71.5
1996-97	97.8	97.7	99.1	99.0	108.1
1997-98	96.5	97.3	97.2	97.9	89.9
1998-99	95.2	96.8	95.2	96.9	78.6
1999-00	96.0	97.6	96.3	98.0	84.9
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	100.7	102.4	101.0	102.7	106.6
2002-03	103.6	103.6	104.6	104.6	111.5

Source: Authors' estimates based on published and unpublished ABS national accounts data.

Table C.13 **Capital services indexes for infrastructure variables, Communication services**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5*
1974-75	28.0	27.3	27.3	26.6	28.5
1975-76	26.4	27.1	26.6	27.3	29.2
1976-77	27.3	27.6	27.6	27.9	30.2
1977-78	29.1	28.9	29.5	29.3	31.0
1978-79	30.6	30.6	31.0	31.0	31.7
1979-80	32.4	32.6	32.8	33.0	32.7
1980-81	35.0	34.6	35.3	35.0	33.7
1981-82	36.5	37.0	37.0	37.5	34.7
1982-83	39.9	38.9	40.5	39.4	36.0
1983-84	40.7	40.7	41.3	41.3	37.8
1984-85	42.1	42.4	42.7	42.9	39.6
1985-86	44.6	44.7	45.3	45.3	42.8
1986-87	47.6	46.9	48.3	47.6	45.0
1987-88	48.7	48.8	49.5	49.6	46.9
1988-89	50.3	51.0	51.2	51.9	49.0
1989-90	54.5	54.1	55.5	55.1	52.1
1990-91	57.5	57.9	58.6	59.0	54.8
1991-92	62.0	62.0	63.2	63.2	57.0
1992-93	67.5	66.8	68.6	67.9	60.3
1993-94	71.0	71.4	72.2	72.6	63.2
1994-95	76.3	75.6	77.6	76.9	67.5
1995-96	80.3	80.5	81.6	81.8	73.7
1996-97	85.9	85.8	87.1	87.0	80.5
1997-98	92.3	91.8	92.9	92.5	84.6
1998-99	98.3	96.7	98.3	96.8	89.3
1999-00	100.0	98.9	100.3	99.3	94.9
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	99.9	101.3	100.2	101.5	104.6
2002-03	104.3	102.7	105.3	103.6	107.5

Source: Authors' estimates based on published and unpublished ABS national accounts data.

Table C.14 **Capital services indexes for infrastructure variables, Finance & insurance**

Index 2000-01 = 100

Year	*roadug2*	*roadug2s*	*l3ug2*	*l3ug2s*	*ci5ioug*
1974-75	58.5	58.2	57.0	56.7	32.4
1975-76	58.1	58.3	58.5	58.7	32.9
1976-77	58.3	58.7	59.0	59.3	33.8
1977-78	59.2	59.2	60.0	60.0	34.4
1978-79	59.7	60.8	60.5	61.6	33.6
1979-80	62.9	62.7	63.6	63.4	41.6
1980-81	64.8	63.8	65.6	64.5	47.7
1981-82	63.1	65.1	63.9	65.9	53.8
1982-83	67.1	65.7	68.0	66.7	52.3
1983-84	67.1	67.4	68.0	68.3	49.7
1984-85	67.9	69.0	68.8	70.0	54.3
1985-86	71.8	72.7	72.8	73.7	61.2
1986-87	77.8	78.9	79.0	80.1	66.7
1987-88	86.4	84.1	87.8	85.5	69.2
1988-89	87.7	88.9	89.3	90.4	72.1
1989-90	92.3	91.6	93.9	93.2	76.5
1990-91	93.5	92.3	95.2	94.0	77.2
1991-92	90.4	91.2	92.1	92.9	77.1
1992-93	90.1	89.9	91.5	91.4	78.2
1993-94	88.0	89.4	89.5	90.9	42.2
1994-95	89.6	89.0	91.2	90.5	39.2
1995-96	88.9	88.8	90.4	90.3	44.6
1996-97	88.0	88.6	89.1	89.8	48.5
1997-98	88.8	90.9	89.4	91.5	49.8
1998-99	95.7	94.6	95.7	94.7	64.6
1999-00	98.6	98.0	99.0	98.4	85.0
2000-01	100.0	100.0	100.0	100.0	100.0
2001-02	100.0	101.2	100.2	101.4	83.1
2002-03	102.6	102.0	103.5	102.9	81.6

Source: Authors' estimates based on published and unpublished ABS national accounts data.

D Control variables

Theoretical and empirical models suggest there are many determinants of productivity. Surveys of these determinants, from an Australian perspective, are provided in Dawkins and Rogers (1998), Rogers (2003) and Parham (2004). The control variables included a range of Australian studies are listed in table D.1.

A core set of control variables have been used (or at least tested) in the aggregate model and all the industry models in this paper (see sections D.1 to D.6). In addition, industry-specific control variables have been used for some individual industries or group of industries (for example, weather for Agriculture) (see sections D.7 to D.9). Other possible control variables, not included in the modelling for this paper, are outlined in section D.10. (Where appropriate, variable names are provided in brackets in the following discussion.)

The details of variable selection for the aggregate and industry models and the ‘test down’ procedure are discussed in appendixes E, F and J. The discussion in this appendix is restricted to the broad theoretical basis for the relationship between these variables and productivity and the data sources for the included control variables.

As the modelling in this paper is an extension of the work on R&D in Shanks and Zheng (2006), material for some of the variables in this appendix draws heavily on that paper. Brief surveys of the empirical literature for those variables can be found in appendix D of Shanks and Zheng (2006) and is not reproduced in this paper.

D.1 R&D

R&D activity forms knowledge assets that generate a flow of services into production and can be a source of spillovers and productivity growth (see Shanks and Zheng 2006).

The R&D stocks used in this paper were constructed for use in Shanks and Zheng (2006). For a full discussion of their construction and their relationship with productivity see appendixes A-C and F of that paper. A brief overview of the main R&D variables used in this paper is provided below.

Table D.1 **Selected Australian productivity studies[a] including a range of control variables**

			Control variables								
Author	*Agg (A) /Ind(I)*	*Dep. variable*	*Infra-structure*	*Openness*	*Int. comp. (Terms of trade)*	*R&D*	*Labour market change*	*Human capital*	*Business cycle*	*Trend*	*Other[b]*
Aggregate and multiple-industry studies											
IC (1995)	A/I	MFP	public (for ind. only)	✓	✓	✓		✓		✓	Energy prices; weather
Madden and Savage (1998)	A	LP	ITT	✓	✓			✓			
Louca (2003)	A	MFP		✓		✓	✓	✓	✓		
Valadkhani (2003)	A	LP	ITT	✓			✓	✓			Real exchange; rate real wage
Connolly et al. (2004)	A	LP		✓		✓	✓	✓			Rainfall; range of financial mkt indicators; Syd. Olympics stocks
Connolly and Fox (2006)	A/I	MFP	ITT, public	✓	✓	✓			✓	✓	Energy prices; financial dereg; weather
Shanks and Zheng (2006)	A/I	MFP	IT, public, comms	✓	✓	✓	✓	✓	✓	✓	Energy prices; weather
Single-industry studies											
Chand et al. (1998)	MAN (2 digit)	Output	public	✓		✓		✓			
Mahadevan (2002)	MAN (2 digit)	TFP	public	✓		✓					Firm number, sales

MFP = multifactor productivity; TFP = total factor productivity; LP = labour productivity; ITT = information and telecommunications technology. [a] Does not include studies by Dowrick's cross-country studies that generally include a variable of interest together with a cycle variable, rather than a range of variables. These studies are discussed in the relevant sections below. [b] These are generally industry-specific variables.

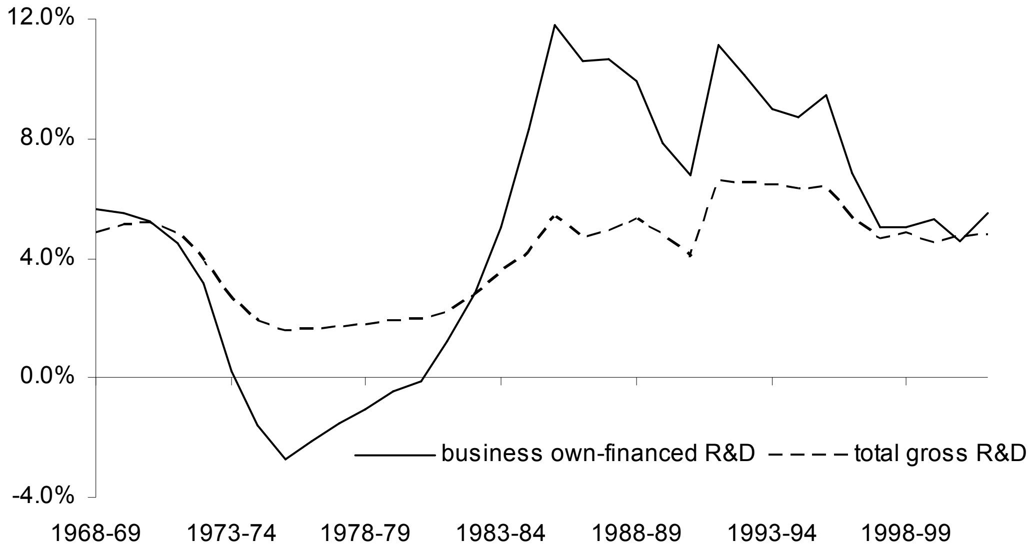
Domestic knowledge stocks

Market sector

The Australian business R&D capital or knowledge stock is based on data from surveys of business R&D expenditure and the perpetual inventory method (PIM) with an assumed decay rate of 15 per cent (figure D.1). Stock of business own-financed R&D capital ('rbus15of') declined in real terms between 1975-76 and 1981-82, followed by a rapid acceleration and high rates of growth in the stock.

Total gross R&D capital is based on data from surveys of all sectors and the PIM with an assumed decay rate of 10 per cent (figure D.1). The stock of total gross R&D capital ('rg10') assumes a lower decay rate reflecting the higher share of basic research in higher education and government R&D expenditures that make up the non-business sector component of the total stock. The non-business sector shows less volatility in its growth patterns than does the business sector, resulting in less volatility in the total gross R&D stock.

Figure D.1 **Growth in business own-financed R&D capital and total gross R&D capital, 1969-70 to 2002-03[a]**



a R&D capital stocks based on expenditures deflated using the GDP implicit price deflator (GDP (IPD)). Market sector business R&D excludes Property & business services other than Scientific research. Business R&D depreciated at 15 per cent and total gross R&D depreciated at 10 per cent.

Data sources: Shanks and Zheng (2006); ABS (*Research and Experimental Development, Businesses, Australia*, Cat. no. 8104.0); ABS (*Research and Experimental Development, All Sector Summary, Australia,* Cat. no. 8112.0); ABS unpublished data.

Industry

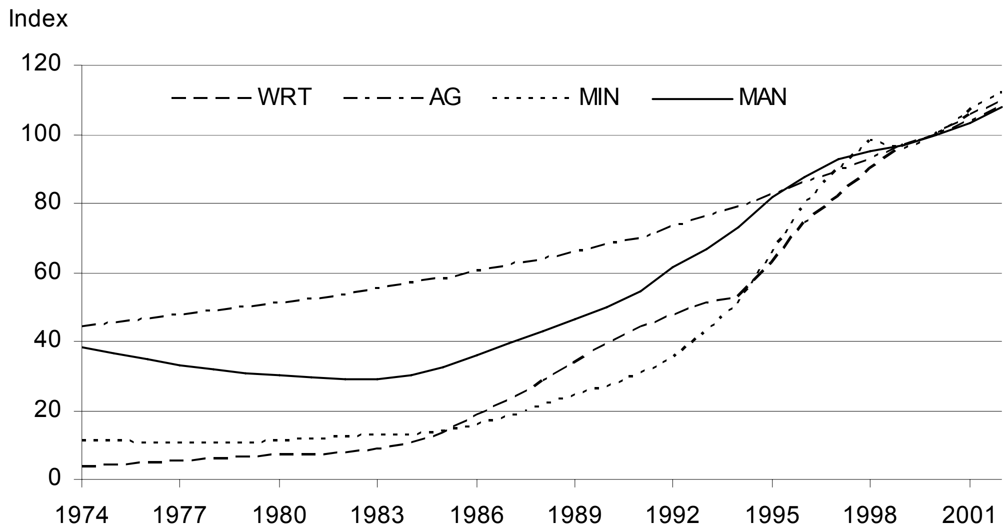
Industry's own R&D capital stock was based on the same data and methods as for the market sector, that is, use of the perpetual inventory methodology with an assumed rate of decay of 15 per cent. However, due to data limitations it was only possible to construct R&D stocks for Mining (MIN), Manufacturing (MAN) and combined Wholesale & retail trade (WRT).

The ABS business enterprise R&D survey excludes enterprises mainly engaged in Agriculture, forestry & fishing (AG). This is largely because such enterprises are believed to have very low levels of R&D activity, as R&D activity for this industry is generally carried out by specialised research institutions, such as state departments of agriculture, CSIRO and the agricultural faculties of universities (Mullen et al. 2000). Therefore, for Agriculture, forestry & fishing the non-business stock of R&D (based on R&D performed by higher education, government and non-profit institutions) was used. These data are only available for the economy as a whole. A 7.5 per cent decay rate was assumed for the non-business R&D stock to reflect that this stock consists of knowledge at a more basic or fundamental level. It is expected that the value of this type of knowledge to economic production 'depreciates' at a rate that is much slower than the bulk of business R&D.

Average growth in industry own-financed R&D was higher in WRT and Mining than the other industries (figure D.2).

Figure D.2 **Industry's R&D capital stock[a], 1974-75 to 2002-03**

Indexes 2000-01 = 100



Financial years beginning 1 July of year specified. [a] Industry's own-financed R&D capital stock depreciated at 15 per cent (rown15_o) for all industries, except Agriculture, forestry and fishing, which is aggregate non-business stock of R&D depreciated at 7.5 per cent (rnb75_u)

Data source: Shanks and Zheng (2006); authors' estimates.

Foreign knowledge stocks

Shanks and Zheng (2006) constructed time series of foreign knowledge stocks using R&D expenditure data from the OECD's Analytical Business Enterprise Research and Development database (ANBERD). The R&D expenditure of fourteen countries was included in the construction of the stocks — Canada; Denmark; Finland; France; Germany; Ireland; Italy; Japan; Netherlands; Norway; Spain; Sweden; United Kingdom; and the United States.

Various weighting schemes were used to aggregate the fourteen stocks into a single stock representing the potential spillover to Australia of knowledge from investment in foreign R&D. The different weighting schemes give different estimates of the growth in Australia's potential spillover pool from abroad (see appendix F, Shanks and Zheng 2006).

In this paper, the main foreign R&D variable used in the market sector regressions is foreign gross stock of R&D with assumed decay rates of 15 per cent weighted by country import intensities ('rfg15ch') (figure D.3, upper panel).

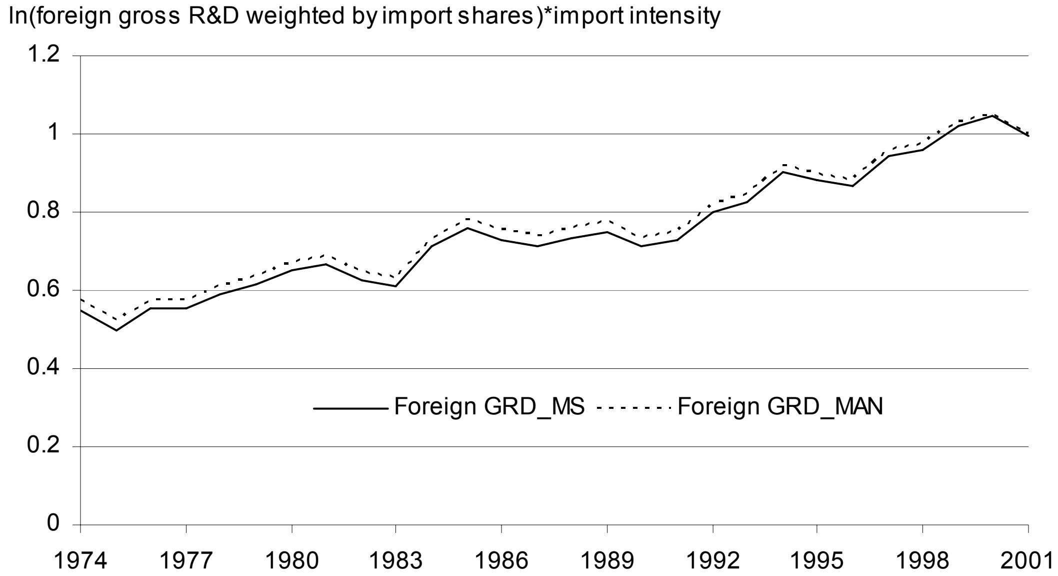
Industry-specific potential spillover pools can be constructed if foreign industry level R&D expenditure data are used rather than country-level data. Aggregating up from industry-level data opens-up the possibility of taking account of both inter-industry and inter-country relationships, hopefully resulting in a more accurate indicator of the unobserved spillover pool. In this paper, industry-specific variables were used when examining Manufacturing.

The Manufacturing equivalent to the import intensity weighted measure for the market sector is shown in figure D.3, upper panel ('rfbtdioch'). An alternative weighting scheme for Manufacturing, based on elaborately transformed manufactures import shares and inter-industry weights, is shown in figure D.3, bottom panel ('rfbteio').

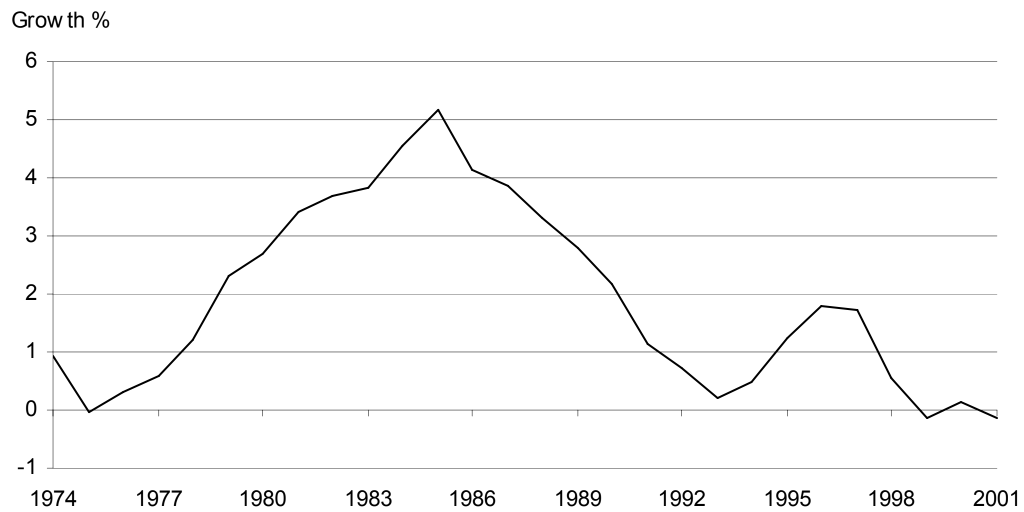
Figure D.3 **Growth in Australia's potential spillover pool, 1974-75 to 2001-02**

Assumed decay rate of 15 per cent

Foreign gross R&D import intensity weighted spillover pool[a]



Total manufacturing ETM weighted spillover pool built from foreign industry-level data[b]



Financial years beginning 1 July of year specified. [a] For Manufacturing the import shares are based on the import share and inter-industry weight. [b] Country weighted by shares in elaborately transformed manufactures and industry weighted by inter-industry weights from the Australian System of National Accounts input-output tables.

Data sources: OECD (Analytical Business Enterprise Research and Development (ANBERD) database); Shanks and Zheng (2006).

The bi-variate relationship between business R&D and productivity

This section investigates the bi-variate relationship between Australian business R&D and productivity.

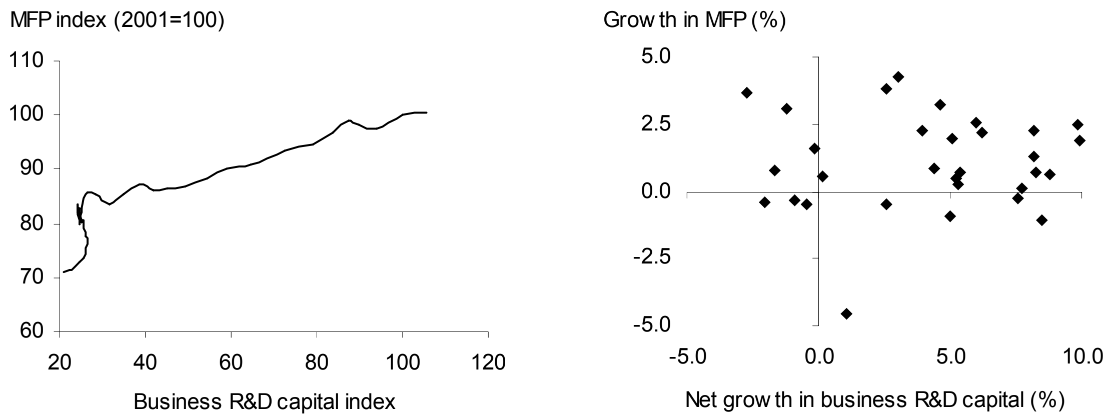
Market sector

The uppermost left-hand panel of figure D.4 plots the MFP index against the index of the Australian business R&D stock. Both indexes are trending upwards over time, which gives the appearance of a strong relationship. The other panels does not show any clear relationship between growth in MFP and growth in R&D stock. Higher levels of R&D activity are not clearly associated with higher productivity growth rates.

The scatter plots are of the contemporaneous relationship between R&D and productivity. Lagged effects of R&D on productivity, which could be obscuring relationships in the MFP growth panel, are not taken into account.

Figure D.4 **Plots of the long-run relationship between R&D and productivity in the market sector**

Business R&D stocks depreciated at 15 per cent.



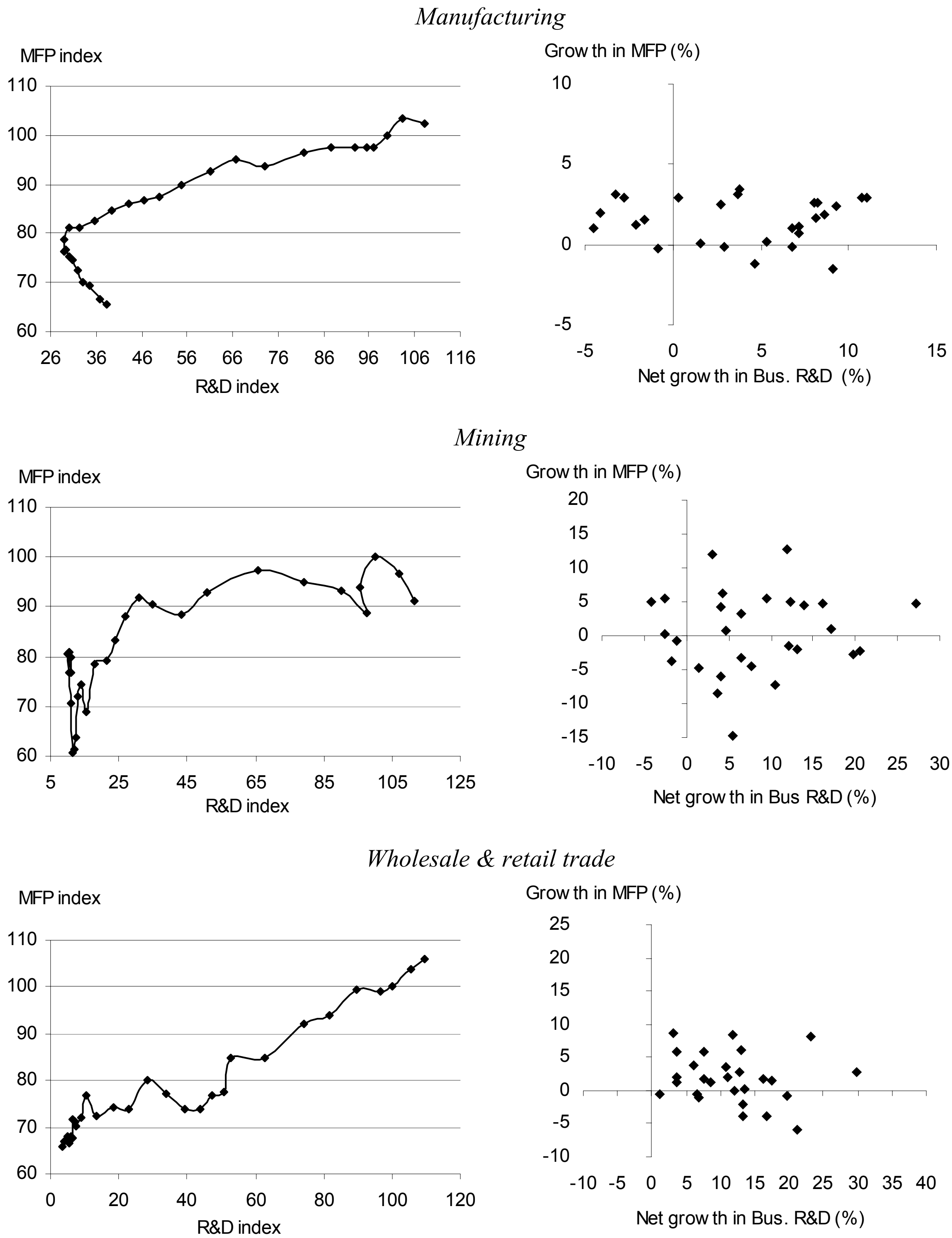
Data source: Shanks and Zheng (2006).

Industry

While the bi-variate relationship between the level of R&D and productivity at the industry-level is not clear-cut when examining the co-movements of the two indexes, there is some evidence of a positive correlation between them (figure D.5, left column).

Figure D.5 **MFP versus industry's own R&D capital, 1974-75 to 2002-03**

Indexes 2001-02 = 100; Growth per cent per year



Data source: Shanks and Zheng (2006).

Manufacturing MFP has largely increased continuously since 1974 with only a small decline in 1994 and 2002. However, the industry's own R&D capital stock declined every year between the second half of the 1970s and early 1980s, reached its trough in 1983, and then exhibited a steady increase. This caused a negative correlation between R&D and MFP in Manufacturing in the early years, followed by a positive correlation thereafter.

The bi-variate relationship in Mining is clearly non-linear. While a positive trend can still be seen to dominate the whole period, several negatively correlated segments are quite visible. This may be partly due to the fluctuations in the rate of MFP growth in the industry.

A positive linear trend is more readily apparent in the plot of MFP against R&D capital in Wholesale & retail trade. The positive correlation appears strongest in this industry.

There is no clear evidence of a contemporaneous correlation between the growth rates of MFP and own-industry R&D capital (figure D.5, right column). Higher growth rates in business R&D capital are not clearly associated with higher growth in MFP. However, lags and other influences on productivity could be obscuring a relationship.

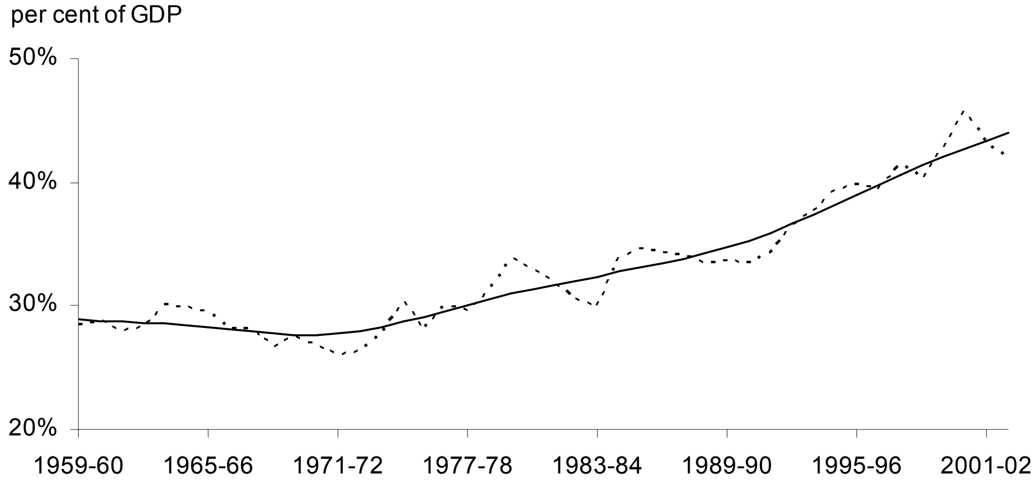
D.2 Trade openness, terms of trade and international competitiveness

Trade openness

The most commonly used index of trade openness ('topen') is the ratio of combined imports and exports over GDP (figure D.6). Alternative measures are the ratio of imports (broadly measured to include imports of capital, intermediate inputs, consumption and other imports) over GDP ('tiopen') and the ratio of imports of elaborately transformed manufactures over GDP ('tiopente').

A recent paper (Bolaky and Freund 2004) finds that, among relatively unregulated economies, such as Australia, an increase in this measure of trade openness is associated with an increase in GDP per person.

Figure D.6 **Trade openness index, 1959-60 to 2002-03**
(Imports + Exports)/GDP



Data source: ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

The reasons why trade openness may be expected to be associated with productivity growth[1] are:

- increased competition
- specialisation
- transfer of knowledge.

However, there are a number of counter-arguments.

- Trade cannot induce growth if factor movements are restricted, for example, where there are regulations preventing firm entry/exit and labour movement (Bolaky and Freund 2004).
- Governance and institutional quality are dominant determinants of economic growth (see, for example, Rodrik et al. 2002).[2]
- The proxies for openness used in empirical studies are more reflective of geographic factors than trade-related policy measures.

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[1] Berg and Krueger (2003) provides further discussion of the channels through which openness may lead to higher productivity including: the diffusion of knowledge through the import of machinery and equipment; spurs to productivity improvement at the firm and industry level as a result of increased import competition and efforts to penetrate export markets; and increases in average productivity growth as a result of resources shifting to exporting firms with relatively higher productivity.

[2] The focus of much of this literature is on explaining the differences in income levels between developed and developing countries.

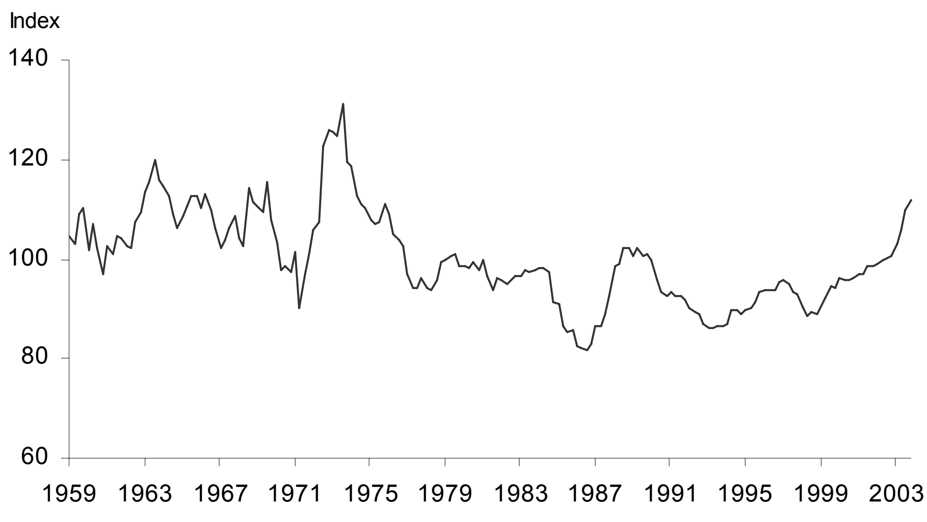
Empirical studies, while generally finding a positive relationship between growth and openness, produce a wide range of results for the size of the effect — in part because of the use of different measures of openness. For a brief discussion of this literature see appendix D of Shanks and Zheng (2006).

Terms of trade

Australia's terms of trade ('ToT') is expressed as an index and is calculated by dividing the implicit price deflator (IPD) for exports of goods and services by the IPD for imports of goods and services, multiplied by 100 (figure D.7). Alternatively the index can be for goods only ('totgoods').

An increase in the index suggests an improvement in Australia's terms of trade, enabling it to purchase more imports from the same amount of exports. A decline in the index suggests a deterioration in Australia's terms of trade, requiring it to export more to purchase the same amount of imports.

Figure D.7 **Goods and services terms of trade (seasonally adjusted), September 1959 to June 2004**



Data source: ABS (*Balance of Payments and International Investment Position, Australia*, Cat. no. 5302.0).

Policy measures

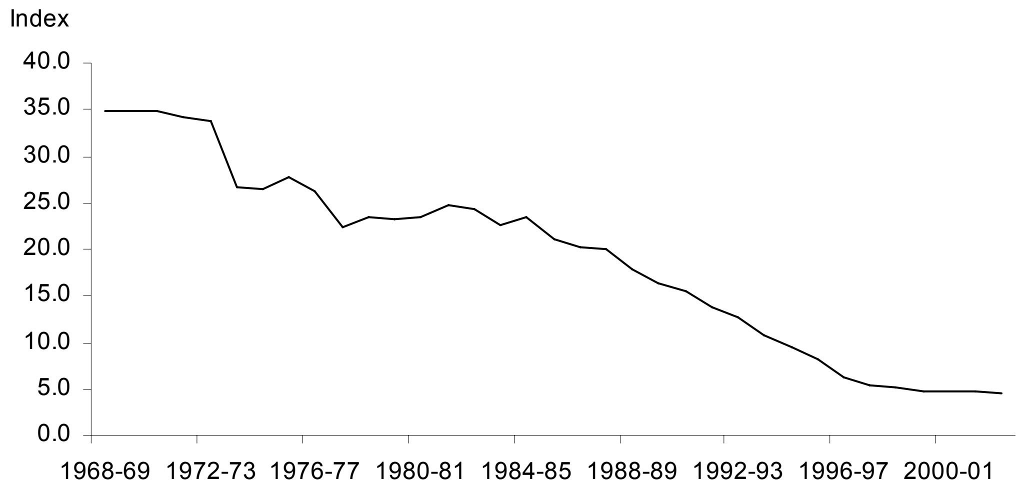
The effective rate of assistance ('era') is the percentage change in returns per unit of output to an activity's value-adding factors due to the assistance structure. The effective rate measures net assistance, by taking into account the costs and benefits of government intervention on inputs, direct assistance to value-adding factors and output assistance. A negative relationship between the effective rate of assistance and productivity is expected.

At an industry level, the effective rates of assistance may be correlated with trade openness. The effective rate of assistance also takes into account the effect of protection and assistance on input costs. In some cases, output assistance — such as tariffs on imported products — may be less than, or equal to the negative assistance — the increased price of inputs resulting from tariff protection of input producing industries. Where this is the case, assistance may seem low (or negative); however it is unlikely that these industries are as 'trade-open' as unprotected industries.

The effective rates of assistance indexes are the best available measures of trade openness at the industry level. Indexes are available at a detailed level for manufacturing covering the time period 1968-69 to 2002-03. Agriculture, forestry & fishing is available from 1970-71 to 2002-03, and Mining is available from 1997-98 to 2002-03.

After being relatively steady in the latter half of the 1970s and into the 1980s, the rate of decline in effective rates of assistance accelerated around 1984 and continued to fall rapidly until around 1997 (figure D.8).

Figure D.8 **Effective rates of assistance for total manufacturing, 1968-69 to 2002-03**



Data source: Commission estimates.

D.3 Human capital

Human capital has been proxied in empirical studies using a variety of measures, including various educational measures and experience measures. For a brief survey of the results of selected empirical studies of human capital and growth see appendix D of Shanks and Zheng (2006). A positive relationship between human capital and productivity is generally found.

For the modelling in this paper two alternative measures have been used — the ABS measure of quality adjusted labour inputs (‘QALI’), which is available only for the market sector in total, and the share of employed persons with post-school qualifications, which is available for the market sector (‘edu’) and individual ANZSIC industries (‘[industry]edu’). These measures are described in the following sections.

The quality adjustment of labour inputs for the market sector

When a labour quantity input measure is used in estimation of productivity growth, the effect of a shift in skill composition toward the skilled on output growth is captured in higher productivity growth and not higher labour input growth. Accounting for changes in composition of the workforce as ‘embodied’ increases in labour input would make productivity estimates more accurate and representative of actual ‘disembodied’ improvements in productivity. An outline of the growth accounting framework is provided in box D.1.

The ABS recently released experimental estimates of a labour services measure that accounts for changes in skill composition. The estimation method used by the ABS is similar to that already being used by the Bureau of Labor Statistics (BLS) in the United States. The ABS method distinguishes between labour force groups on the basis of skill. Groups are defined by educational attainment, work experience and gender. Work experience is used as a proxy for the on-the-job training and skill development that workers receive while employed. The gender distinction accounts for any differences in the productivities of males and females in different educational attainment and experience groups.[3]

While it is assumed that differences in the skill level between workers result in differences in marginal products, these differences are very difficult to observe directly. The ABS has assumed that these differences can be observed indirectly

[3] Differences in male and female experience levels due to females taking time out to have children and the higher proportion of females in part-time work are the main reasons why the ABS decided to have separate male and female wage regressions.

through differences in wage rates. This is based on the assumption that, in competitive markets, firms will pay workers according to their marginal product. And so, wage rate differences reflect productivity differences.

Box D.1 **Framework for analysis of changes in skill composition**

Growth in labour services is equal to growth in labour quantity plus the change in the skill composition of labour. The contribution of skill composition to output growth and productivity growth is equal to the change in skill composition multiplied by the labour income share. These relationships can be demonstrated using the following Cobb-Douglas function

$$Y = AK^{\alpha}L^{1-\alpha}$$

where output (Y) is a function of capital (K), labour services (L) and multifactor productivity (A).

Taking the log of this function and converting to growth rates

$$y = a + \alpha k + (1-\alpha)l$$

where $l = l_{sc} + h$, that is, growth in labour services (l) is equal to growth in labour quantity (h) and growth in skill composition (l_{sc}).

It is assumed that the output elasticities are equal to the factor shares, s_k and s_l, therefore

$$y = a + s_k k + s_l l_{sc} + s_l h$$

Now expressing in terms of labour productivity growth

$$y - h = a + s_k k - s_k h - (1 - s_k)h + s_l h + s_l l_{sc}$$

Which simplifies to

$$y - h = a + s_k(k-h) + s_l l_{sc}$$

Therefore, labour productivity growth is equal to multifactor productivity growth, plus capital deepening ($s_k(k-h)$) plus the contribution of changes in skill composition ($s_l l_{sc}$).

Source: Barnes and Kennard (2002).

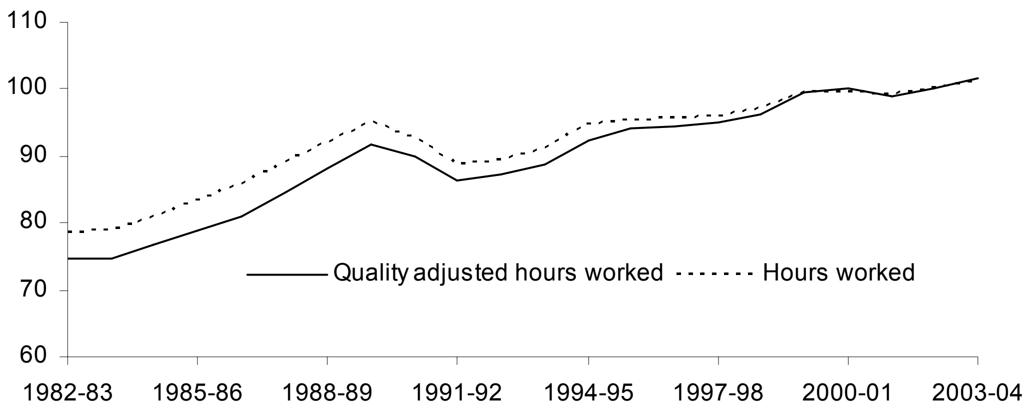
The relative wages of the different labour groups are used as weights to aggregate the hours worked by each group to form an aggregate labour services measure. With the assumption that wages reflect marginal products, the labour services measure reflects the different productivities of the hours worked by the different groups. The greater the education level and experience a classification of worker has, the greater will be the corresponding wage level and the greater will be the weighting in the labour services input index. A shift in composition toward skill will shift the aggregate labour services measure further above the aggregate hours worked measure.

Whilst the ABS methodology is largely similar to the framework used by the BLS, one major difference is the estimation of the work experience measure. The BLS is able to use data on actual work experience, but these data are not available in Australia. Instead potential experience is calculated, based on age, years of education and the number of children in the case of female workers.[4] This measure regards education years and work experience years as mutually exclusive and therefore will not capture work experience gained whilst studying, such as from part-time employment.

Figure D.9 compares quality adjusted hours worked with unadjusted hours worked. The quality adjustment increase the rate of growth in hours worked as 'effective' hours worked are higher due to increase in the quality of labour.

Figure D.9 **Hours worked and quality adjusted hours worked, market sector, 1982-83 to 2003-04**

Indexes 2002-03 = 100



Data source: ABS (*Australian System of National Accounts*, Cat. no. 5204.0).

Education indicators for changes in the quality of labour

Various educational indicators can be used as proxies for changes in the quality of labour at the whole-of-economy, market sector, and/or industry-level. Two common indicators are: the proportion of employed persons with secondary school

4 Potential experience = Age – 5 – Education Years − (Number of children). The relationship between age and experience is not linear as the wage regression involves diminishing returns to experience.

qualifications; or the percentage of employed persons (15-64) with post-school qualifications.

The post-school qualifications measure is used in the modelling for this paper. It is defined to include employed persons with:

(a) a degree or higher (a bachelor degree, a graduate or post-graduate diploma, masters degree or a doctorate); and

(b) other qualifications (including vocational or trade qualifications).

This series was constructed for the R&D modelling in Shanks and Zheng (2006). It is based on data from the ABS supplementary survey to the Labour Force Survey, Survey of Education and Work. There are several minor changes in the series, details of which are provided in *Education and Work* (ABS Cat. no. 6227.0). However, there is a major break in the series in 1993, with the introduction of the ABS Classification of Qualifications. This involved a reclassification by the ABS of people holding qualifications earned as a result of less than one semester's full-time study from the 'with post-school qualifications' group to the 'without post-school qualifications' group. This change, combined with another change to the wording of the questionnaire, is estimated by the ABS to have *lowered* the total for the 'with post-school qualifications' group in 1993 by 400 000 to 500 000 compared with the old methodology (ABS 1993).

This structural break in the series was adjusted for by estimating the following econometric model

$$E_t = \alpha + \beta(t) + \delta(d) + \varepsilon_t$$

where E is the proportion of employed with post-school qualifications at year t, α is the intercept, t is a time trend, d is an intercept dummy equal to 0 prior to 1992-93 and 1 from 1992-93 onwards, and ε_t is the residual.

A consistent series is constructed using the estimated parameters and is defined to be

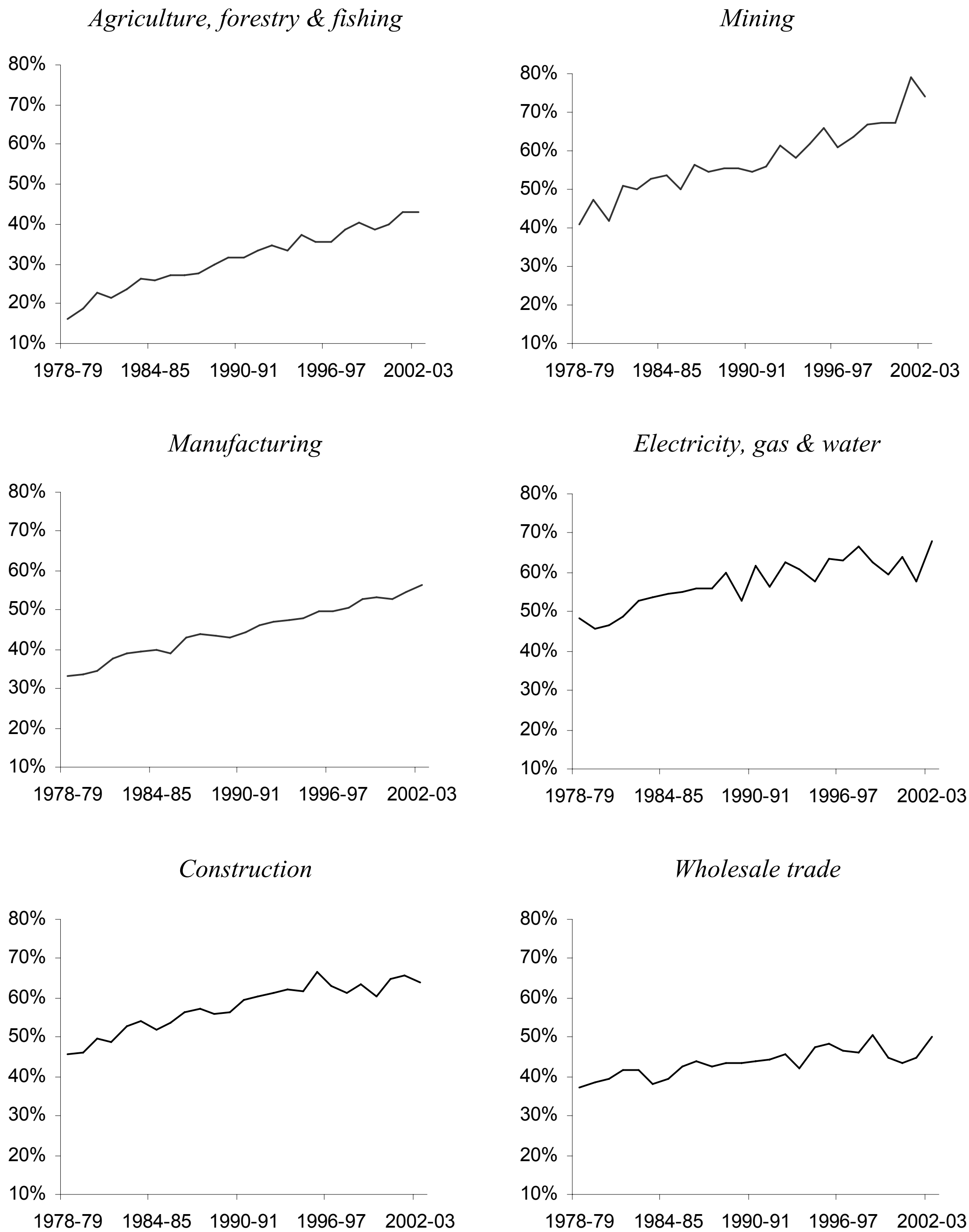
$$E_t - \delta(d) = \alpha + \beta(t) + \varepsilon_t$$

This effectively makes the later observations in the series consistent with the earlier observations. Further background to the method of construction of the education time series is provided in appendix D of Shanks and Zheng (2006).

The share of employed persons in the market sector with some form of post-school qualifications increased from about 30 per cent in 1978-79 to about 50 per cent in 2002-03 (figure D.10). There is significant variation by industry — Mining has the highest share of employed with post-school qualifications (figure D.10).

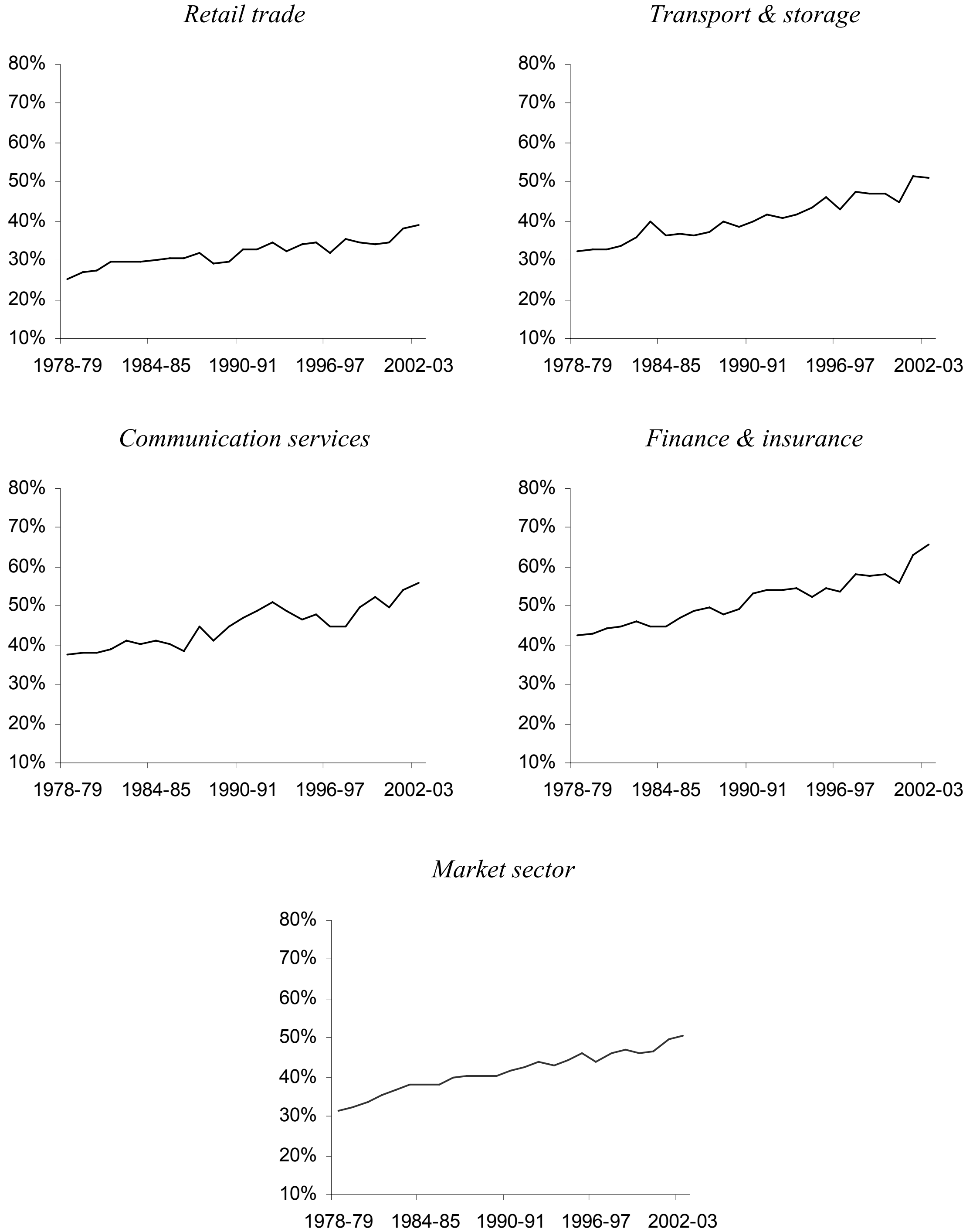
Figure D.10 **Proportion of employed persons with post-school qualifications[a], aggregate and industry divisions, 1978-79 to 2002-03**

Percentage share



(continued on next page)

Figure D.10 **(continued)**



a Adjustments have been made to obtain a consistent time series; they are detailed above, in the text.

Data sources: Based on ABS (*Education and Work, Australia,* Cat. no. 6227.0); Shanks and Zheng (2006); authors' estimates.

This education measure is not directly comparable to the school enrolment rates and average years of education used in most other studies. However, Industry Commission (1995), which used a comparable measure (the percentage of labour force with post-secondary education), reported an elasticity of 0.072 for MFP for Australia over the period 1975-76 to 1990-91.

D.4 Centralised wage bargaining, unionisation and industrial disputes

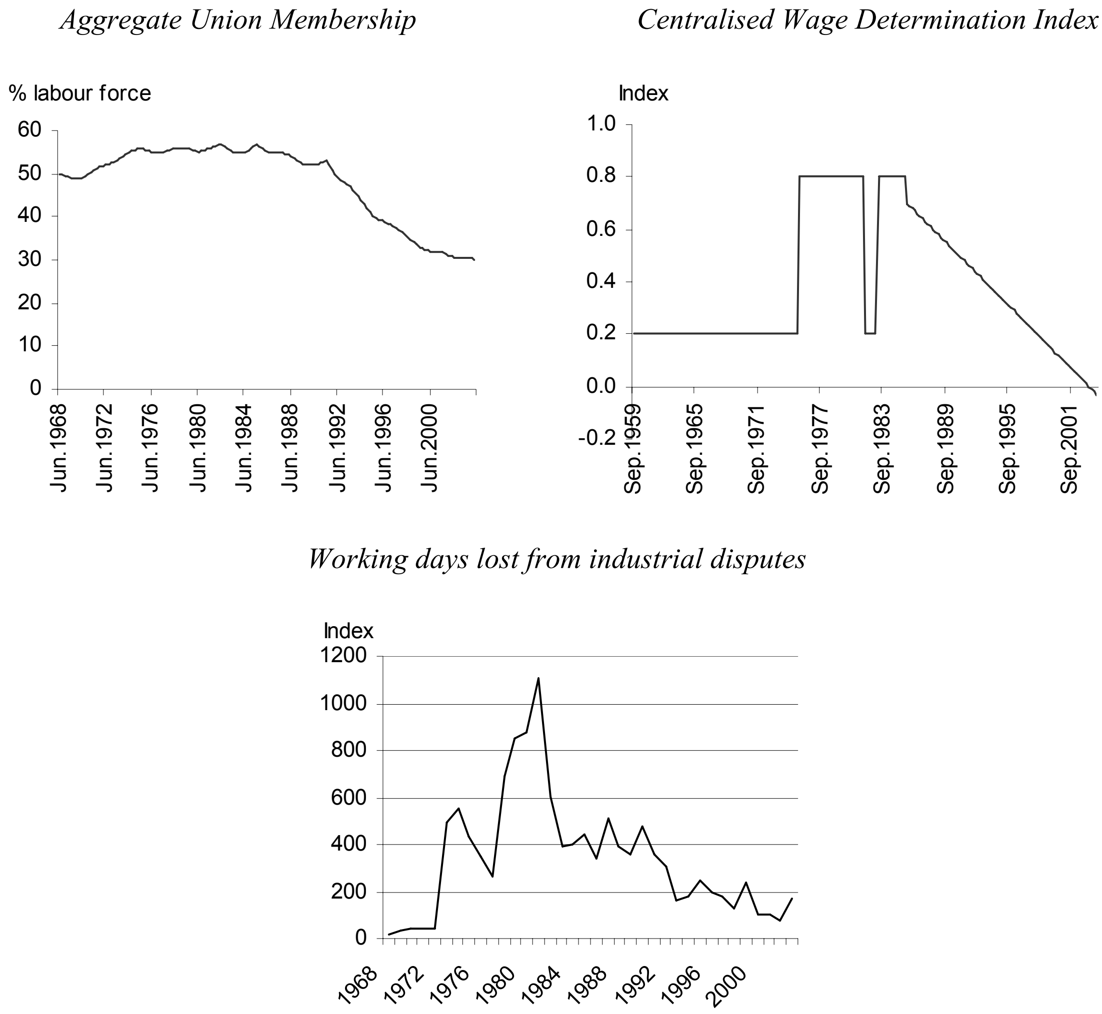
These variables are proxies for changes in the industrial relations operating environment. Indicators of union membership ('union') and the degree of centralisation in wage determination ('centbrg') are sourced from the TRYM modeller's database and working days lost from industrial disputes ('disputes') is sourced from the ABS (figure D.11). This figure shows data for the economy as a whole in the first two cases and for the market sector for disputes. Industry-specific data are available for some industries and these have been used in the modelling — for example, unionisation for EGW and disputes for Mining.

The centralised wage determination index is a subjective indicator:

> The TRYM wage equation also includes a dummy variable (QCC) that attempts to capture the effect of various institutional arrangements such as wage indexation (between 1975 and 1981), the Wages Pause (introduced in 1982) and various Prices and Income Accord agreements (since 1983). This dummy attempts to measure the degree of centralisation in various wage regimes, set to 0.8 in highly centralised periods and 0.2 in relatively decentralised periods. The values broadly represent the proportion of movements in the average minimum wage rate attributable to the national wage case decisions. Since 1987, with the movement towards productivity based enterprise bargaining, QCC has been assumed to be slowly declining. The interest with this dummy is the effect that the degree of centralisation in wage fixation may have had on sources of wage pressure. Allowance has also been made for the Metal Trades wage decision in the third quarter of 1974. (Stacey and Downes 1995, p. 15)

A negative relationship between these three variables and productivity is expected. Louca (2003) used the rate of industrial disputes (to account for labour market reform over the period 1984-85 to 1999-00) in state MFP regressions and found a negative relationship with productivity.

Figure D.11 **Union membership, wage centralisation and industrial disputes, various years**



Data sources: ABS (*Modeller's database-TRYM*, Cat. no. 1364.0.15.003); ABS (*Industrial Disputes,* Australia, Cat. no. 6321.0).

D.5 Business cycle

A business cycle variable is often included to account for the procyclical nature of productivity.

Results in Shanks and Zheng (2006) highlighted the sensitivity of the regression results to the inclusion of a control variable for the business cycle and the choice of cycle variable. In that paper, the initial control variable used was the growth in value added for the market sector, but a number of alternatives were also tested. A discussion of trends in output and MFP volatility, the pro-cyclical nature of productivity measures and the range of alternative controls for the business cycle can be found in appendix L of that paper.

For the purposes of this paper, only a subset of those alternatives was used for the market. The main cycle variables used for the market sector modelling are discussed below — other cycle variables that were used only in single regressions are discussed where these results are reported. Specific cycle variables used for individual industries are discussed in section D.8.

Alternative controls for the business cycle

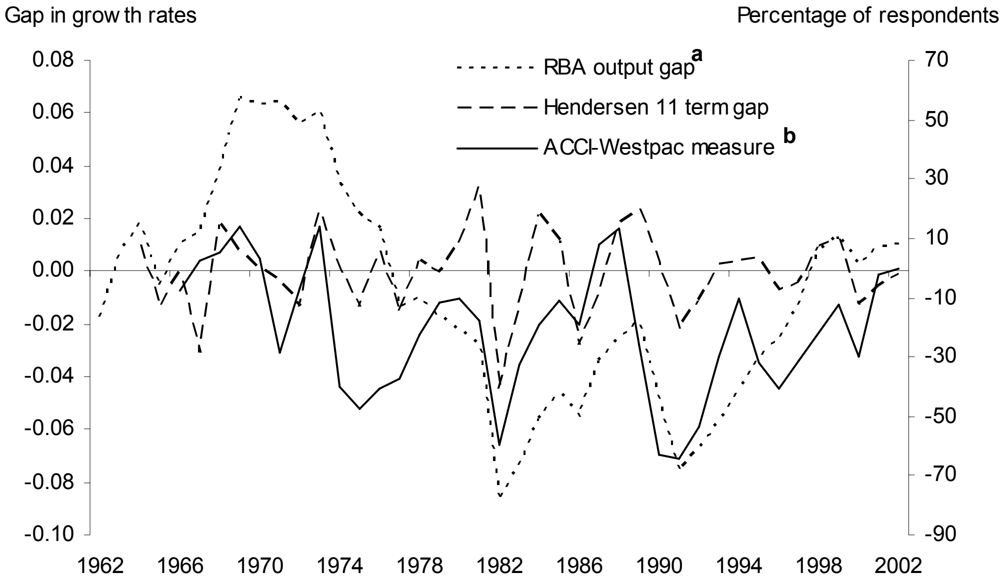
- *Simple measures* that are collinear with movements in output may be used, such as the consumer price index (CPI) or bond yields ('yrbond' or 'shrtbond'). However, they are also affected by structural shifts and may also lead or lag the business cycle and may not adequately 'soak-up' the effects of the cycle.
- *Sentiment-based measures*, such as the ACCI-Westpac capacity utilisation measure, can also be used. It is a subjective measure based on survey respondent's views as to the capacity utilisation they are working at (above, at, or below normal capacity).
- *Output gap measures* provide more sophisticated methods for controlling the effects of the business cycle. The output gap is defined as growth in actual less potential output. When the economy is growing faster than its long-run potential, the measure is positive. It is negative when economic growth is slower than its potential. The different methods for measuring 'potential' output and the output gap include the following.
  - Henderson 11 term moving average filtered output gap ('opgaph11') is arrived at by univariate filtering.
  - Reserve Bank output gap based on the simultaneous estimation of an output gap and Philips curve ('rba051') is arrived at by multivariate filtering (using structural information on the stage of the business cycle from the Philips curve relationship to improve estimates of the output gap).[5]

There can be significant differences in the cycle measures at a point in time, although patterns over time appear broadly similar (figure D.12).

[5] See Gruen et al. (2002).

Figure D.12 **Alternative output gap measures, 1962-63 to 2002-03**

Gap is growth in actual output less growth in measure of potential output



Financial years beginning 1 July of year specified. [a] The Philips curve measure was provided by the Reserve Bank of Australia. The measure is described in an RBA discussion paper by Gruen et al. (2002). It was updated with more recent data using the exact median inflation equation published in the discussion paper for the 'final vintage' of data considered (refer table 1 of the discussion paper). Incorporating the updated data, the specification produces coefficient estimates and t-statistics with very similar values to those reported in table 2. [b] There is a break in the ACCI-Westpac measure in 1987-88 as the capacity utilisation question was changed.

Data sources: ABS (*Australian System of National Accounts*, Cat. no. 5204.0); ACCI-Westpac; Reserve Bank of Australia; authors' estimates.

The bi-variate correlation coefficients of the cycle variables with ln(MFP) can range widely. The coefficients against MFP and labour productivity growth show greater consistency (table D.2).

Table D.2 **Bi-variate correlation between productivity and alternative business cycle controls, 1968-69 to 2002-03[a]**

For ln(MFP) models, cycle variables are first differenced. For productivity growth models, cycle variables are second differenced.

Model	*Market sector output*	*ACCI-Westpac*	*Hendersen 11 term gap*	*RBA output gap*
Ln(MFP)	-0.027	0.122	0.112	0.104
Δln(MFP)	0.789	0.321	0.800	0.682
Δln(Labour Productivity)	0.680	0.278	0.713	0.568

[a] The correlation coefficient between two variables *X* and *Y* is defined as equal to the covariance of *X* and *Y* over the product of the standard deviations of *X* and *Y*. The covariance of *X* and *Y* is $E[(X - u_x)(Y - u_y)]$, where *u* is the mean of the variable. A correlation coefficient of -1 and +1 implies a perfect linear relationship.

Source: Authors' estimates.

D.6 Digitisation of the communications network

Digitisation of the telecommunications network has increased transmission speed and quality and allowed a much wider range of voice and data services. This would imply a positive relationship with productivity in the long run.[6] Madden and Savage (2001) use a digital technology index (one plus the percentage of mainlines served by digital switches). They found a negative relationship with productivity of the telecommunications industry, which they attribute to short-run adjustment costs, in a cross-country study including developing countries (p. 506). Fuss and Waverman (2005) included the interaction between the degree of digitisation of a country's telecommunications infrastructure with the country's stock of personal computers. They found the impact of computer penetration on aggregate labour productivity was enhanced by the digitisation of the telecommunications infrastructure. Barker et al. (2006) extended that study to include Australia in the cross-country panel and found similar results.

In this paper the share of standard access lines that have been digitised ('digi'), from the OECD Telecommunications database 2003, has been included in the modelling — both individually and as an interaction with other types of capital/infrastructure (see appendix E for a discussion of alternative methods of including this variable in the model). This is to account for the effects of digitisation of the copper network that are not reflected in changes in the capital services index for communication infrastructure. The data series for this variable starts in 1990.

D.7 Agriculture-specific variables

The amount of rainfall and farmers' terms of trade were included as being relevant factors affecting productivity in Agriculture, forestry & fishing.

Weather

Connolly and Fox (2006) used the Southern Oscillation Index ('soi') from the Bureau of Meteorology to control for weather-induced volatility in their Agriculture regressions. This measure and the Rain index from the TRYM modelling database ('rain') are both tested in this paper.

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6 Madden and Savage (2001, p. 500) note that in the short run the benefits may be positive or negative or neutral for the productivity of the telecommunications industry. Digitisation may proxy for service quality or the rate of capital obsolescence, for example, which could imply a negative relationship.

Farmers' terms of trade

The farmers' terms of trade variable ('farmtot') is the ratio of prices received by farmers to prices paid by farmers and is used only in the regressions for Agriculture. It specifically takes account of the changes in prices of inputs and outputs that are only relevant to farmers in their production process (see ABARE 2003).

D.8 Prices including oil prices

The CPI and the changes in the oil price or mining export prices were included to control for the cyclical effects in Wholesale trade/Retail trade and Mining, respectively.

Wholesale trade and Retail trade largely serve to meet the demands of final consumption, while final consumption demand can be strongly influenced by the changes in CPI.

The oil price index ('dubai') is used as a proxy to control for some major cycles that may have a direct impact on the world energy market and the mining industry in particular. Connolly and Fox (2006) included energy prices (west Texas crude oil price) in all their industry regressions to control for the three oil price shocks. An alternative price index for the Mining sector as a whole ('minexppri') — the ABS export price index (Cat. no. 6457.0) — was also tested.

D.9 Sydney Olympics, introduction of GST and Y2K bug

Parham (2005) noted three short-term 'shocks' that brought about a combination of a build-up in capacity that then lay under-utilised; a time-shift in some major expenditures that accentuated a 'boom and bust'; and some adjustments costs (pp. 262–3).

These 'shocks' affected some industries more than others. Parham (2005, p. 263) suggests that the main output shock was on Construction (from the introduction of the GST and the Olympics) — in particular, some building activity was brought forward. He also suggests that Wholesale trade (which distributes building materials) and Finance & insurance may have been affected by 'ripples' from the construction 'boom and bust'.

The Sydney Olympics may also have affected Communication services (together with concern about the Y2K bug) and Accommodation, cafes & restaurants (with installation of increased capacity). The introduction of the GST could also have brought about adjustment costs more generally, particularly through the demand for computer and accounting systems (Parham 2005, p. 263).

Control variables for the Sydney Olympics have been used in other productivity studies (see for example, Connolly et al. 2004). In this paper, dummies for the Sydney Olympics and Y2K have been tested in some industry regressions.

D.10 Other control variables not included in the regressions

Financial deregulation

Significant financial deregulations occurred in the Australian economy in the period being modelled. Financial markets were deregulated, interest rate and exchange controls abolished, and banking opened to new entry in the early 1980s (PC 1996, p. 27).

These changes may have led to an increase in the quality of banking output, an increase not captured in measured output. McLachlan et al. (2002, p. 96) notes, for example, that increased convenience from ATMs and online banking does not show up as an increase in output. The difficulty of measuring this extra convenience has been noted in studies of banking deregulation internationally (see, for example, Baily and Zitzewitz 2001).

Oster and Antioch (1995, p. 211) suggest that '… technological innovation often leads to quality enhancement. And this highlights a further problem inherent in any attempt to gauge banking sector productivity — adjusting the measure of bank output for changes in quality becomes virtually impossible when the very nature of that output remains vague'. Some studies of productivity in Australia do include a dummy variable to control for all the effects of financial deregulation. For example, Connolly and Fox (2006, p. 60) include a trend dummy from 1986-87 to capture the productivity-enhancing effect of financial deregulation on Finance & insurance.

It is therefore difficult to construct an appropriate control variable and this has not been attempted for this paper.

Changes in shopping hours

One view is that increased shopping hours may have increased shopper convenience and therefore increased the broad concept of output. This would not have had any substantial effect on the standard measure of output of Retail trade but would have increased hours worked with a consequent fall in measured productivity (Lowe 1995, p. 113).

An alternative view is that the labour cost of opening longer hours may have been met by reductions in customer service, forcing an increased in customer self-service. The change in measured output may therefore be likely to be close to ‘actual’ output (McLachlan et al. 2002, p. 97).

An attempt to control for changes in the ‘quality’ of retail output could be made. However, changes in the regulation of shopping hours took place in different states, and possibly different sub-sectors of retail, at different times. It is therefore difficult to construct an appropriate control variable (as noted by Connolly and Fox 2006) and this has not been attempted for this paper.

E The effect of infrastructure on market sector productivity

This appendix investigates the effects of infrastructure and IT capital on market sector productivity and elaborates on the market sector results presented in chapter 5. The effects are first investigated within the framework of the determinants of multifactor productivity (MFP) (section E.1). An investigation of the determinants of labour productivity is then undertaken (section E.2). Both of these sections use the techniques outlined in chapter 4 and detailed in appendix J. To further test the robustness of estimated effects, results from first differenced regressions are presented (section E.3) and gross fixed capital formation measures are tested in place of the constructed capital services measures (section E.4). Preferred model elasticities are then summarised (section E.5). These results are sensitivity tested to the infrastructure definition (section E.6) and the potential problems that may have arisen in estimating roads are discussed (section E.7). The implied rates of return from the preferred models are then presented (section E.8) and compared with other studies (section E.9). The appendix concludes with a summary of key findings.

The modelling includes a number of control variables from the set listed in table E.1 and was subject to a range of statistical tests described in table E.2

Table E.1 **Description and expected sign of the market sector control variables**[a]

Variable	*Description*	*Data source*	*Expected sign*
Cycle/capacity utilisation variables			
opgaph11	Growth rate of actual output less growth rate of potential output with potential output obtained by applying the Henderson 11 term moving average filter to value added.	Authors' estimates.	(+)
rba051	Based on the simultaneous estimation of an output gap and Philips curve.	RBA Research Discussion Paper 2002-06	(+)
ACCI	Subjective measure of capacity utilisation constructed from ACCI-Westpac business survey.	ACCI-Westpac, *Survey of Industrial Trends*	(+)
minexppri	Export price index for mining	ABS (Cat. nos 6204.0 and 6457.0)	(?)
trend	Linear time trend. Control for steady exogenous (technological) change.		(+)
Cost of capital and its volatility			
yrbond	10 year Commonwealth Treasury bond yield.	Reserve Bank of Australia	(-)
shrtbond	Yield on Commonwealth government securities (combined series of Treasury 2 and 3 year bonds). Measure of cost of holding inventories.	Reserve Bank of Australia	(-)
spread	Spread between long and short Commonwealth bond yields	Reserve Bank of Australia, and authors' estimates	(-)
R&D variables			
rbus	Australian business stock of R&D with assumed decay rate of 15 per cent.	ABS (Cat. no. 8104.0 and unpublished data), and authors' estimates.	(+)
rbusof	Australian business own-financed stock of R&D with assumed decay rate of 15 per cent.	ABS (Cat. no. 8104.0 and unpublished data), and authors' estimates.	(+)
rg	Australian gross stock of R&D with assumed decay rate of 10 per cent.	ABS (Cat. no. 8104.0 and unpublished data), and authors' estimates.	(+)
rfgch	Foreign gross stock of R&D with assumed decay rates of 15 per cent weighted by country import intensities.	OECD (ANBERD database), ASNA input-output tables, and authors' estimates.	(+)

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Table E.1 **(continued)**

Variable	*Description*	*Data source*	*Expected sign*
uspto_ti	US Patent and Trademark Office (USPTO) patents, number of grants for R&D stock countries (weighted by import shares direction and intensity).	OECD Patent database; authors' estimates	(+)
uspto_te	USPTO patents, number of grants for R&D stock countries (weighted by import shares of elaborately transformed manufactures)	OECD Patent database; authors' estimates	(+)
Other variables			
tiopen	Index of imports as a proportion of GDP, where imports include capital, intermediate inputs, consumption and other imports.	ABS (Cat. no. 5204.0).	(+)
tiopente	Index of imports of elaborately transformed manufactures	Department of Foreign Affairs and Trade (Stars database).	(+)
era	Effective rates of assistance to industry.	Commission database.	(-)
edu	Proportion of employed with post-school qualifications.	ABS unpublished data.	(+)
nonggIT	Capital services index for IT capital assets (hardware and software) of the market sector, excluding any general government IT assets allocated to the market sector by the ABS.	ABS unpublished data and authors' estimates.	(-)
rci5	Capital services index for the remainder of market sector capital. That is, total market sector capital less: IT capital (nonggIT) and any infrastructure capital included in other variables such as public economic infrastructure (I3), roads and communications infrastructure (ci5).	ABS unpublished data and authors' estimates.	(+) in labour productivity models
rc5rd	Capital services index for combined 'rci5' and 'roads'.	ABS unpublished data and authors' estimates.	(+) in labour productivity models
ksrv	Capital services index for total market sector capital	ABS (Cat. no. 5204.0)	(+) in labour productivity models

(continued on next page)

Table E.1 **(continued)**

Variable	*Description*	*Data source*	*Expected sign*
Interactions			
ITdigi	IT capital ('nonggIT') scaled by share of access lines digitised ('digi').		(+)
rci5dg	Private 'conventional' capital ('rci5') scaled by share of access lines digitised ('digi').		(+)

a Variations on these variable names have the following meanings: 'd' before a variable name means variable is first differenced; '(t-#)' after a variable name means the named variable has been lagged by # periods; 'hr' after a variable names means the variable is expressed as per hour worked. Detailed definitions of infrastructure variables are provided in table 3.3.

Table E.2 **Statistical tests for model robustness**

Test	*Description and interpretation*
Durbin-Watson (DW) ‘d’ statistic	Test for first order serial correlation in residuals using Durbin-Watson ‘d’ statistic. A statistic close to 2 indicates no serial correlation. A statistic under 2 indicates positive serial correlation or persistence in the data. A test statistic greater than 2 indicates negative serial correlation.
Durbin-Watson (DW) ‘h’ statistic	Test for serial correlation using Durbin-Watson ‘h’ statistic for models that include regressors that are not strictly exogenous, for example, a lagged dependent variable. Prob > Chi^2 in brackets. A small probability rejects the null of no serial correlation.
AIC and SBC information criteria	Akaike’s information criterion (AIC) and Schwarz’s Bayesian information criterion (SBC). Useful for comparing the overall fit of different models (smaller scores indicate better model fit). The SBC is said to be more ‘parsimonious’ as the model’s score is more heavily penalised for the inclusion of additional regressors compared with the AIC. In selecting alternative models, the AIC tends to select models with richer lag structures.
Test for serial correlation	The modified LM statistic (or F statistic) provides a test of the hypothesis of no first order serial correlation. Kiviet (1986) has shown that in small samples the F version is generally preferable to the LM version.
Test for functional form	Ramsey specification error test for omitted variables using powers of the fitted values. The null hypothesis is that there are no omitted variables. A failure to reject the null provides support for the chosen functional form.
Test for normality	Bera and Jarque (1981) test of the null hypothesis that the disturbances have a normal distribution.
Test for heteroskedasticity	Test for heteroskedasticity or non-constant variance in the residuals. The null is that different sub-samples of the data have the same variance (homoskedasticity). P-values are in brackets. A small p-value rejects the null.

E.1 Infrastructure as a determinant of MFP growth

Initial estimates of the effect of communication infrastructure

The first model presented includes communication infrastructure and IT capital, and a range of other explanatory variables, but does not include road infrastructure (model A1 in table E.3). The signs on the coefficients are as expected, and are statistically significant at 1 per cent or greater (with the exception of business R&D which is not statistically significant at 10 per cent). The model passes the suite of statistical tests and the bounds test, but it strongly fails the long-run forcing tests. The degree of over-correction in the error correction method (ECM) term is of concern and there is a fairly high degree of negative residual autocorrelation in the error correction representation (table E.4).

Iterations of the long-run forcing test pointed towards dropping IT capital from the model. When this was done, the sign on communications infrastructure remains positive and highly significant, and the coefficient on business R&D is negative and highly significant (model A2). The model passes the bounds and long-run forcing tests. There is still significant over-correction in the ECM term, but the degree of negative residual autocorrelation is reduced.

The economic magnitude of the elasticity on business R&D implies a rate of return that is negative and substantial. A negative excess effect is not impossible (a social return to business R&D below the private return), but estimation at the level of the market sector should capture inter-firm and inter-industry spillovers leading to an expectation of a positive effect on productivity. If business R&D is lagged two periods (as in model A1), then the coefficients (and standard errors) on communication infrastructure and business R&D become 0.059 (0.022) and -0.029 (0.018), respectively. If trade openness is dropped from the model, the coefficient on business R&D remains negative and highly significant.

Given the magnitude of the negative effect, business R&D was dropped from the model resulting in the coefficient on communication infrastructure being reduced in economic magnitude and a loss of statistical significance (model A3). The model passes the bounds and long-run forcing tests (with some uncertainty over ‘tiopen’ — see the notes to the table). The ECM term is -1.28 and is highly significant with a value of -1.0 falling within the 95 per cent confidence interval.

Table E.3 **Effect of communication infrastructure on market sector MFP, long run coefficients**

Dependent variable is ln(MFP). Maximum lag of 1.

Selection criteria	*AIC*	*SBC*	*AIC*	*SBC*	*AIC/SBC*	*AIC*
Lag order	*(1,1,0,0, 1,0,1)*	*(1,1,0,0, 1,0,0)*	*(1,1,0,1,0,0)*	*(1,1,0,0,0,0)*	*(1,1,0,0,0)*	*(1,1,0,0,0)*
Model	*A1*	*A1*	*A2*	*A2*	*A3*	*A4*
opgaph11 (Stochastic)						0.111 (0.226)
ci5ioug	0.059 *** (0.016)	0.057 *** (0.018)	0.065 *** (0.021)	0.061 ** (0.022)	0.032 (0.022)	
nonggIT	-0.022 *** (0.006)	-0.021 *** (0.006)				
rbusof			-0.036 *** (0.012)	-0.032 ** (0.012)		
rbusof(t-2)	0.012 (0.018)	0.006 (0.019)				
edu	0.205 *** (0.049)	0.210 *** (0.053)	0.058 *** (0.019)	0.061 *** (0.019)	0.057 *** (0.020)	0.077 ** (0.029)
era	-0.065 *** (0.013)	-0.072 *** (0.013)	-0.075 *** (0.013)	-0.074 *** (0.013)	-0.066 *** (0.015)	-0.094 *** (0.010)
tiopen	0.152 *** (0.028)	0.129 *** (0.025)	0.094 *** (0.026)	0.095 *** (0.027)	0.098 *** (0.031)	0.047 (0.058)
intercept	3.032 *** (0.361)	3.181 *** (0.372)	4.114 *** (0.163)	4.091 *** (0.167)	4.044 *** (0.196)	4.465 *** (0.297)
opgaph11 (Deterministic)	0.396 *** (0.068)	0.402 *** (0.073)	0.426 *** (0.084)	0.441 *** (0.087)	0.449 *** (0.104)	
Test statistics						
No. of observations	27	27	27	27	28	25
Time period	76-02	76-02	76-02	76-02	75-02	77-01
Step 1 F-stat	12.817		15.594		17.690	5.227
(l.b.c.v.)	(2.476)		(2.649)		(2.850)	(3.219)
(u.b.c.v.)	(3.646)		(3.805)		(4.409)	(4.378)
Long-run forcing?	No		Yes		?[a]	Yes
R^2	0.996	0.996	0.994	0.994	0.992	0.992
Durbin’s ‘h’ stat.	-1.843 (0.065)	-1.924 (0.054)	-1.188 (0.235)	-0.876 (0.381)	0.873 (0.383)	-2.273 (0.023)
Serial correlation	1.786 (0.203)	2.280 (0.152)	0.743 (0.401)	0.440 (0.516)	0.364 (0.553)	0.363 (0.555)
Functional form	0.056 (0.816)	0.028 (0.870)	0.228 (0.639)	0.004 (0.949)	2.565 (0.126)	0.976 (0.337)
Normality	0.198 (0.906)	0.140 (0.932)	0.180 (0.914)	0.225 (0.894)	1.034 (0.596)	1.140 (0.566)
Hetero.	0.017 (0.898)	0.198 (0.660)	0.090 (0.766)	0.002 (0.961)	0.004 (0.951)	0.329 (0.572)
AIC (SBC)	96(88)	95(88)	92(86)	92(86)	92(87)	86(81)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistic for tiopen of 3.656.

Source: Authors’ estimates.

Table E.4 **Error correction representation of models A1 to A4**
Dependent variable is Δln(MFP)

Selection criteria	*AIC*	*SBC*	*AIC*	*SBC*	*AIC*	*AIC*
Model	*A1*	*A1*	*A2*	*A2*	*A3*	*A4*
Δopgaph11 (Stochastic)	-	-	-	-	-	0.562 *** (0.096)
Δci5ioug	-0.026 (0.029)	-0.018 (0.029)	-0.025 (0.032)	-0.020 (0.032)	-0.046 (0.033)	-
ΔnongglT	-0.032 *** (0.010)	-0.029 *** (0.009)	-	-	-	-
Δrbusof	-	-	-0.051 *** (0.018)	-0.044 ** (0.017)	-	-
Δrbusof(t-2)	0.019 (0.028)	0.009 (0.027)	-	-	-	-
Δedu	0.095 (0.064)	0.133 ** (0.057)	0.024 (0.057)	0.084 *** (0.027)	0.073 *** (0.025)	0.054 ** (0.022)
Δera	-0.099 *** (0.020)	-0.103 *** (0.020)	-0.106 *** (0.019)	-0.102 *** (0.019)	-0.085 *** (0.019)	-0.066 *** (0.015)
Δtiopen	0.180 *** (0.042)	0.185 *** (0.043)	0.133 *** (0.043)	0.130 *** (0.043)	0.125 *** (0.048)	0.033 (0.046)
Δintercept	4.602 *** (0.599)	4.553 *** (0.608)	5.812 *** (0.518)	5.641 *** (0.503)	5.177 *** (0.521)	3.128 *** (0.787)
Δopgaph11 (Deterministic)	0.602 *** (0.089)	0.576 *** (0.088)	0.601 *** (0.098)	0.608 *** (0.099)	0.574 *** (0.109)	-
ECM(-1)	-1.518 *** (0.131)	-1.432 *** (0.114)	-1.413 *** (0.131)	-1.379 *** (0.130)	-1.280 *** (0.137)	-0.701 *** (0.196)
Test statistics						
R^2	0.945	0.940	0.917	0.910	0.876	0.902
Std. Error of Reg.	0.006	0.006	0.007	0.007	0.008	0.007
DW ‘d’ stat .	2.519	2.598	2.335	2.249	1.772	2.174
Log Likelihood	108	106	102	101	101	93
AIC (SBC)	96(88)	95(88)	92(86)	92(86)	93(87)	86(81)

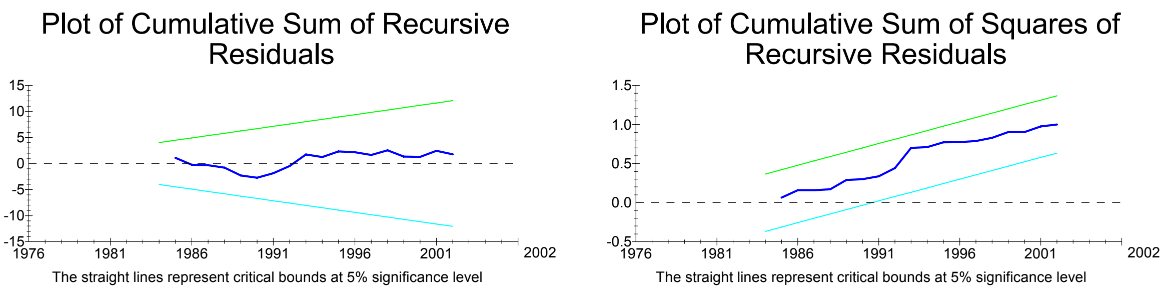
*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The statistical tests are described in table E.2.

Source: Authors’ estimates.

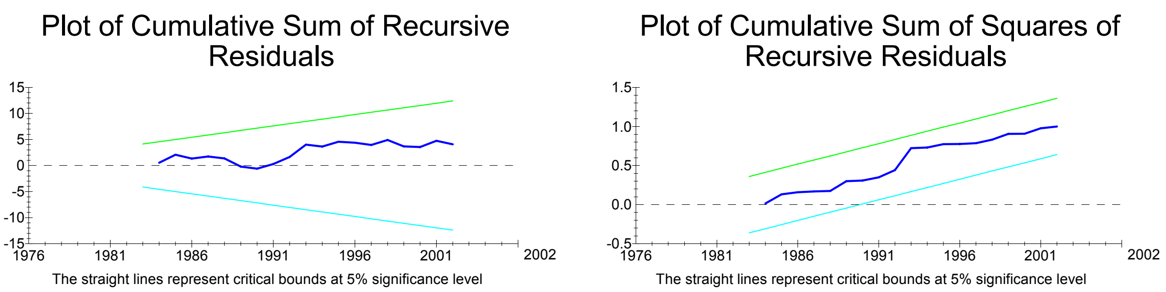
The CUSUM and CUSUM square tests show that models A2 and A3 are stable over time (figure E.1). The sum of the residuals test is intended to detect a systematic structural break in the model. The squares of the residuals test is intended to detect ‘haphazard’ breaks. CUSUM tests do not require prior specification of the date of the structural break. The power of the tests are regarded as being lower than for Chow tests.

Figure E.1 **Stability tests for models A2 and A3**

Model A2



Model A3



Data source: Authors' estimates.

Sensitivity tests

A large number of tests were undertaken to improve the estimate on communication infrastructure, including:

- testing of different measures of communication infrastructure
- alterations to the number of lags in the bounds test and order of the autoregressive distributed lag (ARDL) model in obtaining long-run coefficients
- testing of different business cycle controls, including dropping the cycle control altogether
- different sets of control variables, including various formulations of foreign knowledge stocks, energy prices, terms of trade and labour market regulatory stance indicators.

None of the tests produced a model that was satisfactory overall. Under certain specifications, a positive and statistically significant long-run coefficient on communication infrastructure could be obtained, but only if the model also contained business R&D. However, the coefficient on business R&D was invariably negative (as in model A2 above). The inclusion of a time trend in any of the tests did not improve results.

What to take from these initial results?

Models can be specified that explain MFP well, but it is the non-R&D control variables that appear more robust to specification changes. This was also a key finding, and problem, in Shanks and Zheng (2006).

The model that is open to the least criticism is model A4. This model contains no infrastructure, IT capital or R&D variables. The selected model includes a cycle measure that enters as (t) and (t-1). The estimates for education and industry protection are highly significant.

While it would be ideal to obtain estimates of the effects of road infrastructure, communication infrastructure, IT capital, and various inter-relationships from within the same model, these initial results have highlighted that this may not be possible.

Is a positive effect of IT capital related to the digitisation of the communication network?

The market sector regressions above and those in Shanks and Zheng (2006) tend to produce negative coefficients for IT capital services. If the result is viewed as being an average effect for the full period under observation, then the result is plausible if the wide diffusion of IT capital has entailed substantial disruptive effects and adjustment costs (such as learning costs). Under this scenario, there would be significant instability in the estimated elasticities — the responsiveness and direction of response of output to IT capital.[1]

Why might IT capital have a positive impact on measured MFP? One possible mechanism relates to the role of IT capital in facilitating information flows within firms and across firms. IT capital can play a role in coordinating economic activity in different ways. In wholesaling, for example, IT capital was used to implement the significant changes to the way in which goods were warehoused and transported. IT capital may support better information flows to help decision making (for example,

[1] Negative coefficients on IT capital services are consistent under varying specifications at the level of the market sector and are reasonably well estimated. If the elasticity was varying significantly, it might be expected that the standard errors of the estimates would be wider. Another possible explanation for the negative coefficient relates to the underlying assumptions used in the construction of the services measure, particularly in relation to quality adjustment.

better awareness of market and technological risks) and innovation processes (for example, as a tool which facilitates collaboration and knowledge absorption).

These potential positive effects of IT capital on productivity may have been conditional on the ‘digitisation’ of the copper telecommunications network. Digitisation of the copper network may have particularly affected small and medium enterprises (SMEs). SMEs may not have been able to access the benefits of digitisation through other methods used by larger enterprises, such as private high speed lines. However, digitisation of the copper network may also have affected larger enterprises through their relationships with SMEs (such as facilitating more integrated supplier networks) and with consumers.

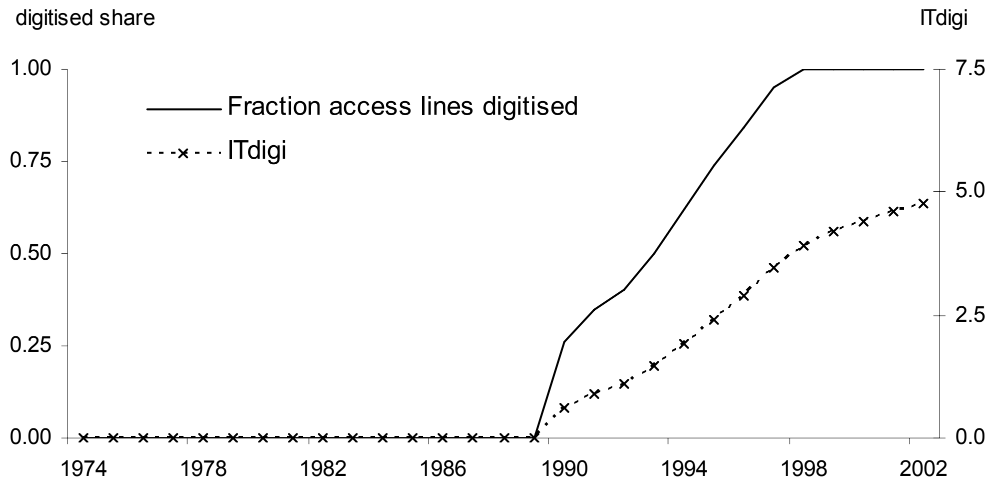
A variable ‘ITdigi’ was constructed as the percentage of access lines that are digital multiplied by the logarithm of IT capital services:

$$ITdigi = \frac{L^D}{L} * \ln(nonggIT)$$

where $\frac{L^D}{L}$ is the share of standard analogue phone access lines that are connected to digital exchanges and ‘nonggIT’ is private IT capital services. This formulation mirrors that used by Coe and Helpman (1995) in investigating the hypothesis that the effect of foreign R&D on a country is dependent on the degree of openness of that country to trade flows.

Twenty-six per cent of access lines were digital in 1990-91 — the first available data point (figure E.2). It has been assumed that the fraction of digital lines prior to 1990-91 was effectively zero.

Figure E.2 **IT capital and digitisation**



Financial years beginning 1 July of year specified. [a] Per cent of access lines connected directly to digital exchanges (switches). Does not include, for example, corporate wireless networks.

Data sources: Authors' estimates based on ABS unpublished data, and OECD Telecommunications database 2003.

The hypothesis that the coefficient on 'ITdigi' was not significantly different from zero was tested.

$$H_o : \beta_1 * ITdigi, \beta_1 = 0$$

The hypothesis is that the effect of IT capital would have strengthened as the telecommunication network increasingly catered for digital transmission. A positive coefficient on 'ITdigi' is interpreted as evidence of complementarity between IT capital and the digitisation of the copper network. But the productivity gains from the networking facilitated by this digitisation could be seen as a 'one-off' opportunity, which has already been exploited with the completion of digitisation of the copper network by the late 1990s.[2]

Model D1 produces a positive and statistically significant effect for both communication infrastructure and IT capital when IT capital is conditioned by the share of access lines 'digitised' (table E.5). Education and the effective rates of assistance ('era') are signed as expected. The short-run effect of 'era' in the error correction representation is negative and highly economically and statistically significant. This model also includes both domestic business and foreign gross R&D (GRD) knowledge stocks. Given that the coefficient on the domestic own-

2 The OECD Telecommunications database 2003 indicates that the share of standard lines directly connected to digital exchanges reached 100 per cent in 1997.

financed business knowledge stock is negative and highly economically and statistically significant, further tests were undertaken.

Models D2 to D5 contain different specifications of the knowledge stocks. If the foreign knowledge stock is dropped and openness to imports and a trend term included, then the domestic business knowledge stock is insignificant (model D2). The positive coefficients on ‘ci5ioug’ and ‘ITdigi’ remain and are statistically significant at greater than 5 per cent.

Communication infrastructure continues to be positive and statistically significant at greater than 5 per cent in each of models D3 to D5. IT capital is also positive in each model, but not as well estimated. A coefficient of zero generally falls within the 95 per cent confidence interval.

Dropping the output gap measure in favour of more direct measures of the possible sources of shocks to capacity utilisation — the export price index for mining and the spread between long and short Commonwealth bond yields — results in IT capital being significant and positive, but communication infrastructure becomes insignificant (model D6).

The statistical properties of the models are acceptable. The ECM terms tend to indicate over-correction, especially in model D6, but a coefficient of -1 is usually within or close to the 95 per cent confidence bound of the estimate (table E.6). Each model passes the bounds test and only model D6 has a variable that fails the long-run forcing test — although a number of tests across the models fall between the critical values.

Table E.5 **Effect of digitisation on market sector MFP, long run coefficients**

Dependent variable is ln(MFP). All models selected by SBC. Maximum lag = 1.

Lag order	*(1,1,0,0,0,1,1)*	*(1,1,0,1,1,0,0)*	*(1,1,0,1,0,1,0)*	*(1,1,0,1,1,0,0)*	*(1,1,0,0,1,0)*	*(1,1,0,0,1,0)*
Model	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*
ci5ioug	0.067 *** (0.020)	0.050 ** (0.022)	0.052 ** (0.024)	0.063 *** (0.022)	0.048 ** (0.021)	0.003 (0.024)
ITdigi	0.013 ** (0.006)	0.015 ** (0.007)	0.013 (0.008)	0.013 * (0.007)	0.005 (0.004)	0.014 ** (0.005)
Aus. Bus. R&D rbusof(t-1)	-0.036 *** (0.012)	0.006 (0.034)				
Aus. GRD rg(t-1)			0.015 (0.146)	0.047 (0.139)		
Foreign GRD rfgch	0.107 *** (0.032)		0.128 ** (0.052)		0.132 *** (0.040)	0.136 *** (0.036)
edu	0.134 *** (0.033)	0.171 ** (0.076)	0.197 ** (0.078)	0.192 ** (0.072)	0.147 *** (0.028)	0.133 *** (0.037)
era	-0.036 (0.022)	-0.054 *** (0.017)	-0.057 *** (0.018)	-0.044 ** (0.018)	-0.069 *** (0.016)	-0.039 ** (0.018)
tiopen		0.100 *** (0.037)		0.104 *** (0.035)		
intercept	4.058 *** (0.232)	3.506 *** (0.525)	3.755 *** (0.743)	3.171 *** (0.799)	4.057 *** (0.157)	4.165 *** (0.207)
trend		-0.006 (0.004)	-0.008 (0.007)	-0.008 (0.006)	-0.005 *** (0.001)	
opgaph11	0.458 *** (0.076)	0.414 *** (0.094)	0.441 *** (0.101)	0.406 *** (0.097)	0.434 *** (0.085)	
minexppri	-0.046 ** (0.017)					-0.043 * (0.022)
spread						-0.008 *** (0.002)
Test statistics						
No. of observations	27	27	27	27	27	27
Time period	75/76-01/02	75/76-01/02	75/76-01/02	75/76-01/02	75/76-01/02	75/76-01/02
Step 1 F-stat (l.b.c.v.) (u.b.c.v.)	24.350 (2.476) (3.646)	13.287 (2.945) (4.088)	13.181 (2.945) (4.088)	13.696 (2.945) (4.088)	16.981 (3.189) (4.329)	9.942 (2.649) (3.805)
Long-run forcing?	?[a]	Yes	Yes[b]	?[c]	?[d]	No[e]
R^2	0.996	0.996	0.995	0.996	0.994	0.988
Durbin's 'h' stat.	-1.762 (0.078)	-0.521 (0.602)	-0.137 (0.891)	-0.675 (0.500)	-0.408 (0.683)	-
Serial correlation	2.686 (0.125)	0.383 (0.547)	0.303 (0.591)	0.709 (0.415)	0.209 (0.654)	1.159 (0.299)

(continued on next page)

Table E.5 **(continued)**

Lag order	*(1,1,0,0, 0,1,1)*	*(1,1,0,1, 1,0,0)*	*(1,1,0,1, 0,1,0)*	*(1,1,0,1, 1,0,0)*	*(1,1,0,0,1,0)*	*(1,1,0,0,1,0)*
Model	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*
Functional form	0.031	0.409	0.439	0.038	0.034	2.160
	(0.862)	(0.533)	(0.519)	(0.848)	(0.857)	(0.162)
Normality	1.554	0.804	0.654	0.811	1.053	0.472
	(0.460)	(0.669)	(0.721)	(0.667)	(0.591)	(0.790)
Hetero.	0.327	0.777	3.233	2.679	0.478	0.154
	(0.573)	(0.386)	(0.084)	(0.114)	(0.496)	(0.698)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. **a** F-statistics from long-run forcing tests for ci5ioug, ITdigi and rbusof(t-1) are indeterminate at 2.962, 2.757 and 3.455, respectively. **b** F-statistic for rfgch of 4.669, but foreign R&D is clearly exogenous. **c** F-statistic for tiopen indeterminate at 3.346. **d** F-statistics for ci5ioug and ITdigi indeterminate at 4.032 and 3.224, respectively. **e** F-statistic for ITdigi of 6.756.

Source: Authors' estimates.

Table E.6 **Error correction representation of models D1 to D6**

Dependent variable is Δln(MFP)

Model	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*
Δci5ioug	-0.051	-0.018	-0.027	-0.012	-0.025	-0.075
	(0.029)	(0.034)	(0.031)	(0.031)	(0.032)	(0.048)
ΔITdigi	0.017 **	0.021 **	0.018	0.019 *	0.007	0.026 **
	(0.007)	(0.009)	(0.011)	(0.010)	(0.006)	(0.011)
Δrbusof(t-1)	-0.047 **	0.169				
	(0.017)	(0.120)				
Δrg(t-1)			0.474	0.532		
			(0.377)	(0.361)		
Δrfgch	0.141 ***		0.176 **		0.187 **	0.256 ***
	(0.048)		(0.083)		(0.067)	(0.073)
Δedu	0.080	0.055	0.068	0.053	0.076	-0.031
	(0.053)	(0.067)	(0.066)	(0.060)	(0.058)	(0.096)
Δera	-0.093 ***	-0.075 ***	-0.078 **	-0.060 **	-0.097 ***	-0.074 *
	(0.025)	(0.024)	(0.027)	(0.025)	(0.025)	(0.040)
Δtiopen		0.140 **		0.143 **		
		(0.059)		(0.056)		
Δintercept	5.355 ***	4.885 ***	5.152 ***	4.384 ***	5.722 ***	7.800 ***
	(0.618)	(0.771)	(1.051)	(1.080)	(0.595)	(1.580)
Δtrend		-0.008	-0.010	-0.011	-0.007 ***	
		(0.006)	(0.010)	(0.009)	(0.002)	
Δopgaph11	0.605 ***	0.576 ***	0.605 ***	0.561 ***	0.612 ***	
	(0.088)	(0.107)	(0.108)	(0.109)	(0.095)	
Δminexppri	-0.061 ***					-0.081 **
	(0.021)					(0.034)
Δspread						-0.014 **
						(0.006)
ECM(-1)	-1.320 ***	-1.393 ***	-1.372 ***	-1.382 ***	-1.410 ***	-1.873 ***
	(0.110)	(0.127)	(0.142)	(0.130)	(0.137)	(0.324)
Test statistics						
R^2	0.951	0.939	0.934	0.941	0.922	0.829
Std. Error of Reg.	0.006	0.007	0.007	0.006	0.007	0.010
DW 'd' stat .	2.555	2.151	2.036	2.192	2.111	2.339
Log Likelihood	109	106	105	107	103	92
AIC (SBC)	96(88)	93(85)	92(84)	94(85)	92(85)	81(74)

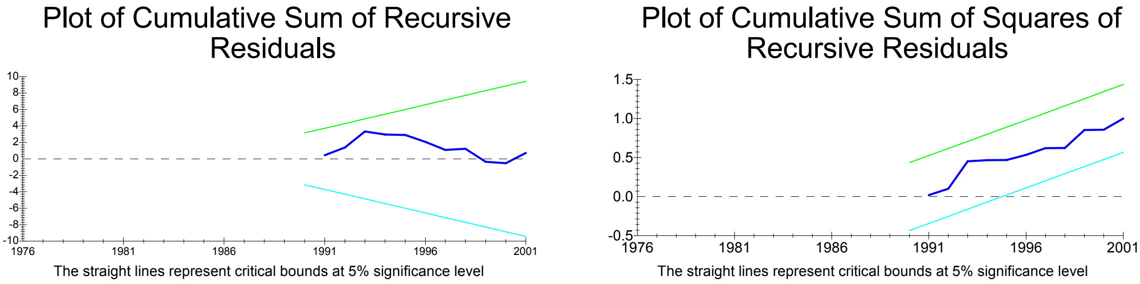
*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The statistical tests are described in table E.2.

Source: Authors' estimates.

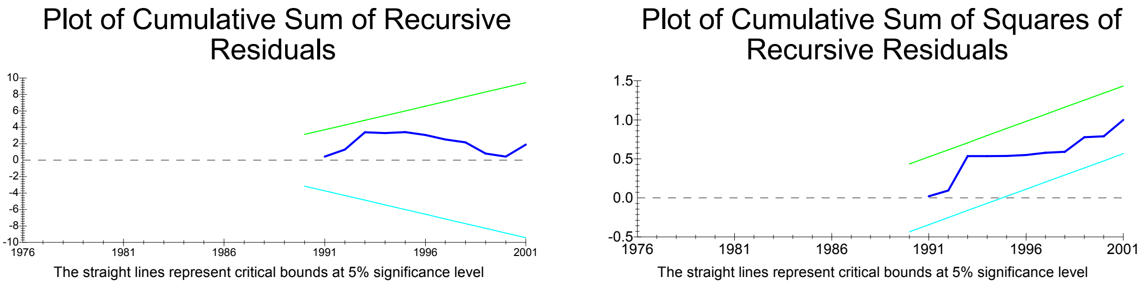
The CUSUM tests for models D2 and D3 indicate that the models are stable (figure E.3). The tests for other models also did not fail.

Figure E.3 **Stability tests for models D2 and D3**

Model D2



Model D3



Data source: Authors' estimates.

An improvement over the initial results?

The tests support a positive effect of communication infrastructure on productivity. The effect of IT capital is positive when conditioned on the share of access lines that are digital, and negative otherwise. These results hold within models where other sources of growth are reasonably well estimated and of the expected signs. As usual, the effect of domestic R&D is elusive.

The results from table E.5 are preferred to those from table E.3 because they:

- obtain significant estimates on variables of interest, while controlling for domestic and/or foreign R&D, and these controls are properly signed
- find evidence that the effect of IT capital on growth might be closely related to the digitisation of the copper network. The effects of IT capital not related to digitisation, at least for the period under observation, appear to be dominated by disruptive effects.

Estimates of the effect of road infrastructure

Both road infrastructure and broader general government infrastructure were modelled. However, the theoretical basis for expecting possible external effects for road infrastructure is stronger than for other forms of general government infrastructure. The share of road infrastructure in general government infrastructure is also very high. Therefore, greater emphasis was placed on modelling road infrastructure. Total general government infrastructure results are shown in section E.6.

At the level of the market sector, road infrastructure is included in the capital services measure used to construct MFP. Therefore, the estimated elasticities in table E.7 are interpreted as excess effects.

Testing indicated that if road infrastructure and communication infrastructure ('ci5ioug') were both included in the initial variable sets, then road infrastructure tested out of the models. Therefore, the treatment of the relationship between digitisation of the communication network and IT capital from the previous section was continued in this section, rather than having the potential effects of communication infrastructure excluded altogether. Communication infrastructure was not included separately.

With this specification, road infrastructure is positively signed and significant in explaining MFP. The better models are RI5 and RI6 as these models pass the bounds and long-run forcing tests, in addition to the suite of standard statistical tests. Domestic R&D tested out of these two models, although foreign GRD is included and is positive and significant. The effects of education and reductions in industry protection (which changed the incentives facing industrial firms to improve production processes and innovate) were controlled for in the regressions.

A 1 per cent increase in road infrastructure services produces a 0.43 per cent increase in the level of MFP (model RI5). IT capital conditioned on digitisation, the foreign knowledge stock, education and effective rates of assistance to industry are all significant and of the expected signs. The point estimate is lower in model RI6 at 0.3. However, taking account of the standard error produces a broad range of possible effects in both models.

Table E.7 **Effect of road infrastructure, long run coefficients**

Dependent variable is ln(MFP). All models selected by SBC. Maximum lag = 1.

Lag order	*(1,0,0,0,0,0)*	*(1,0,0,1, 1,0,0)*	*(1,0,0,1, 0,1,0)*	*(1,0,0,1, 1,0,0)*	*(1,0,0,0,0,0)*	*(1,0,0,0,0,0)*
Model	*RI1*	*RI2*	*RI3*	*RI4*	*RI5*	*RI6*
roads	0.405 *** (0.076)	0.383 ** (0.147)	0.461 *** (0.164)	0.476 *** (0.151)	0.427 *** (0.155)	
roadug2s						0.308 ** (0.141)
ITdigi	0.012 ** (0.004)	0.020 *** (0.006)	0.018 * (0.009)	0.018 ** (0.008)	0.008 * (0.004)	0.006 (0.005)
Aus. Bus. R&D rbusof(t-1)	-0.045 *** (0.012)	0.027 (0.031)				
Aus. GRD rg(t-1)			0.052 (0.137)	0.083 (0.134)		
Foreign GRD rfgch	0.026 (0.044)		0.091 (0.054)		0.093 ** (0.041)	0.105 ** (0.048)
edu		0.177 ** (0.073)	0.170 * (0.080)	0.167 ** (0.074)	0.092 *** (0.030)	0.097 ** (0.041)
era	-0.079 *** (0.016)	-0.065 *** (0.016)	-0.068 *** (0.017)	-0.061 *** (0.017)	-0.083 *** (0.015)	-0.075 *** (0.020)
tiopen		0.087 *** (0.034)		0.073 * (0.035)		
intercept	3.226 *** (0.345)	2.073 *** (0.653)	2.012 ** (0.762)	1.545 * (0.802)	2.679 *** (0.604)	3.075 *** (0.582)
trend		-0.009 ** (0.004)	-0.011 (0.006)	-0.011 * (0.006)	-0.005 *** (0.002)	-0.003 * (0.002)
opgaph11	0.517 *** (0.090)	0.391 *** (0.090)	0.422 *** (0.097)	0.396 *** (0.094)	0.443 *** (0.090)	0.413 *** (0.104)
Test statistics						
No. of observations	27	27	27	27	27	26
Time period	75/76-01/02	75/76-01/02	75/76-01/02	75/76-01/02	75/76-01/02	76/77-01/02
Step 1 F-stat (l.b.c.v.) (u.b.c.v.)	13.997 (2.649) (3.805)	11.032 (2.945) (4.088)	14.314 (2.945) (4.088)	12.301 (2.945) (4.088)	16.267 (3.189) (4.329)	16.369 (3.189) (4.329)
Long run forcing?	?[a]	No[b]	No[c]	No[d]	?[e]	Yes
R^2	0.992	0.995	0.995	0.995	0.993	0.991
Durbin's 'h' stat.	0.286	-0.101 (0.919)	-0.136 (0.892)	-0.276 (0.782)	-0.102 (0.919)	0.662 (0.508)
Serial correlation	0.033 (0.857)	0.042 (0.840)	0.072 (0.793)	0.115 (0.739)	0.007 (0.936)	0.067 (0.800)

(continued on next page)

Table E.7 **(continued)**

Lag order	*(1,0,0,0,0,0)*	*(1,0,0,1, 1,0,0)*	*(1,0,0,1, 0,1,0)*	*(1,0,0,1, 1,0,0)*	*(1,0,0,0,0,0)*	*(1,0,0,0,0,0)*
Model	*RI1*	*RI2*	*RI3*	*RI4*	*RI5*	*RI6*
Functional form	0.383	0.006	0.187	0.012	0.046	0.483
	(0.543)	(0.938)	(0.672)	(0.914)	(0.832)	(0.497)
Normality	1.193	1.687	2.220	1.987	1.004	1.051
	(0.551)	(0.430)	(0.330)	(0.370)	(0.605)	(0.591)
Hetero.	0.042	0.134	0.664	0.148	0.231	0.827
	(0.840)	(0.717)	(0.423)	(0.704)	(0.635)	(0.372)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistics from long-run forcing test for ITdigi, rbusof(t-1) and era indeterminate at 3.712, 2.905 and 3.295, respectively. [b] F-statistics for roads and era of 4.426 and 5.263, respectively. [c] F-statistics for rfgch and era of 5.821 and 4.204, respectively. F-statistics for roads, ITdigi and rg(t-1) all between critical values. [d] F-statistics for roads, era and tiopen of 4.597, 4.773 and 4.503, respectively. [e] The long-run forcing test for ITdigi is indeterminate with a F-statistic of 3.935. All other variables pass.

Source: Authors' estimates.

Table E.8 **Error correction representation of models RI1 to RI6**
Dependent variable is Δln(MFP)

Model	*RI1*	*RI2*	*RI3*	*RI4*	*RI5*	*RI6*
Δroads	0.553 ***	0.560 **	0.670 **	0.698 ***	0.615 **	0.441 *
	(0.107)	(0.238)	(0.252)	(0.241)	(0.248)	(0.226)
ΔITdigi	0.016 **	0.289 ***	0.025 **	0.026 **	0.011 *	0.009
	(0.006)	(0.009)	(0.012)	(0.011)	(0.006)	(0.007)
Δrbusof(t-1)	-0.062 ***	0.217			*	
	(0.019)	(0.122)				
Δrg(t-1)			0.596	0.661 *		
			(0.379)	(0.373)		
Δrfgch	0.036		0.133		0.134 *	0.150 *
	(0.061)		(0.086)		(0.067)	(0.080)
Δedu		0.084	0.072	0.062	0.132 ***	0.138 **
		(0.066)	(0.068)	(0.062)	(0.045)	(0.062)
Δera	-0.109 ***	-0.095 ***	-0.099 ***	-0.089 ***	-0.120 ***	-0.108 ***
	(0.025)	(0.026)	(0.029)	(0.028)	(0.027)	(0.035)
Δtiopen		0.127 **		0.107 *		
		(0.056)		(0.057)		
Δintercept	4.397 ***	3.036 ***	2.926 **	2.264 *	3.856 ***	4.403 ***
	(0.710)	(0.906)	(1.102)	(1.143)	(0.877)	(0.833)
Δtrend		-0.013 **	-0.015	-0.016 *	-0.008 **	-0.005
		(0.005)	(0.009)	(0.009)	(0.003)	(0.003)
Δopgaph11	0.705 ***	0.573 ***	0.614 ***	0.580 ***	0.638 ***	0.592 ***
	(0.100)	(0.108)	(0.111)	(0.113)	(0.100)	(0.112)
ECM(-1)	-1.363 ***	-1.465 ***	-1.454 ***	-1.466 ***	-1.439 ***	-1.432 ***
	(0.138)	(0.145)	(0.153)	(0.144)	(0.156)	(0.178)
Test statistics						
R^2	0.892	0.929	0.926	0.931	0.900	0.891
Std. Error of Reg.	0.007	0.007	0.007	0.007	0.007	0.008
DW ‘d’ stat .	1.924	2.026	2.032	2.071	2.023	1.891
Log Likelihood	99	104	104	105	100	94
AIC (SBC)	91(86)	92(84)	92(84)	93(85)	91(85)	85(80)

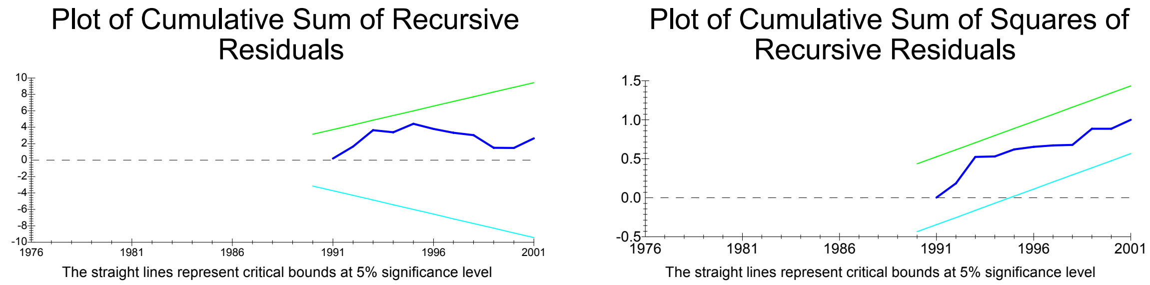
*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The statistical tests are described in table E.2.

Source: Authors’ estimates.

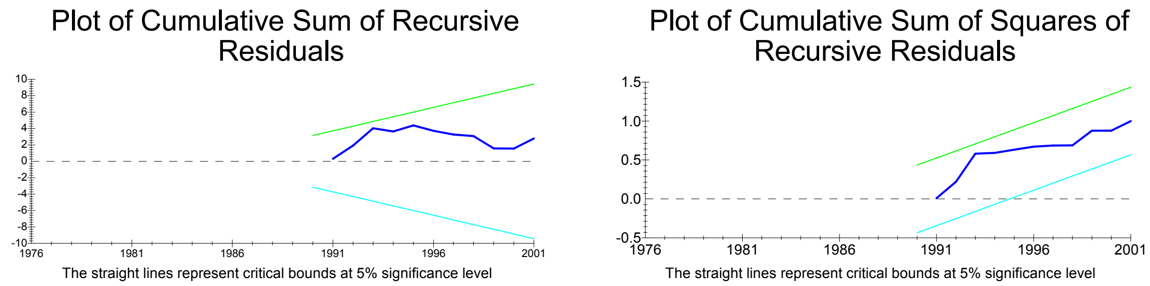
The CUSUM and CUSUM square tests show that models RI5 and RI6 are stable over time (figure E.4).

Figure E.4 **Stability tests for models RI5 (upper panels) and RI6**

Model RI5



Model RI6



Data source: Authors' estimates.

Are these models with road infrastructure better models?

There is not much to separate these results from earlier results except for the presence of road infrastructure. A positive coefficient on 'ITdigi', highly significant coefficients on education, industry protection and foreign R&D (in the better models), reasonable statistical properties, rejection of the null of no long-run relationship, over-correction in the ECM representations, and similar information criteria scores are common features of the alternative model results.

A coefficient of 0.3 to 0.43 on road infrastructure seems too high given that it is interpreted as an excess effect that does not include the free input effect.

The coefficient on roads is sensitive to the particular formulation of the variable. If roads is usage adjusted, and the model is re-tested down, then the coefficient on roads is 0.255 with a very large standard error of 0.204. A more parsimonious model results from dropping road infrastructure altogether. If roads is usage adjusted with a smoothed adjustment factor, then it tests out.

Thus far, there is evidence that IT capital services conditioned on digitisation has a positive effect on MFP where either communication infrastructure or road infrastructure is included in the model. The positive effect appears fairly robust to specification changes.

E.2 Infrastructure as a determinant of labour productivity growth

Labour productivity (LP) regressions were used to test whether the measured effects found in the MFP regressions hold in the absence of the assumptions used to construct MFP. It would be expected that results from labour productivity regressions would only differ in the addition of the capital to labour ratio for conventional capital.

Earlier MFP models tested the hypothesis that the effect of IT capital services was conditioned by the digitisation of the telecommunications network. This section tests the hypothesis in the context of the determinants of labour productivity.

Prior testing of the inclusion of road infrastructure resulted in the coefficient on capital services per hour worked ('ksrv' or 'rci5') being insignificant with an implausible point estimate (say -0.030). This occurred whether road infrastructure was usage adjusted or not. Therefore, the final initial variable sets in table E.9 did not include road infrastructure in most cases (LP5 includes roads with additional dynamics as discussed below).

Table E.9 **General-to-specific initial variable set with IT capital * digital**

Capital, infrastructure and R&D variables are per hour worked

Model	*LP1*	*LP2*	*LP3*	*LP4*	*LP5*	*LP6*
Max. lag	*1*	*1*	*1*	*1*	*2*	*1*
ksrv	✓	✓	✓	✓	✓	✓
roads	-	-	-	-	✓	-
ci5ioug	✓	✓		✓	✓	-
nonggIT	✓	-	-	-	-	✓
ITdigi		✓	✓	✓	✓	✓
rbus(t-1)	✓	✓	✓		-	✓
rfgch	✓	✓	✓	✓	-	✓
edu	✓	✓	✓	✓	-	✓
era	✓	✓	✓	✓	-	✓
intercept	✓	✓	✓	✓	✓	✓
trend	-	✓	✓	✓	✓	✓
opgaph11	✓	✓	✓	✓	✓	✓

A negative coefficient on the primary IT capital services variable 'nonggIThr' occurs in the labour productivity models as it did in MFP models (models LP1 and LP6 in table E.10). The coefficient on communication infrastructure is positive in model LP1, but not quite statistically significant at 10 per cent. The controls are signed as expected and are significant, pass standard statistical tests, and the ECM term is signed properly and highly significant. However, the bounds test is indeterminate and the model fails the long-run forcing tests.

When 'ITdigihr' is introduced, the coefficient on communication infrastructure remains positive and significant. As in the MFP regressions, the results support a positive excess effect of IT capital when considered in conjunction with the digitisation of the telecommunications network, but not otherwise. When the primary IT capital services variable 'nonggIThr' is included along with 'ITdigihr' (model LP6), then the primary coefficient is negative pointing to external disruptive effects, but there remains positive external effects associated with digitisation. The types of positive external effects possibly being captured include system or network effects and effects related to changes in the organisation of economic activity dependent on digitisation. If the separate primary communication variable 'ci5ioughr' is dropped from model LP6, then the coefficient (and standard errors) for 'nonggIThr' and 'ITdigihr' are -0.020 (0.008) and 0.049 (0.026), respectively.

Adding additional dynamics severely limits the number of control variables that can be included in the initial variable sets (model LP5). With a maximum lag of 2, road infrastructure, communication infrastructure and 'ITdigihr' are all positive and significant suggesting that these variables all have some form of excess effect on labour productivity.

The positive effects of 'ci5ioughr' and 'ITdigihr' hold across the models. However, the only model that clearly passes all standard tests plus the bounds and long-run forcing tests is LP2.

A linear time trend was highly insignificant in the tests. Foreign R&D (knowledge stock or patent measures under various weighting schemes) were usually not significant in the models.

The result for road infrastructure in model LP5 are not convincing. Adding additional dynamics helped obtain the estimate while producing a plausible coefficient on 'ksrvhr' (although estimated 'too precisely'). The other models and earlier results indicate that there are other sources of growth that are omitted from this model. The additional variable test produces an F-statistic solidly below the lower bound critical value indicating that the variables do not form a long-run relationship.

Private conventional capital 'rci5hr' and road infrastructure (unadjusted) 'roadshr' was combined into a single variable 'rc5rdhr'. This variable does not include either private IT capital or communication infrastructure. The variable was included in the test procedure for model LP2 in place of 'ksrvhr' expecting that the coefficients on IT capital and communication infrastructure would increase as now both the direct and excess effects are being captured.

With 'rc5rdhr', the coefficient and standard errors on 'ci5ioughr' and 'ITdigihr' were highly significant and economically larger at 0.084 (0.019) and 0.030 (0.003), respectively. While standard statistical tests and long-run forcing tests were acceptable, the bounds test was below the lower bound critical value.

When 'rc5rdhr' was included in the test procedure for model LP3, plus 'nonggIThr' was included, then 'nonggIThr' tested out and the coefficient on 'ITdigihr' increased to 0.055 with a standard error of 0.006. The coefficient on domestic business R&D 'rbus(t-1)' also increased in significance with a coefficient of 0.046 and standard error of 0.020. While standard statistical tests and long-run forcing tests were acceptable, the bounds test was again below the lower bound critical value.

Table E.10 **Labour productivity, long run coefficients**[a]

Dependent variable is ln(labprod). Models selected by SBC. Maximum lag = 1.

Lag order	*(1,0,1,0,0,1, 1,0)*	*(0,1,1,0, 1,1)*	*(0,1,0,1, 0,0)*	*(1,1,1,0,1,1)*	*(2,3,1,2,3)*	*(0,0,1,0, 0,1,1,1)*
Model	*LP1*	*LP2*	*LP3*	*LP4*	*LP5*	*LP6*
ksrvhr	0.448 ***	0.232 ***	0.295 ***	0.286 ***	0.426 ***	0.287 ***
	(0.053)	(0.061)	(0.053)	(0.036)	(0.013)	(0.074)
roadshr	-	-	-	-	0.074 **	-
					(0.032)	
ci5ioughr	0.042	0.061 **	-	0.043 **	0.070 ***	0.051 **
	(0.025)	(0.024)		(0.020)	(0.014)	(0.023)
nongglThr	-0.032 ***	-	-	-	-	-0.017 *
	(0.007)					(0.008)
ITdigihr	-	0.031 ***	0.032 ***	0.026 ***	0.021 ***	0.023 ***
		(0.006)	(0.005)	(0.004)	(0.002)	(0.006)
rbus(t-1)hr	0.052 **	0.029 *	-0.004	-	-	0.056 **
	(0.022)	(0.015)	(0.024)			(0.022)
rfgchhr	0.218 ***	-	-	-	-	0.150 **
	(0.048)					(0.055)
edu	0.301 ***	0.157 ***	0.131 ***	0.150 ***	-	0.267 ***
	(0.083)	(0.054)	(0.047)	(0.035)		(0.084)
era	-0.048 **	-	-0.042 *	-0.030 **	-	-
	(0.017)		(0.020)	(0.013)		
intercept	0.879 *	2.271 ***	2.714 ***	2.430 ***	1.889 ***	1.392 ***
	(0.442)	(0.080)	(0.213)	(0.124)	(0.150)	(0.511)
opgaph11	0.614 ***	0.614 ***	0.677 ***	0.534 ***	0.361 ***	0.653 ***
	(0.095)	(0.077)	(0.082)	(0.060)	(0.057)	(0.080)
Test statistics						
No. of observations	27	27	27	27	26	27
Time period	76/77-02/03	76/77-02/03	76/77-02/03	76/77-02/03	77/78-02/03	76/77-02/03
Step 1 F-stat	3.425	3.306	4.468	4.823	1.203	3.244
(l.b.c.v.)	(2.365)	(2.649)	(2.649)	(2.649)	(2.850)	(2.365)
(u.b.c.v.)	(3.553)	(3.805)	(3.805)	(3.805)	(4.049)	(3.553)
Long-run forcing?	No[b]	Yes	?[c]	No[d]	No[e]	No[f]
R^2	0.999	0.999	0.999	0.999	1.000	0.999
Std. Error of Reg.	0.006	0.006	0.006-	0.005	0.003	0.005
DW ‘d’ stat .	-	2.061	2.152	-	-	2.104
Durbin’s ‘h’ stat.	-0.701	-	-	-1.539	-	-
	(0.483)			(0.124)		
Serial correlation	0.234	0.070	0.255	3.885	0.599	0.211
	(0.637)	(0.794)	(0.620)	(0.069)	(0.461)	(0.654)
Functional form	1.083	2.565	0.039	0.944	1.244	4.435
	(0.317)	(0.130)	(0.846)	(0.348)	(0.297)	(0.055)
Normality CHSQ(2)	1.013	1.107	1.154	1.079	1.169	1.792
	(0.603)	(0.575)	(0.562)	(0.583)	(0.557)	(0.408)
Hetero.	0.021	0.027	5.437	2.862	0.132	0.418
	(0.886)	(0.871)	(0.028)	(0.103)	(0.720)	(0.524)
AIC (SBC)	97(88)	98(91)	96(90)	101(93)	109(98)	100(92)

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Table E.10 **(continued)**

Model	*LP1*	*LP2*	*LP3*	*LP4*	*LP5*	*LP6*
Error correction representation						
ECM(-1)	-1.167	-	-	-1.235 ***	-1.625 ***	-
	(0.117)			(0.079)	(0.110)	
DW ‘d’ stat .	2.214	-	-	2.540	2.270	-

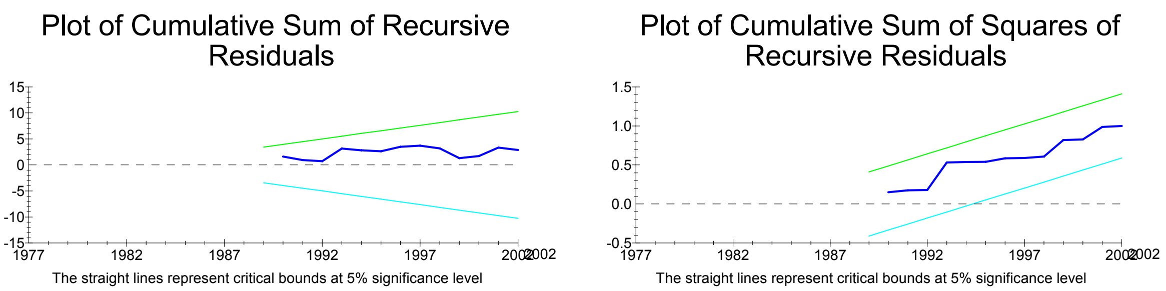
*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] All variables are in logs (except the linear time trend and output gap) with slope coefficients interpreted as elasticities. All capital infrastructure and R&D variables are per hour worked. [b] F-statistics for most variables are above upper critical value bound. [c] F-statistics for ITdigihr and era indeterminate at 3.702 and 3.082, respectively. [d] F-statistics for ITdigihr of 4.140. [e] F-statistic for ITdigihr of 5.187. [f] F-statistic for nongglThr, rfgchhr and edu of 6.841, 7.584 and 11.562, respectively.

Source: Authors’ estimates.

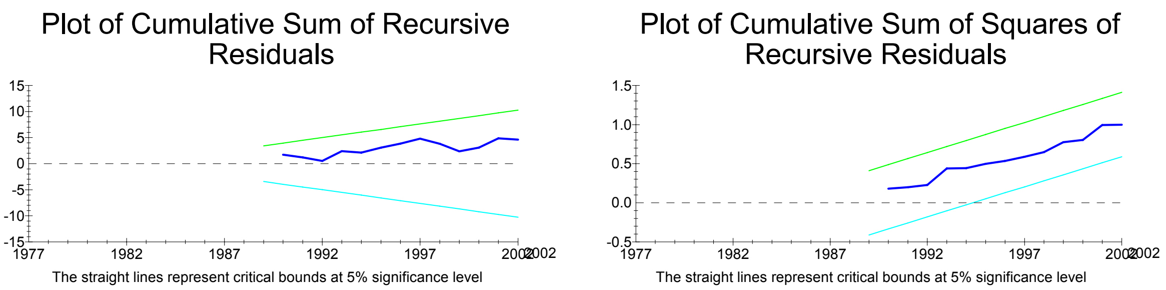
The CUSUM and CUSUM square tests show that models LP2 and LP3 are stable (figure E.5).

Figure E.5 **Stability tests for models LP2 (upper panel) and LP3**

Model LP2



Model LP3



Data source: Authors’ estimates.

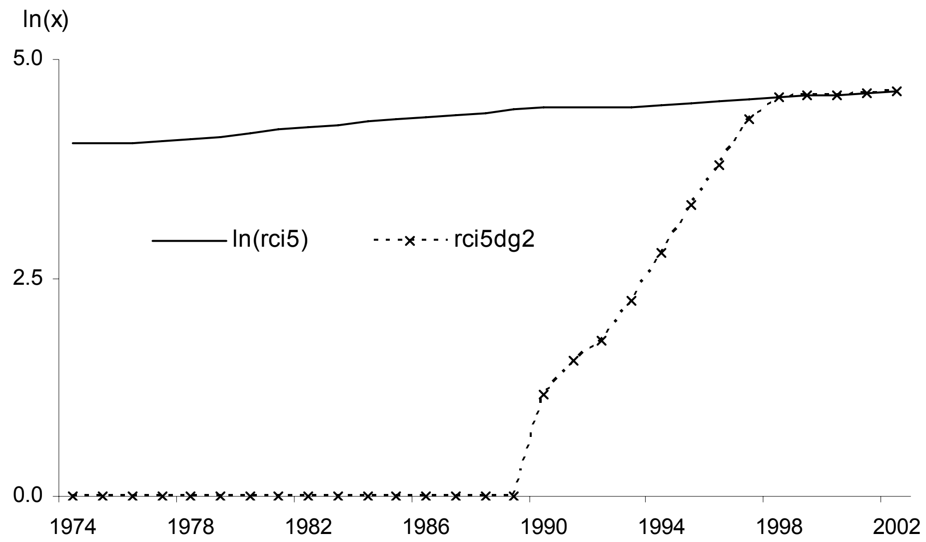
Broader impacts of digitisation

To investigate whether digitisation had an effect on the marginal product of private conventional capital, in addition to that which it appears to have had on IT capital, the capital measure 'rci5' was combined with the share of access lines digitised in the same manner as for the IT capital tests (figure E.6).

$$rci5dg = digi * \ln(rci5)$$

where 'digi' is the share of access lines digitised, and 'rci5' is private conventional capital services.

Figure E.6 **Private conventional capital and digitisation**



Data sources: Authors' estimates based on ABS unpublished data, and OECD Telecommunications database 2003.

Models D7 and D8 use the primary capital variable 'rc5rdhr', which is a combined measure including 'rci5' and 'roads'. This measure does not include IT capital or communication infrastructure. Models D9 and D10 use the variable 'ksrvhr' which includes all capital and infrastructure. Therefore, the effects being captured between these two sets of models differs.

The labour productivity results do not indicate that digitisation increased the elasticity on private conventional capital. The coefficient on the variable 'rci5dg' is not positive and significant in any of the models in table E.11.

Private IT capital 'nonggIThr' was included in the testing procedure for models D7 and D9. As with earlier results, its coefficient is negative and significant, while the coefficient on ‘ITdigihr’ is positive and significant. Private IT capital repeatedly fails long-run forcing tests, therefore it was dropped from both D8 and D10. The null of no long-run relationship between the variables is rejected for both models, and education is the only variable that either fails the long-run forcing test (model D8) or is indeterminate (model D9). For ‘ITdigihr’, models D7 and D8 capture both the direct and excess effects. The economic magnitude of the effects are larger, as expected, than in models D9 and D10 (comparing models D7 versus D9 and D8 versus D10), as the latter models capture only the excess effects.

Testing interaction terms did not produce acceptable results. Including the primary coefficients and an interaction term between ‘rc5rdhr’ and ‘ci5ioughr’, ‘rci5hr’ and ‘ci5ioughr’, and ‘rci5hr’ and ‘nonggIThr’ all had major negative impacts on the models.

Overall, the results from model D10 are preferred, but do not advance the results obtained earlier. There is no evidence of complementarity between private conventional capital ‘rci5hr’ and either communication infrastructure ‘ci5ioughr’, IT capital ‘nonggIThr’, or digitisation of the telecommunications network ‘rci5dghr’ at the level of the market sector. The finding that digitisation has a positive impact on the marginal product of private IT capital holds in these specifications.

Table E.11 **Digitisation and private capital**[a]

Dependent variable is log of labour productivity. Models selected by SBC. Maximum lag = 1.

Lag order	*(0,1,0,1,0,1,0)*	*(1,1,0,0,0,1,0)*	*(0,1,0,0,0,0,1,0)*	*(0,1,0,0,0,1,0)*
Model	*D7*	*D8*	*D9*	*D10*
ksrvhr	-	-	0.372 ***	0.344 ***
			(0.079)	(0.082)
rc5rdhr	0.463 ***	0.306 ***	-	-
(rci5 + roads)	(0.097)	(0.063)		
rci5dghr	-0.006	-0.016 ***	0.001	-0.007
	(0.006)	(0.005)	(0.005)	(0.006)
nongglThr	-0.042 ***	-	-0.019 **	-
	(0.011)		(0.007)	
ITdigihr	0.032 ***	0.053 ***	0.020 ***	0.036 ***
	(0.004)	(0.004)	(0.006)	(0.007)
rbus(t-1)hr	-	-	0.045 *	-
			(0.025)	
uspto_te	-	0.117 ***	-	0.141 ***
		(0.021)		(0.045)
edu	0.238 ***	0.176 ***	0.325 ***	0.286 ***
	(0.069)	(0.039)	(0.081)	(0.071)
era	-0.025	-0.030	-0.047 *	-0.055 **
	(0.021)	(0.019)	(0.024)	(0.025)
intercept	0.795	1.816 ***	1.414 ***	1.594 ***
	(0.489)	(0.174)	(0.412)	(0.355)
trend	0.019 ***	-	-	-0.010 **
	(0.004)			(0.004)
opgaph11	0.671 ***	0.560 ***	0.657 ***	0.662 ***
	(0.080)	(0.078)	(0.085)	(0.084)
Test statistics				
No. of observations	28	27	27	27
Time period	75-76 to 02-03	75-76 to 01-02	75-76 to 01-02	75-76 to 01-02
Step 1 F-stat	6.617	4.333	4.505	4.944
(l.b.c.v.)	(2.945)	(2.476)	(2.365)	(2.945)
(u.b.c.v.)	(4.088)	(3.646)	(3.553)	(4.088)
Long-run forcing?	No[b]	No[c]	No[d]	Yes[e]
R^2	0.999	0.999	0.999	0.999
Std. Error of Reg.	0.006	0.006	0.006	0.006
Durbin's 'h' stat.	-	-0.468	-	-
		(0.640)		
Serial correlation	0.775	0.260	0.431	1.614
	(0.392)	(0.618)	(0.521)	(0.223)
Functional form	2.461	0.007	4.711	1.499
	(0.138)	(0.933)	(0.046)	(0.240)
Normality	1.521	0.549	1.401	1.228
CHSQ(2)	(0.467)	(0.760)	(0.496)	(0.541)
Hetero.	0.772	3.784	0.349	0.706
	(0.388)	(0.063)	(0.560)	(0.409)

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Table E.11 **(continued)**

Lag order	*(0,1,0,1,0,1,0)*	*(1,1,0,0,0,1,0)*	*(0,1,0,0,0,0,1,0)*	*(0,1,0,0,0,1,0)*
Model	*D7*	*D8*	*D9*	*D10*
ECM representation				
ECM(-1)	-	-1.131 ***	-	-
		(0.086)		
R^2	-	0.947	-	-
DW 'd' stat .	2.311	2.161	2.221	2.362
Log Likelihood	112	109	107	107
AIC (SBC)	100(92)	98(91)	96(89)	96(89)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. **a** Infrastructure, capital and R&D variables are per hour worked in labour productivity models. **b** F-statistics for nongglT and education of 7.165 and 16.864, respectively. **c** F-statistic for education of 3.971. **d** F-statistics for nongglT and education of 5.408 and 11.088, respectively. **e** F-statistic for education is indeterminate at 3.404.

Source: Authors' estimates.

E.3 Do the measured effects hold in differenced regressions?

All of the results to this point are based on dynamic specifications estimated in levels. If the data is non-stationary and estimation is in levels, then valid inference relies on the existence of a co-integrating relationship between the variables. Hurlin (2003), Crowder and Himarios (1997), Sturm and de Haan (1995), Gramlich (1994) and Tatom (1991) point to important upward biases in the magnitude of the elasticity on public infrastructure. They do not find support for a co-integrating relationship between the level of public infrastructure and productivity. Elasticity estimates from first differenced regressions do not support the positive and economically large impacts found in most levels regressions. These studies view the estimated large contributions of infrastructure to productivity growth with great scepticism.[3]

The results from first differenced regressions below appear to support these concerns, at least for road infrastructure.

Initial variables sets for the general-to-specific testing procedure for the differenced regressions are presented in table E.12. Models DMFP1 to DMFP5 investigated the determinants of MFP, while DLP1 and DLP2 investigated the determinants of

3 A counter-argument has been put that there is a loss of information about the long-run relationship when data is differenced (see, for example, Fernald 1999).

labour productivity. The treatment of road infrastructure and IT capital varies by model.

For the labour productivity models, with the inclusion of a road infrastructure variable the coefficient on conventional capital services ('ksrvhr' or 'rci5hr') became insignificant, as was the case in the earlier levels regressions. A road infrastructure contribution to labour productivity growth separate from conventional capital services could not be identified, although it would be expected to exist.

Table E.12 **Initial variable sets for differenced regressions**

For labour productivity models, variables are per hour worked as appropriate

Dep. var.	*Δln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*Δln(LP)*	*Δln(LP)*
Model	*DMFP1*	*DMFP2*	*DMFP3*	*DMFP4*	*DMFP5*	*DLP1*	*DLP2*
Δksrvhr	-	-	-	-	-	✓	-
Δ [combined rci5+roads]	-	-	-	-	-	-	✓
Δroads	✓	-	-	✓	-	-	-
Δroadug2	-	✓	-	-	✓	-	-
Δci5ioug	✓	✓	✓	✓	✓	✓	✓
ΔnonggIT	✓	✓	✓	-	-	✓	✓
ΔITdigi	-	-	-	✓	✓	✓	✓
Δrbus(t-1)	✓	✓	✓	✓	✓	✓	✓
Δuspto_ti	✓	✓	✓	✓	✓	✓	✓
Δedu	✓	✓	✓	✓	✓	✓	✓
Δera	✓	✓	✓	✓	✓	✓	✓
intercept	✓	✓	✓	✓	✓	✓	✓
Δopgaph11	✓	✓	✓	✓	✓	✓	✓

Model DMFP1 (road infrastructure not usage adjusted), model DMFP2 (road infrastructure adjusted by value added shares) and model DMFP3 (no road infrastructure in the initial variable set) all test down to the same model (table E.13). Road infrastructure is not significant in explaining MFP in these models. Communication infrastructure, domestic business R&D and USPTO patents also test out. The coefficient on IT capital services is negative.

The statistical properties of the models are acceptable. If the cycle variable is excluded, none of the variables are statistically significant.

The effect of IT capital conditioned on digitisation of the communication network 'ITdigi' is positive (models DMFP4 and DMFP5). Usage and non-usage adjusted road infrastructure, communication infrastructure, and domestic own-financed business R&D are again insignificant.

For the labour productivity models, the separate variables representing communication infrastructure ‘ci5ioug’ and IT capital services ‘nonggIT’ are not significant and test out of the models. Domestic business R&D is also not close to being statistically significant at 10 per cent and was dropped.

The effect of IT capital conditioned on digitisation of the communication network remains positive and significant. Its point estimate is lower in DLP1 with ‘ksrvhr’. This makes sense as the coefficient captures an excess effect only since IT capital and communication infrastructure are also included in ‘ksrvhr’. Model DLP2 uses ‘rci5hr’ so that the coefficient captures a total effect incorporating both a private conventional return and an additional or excess effect.

The MFP models test the separate effect of road infrastructure, but do not find it to be significant. Point estimates are large and positive, but the standard errors are extremely large allowing for almost any effect on MFP. Therefore, road infrastructure was allowed to test out of the models DMFP1 to DMFP4, but was retained in DMFP5 to illustrate the point. The labour productivity models are unable to investigate the separate contribution of road infrastructure.

The effect of IT capital services is negative and significant or insignificant, depending on specification. The effect of IT capital services conditioned on digitisation is positive in each specification tested. A positive contribution of communication infrastructure separate from the relationship between IT capital and digitisation is not supported as it tested out of each specification.

Table E.13 **Coefficients from first differenced regressions[a]**

Dep. var.	*Δln(MFP)*	*Δln(MFP)*	*Δln(MFP)*	*Δln(LP)*	*Δln(LP)*
Model	*DMFP1/2/3*	*DMFP4*	*DMFP5*	*DLP1*	*DLP2*
Δopgaph11	0.750 *** (0.077)	0.744 *** (0.077)	0.646 *** (0.120)	0.787 *** (0.076)	0.767 *** (0.076)
Δksrvhr	-	-	-	0.450 *** (0.097)	-
Δrci5hr	-	-	-	-	0.418 *** (0.093)
Δroadug2	-	-	0.365 (0.343)	-	-
ΔnonggIT	-0.061 ** (0.027)	-	-	-	-
ΔITdigi	-	0.018 * (0.009)	0.021 ** (0.010)	0.022 ** (0.009)	0.036 *** (0.008)
Δuspto_ti	-	0.042 (0.027)	0.039 (0.027)	0.051 ** (0.024)	0.050 ** (0.024)
Δedu	0.196 *** (0.060)	0.156 ** (0.060)	0.136 ** (0.064)	0.112 * (0.056)	0.087 (0.059)
Δera	-0.044 (0.027)	-0.052 * (0.027)	-0.043 (0.028)	-0.045 * (0.024)	-0.034 (0.025)
intercept	0.018 ** (0.008)	-0.002 (0.003)	-0.004 (0.004)	-0.004 (0.004)	0.003 (0.003)
Test statistics					
No. of observations	28	28	28	28	28
Time period	75-02	75-02	75-02	75-02	75-02
R^2	0.818	0.824	0.833	0.859	0.855
Std. error of reg.	0.009	0.009	0.009	0.008	0.008
DW ‘d’ stat .	1.617	1.690	1.715	1.507	1.476
Functional form	0.001 (0.972)	0.980 (0.333)	1.100 (0.307)	0.324 (0.575)	0.849 (0.368)
Normality	2.355 (0.308)	2.628 (0.269)	0.322 (0.851)	4.426 (0.109)	5.645 (0.059)
Hetero.	1.349 (0.256)	0.521 (0.477)	1.115 (0.301)	0.232 (0.634)	0.504 (0.484)
AIC (SBC)	90(87)	90(86)	90(85)	92(88)	92(87)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The statistical tests are described in table E.2. **a** All variables are in logs except the output gap with slope coefficients interpreted as elasticities.

Source: Authors’ estimates.

The choice of cycle variable can make a large difference in the test down procedures for the differenced models. For example, if ‘opgaph11’ is replaced with ‘ACCI’ — a variable based on the subjective measure of capacity utilisation constructed from data in the ACCI-Westpac survey — then the variable ‘roadug2’ survives a test down procedure with a highly positive, economically very large and statistically significant coefficient. However, the model fails in many other respects including that almost all other controls test out. If road infrastructure is not usage adjusted, then it also tests out.

If changes in capacity utilisation are not adequately controlled for, then the usage adjustment factor used in the construction of 'roadug2' will drive the result because it ensures a high degree of correlation between movements in output (and by implication MFP) and road infrastructure services.

Some support and some scepticism

The differenced regressions support a positive effect of IT capital services in conjunction with digitisation. The effect is reasonably well estimated in both the MFP and labour productivity regressions.

In contrast, the MFP differenced regressions increase scepticism about the very large effects on growth of road infrastructure often found in aggregate studies. The differenced results provide no support for a positive effect of road infrastructure at the level of the market sector. An important positive effect may in fact exist, but it cannot be identified utilising the methods and data in this appendix.

E.4 Tests of the gross fixed capital formation measure of infrastructure

Theory suggests a preference for the use of stock or capital services measures in production function analysis. Kamps (2006, p. 121) suggests that a drawback of using public investment data rather than public capital stock is

> … the implicit assumption that the effects of public investment are independent of the level of the corresponding capital stock. Economic theory suggests that this assumption is dubious. According to the law of diminishing returns, an increment to the public capital stock (that is, public investment corrected for fixed capital consumption) would have a small (large) output effect if the capital stock in the previous period were large (small).

However, there is a tendency for selected models to include negative lagged dependent variables (giving an ECM term < -1) and relatively high negative serial correlation in the ECM representations. This section therefore:

- tests whether these problems are related to the use of highly constructed capital services measures by re-estimating models using gross fixed capital formation variables
- tests 'smoothed' versions of MFP in conjunction with gross fixed capital formation variables.

The variable ‘roadgfcf’ is gross fixed capital formation (GFCF) for non-dwelling construction for the general government sector for the purpose of transport. The variable ‘cigfcfnd’ is gross fixed capital formation for non-dwelling construction for the Communication services industry. Due to limitations on data availability, the asset scope of these variables differs from that used for the capital services indexes for infrastructure.

Model GF3 uses a measure of MFP that is smoothed using two period averaging (table E.14). In model GF4, MFP is trend MFP. Model GF5 uses the ‘opgaph11’ measure to control for the business cycle. The model contains fewer parameters as trade openness ‘tiopente’ was dropped from the model and the maximum lag order was reduced to one lag.

The bounds test F-statistic rejects the null of no long-run relationship in models GF1 and GF5. The test is indeterminate in models GF2 and GF3 with the F-statistic falling between critical values. The bounds test clearly does not reject the null for model GF4. Introducing ‘opgaph11’ as the cycle control in place of ‘shrtbond’ and/or reducing the maximum number of lags to one does not produce a model which passes the bounds test.

The gross fixed capital formation models provide some support for a positive and non-zero excess effect of road infrastructure on output. There is some concern that models GF2, GF3 and GF5 have at least one variable that does not provide a clear non-rejection of the null hypothesis in the long-run forcing tests, although the F-statistics are close to the lower bound critical values and would pass if small sample values were calculated.[4] However, these coefficients imply implausibly large returns to road investment.

The support for a significant positive effect of communication infrastructure is weak. In models GF1 and GF4, communication infrastructure is positive and statistically significant at 10 per cent or greater. However, the 95 per cent confidence interval takes in an estimate of zero, and the models fail one or both of the long-run forcing and bounds tests.

The ECM terms in models GF1 and GF2 highly over-correct and point to possible over-parameterisation of the model (table E.15). Models GF3 and GF4 use different MFP smoothing techniques and this has a large influence on why the ECM terms tell significantly different stories in terms of the speed of adjustment to equilibrium

4 The critical values used in the paper were the asymptotic values report by Pesaran, et al. (1996, 2001). Finite sample critical values were not calculated for this study. Narayan and Smyth (2004) calculated exact small sample critical values for their dataset of 40 observations. The result was that the lower and upper bound values increased (raising the upper bound from, say, 3.8 to 4.0). This would not be material to the results of this paper.

(ECM coefficients of -1.269 versus -0.360). Which is closer to the truth partly depends on one's views about whether the year-to-year variation in MFP growth rates accurately reflects true changes in the relationship between aggregate outputs and inputs. Model GF5 uses fewer parameters and an output gap measure to control for cyclical effects, which also helps reduce the degree of over-correction.

Information criteria indicate that models GF3 and GF4 fit the data best. However, on balance, model GF5 is the preferred model.

In model GF5, the effect of road infrastructure is positive and significantly different from zero, whereas communication infrastructure is insignificant. The bounds test indicates that the model forms a long-run co-integrating relationship. The long-run forcing tests provide support for the model.

Table E.14 **Gross fixed capital formation, long run coefficients**[a]
All models selected based on SBC

Dep. var.	*MFP*	*MFP*	*MFP2pavg*	*MFPt*	*MFP*
Max. lag	*2*	*2*	*2*	*2*	*1*
Lag order	*(2,0,1,0,1,1)*	*(2,1,0,1,2,0)*	*(2,1,0,1,2,0)*	*(2,0,0,0,0,0)*	*(1,1,0,0,0)*
Model	*GF1*	*GF2*	*GF3*	*GF4*	*GF5*
roadgfcf	0.033 *	0.028 ***	0.025 ***	0.030 **	0.059 ***
	(0.016)	(0.007)	(0.008)	(0.011)	(0.014)
cigfcfnd	0.022 *	0.004	0.002	0.021 **	0.003
	(0.011)	(0.006)	(0.006)	(0.010)	(0.008)
rbusof	0.016	-	-	-	-
	(0.015)				
edu	0.092 ***	0.086 ***	0.097 ***	0.092 ***	0.108 ***
	(0.026)	(0.010)	(0.012)	(0.019)	(0.013)
era	-0.072 ***	-0.087 ***	-0.087 ***	-0.071 ***	-0.091 ***
	(0.013)	(0.003)	(0.003)	(0.008)	(0.005)
tiopente	-	0.080 ***	0.073 ***	0.038 **	
		(0.013)	(0.017)	(0.017)	
intercept	4.349 ***	4.198 ***	4.222 ***	4.181 ***	4.239 ***
	(0.176)	(0.071)	(0.077)	(0.110)	(0.113)
yrbond	-0.109 **	-0.074 ***	-0.081 ***	-	-
	(0.044)	(0.021)	(0.022)		
shrtbond	-	-	-	-0.017 **	-
				(0.007)	
opgaph11	-	-	-	-	0.595 ***
					(0.081)
Test statistics					
No. of observations	27	27	27	27	28
Time period	76-02	76-02	76-02	76-02	75-02
Step 1 F-stat	4.527	2.434	3.524	1.388	12.638
(l.b.c.v.)	(2.649)	(2.649)	(2.649)	(2.649)	(2.850)
(u.b.c.v.)	(3.805)	(3.805)	(3.805)	(3.805)	(4.409)
Long run forcing?	No	?[b]	?[c]	No	?[d]
R^2	0.987	0.996	0.999	1.000	0.993
Serial correlation	0.513	0.008	0.245	0.437	0.999
	(0.485)	(0.928)	(0.629)	(0.517)	(0.330)
Functional form	3.559	1.824	1.964	0.074	0.032
	(0.080)	(0.200)	(0.185)	(0.789)	(0.860)
Normality	0.679	0.294	3.640	0.874	3.856
	(0.712)	(0.863)	(0.162)	(0.646)	(0.145)
Hetero.	2.059	2.067	1.720	1.763	0.332
	(0.164)	(0.163)	(0.202)	(0.196)	(0.570)
AIC (SBC)	79(72)	95(87)	109(100)	131(125)	94(89)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. **a** All variables are in logs with slope coefficients interpreted as elasticities. **b** F-statistic of cigfcfnd and edu of 3.092 and 2.873, respectively. **c** F-statistic for cigfcfnd of 3.196. **d** F-statistic for edu of 2.882.

Source: Authors' estimates.

Table E.15 **Error correction representation[a] of models GF1 to GF5**

Model	*GF1*	*GF2*	*GF3*	*GF4*	*GF5*
ΔMFP1	0.467 **	0.401 ***	-	-	
	(0.176)	(0.099)			
ΔMFP2pavg1	-	-	0.218 *	-	
			(0.118)		
ΔMFPt1	-	-	-	0.383 ***	
				(0.125)	
Δroadgfcf	0.058 *	-0.016	-0.013	0.011 **	0.029
	(0.028)	(0.017)	(0.010)	(0.004)	(0.019)
Δcigfcfnd	0.070 ***	0.009	0.003	0.008 **	0.003
	(0.021)	(0.012)	(0.007)	(0.003)	(0.009)
Δrbusof	0.028	-	-	-	-
	(0.025)				
Δedu	-0.024	-0.030	-0.020	0.033 ***	0.132 ***
	(0.106)	(0.062)	(0.039)	(0.008)	(0.021)
Δera	0.077	-0.051 *	-0.034 *	-0.026 ***	-0.111 ***
	(0.049)	(0.028)	(0.016)	(0.006)	(0.011
Δera(1)	-	0.060 ***	0.045 ***	-	
		(0.019)	(0.012)		
Δtiopente	-	0.175 ***	0.092 ***	0.014 *	
		(0.030)	(0.019)	(0.007)	
Δintercept	7.546 ***	9.191 ***	5.359 ***	1.504 ***	5.139 ***
	(1.238)	(0.677)	(0.452)	(0.253)	(0.465)
Δyrbond	-0.190 *	-0.162 ***	-0.103 ***	-	
	(0.091)	(0.051)	(0.030)		
Δshrtbond	-	-	-	-0.006 **	
				(0.003)	
Δopgaph11					0.722 ***
					(0.089)
ECM(-1)	-1.735 ***	-2.190 ***	-1.269 ***	-0.360 ***	-1.212 ***
	(0.269)	(0.160)	(0.103)	(0.059)	(0.110)
Test statistics					
R^2	0.816	0.947	0.949	0.945	0.890
Std. Error of Reg.	0.011	0.006	0.004	0.002	0.007
DW 'd' stat .	2.236	1.868	2.120	1.705	1.646
Log Likelihood	91	108	122	140	102
AIC (SBC)	79(72)	95(87)	109(100)	131(125)	94(89)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The statistical tests are described in table E.2. [a] All variables are in logs (except the linear time trend and output gap) with slope coefficients interpreted as elasticities.

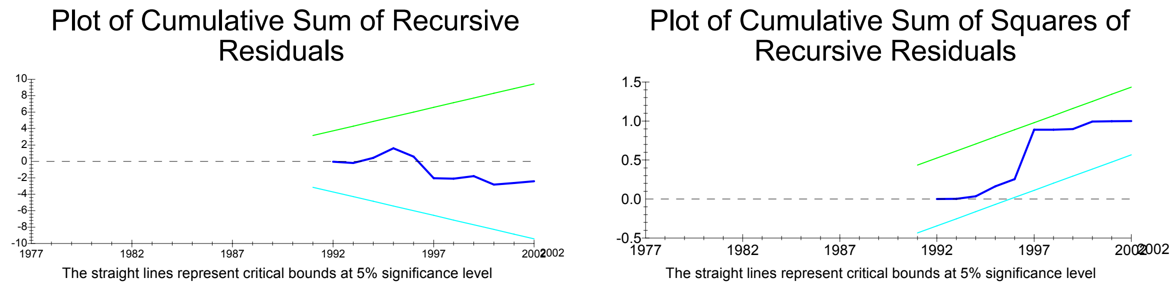
Source: Authors' estimates.

The CUSUM and CUSUM square tests show that the gross fixed capital formation models are stable over time (figure E.7).

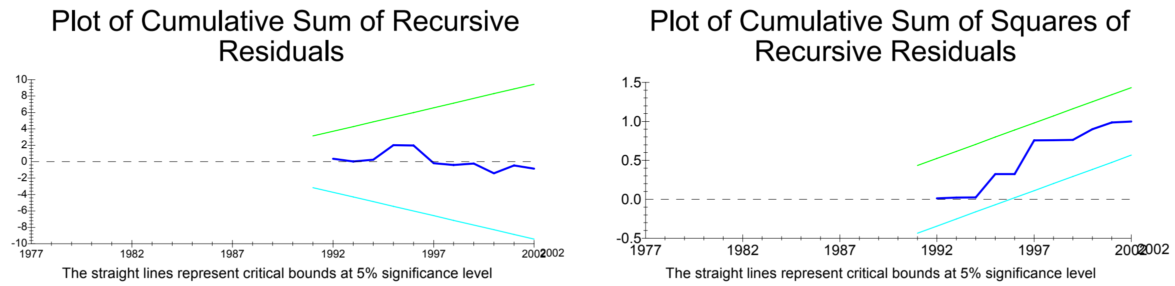
Figure E.7 **Stability tests for models GF2, GF3, GF4 and GF5**

Tests based on the bounds test equation

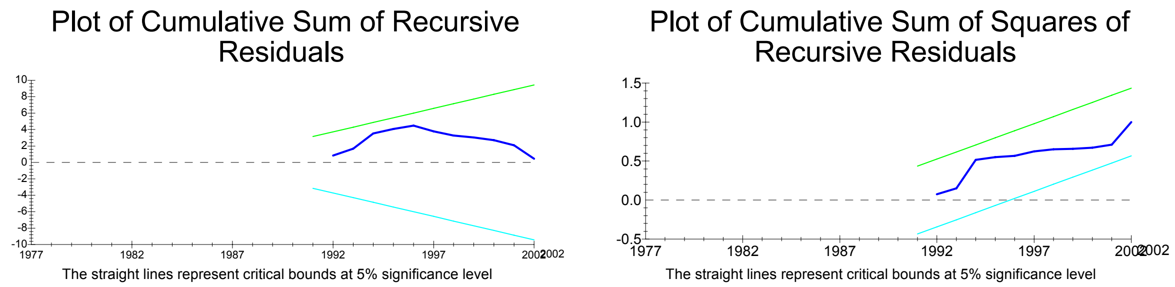
Model GF2



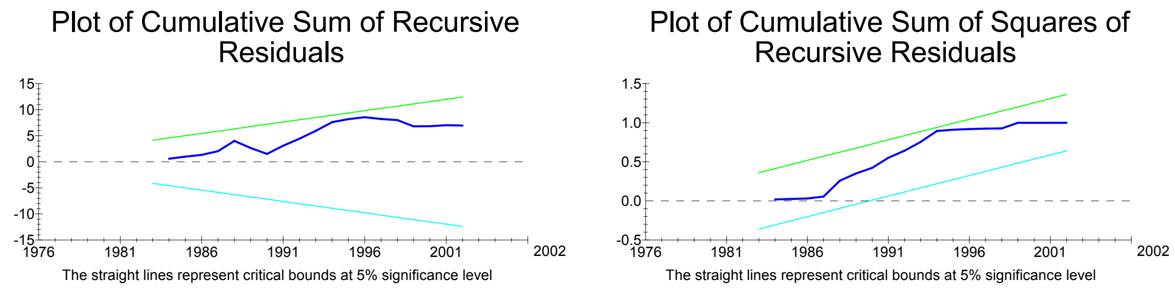
Model GF3



Model GF4



Model GF5



Data source: Authors' estimates.

External effects and alternative measures of capital

As well as dealing with potential problems of using highly constructed capital service index measures (for example, road capital services is very 'smooth' and the statistical techniques used require variation in the data), alternative measures of capital may be more closely related to particular types of external effect.

The capital services index measures represent the service provide by the sum total of accumulated past investments in the particular type of infrastructure. They are constructed from the productive capital stock estimates, which in turn are constructed from applying asset life and retirement distributions and age-efficiency profiles to gross fixed capital formation flow data.

If the effect under investigation is the free input effect, then the entire 'service' is what matters. If the effect under investigation is an external effect, and that effect is expected to be captured in measured MFP, and it is suspected that it is the recent vintages of capital that drive the effect, then gross fixed capital formation measures might be more useful in uncovering the direction and strength of the effect.

If various advances in communication infrastructure have facilitated organisational innovations, and these innovations are thought to be reflected in MFP as they alter the ability of firms to combine inputs into outputs, then including, for example, the entire copper network in the capital measure may just be introducing a form of white noise into regressions. This may hamper attempts to identify various enabling effects from recent technological change.

On the other hand, network effects associated with the copper network and the external effects of road infrastructure might be expected to have a weaker relationship between recent vintages of investment and any external effects.

The robustness of the positive effect of road infrastructure using GFCF data is somewhat surprising as the arguments above support an expectation that uncovering the external effects of communication infrastructure might benefit most from the use of GFCF data.

On the other hand, the argument that different capital measures may be more or less suitable for capturing a certain type of effect may be of less importance than the increase in variation introduced by the use of roads GFCF data.

E.5 Elasticities from preferred market sector models

The elasticities below have been selected from the large number of regressions detailed above. The elasticities are from models that were judged to be 'acceptable'. The criteria for acceptance included:

- no glaring failures in terms of statistical properties
- coefficient estimates imply plausible economic magnitudes, or at least within the range found in some other studies
- the existence of evidence that the variables form a long-run co-integrating relationship
- no clear breaches of the long-run forcing tests, which would heighten concern about the direction of causation
- other potentially important sources of growth are either controlled for or tested out of the regressions, and estimated signs are as expected.

This set of criteria is quite rigorous and it rejected many models, including many of the models detailed above. However, a number of acceptable MFP and labour productivity models were found (table E.16). First differenced regressions were also estimated to provide a check on the levels regressions.

Robust estimates of the effect of road infrastructure, communication infrastructure and IT capital could not be obtained within the same test down procedure. The best estimates of a positive effect of road infrastructure were from models that did not include communication infrastructure (models RI5, RI6 and DMFP5) and vice versa (models D2, D3 and LP5). Initially this was a concern as it was expected that investment in both forms of infrastructure resulted in positive spillovers. However, in the roads infrastructure models, an effect of communication infrastructure is present through digitisation.

The effect road infrastructure

There is contradictory evidence concerning the effects of road infrastructure on productivity. The coefficient estimates from models RI5 and RI6 are statistically significant at greater than 5 per cent. The economic magnitude of the coefficients at 0.31 to 0.43 is very large, particularly considering which effects are thought to be captured and which effects are not. As discussed in chapter 3, road infrastructure is included in the capital services measure used by the ABS to construct their market sector MFP index. The interpretation of the coefficients is therefore based on an excess effect.

The regressions test whether there is an effect on output over and above that assumed for road infrastructure in the national accounts. In broad terms, this means that the coefficients are not the result of a 'free' input effect.[5] Testing suggested that the coefficients are not biased upward from the constant returns to scale (CRS) assumption used in the construction of MFP estimates. A combined input services index (net of infrastructure, IT capital and R&D as these were included as regressors) was included in the testing procedures for models RI5 and RI6 to control for any aggregate scale effects. As discussed in appendix H, the CRS assumption is generally found to be a reasonable assumption when working with highly aggregated data. Inclusion of the scale control did not reduce the coefficients on road infrastructure.

Table E.16 **Summary of estimated elasticities from preferred models**

Standard errors are in brackets

Model	*D2*	*D3*	*RI5*	*RI6*	*LP2*	*DMFP5*
Dependent variable	*Ln(MFP)*	*Ln(MFP)*	*Ln(MFP)*	*Ln(MFP)*	*Ln(LP)*	*ΔLn(MFP)*
Road infrastructure[b]	-	-	0.427 (0.155)	0.308 (0.141)	-	0.365[f] (0.343)
Comm. infrastructure[c]	0.050 (0.022)	0.052 (0.024)	-	-	0.061 (0.024)	-
IT conditioned on digitisation[d]	0.015 (0.007)	0.013[f] (0.008)	0.008 (0.004)	0.006[f] (0.005)	0.031 (0.006)	0.021 (0.010)
Acceptance criteria[e]						
Passes standard statistical tests?	Yes	Yes	Yes	Yes	Yes	Yes
Passes bounds test?	Yes	Yes	Yes	Yes	Yes	-[a]
Any clear long-run forcing test failures?	No	No	No	No	No	-[a]
Other sources of growth controlled?	Yes	Yes	Yes	Yes	Yes	Yes
All signs as expected?	Yes	Yes	Yes	Yes	Yes	Yes
Plausible magnitudes on all variables?	Yes	Yes	?[g]	?[g]	Yes	?[g]

[a] Model DMFP5 is estimated in first differences. The tests are not applicable. [b] Model RI5 used 'roads', RI6 'roadug2s', and DMFP5 'Δroadug2'. [c] All results based on input-output adjusted communication infrastructure 'ci5ioug'. [d] All results based on use of 'ITdigi'. [e] The bounds test and long-run forcing tests are described in appendix J and the other statistical tests are described in appendix E. [f] Not statistically significant. [g] The magnitude of the road infrastructure coefficient is within the range of coefficients produced by other studies. However, it is implausibly large in terms of the rate of return it implies.

Source: Authors' estimates.

[5] The existence of fuel taxes and various types of road charges (for example, registration fees) gives rise to the question as to how 'free' roads would be as an input in any case, even if roads were not included in the market sector capital stock.

The fact that the inclusion of the scale control did not result in a much reduced or economically insignificant coefficient on road infrastructure also indicated that the CRS assumption was not the reason estimates of the effect of road infrastructure could be obtained from MFP models but not labour productivity models. When road infrastructure was included in labour productivity regressions, the coefficient on the primary capital to labour ratio (including, for example, all private machinery and equipment) became insignificant. Therefore, the effect of road infrastructure on output per hour could not be investigated. Part of the problem was collinearity between capital services per hour and road infrastructure per hour.

The estimation procedure provides confidence that estimated effects are not purely the outcome of trending data giving the impression of a relationship between variables, when in fact there is only statistical correlation.

Additional confidence can be obtained from differenced regressions if the results of those regressions are roughly similar. The point estimate of the coefficient on road infrastructure in model DMFP5 is of the same economic magnitude, but estimated very imprecisely.

The coefficient estimates for road infrastructure are very sensitive to the form of the variable included in the regressions. The particular road infrastructure variable in model DMFP5 is usage adjusted by value added shares and not smoothed. If it is not usage adjusted or a smoothed usage adjustment is employed, then the coefficient is economically insignificant and highly statistically insignificant. This contrasts to model RI5 where the preferred form of the variable is not usage adjusted (that is, the services provided by the entire road productive capital stock rather than the market sector's share of that stock determined by value added shares). The use of 'roadug2' in the test procedure for model RI5 results in a coefficient of 0.255 and a large standard error of 0.204. At that point in the test procedure, dropping road infrastructure results in a more parsimonious model.

The robustness of the estimated effects of road infrastructure, and general government infrastructure more generally, are discussed further below.

The effect of communication infrastructure

There is more reliable evidence of a positive excess effect of communication infrastructure on productivity and output. There are two types of effects that are supported:

- those related to the digitisation of the communication network and its interaction with IT capital services

- communication network effects not dependent on digitisation, and possible effects of digitisation not specifically tied to IT capital services.

Testing procedures that included a separate IT capital services variable always produced a negative coefficient on IT capital under many different MFP and labour productivity specifications (examples are models A1 and LP5 above). It is possible that the average net effect over the period under observation could have been negative if the process of the widespread diffusion of IT technologies entailed substantial learning costs and/or disruptive effects.

It is generally believed that the use of IT technologies began to have productivity payoffs in Australia sometime in the 1990s. Testing of breaks in the slope coefficient on IT capital provided some evidence of an increased partial effect in some models. For example, retesting model LP1 and including IT capital services and slope shifts at 1992 and 1995, resulted in a coefficient (and standard error) on IT capital of -0.049 (0.012), and a significant slope shift at 1992 of 0.012 (0.003). Other variables that remained following the test procedure included the capital to labour ratio, communication infrastructure (0.051 (0.028)), foreign gross R&D stock (although not significant at 10 per cent), education (0.325 (0.068)), a trend term, and the cycle control. However, the slope change was not of sufficient magnitude to produce a net positive effect of IT capital in the 1990s.

An attempt was made to parcel-out the potential effects of IT capital and investigate the effect of IT capital that is dependent on, or conditioned by, the digitisation of the telecommunications network. The type of effects captured are thought to include:

- support for spillovers between firms and individuals in terms of information and knowledge flows that help businesses produce more efficiently or innovate
- support for information flows that impact on strategic and operational decision making within firms potentially facilitating alternative organisational structures and processes.

A variable 'ITdigi' was constructed as the percentage of access lines that are digital multiplied by the logarithm of IT capital services. The hypothesis is that the effect of IT capital would have strengthened as the telecommunication network increasingly catered for digital transmission. The effective service of IT capital increased with digitisation.

In the preferred models, the coefficient estimate ranged between 0.006 and 0.015 in the MFP models, and was 0.031 in the preferred labour productivity model. The bottom bound of the 95 per cent confidence interval did not always exclude an estimated effect of zero. However, the direction of the effect held under many specifications and was often statistically significant at greater than 5 per cent (for example, in models D2 and LP1).

A positive effect of IT capital conditioned on digitisation held whether estimated in the framework of the determinants of MFP or labour productivity. The effect held controlling for human capital, the level of industry protection, domestic and foreign R&D, and the business cycle. While the preferred models also included a separate communication infrastructure variable, the positive effect of 'ITdigi' remained if this variable was dropped from the regression. A positive and statistically significant effect was also obtained in first differenced regressions (preferred model DMFP5 and the differenced labour productivity regressions above).

Alternative methods of modelling digitisation are examined in the next section.

E.6 Sensitivity testing of results

Sensitivity testing of results to infrastructure definition

The sensitivity of the preferred model results in section E.5 to the way in which the infrastructure variables are defined is illustrated in tables E.17 to E.19.

Model D3 sensitivity tests

Table E.17 shows that the results of MFP model D3 are sensitive to the definition of communication infrastructure. In model D3, the estimated coefficient on 'ci5ioug' was 0.052 with a standard error of 0.024.

The coefficients on the communication infrastructure variable are generally larger for the alternative definitions than for 'ci5ioug' used in the preferred model (except for 'ci8ioug'). The communication infrastructure variables with no usage adjustment ('ci5') produces the largest coefficient. Of the usage adjustment factors, the value-added factors result in larger coefficients than the input-output (IO) factors. Including Communication services IT capital in the scope of communication infrastructure ('ci8', 'ci8vaug' and 'ci8ioug') lowers the variable coefficients compared with those based on the narrower asset scope (the ci5-based variables). Use of the alternative definitions of communication infrastructure also results in smaller coefficients on 'ITdigi', which are also not statistically significant.

Table E.17 **Sensitivity tests using model D3**

Standard errors in brackets. Selected by SBC.

Lag order	*(1,1,0,0,1,0)*	*(1,0,0,0,1,0)*	*(1,1,0,0,1,0)*	*(1,1,0,0,1,0)*	*(1,1,0,0,1,0)*
Test	*1*	*2*	*3*	*4*	*5*
ci5	0.141 *	-	-	-	-
	(0.072)				
ci5vaug	-	0.102	-	-	-
		(0.069)			
ci8	-	-	0.099 *	-	-
			(0.048)		
ci8ioug	-	-	-	0.043 **	-
				(0.018)	
ci8vaug	-	-	-	-	0.083 *
					(0.045)
ITdigi	0.002	0.006	0.004	0.005	0.004
	(0.006)	(0.005)	(0.005)	(0.004)	(0.005)
rfgch	0.136 ***	0.113 **	0.161 ***	0.142 ***	0.154 ***
	(0.046)	(0.048)	(0.048)	(0.040)	(0.049)
edu	0.184 ***	0.170 ***	0.220 ***	0.165 ***	0.205 ***
	(0.037)	(0.038)	(0.046)	(0.029)	(0.044)
era	-0.077 ***	-0.067 ***	-0.087 ***	-0.073 ***	-0.085 ***
	(0.018)	(0.019)	(0.017)	(0.015)	(0.017)
intercept	3.727 ***	3.811 ***	3.857 ***	4.071 ***	3.916 ***
	(0.319)	(0.329)	(0.216)	(0.138)	(0.213)
trend	-0.010 **	-0.007 **	-0.012 **	-0.006 ***	-0.010 **
	(0.004)	(0.004)	(0.005)	(0.019)	(0.004)
opgaph11	0.447 ***	0.444 ***	0.470 ***	0.440 ***	0.460 ***
	(0.096)	(0.108)	(0.095)	(0.083)	(0.098)
ECM(-1)	-1.418 ***	-1.354 ***	-1.376 ***	-1.403 ***	-1.440 ***
	(0.159)	(0.158)	(0.151)	(0.133)	(0.167)
Test statistics					
No. of observations	27	27	27	27	27
Time period	75-76 to 01-02	75-76 to 01-02	75-76 to 01-02	75-76 to 01-02	75-76 to 01-02
R^2	0.993	0.992	0.993	0.995	0.993
Std. Error of Reg.	0.008	0.008	0.007	0.007	0.008
DW ‘d’ stat .	1.827	1.650	1.744	2.093	1.792
Durbin’s ‘h’ stat.	0.795	1.592	1.074	-0.334	1.095
	(0.427)	(0.111)	(0.283)	(0.739)	(0.274)
Serial correlation	0.129	0.729	0.451	0.129	0.297
	(0.725)	(0.406)	(0.512)	(0.724)	(0.594)
Functional form	0.259	0.222	0.003	0.007	0.022
	(0.618)	(0.644)	(0.957)	(0.933)	(0.885)
Normality	1.224	1.558	0.895	1.087	1.173
	(0.542)	(0.459)	(0.639)	(0.581)	(0.556)
Hetero.	0.205	0.485	0.959	0.116	0.803
	(0.655)	(0.492)	(0.337)	(0.736)	(0.379)
AIC (SBC)	89(82)	88(82)	90(83)	93(85)	89(82)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The other statistical tests are described in table E.2.

Source: Authors’ estimates.

Model LP2 sensitivity tests

Table E.18 shows the equivalent sensitivity tests for the labour productivity model LP2.

The purpose of these tests was to test the sensitivity of the communication infrastructure results within a labour productivity model to ensure that estimated effects are not sensitive to the removal of the assumptions used in constructing MFP.

In the estimation of the labour productivity models, the education and industry protection variables were not normalised by hours worked. Therefore, the first test uses the variable 'ci5ioug' (as per model LP2) and an education variable specified as per hour worked. The result is that model fit is higher, but the coefficient on business R&D becomes implausibly large. Education is highly significant whichever approach is used. The remainder of the tests use education without the per hour adjustment.

Tests 2 to 6 test five alternative measures of communication infrastructure. The main results are as follows.

- Unadjusted 'ci5' increases the coefficient from 0.061 (0.024) to 0.247 (0.062) (test 2). An increase was expected as 'ci5' represents an economywide capital service, rather than an estimate of the capital service for the market sector only. The movement in the rate of return would be less.
- 'ci5vaug' also increases the coefficient (test 3), but this time the increase is driven by the value added shares which, as is the case with road infrastructure, results in inputs and outputs not being measured independently. For both 'ci5' and 'ci5vaug', the coefficient on 'ksrv' is too low.
- Including IT capital in the measure and using an input-output adjustment 'ci8ioug' results in a reduction in the point estimate to 0.043 (0.021) (test 4).
- The various 'ci5' measures that exclude the IT capital of the communication services industry result in better fitting models with more precision in the estimate of the communication infrastructure variable. Communication infrastructure is statistically insignificant in tests of both 'ci8' and 'ci8vaug'.

A plausible interpretation of these results is that focusing in more closely on the network assets of the communication services industry allows a network effect to be identified. The tests also include an additional positive effect of digitisation of the network in conjunction with IT capital.

The variable 'ITdigi' also includes private IT capital with a value of zero until 1990. To make sure the presence of this variable was not driving the poorer outcome for the communication measures incorporating IT capital, a number of additional tests were undertaken. Re-running tests 4 to 6 without 'ITdigi' resulted in a coefficient of 0.028 (0.015) for test 4, and tests 5 and 6 were just as insignificant. The industry protection variable 'era' did not test out of these models. It was negatively signed and highly significant in each of the three tests.

Table E.18 **Sensitivity tests using model LP2**

Standard errors in brackets. Selected by SBC. Variables are per hour worked (except education as noted)

Lag order	*(0,0,1,0,0,1)*	*(0,0,1,0,1,0)*	*(0,0,1,0,1,0)*	*(0,0,1,0,1,1)*	*(1,0,0,0,1,0)*	*(1,0,0,0,1,0)*
Test	*1*	*2*	*3*	*4*	*5*	*6*
ksrv	0.222 *** (0.039)	0.136 * (0.065)	0.143 ** (0.060)	0.211 *** (0.068)	0.229 ** (0.098)	0.224 ** (0.095)
ci5ioug	0.100 *** (0.018)	-	-	-	-	-
ci5	-	0.247 *** (0.062)	-	-	-	-
ci5vaug	-	-	0.263 *** (0.062)	-	-	-
ci8ioug	-	-	-	0.043 * (0.021)	-	-
ci8	-	-	-	-	0.010 (0.061)	-
ci8vaug	-	-	-	-	-	0.017 (0.061)
ITdigi	0.019 *** (0.002)	0.026 *** (0.004)	0.023 *** (0.004)	0.033 *** (0.006)	0.044 *** (0.008)	0.044 *** (0.008)
rbushr(t-1)	0.070 *** (0.014)	-0.021 (0.020)	-0.018 (0.019)	0.026 (0.018)	0.020 (0.034)	0.017 (0.033)
edu	-	0.086 * (0.043)	0.093 ** (0.042)	0.162 *** (0.060)	0.146 ** (0.068)	0.143 ** (0.068)
eduhr	0.188 *** (0.038)	-	-	-	-	-
intercept	1.854 *** (0.085)	2.424 *** (0.085)	2.285 *** (0.073)	2.428 *** (0.106)	2.536 *** (0.278)	2.552 *** (0.251)
opgaph11	0.687 *** (0.060)	0.702 *** (0.077)	0.680 *** (0.070)	0.627 *** (0.084)	0.876 *** (0.146)	0.869 *** (0.147)
ECM(-1)	-	-	-	-	-0.784 *** (0.103)	-0.789 *** (0.101)

(continued on next page)

Table E.18 **(continued)**

Test	*1*	*2*	*3*	*4*	*5*	*6*
Test statistics						
No. of observations	27	27	27	27	27	27
Time period	76-77 to 02-03	76-77 to 02-03	76-77 to 02-03	76-77 to 02-03	76-77 to 02-03	76-77 to 02-03
R^2	0.999	0.999	0.999	0.999	0.999	0.999
Std. Error of Reg.	0.004	0.005	0.005	0.006	0.007	0.007
DW ‘d’ stat .	2.126	2.045	2.027	1.388	1.675	1.667
Durbin’s ‘h’ stat.	-	-	-	-	0.998	1.018
					(0.318)	(0.309)
Serial correlation	0.071	0.099	0.076	1.814	0.719	0.732
	(0.793)	(0.757)	(0.786)	(0.197)	(0.408)	(0.404)
Functional form	0.000	0.150	0.061	4.180	1.527	1.577
	(0.989)	(0.704)	(0.808)	(0.058)	(0.233)	(0.226)
Normality	1.029	1.191	1.023	0.709	1.368	1.329
	(0.598)	(0.551)	(0.600)	(0.702)	(0.505)	(0.515)
Hetero.	0.296	7.788	6.191	0.353	4.549	4.649
	(0.591)	(0.010)	(0.020)	(0.558)	(0.043)	(0.041)
AIC (SBC)	105(99)	99(93)	100(94)	95(89)	94(88)	94(88)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The other statistical tests are described in table E.2.

Source: Authors’ estimates.

Model RI5 sensitivity tests

Table E.19 shows the sensitivity tests for the MFP model RI5 to the definition of public infrastructure. Model RI5 was used to test the effect of different measures of general government infrastructure and to compare effects with road infrastructure results. Both the ‘I3’ (computer hardware and software excluded) and ‘I8’ (computer hardware and software included), measures that do not include a usage adjustment, have larger estimated elasticities. The volume of services for these measures are for the whole of the economy, whereas, the volume of services for ‘I3ug2’ and ‘I8ug2’ are an estimate of that part of the service used by the market sector.

General government infrastructure is significant in each test and a set of control variables are signed as expected and are estimated well. The models are statistically acceptable. Like other market sector results, there is a concern surrounding the over-correction in the ECM term.

The equivalent road infrastructure estimates for non-usage adjusted road infrastructure is 0.427 (0.155) (model RI5) and usage-adjusted road infrastructure is 0.308 (0.141). The general government measures incorporate road infrastructure plus other types of infrastructure. Therefore, the larger point estimates below, for comparable measures, are expected.

Table E.19 **Tests of general government infrastructure in model RI5**

Standard errors in brackets. Selected by SBC.

Lag order	*(1,0,0,0,1,0)*	*(1,0,0,0,1,0)*	*(1,0,0,0,1,0)*	*(1,0,0,0,1,0)*
Test	*1*	*2*	*3*	*4*
I3ug2	0.385 ** (0.144)	-	-	-
I3	-	0.490 *** (0.170)	-	-
I8ug2	-	-	0.375 ** (0.160)	-
I8	-	-	-	0.467 ** (0.193)
ITdigi	0.013 ** (0.005)	0.015 *** (0.005)	0.010 ** (0.005)	0.012 ** (0.005)
rfgch	0.105 ** (0.040)	0.087 ** (0.040)	0.113 ** (0.042)	0.097 ** (0.042)
edu	0.103 *** (0.031)	0.104 *** (0.030)	0.132 *** (0.029)	0.141 *** (0.028)
era	-0.067 *** (0.015)	-0.075 *** (0.015)	-0.068 *** (0.016)	-0.076 *** (0.016)
intercept	2.669 *** (0.605)	2.325 *** (0.678)	2.673 *** (0.688)	2.372 *** (0.788)
trend	-0.004 (0.001)	-0.007 *** (0.002)	-0.006 *** (0.002)	-0.009 *** (0.003)
opgaph11	0.337 *** (0.101)	0.441 *** (0.085)	0.341 *** (0.108)	0.444 *** (0.091)
ECM(-1)	-1.445 *** (0.151)	-1.457 *** (0.149)	-1.431 *** (0.156)	-1.436 *** (0.155)
Test statistics				
No. of observations	27	27	27	27
Time period	75-76 to 01-02	75-76 to 01-02	75-76 to 01-02	75-76 to 01-02
R^2	0.993	0.994	0.993	0.993
Std. Error of Reg.	0.007	0.007	0.008	0.007
DW 'd' stat .	1.915	2.051	1.855	1.928
Durbin's 'h' stat.	0.356 (0.722)	-0.208 (0.835)	0.646 (0.518)	0.315 (0.753)
Serial correlation	0.018 (0.896)	0.050 (0.825)	0.092 (0.865)	0.014 (0.907)
Functional form	0.035 (0.854)	0.138 (0.715)	0.002 (0.967)	0.256 (0.620)
Normality	1.647 (0.439)	1.871 (0.392)	1.790 (0.409)	2.050 (0.359)
Hetero.	0.833 (0.370)	0.261 (0.614)	0.631 (0.435)	0.141 (0.710)
AIC (SBC)	91(84)	91(85)	90(83)	90(84)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The other statistical tests are described in table E.2.

Source: Authors' estimates.

Summary of tests for sensitivity to infrastructure definition

The preferred models were sensitivity tested to alternative definitions of infrastructure. Table E.20 provides a summary of the effects of alternative definitions on the coefficients of the infrastructure variables.

The results are clearly sensitive to the definition of both communication infrastructure and public infrastructure used. The precision with which alternative definitions are estimated varies a lot. The magnitudes of estimated elasticities also change, although given that the underlying infrastructure volumes are different the differences in estimated returns may be less.

In the MFP models with communication infrastructure, the coefficients on the communication infrastructure variable are generally larger for the alternative definitions than for 'ci5ioug' used in the preferred model. The communication infrastructure variable with no usage adjustment ('ci5') produces the largest coefficient. Of the usage-adjusted measures, the value-added factors result in larger coefficients than the IO factors. Including the IT capital of Communication services in the scope of communication infrastructure lowers the variable coefficients compared with the equivalent variables based on the narrower asset scope. The effect of IT conditioned on digitisation is not statistically significant in any of the models testing alternative definitions.

In the labour productivity models, there is a similar pattern. The extension of the asset scope (the ci8-based variables) results in coefficients that are all smaller than those based on the narrower asset scope and generally estimated with less precision. A plausible interpretation of these results is that focusing in more closely on use of the network assets of the communication services industry allows a network effect to be identified. The coefficients on the unadjusted 'ci5' and the value-added adjusted 'ci5vaug' are around four times larger than that of 'ci5ioug' in the preferred model. The result for 'ci5vaug' is driven by the value added shares, which results in inputs and outputs not being measured independently. The effect of IT conditioned on digitisation is less sensitive to the specific communication infrastructure variable included in the regressions.

Table E.20 **Sensitivity of preferred models to alternative infrastructure definitions**

Model and variable[b]	*General government infrastructure*	*Communication infrastructure*	*IT conditioned on digitisation*
Model D3 with alternative communication infrastructure variables			
'ci5ioug' (IO usage adj.) (preferred model)	-	0.052	0.013[a]
'ci5' (no usage adjustment)	-	0.141	0.002[a]
'ci5vaug' (value added adjustment)	-	0.102[a]	0.006[a]
'ci8' (including Comm. services IT capital)	-	0.099	0.004[a]
'ci8vaug' ('ci8' with value added adjustment)	-	0.083	0.004[a]
'ci8ioug' ('ci8' with IO usage adjustment)	-	0.043[a]	0.005[a]
Model LP2 with alternative communication infrastructure variables			
'ci5ioug' (IO usage adj.) (preferred model)	-	0.061	0.031
'ci5' (no usage adjustment)	-	0.247	0.026
'ci5vaug' (value added adjustment)	-	0.263	0.023
'ci8' (including Comm. services IT capital)	-	0.010[a]	0.044
'ci8vaug' ('ci8' with value added adjustment)	-	0.017[a]	0.044
'ci8ioug' ('ci8' with IO usage adjustment)	-	0.043	0.033
Model RI5 with alternative public infrastructure variables			
'roads' (preferred model)	0.427	-	0.008
'I3' (no usage adjustment)	0.490	-	0.015
'I3ug2' (value added usage adjustment)	0.385	-	0.013
'I8' (including gen. govt IT capital)	0.467	-	0.012
'I8ug2' ('I8' with value added usage adj.)	0.375	-	0.010

[a] Not statistically significant at 10 per cent. [b] Full variable definitions in table 3.3

Source: Authors' estimates.

MFP model RI5 was used to test alternative definitions of public infrastructure with an expansion in the assets covered to all general government infrastructure and not just roads. The measures that do not include a usage adjustment, 'I3' (computer hardware and software excluded) and 'I8' (computer hardware and software included), have the largest estimated elasticities. The usage-adjusted measures 'I3ug2' and 'I8ug2' are meant to approximate a smaller volume of capital services corresponding to the market sector's share of use. The effect of IT capital conditioned on digitisation is higher where a broader public infrastructure variable is included in the regression. However, which broader measure is used makes little difference.

Sensitivity testing of results to method of accounting for digitisation

The sensitivity of some of the preferred model results in section E.5, to the way in which the effect of digitisation of the copper network is included, is illustrated in table E.21.

Table E.21 **Further market sector tests of digitisation using model D3**
Domestic GRD dropped due to insignificance

Test	*ci5io-shift90*	*ci5ioug*	*ITdigi*	*ci5iodg*	*digital*	*nonggIT*	*ci5ioug *nonggIT*
Test A: Add variable 'ci5iodg'	0.051* (0.029)		0.004 (0.007)	0.001 (0.008)			
Test A, but drop ITdigi	0.061*** (0.024)			0.005 (0.005)			
Test B: drop 'ITdigi', enter log of 'digital' index separately	0.022 (0.019)				0.000** (0.000)		
Test C: include 'nonggIT' and add interaction term	0.022 (0.021)					-0.069*** (0.024)	-0.001 (0.003)
Test D: drop 'ITdigi' and add slope shift at 1990	0.053** (0.023)	0.001 (0.002)					

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets.

Source: Authors' estimates.

Model D3 was used for the tests with the only difference being that domestic GRD was dropped from the model (given its insignificance). Under each of the tests, the results for foreign R&D, education, and industry protection held.

- Test A: the variable 'ci5iodg' was added to the model and constructed using the same methodology as for 'ITdigi' and 'otrcapdg'.
  - Result: 'ci5iodg' is highly insignificant. Dropping 'ITdigi' from the model does not result in a significant additional effect of communication infrastructure conditioned on digitisation.
- Test B: the variable 'digital' was constructed as the index of the share of access lines digitised, in log terms (as per other variables). The variable 'ITdigi' was dropped.
  - Result: the significance on 'ci5ioug' is negatively impacted compared with the original results for model D3. The estimate for 'digital' is statistically significant, but economically insignificant.
- Test C: 'nonggIT' is added to the model together with an interaction term 'ci5ioug'*'nonggIT'. A positive and significant interaction would be interpreted

as representing complementarity between communication infrastructure and private IT capital.

  – Result: the interaction term is insignificant.

- Test D: ‘ITdigi’ is dropped. A term that allows the estimated elasticity on communication infrastructure to shift at 1990 (the first observation for the ‘digital’ variable) is added. This tests whether an effect of digitisation can be detected related strictly to communication infrastructure, as opposed to a robust effect being found in conjunction with IT capital.
  – Result: estimates of slope shifts for communication infrastructure are not significant.

These test results further highlight the preference of the data for an additional effect of communication infrastructure in conjunction with the process of digitisation and the accumulation of IT capital. An additional effect related to digitisation is not found when communication infrastructure is considered in isolation.

E.7 Potential sources of the problems in modelling roads

A failure of the CRS assumption does not appear to be the problem

The MFP models that contain road infrastructure suggest a very large and positive effect of road infrastructure irrespective of whether a scale control variable is included in the final model or not. When models RI5 or RI6 were retested with the inclusion of a scale control the coefficient on road infrastructure held or increased. The scale control variable is a combined input services index less those capital and R&D components included as regressors. The tested down models pass bounds and long-run forcing tests and produce ECM terms of -1.2 that are highly statistically significant with DW statistics of 1.8-2.1. The coefficients on the scale variable are negatively signed and highly statistically significant pointing towards decreasing returns.

As discussed in box H.1, the CRS assumption is generally viewed as a very ‘safe’ assumption when working with highly aggregated data. If road infrastructure is not included in the test procedures then scale is insignificant.

There is very little variation in road capital services

Road capital services have grown relatively slowly and smoothly over time compared with other capital variables (table E.22). The usage adjustment of the road index does increase the variation slightly but it is still relatively low. This lack of variation affects the ability of statistical methods to reliably identify relationships.

Table E.22 **Growth in capital services index variables, 1974-75 to 2002-03**

Variable	*Average annual growth*	*Standard deviation*
	(per cent per year)	
Road infrastructure (roads)	0.9	0.6
Usage-adjusted road infrastructure (roadug2)	0.6	0.8
Public economic infrastructure (I3)	1.0	1.0
Communication infrastructure (ci5)	4.9	1.9
IT (ITcap)	30.1	10.2
Total capital (ksrv)	3.9	1.1

Source: Authors' estimates.

A changing effect?

Fernald (1999) finds that the marginal product of road investment in the United States was high in the 1950s and 1960s. During this period, rates of investment were also high associated with the building of the interstate highways. However, he found no evidence that the post-1973 marginal product of road infrastructure had an above normal return. The construction of the interstate highways offered a one-off opportunity for productivity improvement. Fernald noted that his specification sought to measure the direct or free input effects of road infrastructure only, so that the computed returns were biased downwards if externalities were important.

Using Canadian data, Harchaoui and Tarkhani (2003) also find that the elasticity of public capital declined dramatically. The elasticities of private and public capital were similar in the pre-1973 period (0.15 to 0.18). By the year 2000, while the private capital elasticity remained stable, the elasticity of public capital declined to around 0.019.

Both of these studies use much longer time series than is available for this study with the time period in this study corresponding to their post-1973 period only.

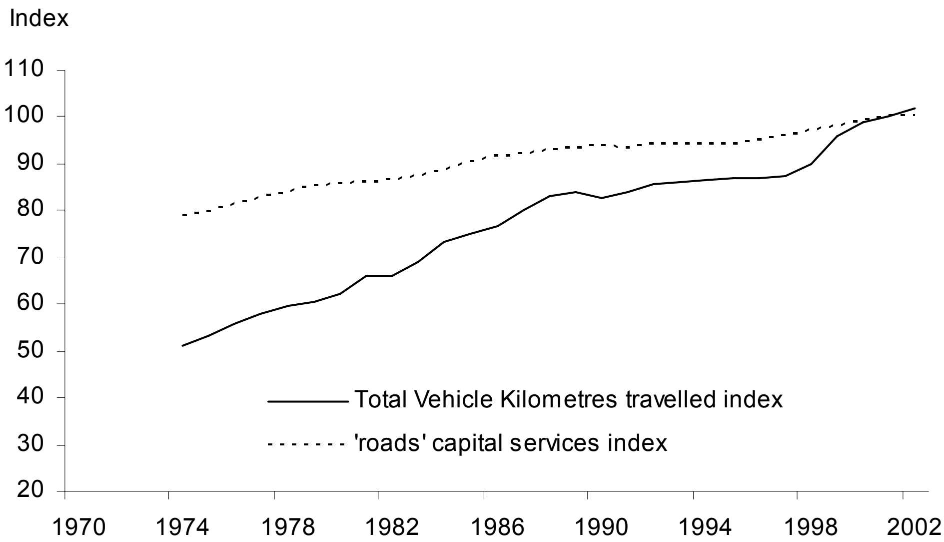
Is the service provided by road infrastructure mismeasured?

It is common to seek to control for the effects of the business cycle or shocks on MFP as variation in MFP can arise solely due to changes in capacity utilisation. Labour can be hoarded during economic downturns and capital can sit idle.

Economic fluctuations in the demand for roads can alter the utilisation of roads — the quantity of goods transported depends on the level of economic activity. With roads, there can be significant longer term underutilisation of a given road or overutilisation in the sense of congestion. However, while a particular road may be under or overutilised, the net additions to the pre-existing aggregate capital stock and services of roads is small in any one year. With relatively smooth investment patterns, the fact that it might take ten years for a particular road to reach an ‘average’ level of utilisation may not matter much in terms of studies that seek to measure an average effect at a highly aggregated level. But if there have been changes in the average utilisation of roads, then this may matter for attempts to measure the economic contribution of road infrastructure to productivity.

Total vehicle kilometres travelled (TVK) has consistently grown faster than measured road capital services (figure E.8). This suggests that average capacity utilisation would have increased significantly over the period.

Figure E.8 **Total vehicle kilometres travelled and average capacity utilisation**



Data sources: ABS (*Survey of Motor Vehicle Use*, Cat. no. 9208.0), ABS unpublished data and authors' estimates.

It is possible that estimates of the effect of road infrastructure (the elasticities estimated in this study and estimates of public capital from other studies, given that roads dominates public capital) are biased upward by ignoring the apparent long-term trend increase in capacity utilisation. The increasing scale of economic activity has meant that greater use is now made of a given level of road capital stock. Effective road capital services is actually substantially higher than is assumed.

A continuation of this trend would at some point start to increase average travel times which has an opportunity cost. It is unclear if the costs of increased travel time are economically significant at the level of the market sector or at the economywide level. These costs certainly matter for certain cities, or parts of cities, at certain times of day. Congestion costs tend to be studied at this more microeconomic level (for example, the costs of congestion on particular road links).

There is little or no congestion on many roads across the country, or on many roads for most times in the day. Therefore, the 'average' effect of congestion may or may not need to be taken into account when examining the macroeconomic effect of road infrastructure on output. Even if it should be taken into account, congestion may not be of sufficient economic magnitude, relative to the economywide stock of road infrastructure, to be identifiable using statistical methods.

Preliminary attempts to replicate the Fernald (1999) study and extend it did not produce encouraging results — although there is some indication that it is an increasing capacity utilisation story rather than a congestion effect story. One possible explanation is that the congestion parameter was assumed to be constant over time or subject to one or two breaks as per Fernald. Techniques that allow for a smooth transition in the parameter may be more successful as they align better with the trends evident in figure E.8. Further examination is beyond the scope of this paper.

Are spatial/locational dimensions important?

Infrastructure can have localised benefits and network benefits. Localised infrastructure benefits may give rise to negative spillovers in other locations from which production and factors of production are drawn. But there may also be countervailing positive spillovers from network benefits of infrastructure. Haughwout (1998, p. 226) notes "from a national perspective it is important to distinguish investment in public goods which add to the productive capacity of the nation as a whole from those that simply provide advantages to some places over others".

More disaggregated analysis may make the links between infrastructure and productivity more apparent than in aggregate analysis. For example, Boarnet 1998 and Haughwout 2002 have examined public infrastructure at a regional level and found localised effects and network benefits. However, the extensive data requirements for such analysis may be a limiting factor for Australian analysis.

E.8 Implied gross rates of return

While the level of estimated elasticity is informative, it is often of more interest to derive the rate of return to infrastructure. Some of the criticisms of Aschauer (1989a) and similar studies are based on the implausibility of the rates of return — the rates of return making the size of the effect more obvious than the actual elasticities.

It should be noted that, even aside from any imprecision in estimation, the rates of return presented in this paper should be interpreted as indicative. A rate of return on capital (as conceived in the economics literature) generally measures the additional output generated from an increase in capital — by multiplying the output elasticity (from an estimated production function) by the observed ratio of output to capital. However, the rates of return presented in this paper are based on MFP elasticities rather than output elasticities. Nevertheless, even though they are conceptually different, estimated MFP and output elasticities are likely to be quite similar in magnitude.[6] Consequently, the MFP-based rates of return presented here are likely to be close approximations to output-based rates of return.

Rates of return to infrastructure are calculated by multiplying the estimated MFP elasticity with respect to infrastructure by the ratio of output to the average productive capital stock of infrastructure. The real values of the productive capital stocks and relevant ratios are listed in table E.23. The ratio for the business knowledge stock is also listed for comparative purposes.

The ratio for business R&D for the period 1989-90 to 2002-03 is much lower than for the period 1974-75 to 1988-89 resulting from rates of business R&D investment outpacing market sector output growth. This pattern of relative ratios also applies to communications infrastructure. In contrast, the ratio for road infrastructure services is higher in the later period indicating that the service provided by road infrastructure has declined relative to the size of the market sector measured by gross value added output.

6 These elasticities will differ to the extent that the assumptions used in the construction of MFP estimates (constant returns to scale and factors paid according to their marginal products) do not hold.

Table E.23 **Market sector inverse intensities for rate of return calculations**

Productive Capital Stocks (PKS) in chain volume terms[a]

	Means, $million			*Intensity (Y/x)*		
	1974-75 to 2002-03	*1974-75 to 1988-89*	*1989-90 to 2002-03*	*1974-75 to 2002-03*	*1974-75 to 1988-89*	*1989-90 to 2002-03*
Means						
Roads PKS[b]	65185	61813	68798	4.8	4.0	5.6
Public eco. infra. (I3) PKS[c]	88176	84280	92350	3.5	2.9	4.2
Comm. infra. PKS[c]	39831	27363	53191	7.9	9.1	7.2
Bus. R&D stock (Rbus15)	11467	6326	16974	32.0	39.7	23.7
Value added (Y)	314800	249050	385246			

[a] Base year for prices equals 2001-02. [b] Fernald (1999) reports an intensity of 4 for the United States in 1989. [c] These PKS estimates are very crude estimates based on simple aggregation across different asset types included in the infrastructure total. PKSs are not strictly additive across asset types and CVMs are also not strictly additive at years other than the base year.

Source: Published and unpublished ABS national accounts data and authors' estimates.

The elasticities from table E.16 are combined with the ratios of output to the productive capital stock in table E.23 to give the indicative rates of return listed in table E.24. The band of returns is based on elasticities using plus or minus two standard deviations from the point estimate. This corresponds to the 95 per cent confidence interval.

Table E.24 **Implied gross rates of return[a] to infrastructure from the market sector models**

Rate of return band based on minus or plus two standard errors, per cent

			Rate of return		
Infrastructure type	*Model*	*Elasticity (Std. error)*	*1974-75 to 2002-03*	*1974-75 to 1988-89*	*1989-90 to 2002-03*
Road infrastructure	RI5	0.427 (0.155)	56 - 352	47 - 296	65 - 412
Road infrastructure	RI6	0.308 (0.141)	12 - 282	10 - 237	15 - 359
Comm. infrastructure	D2	0.050 (0.022)	5 - 78	6 - 86	4 - 69
Comm. infrastructure	D3	0.052 (0.024)	3 - 83	4 - 92	3 - 74
Comm. infrastructure	LP2	0.061 (0.024)	11 - 91	12 - 100	10 - 80

[a] The rates of returns for communication infrastructure are only indicative. They use the average of the simple sum of productive capital stocks of several asset types in chain volume terms — productive capital stocks are not strictly additive and the addition will also be less accurate the further away from the base year (2001-02).

Source: Authors' estimates.

Even with estimates that are statistically significant at greater than 5 per cent, the possible returns to road infrastructure cover a very wide band. Evaluated at the mean intensity for the period 1974-75 to 2002-03, the return to road infrastructure from model RI5 ranges between 56 per cent and 352 per cent. Road infrastructure would also have effects on the utility of consumers and (non-market sector) producers not captured in the estimated coefficients for the market sector. Therefore, other studies have interpreted returns from these types of regression exercises as implying a lower bound estimate of the economywide (social) rate of return (for example, Paul 2003).

The possible returns to communication infrastructure cover a narrower band than those to road infrastructure. Evaluated at the mean intensity for the period 1974-75 to 2002-03, the return to communications infrastructure from model D2 ranges between 5 per cent and 78 per cent.[7]

E.9 Comparison with other studies

Comparisons with other studies are not straightforward because of the different approaches taken, different time periods and the varying amounts of information reported. For example, it is not possible to directly compare the elasticities and rates of return from cost function studies with those of production function studies.[8]

Public infrastructure

The range of estimates for public infrastructure in other studies is very wide. For Australian aggregate studies, the elasticity estimates range from 0.008 to 1.19 — although the majority of studies fall in the 0.2 to 0.5 range (see tables 2.1 and 2.2 for further details). The preferred models in this paper produce results (0.31 to 0.43) that are in line with the majority of these studies and that are subject to the same concerns about implausible magnitudes (table E.25).

However, the preferred models in this paper use road infrastructure, whereas most Australian studies use broader measures of public infrastructure. These broader public infrastructure measures were used in the sensitivity tests in this paper. Again,

[7] These results are only indicative because the mean intensity of communication infrastructure is based on an aggregation across productive capital stocks of different asset types in chain volume terms. Aggregation across asset types will be inaccurate to the extent that the assets have different rental prices. The use of chain volume measures also mean that aggregation will be less accurate the further away it is from the base year (2001-02).

[8] It is possible to derive the primal (output-side) measure from the cost function but these measures will still only be comparable if the assumption of constant returns to scale holds.

these results fall within the range of other studies. For example, the broader measure ('I3'), with an elasticity estimate of 0.49, is closer[9] to the measure used by Otto and Voss (1994a) to obtain an elasticity of 0.45. Paul (2003) estimated an elasticity of 0.47 in a Cobb-Douglas function and 1.19 in a translog function for a usage-adjusted measure[10] closer to 'I3ug2' (which is estimated at 0.39 in this paper).

Few Australian studies report rates of return (or sufficient information to derive them). Paul (2003) reports rates of return significantly lower than the point estimates from the preferred models in this paper. However, his estimates are still implausibly large (table E.25).

Table E.25 **Comparison of aggregate public infrastructure models**

Rate of return band based on minus or plus two standard errors, per cent

		Elasticity (standard error)		*Rate of return Point estimate (range)*	
		This study	*Other studies*	*This study*[a]	*Other studies*
Infrastructure type	*Model*	*output-side elasticity*	*output-side elasticity*	*1974-75 to 2002-03*	*1968-69 to 1995-96*
Road infrastructure	RI5	0.427 (0.155)		204 (56 – 352)	
Road infrastructure	RI6	0.308 (0.141)		147 (12 – 282)	
Public infrastructure[d]	RI5(2)	0.490 (0.170)		173 (53 – 293)	
Public infrastructure[e]	RI5(1)	0.385 (0.144)		136 (34 – 238)	
Public infrastructure	Paul (2003)[f]		0.47 – 1.187 (0.1648 – 0.1651)		96.4[b]
	Otto & Voss (1994a)		0.38 – 0.45 (0.1425 – 0.2406)		
Public infrastructure	Other Aust. studies[c]		0.008 – 0.45		

[a] Rate of return is calculated as infrastructure elasticity multiplied by the ratio of output to infrastructure stock (at mean values). The rates of returns for public infrastructure are only indicative. They use the average of the simple sum of productive capital stocks of several asset types in chain volume terms — productive capital stocks are not strictly additive and the addition will also be less accurate the further away from the base year (2001-02). [b] Marginal benefit to the 'private' sector. Equivalent to rate of return as calculated in this paper. Paul (2003) also calculates rate of return of public investment to 'private sector' industries (not including benefits to consumers and other producers outside the 'private sector') as the ratio of the marginal output benefit to the marginal cost of public investment. Marginal output benefit is infrastructure elasticity multiplied by the ratio of output to infrastructure stock. Marginal cost is the ratio of social opportunity cost (that is, nominal project cost plus deadweight loss) to value of additional tax revenues required to finance the project. Paul (2003) uses marginal costs estimated in other studies Campbell and Bond of 1.20 (giving a rate of return of 80.3) and Findley and Jones of 1.40 (giving a rate of return of 68.8). See Paul (2003, p. 458) for a discussion. [c] See table 2.1 for details. [d] Variable is 'I3'. [e] Variable is 'I3ug2'. [f] Primal measures derived from cost function approach.

Source: Authors' estimates; Paul (2003); Otto and Voss (1994a); table 2.1.

[9] The Otto and Voss measure includes non-market sector general government infrastructure.

[10] The Paul measure also includes non-market sector general government infrastructure.

One advantage of the methods used by Paul (2003) is that the translog is a flexible functional form. The main advantages of this study are the use of the ARDL co-integration framework, the use of a more comprehensive set of control variables and the use of a services measure of infrastructure rather than a stock measure.

Communication infrastructure

There appear to be no studies that provide enough information to make direct comparisons of results of the effect of communications infrastructure (as defined in this paper[11]). The US study by Nadiri and Nandi (2001) used a cost function approach rather than the production function approach used in this study. While both this study and Nadiri and Nandi (2001) find positive spillovers from communication infrastructure, the different approaches taken mean the magnitudes of the results are not directly comparable.

However, it is possible to make some broad comparisons. At the aggregate level, the output-side elasticity can be derived from the Nadiri and Nandi cost elasticity if it is assumed that constant returns to scale hold. Under constant returns to scale, the primal (output) elasticity is the negative of the cost elasticity. On this basis, the results in the preferred models in this paper are generally larger than the US estimates (0.05 compared with 0.014) (table E.26).

Table E.26 **Comparison of aggregate communication infrastructure models**
Rate of return band based on minus or plus two standard errors, per cent

	Elasticity (standard error)		*Rate of return Point estimate (range)*	
	This study	*Other studies*	*This study*[a]	*Other studies*[b]
Model	*output-side elasticity*	*cost-side elasticity*	*1974-75 to 2002-03*	*1950 to 1991*[c]
D2	0.050		42	
	(0.022)		(5 – 78)	
D3	0.052		43	
	(0.024)		(3 – 83)	
Nadiri & Nandi (2001) - US		-0.0136[d]		32.80

a Rate of return is calculated as infrastructure elasticity multiplied by the ratio of output to infrastructure stock (at mean values). The rates of returns are only indicative. They use the average of the simple sum of productive capital stocks of several asset types in chain volume terms — productive capital stocks are not strictly additive and the addition will also be less accurate the further away from the base year (2001-02). **b** Marginal cost benefit to the 'private' sector. Not directly comparable with rate of return as calculated in this paper. **c** Evaluated at 1987. **d** This is not directly comparable with the output-side elasticity — the primal (output) elasticity will be the negative of the cost elasticity provided the assumption of constant returns to scale holds. This was not reported by Nadiri and Nandi.

Source: Authors' estimates; Nadiri and Nandi (2001).

[11] Communication network infrastructure rather than information and (tele)communications technology capital in general.

For the effect of digitisation there are also few direct comparisons available. However, the generally positive estimates for the interaction between digitisation and IT capital found in this paper accord with the results of Barker et al. (2006) — that digitisation of telecommunications infrastructure improved the productivity impact of increases in the penetration of personal computers.

Assuming communication infrastructure plays broadly the same role in influencing productivity as in the United States, it might be expected that estimated returns in Australia would be somewhat higher if Australia lags the United States in the completion of major networks or the significant upgrading of those networks.

E.10 Summary of findings for the market sector

The key findings for the market sector are as follows.

- The coefficient on private IT capital services was negative in all models in which it survived a test down procedure.
- There is robust evidence of a positive effect of IT capital services on productivity only when the effect of IT is conditioned by the digitisation of the communication network.
- There is evidence of a positive excess effect of communications infrastructure.
  - Acceptable specifications of MFP models show a positive effect of communication infrastructure in addition to any effect related to the variable 'ITdigi'. However, MFP is also explained well by models that do not include communication infrastructure.
  - In addition, differenced regressions do not support an effect different from zero.
- There is conflicting evidence of the effect of road infrastructure.
  - There is some evidence of a positive coefficient in the range of 0.3 to 0.43 from MFP regressions. Even though the estimates are statistically significant at greater than 5 per cent, the standard errors result in a very broad range of possible effects. The indicative gross rates of return implied by these elasticities are 12 to 352 per cent.
  - These very large effects are not corroborated by differenced models or labour productivity regressions.
  - Despite the estimation and testing procedures employed, there is enough contradictory evidence that there remains concerns that such large positive coefficients may in fact be spurious. Economic priors certainly suggest that they are nonsensical. It is possible that further investigations will be

undertaken to examine whether a large part of the problem is that the road capital services measure does not take account of changes in capacity utilisation and/or congestion.

- Education and effective rates of assistance are of the expected sign, are usually significantly different to zero, and are robust to different specifications. Foreign R&D is economically and statistically significant in some preferred specifications. Controlling for these effects increases the confidence that can be attached to the key findings.
- Sensitivity testing showed that the results are quite sensitive to the definition of infrastructure.
  - Alternative definitions of communication infrastructure generally produced larger effects than that in the preferred model. While significant in one of the preferred MFP models, the effect of digitisation on IT became insignificant when alternative definitions of communication infrastructure were used. However, the effect in the preferred labour productivity model was significant under all definitions of communication infrastructure.
  - Widening the scope of public infrastructure to general government infrastructure also produced larger effects than for roads.

The findings should be considered within the context and constraints of the available data and methods adopted. These include the following factors in particular.

- The adoption of a production function framework.
  - The two-step MFP approach depends on the reliability of the assumptions underlying the construction of MFP. However, at the level of the market sector, the CRS assumption is usually not rejected.
- Co-integration analysis techniques based on Pesaran and Shin (1999).
- Linear estimation techniques.
- The adopted proxies for the business cycle and unobserved changes in capacity utilisation.

F The effect of infrastructure on industry productivity

This appendix investigates the effect of infrastructure on industry productivity and elaborates on the industry results presented in chapter 5. The effects are investigated within the framework of the determinants of multifactor productivity (MFP), with regressions specified in levels and estimated using the techniques outlined in appendix J. All of the results are based on linear models with breaks in slopes incorporated in some cases, for example, in relation to IT capital and the effects of digitisation.

The industry coverage is restricted to industries included in the ABS's market sector — those industries for which multifactor productivity is estimated by the Commission. Accommodation, cafes & restaurants and Cultural & recreational services, although in the market sector, are not included because of concerns about the accuracy of the measurement of productivity for these industries. Although there is greater uncertainty about the accuracy of industry productivity estimates in general than market sector productivity, the continuous decline over a long period for these two industries raises particular suspicions of measurement error (see PC 2007b for further discussion).

It should be noted that the data used in the modelling exercise cover the period 1974-75 to 2002-03 and do not include any ABS revisions since November 2003. The data therefore differ from the most recent MFP data presented in chapter 3, which incorporate significant revisions resulting from changes in methodology by the ABS in 2005. These changes affected levels more significantly than growth rate patterns. Of the ten industries examined in this paper the most significant changes to the growth rate patterns were in Finance & insurance and Retail trade — over the period 1974-75 the average growth was revised from -0.5 to 0.5 per cent a year for Finance & insurance and from 0.6 to 0.9 per cent a year for Retail trade.

The modelling includes a number of control variables from the set listed in table and was subject to a range of statistical tests described in table E.2. The suite of control variables are described in more detail in appendix D.

Table F.1 **Description and expected sign of the industry control variables**[b]

Variable	*Description*	*Level of agg.*[a]	*Data source*	*Expected sign*
Cycle/capacity utilisation variables				
opgaph11	Growth rate of actual output less growth rate of potential output with potential output obtained by applying the Henderson 11 term moving average filter to value added.	EW,I	Authors' estimates.	(+)
ACCI	Subjective measure of capacity utilisation constructed from ACCI-Westpac business survey.	EW	ACCI-Westpac, *Survey of Industrial Trends*	(+)
dva	Growth in industry value added	I	ABS (Cat. no. 5204.0)	(+)
CPI	Consumer price index (8 capital city index)	EW	ABS (Cat. no. 6401.0)	(?)
minexppri	Export price index for mining		ABS (Cat. nos 6204.0 and 6457.0)	(?)
soi	Southern Oscillation Index. +/- values, therefore, not logged. Calculated from fluctuation in air pressure, with negative values associated with less rain and positive values with more rain.	EW	Bureau of Meteorology.	(+)
rain	Rainfall index. +/- values, therefore, not logged.	EW	TRYM database.	(+)
dubai	Energy Price Index (Oil price Dubai $US per barrel).	EW	Based on ABARE, *Australian Commodity Statistics* (various issues).	(-)
trend	Linear time trend. Control for steady exogenous (technological) change.			(+)
trnd19##	Trend shift at year 19## (eg 1984 and 1995)			(?)
shift19##	Shift in intercept at year 19##			(?)
Cost of capital and its volatility				
yrbond	10 year Commonwealth Treasury bond yield	EW	Reserve Bank of Australia	(-)
shrtbond	Yield on Commonwealth government securities (combined series of Treasury 2 and 3 year bonds). Measure of cost of holding inventories.	EW	Reserve Bank of Australia	(-)
bondvol	Average of three prior periods change in shrtbond	EW	Reserve Bank of Australia and authors' estimates	(-)

(continued on next page)

Table F.1 **(continued)**

Variable	Description	Level of agg.[a]	Data source	Expected sign
R&D variables				
rown_o	Own-industry, own-financed stock of R&D with assumed decay rate of 15 per cent.	I	ABS (Cat. no. 8104.0 and unpublished data), and authors' estimates.	(+)
rext_t	Inter-industry stock of business R&D (depreciated at 15 per cent) weighted by inter-industry trade relationships.	I	ABS (Cat. no. 8104.0 and unpublished data), and authors' estimates.	(+)
rfbteio	Foreign stock of business R&D with assumed decay rate of 15 per cent weighted by elaborately transformed manufactures (ETMs) country import shares ('te') and inter-industry trade relationships ('io').	I	OECD (ANBERD database), ASNA input-output tables, and authors' estimates.	(+)
rfbtdioch	Foreign stock of business R&D with assumed decay rate of 15 per cent weighted by country import intensities (import share 'td' and inter-industry weight 'io'). The stock is scaled by Australia's import intensity 'ch'.	I	OECD (ANBERD database), ASNA input-output tables, and authors' estimates.	(+)
rnb_u	Non-business stock of R&D with assumed decay rate of 7.5 per cent.	EW	ABS (Cat. no. 8112.0), and authors' estimates.	(+)
Trade openness, terms of trade and international competitiveness				
topen	Index of imports plus exports as a proportion of GDP.	EW	ABS (Cat. no. 5204.0).	(+)
tiopen	Index of imports as a proportion of GDP, where imports include capital, intermediate inputs, consumption and other imports.	EW	ABS (Cat. no. 5204.0).	(+)
tiopente	Index of imports of ETMs.	EW	DFAT (Stars database).	(+)
ToT	Ratio of export prices for goods and services over import prices for goods and services	EW	ABS (Cat. no. 5306.0).	(?)
Totgdsvl	Volatility in the terms of trade for goods. Calculated as the standard deviation in the 3 most recent growth rates for the terms of trade in goods only.	EW	ABS (Cat. no. 5306.0).	(-)

(continued on next page)

Table F.1 **(continued)**

Variable	*Description*	*Level of agg.*[a]	*Data source*	*Expected sign*
farmtot	Farmers' terms of trade. Ratio of index of prices received by farmers and index of prices paid by farmers.	I	ABARE, *Australian Commodity Statistics* (various issues).	(?)
farmtotsd	Volatility in farmers' terms of trade. Calculated as the standard deviation in the 3 most recent growth rates for farmers' terms of trade only.	I	ABARE, *Australian Commodity Statistics* (various issues); authors' estimates.	(-)
era	Effective rates of assistance to industry.	I	Commission database.	(-)
Human capital				
[industry]edu	Proportion of industry employed with post-school qualifications.	I	ABS unpublished data.	(+)
QALI	ABS Quality Adjusted Labour Index (QALI).	MS	ABS (Cat. no. 5204.0).	(+)
union	Proportion of industry employees with union membership.	I	ABS (Cat. nos 6310.0 and 6325.0) and authors' estimates	(-)
Labour market				
centbrg	Centralised wage determination index	EW	ABS (TRYM Modeller's database).	(-)
disputes	Total working days lost from industrial disputes. Time series not available for some industries.	I/MS	ABS (Cat. no. 6321.0) and authors' estimates.	(-)
Other				
syddmmy	Dummy control variable for the Sydney Olympics			(-)
inptxadj, inpxadj2	Combined input services indexes to control for scale economies. Input services index adjusted to exclude other quantities re-entered as explanatory variables — infrastructure variables, IT capital (inptxadj) and also own-industry R&D capital for some industries (inpxadj2).	I	ABS unpublished data and authors' estimates.	(?)
nonggIT	Capital services index for IT capital assets (hardware and software) of the industry, excluding any general government IT assets allocated to the industry by the ABS.	I	ABS unpublished data and authors' estimates.	vary by industry

(continued on next page)

Table F.1 **(continued)**

Variable	*Description*	*Level of agg.*[a]	*Data source*	*Expected sign*
nongtrnd	Trend in the effect of IT capital 'nonggIT'.			(+)
nongs##	Slope shifts on 'nonggIT' at year 19##, for example, at year 1995.			(+)
otrcap	Capital services index for the remainder of industry capital. That is, total industry capital less: IT capital (nonggIT) and any that is included in public economic infrastructure (I3) and, for Communication services, communications infrastructure (ci5).	I	ABS unpublished data and authors' estimates.	(+) in labour productivity models
ksrv	Capital services index for total industry capital.	I	ABS (Cat. no. 5204.0)	(+) in labour productivity models
hrs	Hours worked as scale control	I	ABS (Cat. no. 5204.0)	(-)
Interactions				
ITdigi	IT capital ('nonggIT') scaled by share of access lines digitised ('digi').			(+)
ci5iodg	Communications infrastructure ('ci5ioug') scaled by share of access lines digitised ('digi')			(+)
ksrvdg	Total capital ('ksrv') scaled by share of access lines digitised ('digi').			(+)
otrcapdg	Industry other capital ('otrcap') scaled by share of access lines digitised ('digi').			(+)
nonggIT* ci5ioug	Interaction between IT capital ('nonggIT') and communications infrastructure ('ci5ioug').			(+)

[a] 'I' represents variables which are specific to each industry. 'MS' and 'EW' represent variables for the market sector and economy as a whole, respectively, for which industry-specific measures are not available and/or relevant. [b] Variations on these variable names have the following meanings: 'd' before a variable name means variable is first differenced; (t-#) after a variable name means the named variable has been lagged by # number of periods; 'sq' after a variable name means variable is squared. Detailed definitions of infrastructure variables are provided in table 3.3.

F.1 Agriculture, forestry & fishing (AG)

Data description

Figure F.1 presents the trends in the main variables for Agriculture, forestry & fishing.

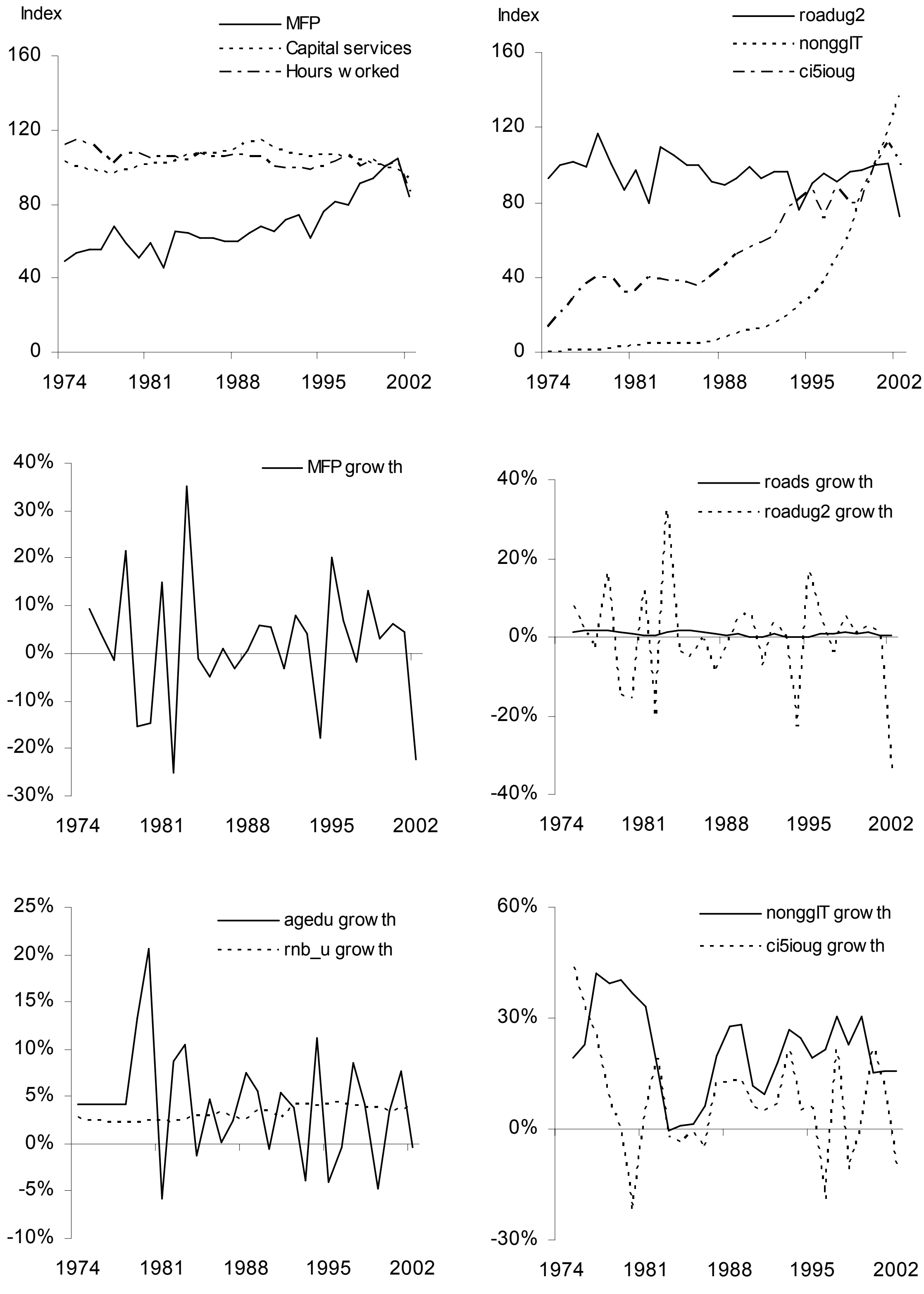
The key time series properties from the charts in figure F.1 are listed below.

- *Productivity*: MFP has increased over time although its rate of growth appears subject to shocks (for example, droughts) and there are periods where it has consistently grown slower or faster. MFP growth is particularly volatile in Agriculture. Inspection of its growth pattern suggests MFP is I(1) which is confirmed with unit root testing. Growth is capital services and hours worked has been flat to declining.
- *Road infrastructure*: the service available from road infrastructure does not appear to have increased over time when road infrastructure is adjusted by value added shares (roadug2). The usage adjustment factor introduces a high degree of volatility into the series, and a very high degree of correlation with the growth rate of MFP.
  - Determining the service provided by road infrastructure to AG is a difficult problem because the industry's relatively high output volatility translates into large variations in its share of market sector output. When combined with the pro-cyclical characteristic of MFP, using output shares as a mechanism for allocating a portion of the aggregate road infrastructure service to AG effectively imposes a strong, positive relationship between MFP and road infrastructure (discussed further below).
- *Communication infrastructure*: usage-adjusted communication infrastructure has grown strongly compared with total capital services, but less strongly than private IT capital.
- *Education*: the proportion of AG employed with post-secondary school qualifications has increased over time. The year-to-year growth rates appear to be somewhat counter-cyclical to value added and MFP growth rates.
- *Non-business R&D*: the growth rate of the non-business knowledge stock has been very stable.

Trends in other control variables are shown in figure F.2. The volatility in prices faced by farmers relative to their input prices has been much lower in the ten years to 2002-03 than in the 1980s or, especially, the early 1970s.

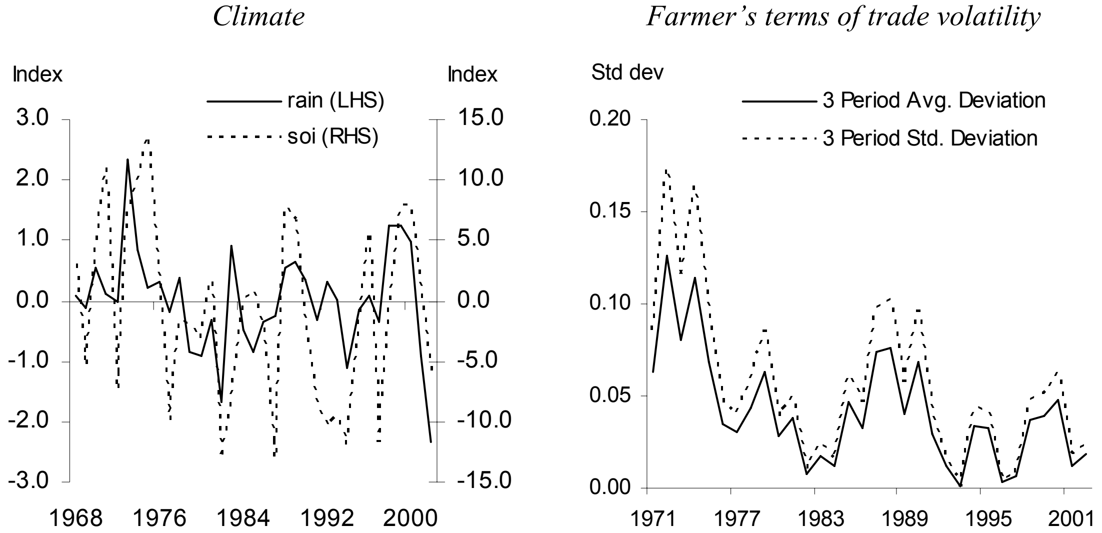
Figure F.1 **Trends in key variables for Agriculture, forestry & fishing**

Index 2000-01 = 100; Percentage growth



Data source: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Figure F.2 **Trends in climate and terms of trade variables**
Index 2000-01 = 100



Data source: Authors' estimates based on unpublished ABS data; Bureau of Meteorology.

Results including general government or road infrastructure

Road infrastructure with usage adjustment

The first set of tests investigating the effect of road infrastructure and communication infrastructure included different combinations of a linear time trend, cycle and scale control (models AG1 to AG5 in table F.2). With a maximum allowable lag of one period, there were sufficient observations to control for a substantial number of potential influences on industry productivity other than the key variables of interest.

Table F.2 **General-to-specific initial variable set for Agriculture, forestry & fishing with 'roadug2'**

Maximum allowable lag equals one.

Variable	*AG1*	*AG2*	*AG3*	*AG4*	*AG5*	*AG6*
road infra. (roadug2)	x	x	x	x	x	x
ci5ioug	x	x	x	x	x	x
nonggIT	x	x	x	x	x	x
agedu	x	x	x	x	x	x
rnb_u	x	x	x	x	x	x
era	x	x	x	x	x	x
dubai	x	x	x	x	x	-
farmtot	x	x	x	x	x	-
rain	x	x	x	x	x	-
intercept	x	x	x	x	x	x
trend	x	-	x	x	x	-
inptxadj[a]	x	x	x	-	-	x
opgaph11 (fixed)	x	x	-	x	-	-

[a] Combined input services index. Does not include road infrastructure, communication infrastructure, or IT capital.

None of the resulting models were considered acceptable and the results are not shown. The key results and problems are discussed below.

- Road infrastructure has an economically and statistically highly significant impact on MFP if the road infrastructure variable is usage adjusted by value added shares 'roadug2'. The coefficients were between 0.9 and 1.1 and statistically significant at greater than 1 per cent.
- However, the results for road infrastructure were being driven solely by the usage adjustment factor. When the variable 'roads' is used, which is the entire road service provided to the market sector, the effect of road infrastructure is insignificant, and overall model results are very poor. Most variables become insignificant or have implausible magnitudes and/or are of the incorrect sign. The presence of the usage adjustment makes it easier to obtain correctly signed and statistically significant control variables.
- Some tests produced variables that were wrongly signed. Testing down of model AG4 resulted in a positive and insignificant error correction method (ECM) term indicating that this model can clearly be rejected.
- The scale control variable in models AG1 to AG4 suggests an implausibly large failure in the constant returns to scale (CRS) assumption.
- The economic magnitude of the implied rate of return on non-business R&D is implausible.

- The industry education variable 'agedu' was dropped from models AG1 to AG5 as its coefficient was negative and highly significant. If education is not dropped, then it helps the estimation of other explanatory variables in terms of obtaining variables signed as expected, and significant estimates.
  - The proportion of employed persons with post-secondary school qualifications could be negatively correlated with MFP if the decision to start/postpone or complete qualifications is responsive to employment conditions, employment conditions are correlated with broader economic conditions, and MFP is pro-cyclical with industry output. However, a negative relationship would only be expected in the short run. In the long-run, education would be expected to either positively influence productivity or be insignificant. It is possible that the models contain insufficient dynamics to separate out these effects.
- The bounds test did not reject the null of no long-run relationship for any of the models.

General government infrastructure with usage adjustment and results from alternative estimation strategies

The motivation for the tests in this section were as follows.

- *Model AG8*: tests the effect of usage-adjusted general government infrastructure 'I3ug2'. A test down procedure was employed with the final variable set being equivalent to the preferred results for this industry in chapter 8 of Shanks and Zheng (2006). Those results were based on the rate of return framework (where the model is first differenced and the knowledge stock is specified as an intensity), with an assumed decay rate for non-business R&D of 0 per cent rather than the 7.5 per cent rate used below.
- *Model AG10*: tests the inclusion of the variable 'digi' in the variable set prior to testing down. A cycle variable and general government infrastructure was not included in the initial variable set. Farmers' terms of trade and a dummy for the 1982 drought were included. Tests of whether the effect of other forms of capital has been affected by digitisation of the copper network are included separately below.
- *Model AG11*: tests the effect of usage-adjusted road infrastructure using hours worked 'hrs' as the scale variable rather than the combined input services index 'inpxadj2'.
- *Model AG11FD*: re-estimated model AG11 in first differences to check whether results held.

General government infrastructure is highly significant if it is usage adjusted (model AG8 of table F.3). Tests of a smoothed usage adjustment for general government infrastructure 'I3ug2s' resulted in a coefficient and standard error of 0.988 (0.055).

However, other tests strongly showed that without the usage adjustment general government infrastructure is insignificant, or at least its contribution cannot be detected with the data and methods used in this appendix. This is also true of road infrastructure. The measure of the service provided by both types of infrastructure is not measured independent of AG outputs: a positive relationship with productivity is imposed on the model through the usage adjustment. Therefore, the results do not provide evidence of an effect running from road services to productivity.

The coefficient on communication infrastructure is positive and highly significant in model AG10, but it is insignificant in other models. The coefficient on communication infrastructure may be picking up a cyclical effect operating on MFP through the input-output adjustment, as this model does not include 'opgaph11'.

While model AG11 is the only model to pass both the bounds and forcing tests, and first differencing provides supporting evidence, the magnitude of the estimated elasticities for usage-adjusted road infrastructure and non-business R&D are implausible.

Other results of interest and issues are as follows.

- Farmers' terms of trade was positive in Shanks and Zheng, whereas it is negative in model AG8 and other tests. It was also negative and economically more significant in IC (1995). Model AG8 passes the bounds test, but fails the long-run forcing tests.
- The coefficient on the linear time trend is consistently negative. The trend is meant to capture steady technological change, and would normally be expected to be positive but it could be capturing the following.
  - Deterioration in the quality of land — increasing use of more marginal land, or land degradation (for example, rising salinity).
  - Mismeasurement of input and/or output price/quality trends. Any mismeasurement of inputs or outputs will flow through to measured MFP.
- The capital services provided by private IT capital (variable 'nonggIT') is not significant in explaining AG MFP. This contrasts with Connolly and Fox (2006) who found that the ratio of electronics, computers and software to other capital is positive and highly significant. A 'ratio' variable, which draws from a particular theoretical framework, was not tested.

Table F.3 **Effects on Agriculture, forestry & fishing MFP**[a]

Dependent variable is ln(MFP)

Selection criteria	*SBC*	*SBC*	*SBC*		*Max lag=2*	*Max lag=1*
Lag order	*(0,0,0,1, 1,0,0)*	*(0,0,1,0,0)*	*(1,0,0,1, 1,1,0,0)*	*First Differenced*	*(0,0,0, 0,0,0)*	*(0,0,1,1, 0,0,0)*
Model	*AG8*	*AG10*	*AG11*	*AG11FD*	*AGS1*	*AGS2*
opgaph11	0.376 *** (0.053)					
hrs	-0.354 *** (0.052)		-0.485 *** (0.054)	-0.460 *** (0.058)		
l3ug2	0.938 *** (0.029)					
roadug2			0.852 *** (0.039)	0.931 *** (0.038)		
ci5ioug		0.220 ** (0.087)	-0.025 (0.016)	-0.020 (0.020)	0.097 (0.072)	0.318 *** (0.087)
digi		-0.026 *** (0.007)				
ITdigi					0.063 *** (0.018)	
nonggIT						-0.062 *** (0.029)
nongs95						0.059 *** (0.012)
rnb_u	1.926 *** (0.078)	2.010 *** (0.410)	1.807 *** (0.095)	1.533 *** (0.339)		
agedu farmtot[b]	-0.085 ** (0.033)				-0.499 * (0.289)	-0.726 *** (0.260)
rain	0.008 ** (0.003)	0.073 *** (0.014)	0.006 (0.004)	-0.003 (0.005)	0.062 *** (0.016)	0.060 *** (0.013)
dubai			-0.027 *** (0.006)	-0.007 (0.010)		
era			-0.032 *** (0.008)	-0.043 *** (0.008)	-0.135 * (0.067)	-0.188 *** (0.058)
intercept	-6.058 *** (0.331)	-4.326 *** (1.445)	-3.839 *** (0.368)	-0.025 ** (0.011)	6.759 *** (1.720)	7.433 *** (1.454)
linear time trend	-0.038 *** (0.003)	-0.039 *** (0.014)	-0.034 *** (0.003)			
opgaph11			0.283 *** (0.078)	0.057 ** (0.026)		
dummy82		-0.198 ** (0.062)				
ECM(-1)			-0.845 *** (0.056)			

(continued on next page)

Table F.3 **(continued)**

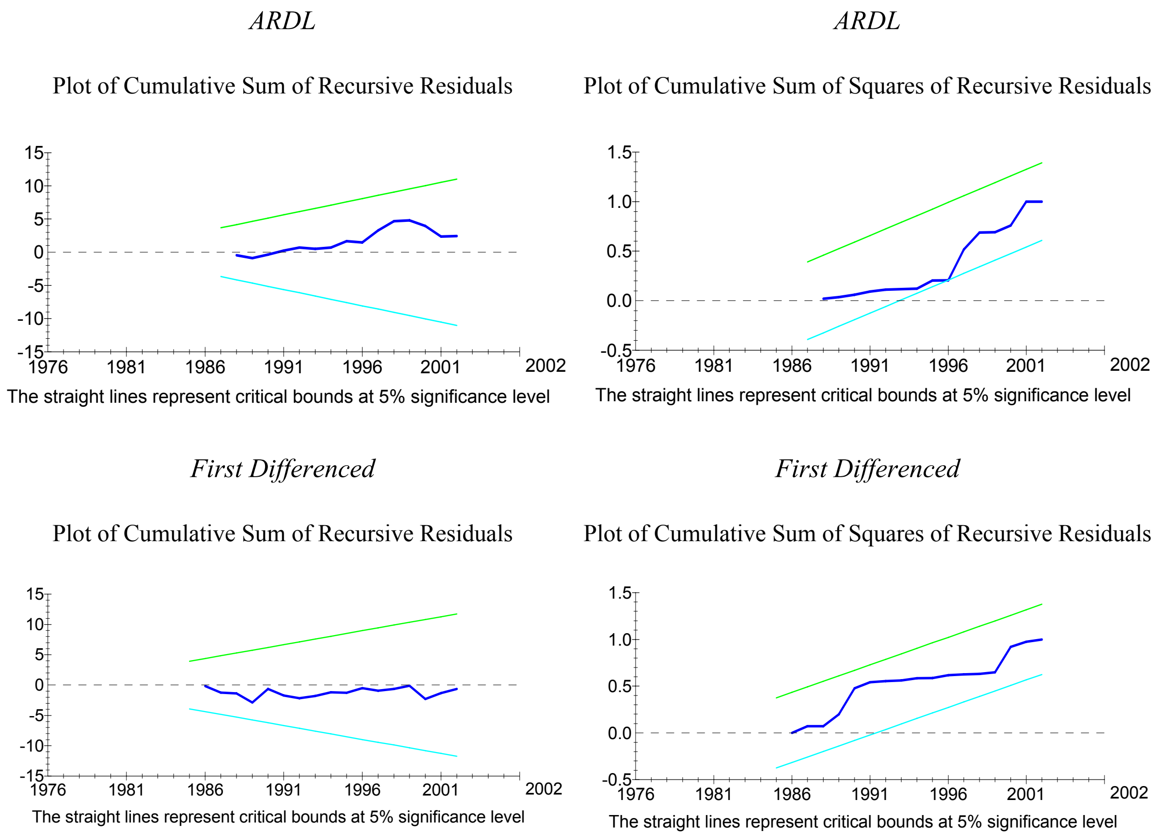
Selection criteria	*SBC*	*SBC*	*SBC*		*Max lag=2*	*Max lag=1*
Lag order	*(0,0,0,1, 1,0,0)*	*(0,0,1,0,0)*	*(1,0,0,1, 1,1,0,0)*	*First Differenced*	*(0,0,0, 0,0,0)*	*(0,0,1,1, 0,0,0)*
Model	*AG8*	*AG10*	*AG11*	*AG11FD*	*AGS1*	*AGS2*
Test statistics						
No. of observations	27	28	27	27	28	28
Time period	76-02	75-02	76-02	76-02	76-02	76-02
Step 1 test	4.275	4.284	10.756	na	5.557	3.277
Long-run forcing?	No[c]	?[d]	Yes	na	Yes[e]	?[f]
R^2	0.999	0.948	1.000	0.994	0.907	0.947
DW ‘d’ stat .	1.804	2.276		2.185	1.732	2.496
Durbin’s ‘h’ stat .			-0.701 (0.483)			
Serial correlation	0.158 (0.697)	0.570 (0.460)	0.835 (0.379)	0.784 (0.388)	0.575 (0.457)	2.134 (0.161)
Functional form	1.101 (0.310)	0.001 (0.972)	6.878 (0.022)	1.097 (0.310)	2.024 (0.170)	3.369 (0.083)
Normality	0.865 (0.649)	0.214 (0.899)	0.328 (0.849)	2.600 (0.273)	0.133 (0.936)	0.274 (0.872)
Hetero.	0.681 (0.417)	0.233 (0.633)	0.429 (0.519)	0.200 (0.659)	0.061 (0.807)	0.227 (0.638)
AIC (SBC)	88(82)	38(33)	95(86)	77(72)	32(28)	37(31)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] All variables are in logs (except the linear time trend, rainfall measure and output gap) with slope coefficients interpreted as elasticities. [b] Farmers’ terms of trade is the ratio of the index of prices received by farmers and index of prices paid by farmers. The index is sourced from ABARE. [c] F-statistics for opgaph11, rain and farmtot of 4.192, 6.341 and 5.718, respectively. [d] F-statistic for ci5ioug of 4.015. [e] The model passes forcing tests, except for the variable rain which can be ignored as it is clearly exogenous. [f] F-statistics for rain, farmtot and era of 3.532, 3.427 and 3.292, respectively.

Source: Authors’ estimates.

The CUSUM tests indicate that models AG11 and AG11FD are stable (figure F.3).

Figure F.3 **Tests for preferred model AG11 and AG11FD**



Data source: Authors' estimates.

Results excluding general government and road infrastructure

General government infrastructure and road infrastructure were excluded from the test procedures in order to see if more reliable estimates of the effect of communication infrastructure, IT capital and digitisation could be obtained.

Variables that were not significant in tests of model AGS1 were 'otrcapdg', 'nonggIT', 'rnb_u' and 'agedu' (table F.3). A linear trend term and the cycle measure 'opgaph11' were also not significant. The final model was estimated with a maximum of two lags, although the SBC selected a static model.

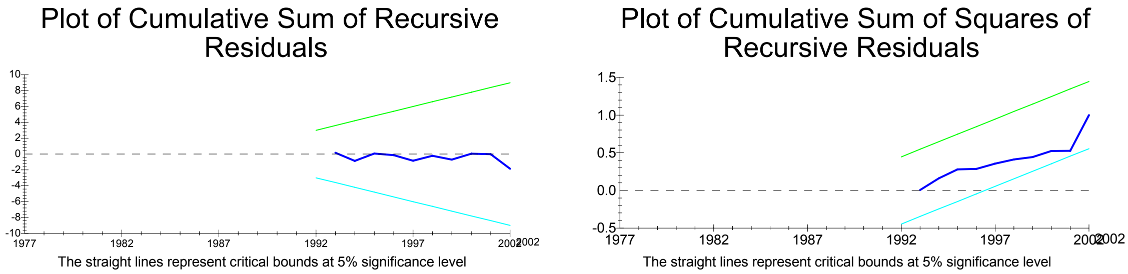
There is support for a significant positive effect of digitisation of the copper network on AG MFP. The null of no long-run co-integrating relationship is rejected, and the variables pass forcing tests (except for 'rain', which is not a problem). Other statistical tests are all acceptable and the parameters of the model are stable. Overall model fit is not particularly good (as indicated by information criteria and the standard error of the regression), at least compared with some industries and the market sector.

The signs on control variables accord with expectations. Rainfall is positive and significant. IC (1995) modelled broadacre agriculture only and found that ABARE's pasture growth index was highly significant in explaining MFP with a coefficient of 0.132.[1] Farmers' terms of trade is highly negative possibly pointing to the productivity dampening effects of external price shocks that induce more marginal land into production (similar to export price shocks in mining inducing the exploitation of increasingly lower grade deposits). Reductions in industry protection ('era') had a positive impact on AG productivity.

Model AGS2 allows the slope of IT capital to shift. The model generates a very significant effect of communication infrastructure. The effect of IT capital increased strongly from 1995, although the point estimate becomes roughly zero. The results for the control variables are consistent between the two models. The bounds and forcing tests are indeterminate for model AGS2. The inclusion of 'opgaph11' had a negative impact on the model, while 'ACCI' was insignificant. Overall, AGS1 is the preferred model.

The CUSUM tests indicate that model AGS1 is stable (figure F.4).

Figure F.4 **Stability tests for model AGS1**



Data source: Authors' estimates.

[1] IC (1995) found very unsatisfactory model results for regressions based on AG, and thought that this was because of the aggregation of heterogeneous industries. When regressions were based on broadacre agriculture only, with TFP estimates for broadacre agriculture obtained from ABARE, the results were substantially improved. Broadacre agriculture includes: wheat and other crops; mixed livestock-crops; sheep; beef and sheep-beef industries. IC (1995) used ABARE's pasture growth index as the weather variable. The index is based on the broadacre Australian Agricultural and Grazing Industries Survey regions and is therefore consistent with the TFP measure. The effect of weather was much more significant than the effects of the TRYM rain index or the Bureau of Meteorology's Southern Oscillation Index in the AG regressions in this study.

Summary

If the estimated coefficients on ‘I3ug2’ and ‘roadug2’ were not being driven by the usage adjustment then the results would provide evidence of a very large free input effect. However, the year-to-year variation in the service provided by road infrastructure to AG production is driven almost entirely by the usage adjustment.

Some form of usage adjustment is not unreasonable as AG’s use of road infrastructure will vary with output shocks — an increase/decrease in products requiring transportation as output changes. However, to be a test of the effect of roads on productivity, the usage adjustment needs to be independent of the measurement of outputs. The effect of road infrastructure is further complicated by the existence of various charges for accessing and using roads (for example, fuel taxes and registration fees).

The best model (model AGS1) suggests that digitisation of the copper network had the effect of increasing the marginal product of private IT capital. Model AGS2 allowed the elasticity of IT capital to increase without conditioning it on any other factor or characteristic of the industry. It provided supporting evidence that the effect of IT capital had changed substantially over time with an upward shift in the elasticity post-1995. This model pointed to a positive but much larger effect of communication infrastructure. The magnitude of the point estimate at 0.3 seems too large, as does the coefficient on terms of trade.

F.2 Mining (MIN)

Data description

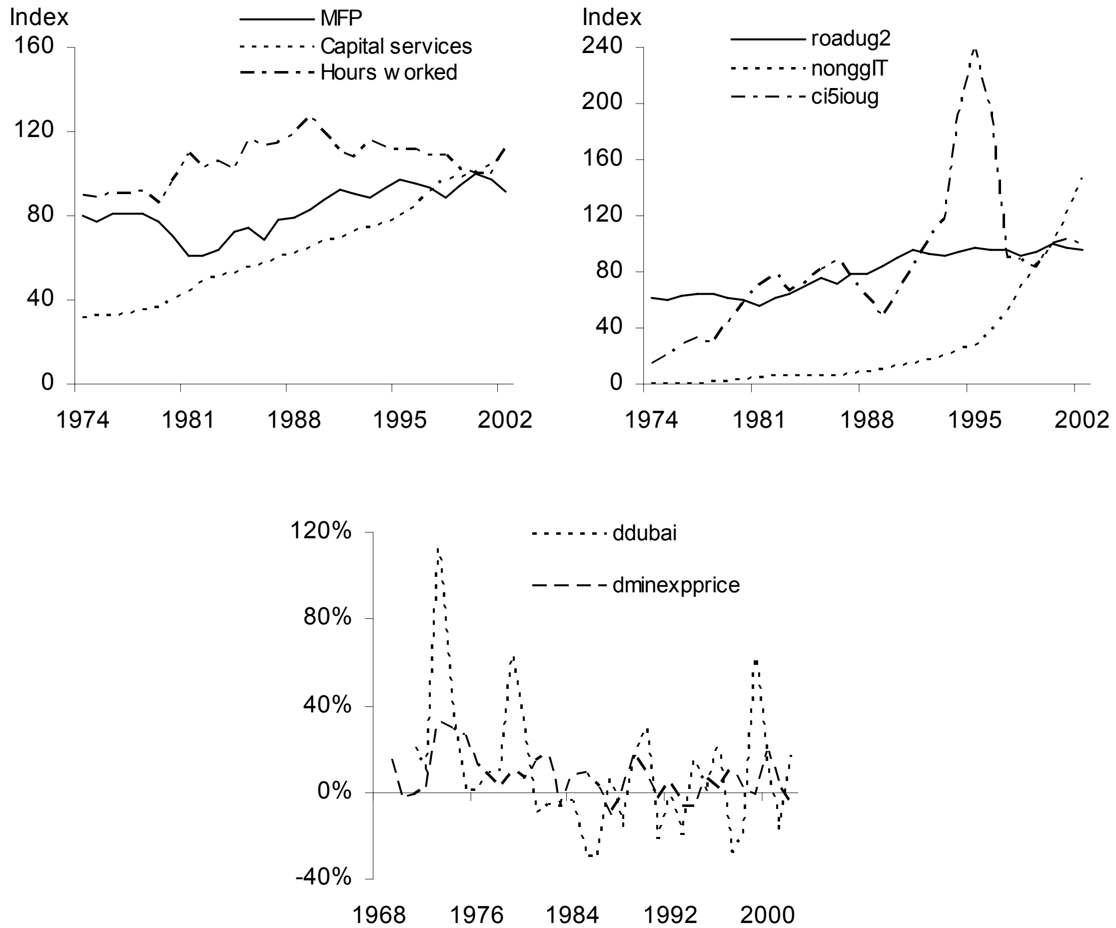
Hours worked in Mining increased up until the end of the 1980s (figure F.5). Capital services grew much more rapidly. From the early 1980s, Mining has averaged solid productivity growth to 2002-03.

The service provided by communication infrastructure first increased then declined rapidly in the 1990s, driven by the usage adjustment. The usage adjustment for general government and road infrastructure is based on industry value added shares, so there is a concern about the lack of independence between measured inputs and outputs. However, the usage adjustment for 'ci5ioug' is based on the Australian System of National Accounts input-output tables and is not driven by industry relative growth rates in value added output. This means that, although the usage adjustment introduces significant volatility, independence between inputs and outputs is maintained, so that the usage adjustment does not undermine the intended interpretation of estimated elasticities (that is, the direction of causation is from changes in communication infrastructure to productivity growth).

Mining is subject to significant change in the export prices available to it. These types of terms of trade shocks can have varied impacts (as discussed in box F.1). The key point for the analysis below is the importance of specifying dynamic models, and possibly including specific measures of shocks to prices. Oil prices are more volatile than average mining export prices (figure F.5, bottom panel).

Figure F.5 **Trends in key variables for Mining**

Index 2000-01 = 100; Percentage growth



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Box F.1 **Terms of trade and Mining**

Terms of trade (the ratio of export prices to import prices) is used in a number of Australian studies of productivity (for example, IC 1995, Madden and Savage 1998 and Connolly and Fox 2006).

The terms of trade is sometimes used as a measure of international competitiveness. IC (1995, p. QB.16) states that "In Australia's primary sectors, declines in world commodity prices can spur producers to find better production methods in order to survive." Connolly and Fox (2006, p. 53) include international competitiveness (measured by the terms of trade), together with openness, to control for the role of microeconomic reform in Australia's improved productivity performance in the late 1990s. They note that Otto (1999) finds that the terms of trade has strong 'predictive content' for Australian MFP.

IC (1995) found the terms of trade to be a significant and negative explanator of Mining MFP with an elasticity estimate of -0.57. IC (1995, p. QB.35) noted that "This result is consistent with Beck et al. (1985), who argue that in high income periods (an increase in the terms of trade), expenditure on inputs will increase but in the short term the relative inelastic supply will be little affected, thus resulting in an apparent short term decline in productivity." In contrast, in Connolly and Fox the terms of trade is highly positive and significant with a coefficient of 0.508.

In the context of the current prices boom (which is not covered within the sample of this study), analysis by Sibma (2006) highlights the dynamic nature of business investment. There are substantial lagged effects of business investment on mining output. The presence of the lags tends to support negative short-term effects, and an expectation — but no guarantee — of future productivity benefits.

Sibma (2006) also highlights the complexities of tracing through impacts to MFP that arise from complications, such as needing to take account of the degree to which capital equipment is imported.

Results

Results from previous studies

The results of tests for this study indicate that Mining is a difficult industry to model as can be seen from the different results obtained from previous studies.

Connolly and Fox (2006) regressed ln(value added) on a combined high-tech capital stock variable (including electronics, electrical machinery, communications equipment, computer hardware and software), a variable representing the industry's other capital, labour inputs, terms of trade, a linear time trend and an intercept. The coefficients were -0.346, 1.046, 0.300, 0.508, 0.007 and -3.419, respectively. CRS was imposed on the first three variables (that is, the coefficients were forced to sum to one).

IC (1995) regressed ln(MFP) on R&D stocks (external, own interacted with external and public), time, conventional capital stock, education, terms of trade, and an energy price index. The coefficients were 0.109, 0.003, 0.094, 0.002, -0.098, -0.086, -0.570, -0.274, respectively.

Shanks and Zheng (2006) regressed ln(MFP) on industry R&D, public sector R&D, general government infrastructure ('I3ug2'), trade openness, the change in oil prices, the industry's capital stock (as a control for the double counting bias in R&D, but also, possibly, picking-up errors in the CRS assumption), and a linear time trend. The coefficients were 0.061, 2.55, 1.066, 0.187, 0.036, -0.477, and -0.082, respectively.

Comparing these three sets of results, it is evident that very different models can be generated to explain mining output and productivity. The results can even point to very different effects, for example, large and oppositely signed effects for the terms of trade. The responsiveness of output or productivity to some of the variables appears too high.

One advantage of the results below is that the models are dynamic models. Selected models below include ECM terms that imply relatively slow corrections back to equilibrium (compared with other industries or market sector tests). The long transition paths are probably related to the role of large scale capital investments in this industry and the substantial time lags between initial investment and effects on output.

The 'cyclical' character of the industry's investment patterns is closely related to expected prices that are largely exogenous to Australia. To possibly control for these effects, the mining export price index was used in the results below rather than more general terms of trade indexes. The export price index seeks to remove pure price change for the derivation of real industry output. Other indexes based on the difference between export and import prices were also used in tests (a goods and services index of the terms of trade, and a goods only index).

Results with roads and general government infrastructure

The long-run coefficient on export prices is negative and highly significant (model MIN1 in table F.4). The short-run effect in the ECM (not shown) is also highly negative and significant. The dynamic ordinary least squares (DOLS) estimator for this model produces the same result (model MIN2). Prior to the test, the expectation was that mining export prices would have a significant negative short-run effect, but that the long-run estimate would be insignificant.

Usage-adjusted road infrastructure is highly significant (models MIN1 and MIN2) as is usage-adjusted general government infrastructure (model MIN3). However, both variables strongly fail the forcing tests. This result is the same as for most other industries in that it is the usage adjustment driving the result. Without the usage adjustment, neither roads or general government infrastructure is significant under any specification.

Results without roads or general government infrastructure

When usage-adjusted road and general government infrastructure is excluded from the tests, two differences in control variable results stand out.

- The cycle measure ‘opgaph11’ does not test out of the model. Its effect becomes highly significant and is larger than for most industries. It suggests that there are very large changes in capacity utilisation in Mining. The relative growth rate of the industry captured in the usage adjustment factor for road or general government infrastructure could be picking up the same effect.
- The sign of the effect of export prices and its significance is dependent on the inclusion of road or general government infrastructure. Without them, tests tended to favour a positive long-run effect of substantially less magnitude. However, the effect was usually not statistically significant, and it tested out of preferred models.

There is some support for a positive effect of communication infrastructure. It is positively signed and significant at 10 per cent in model MIN4. The bounds test result suggested that other estimation strategies should be attempted. When model MIN4 is estimated with ordinary least squares (OLS) in first differences, none of the variables are statistically significant. However, the DOLS results provide support for a positive effect.

Industrial disputes and oil prices both remain negatively signed and significant whether or not road or general government infrastructure, export prices or a cycle variable is included in the model.

The dynamic model tests could not validate some of the results from previous studies. For example, the inclusion of different specifications of IT capital did not produce acceptable models (‘nonggIT’, various slope shifts, or ‘otrcapdg’). The inclusion of R&D variables also resulted in unsatisfactory models (some signs were not as expected (depending on specification), coefficient estimates were often implausibly large on either the R&D variables or controls, and results were fragile to the inclusion or exclusion of certain variables).

Table F.4 Effects on Mining MFP, long run coefficients

Dependent variable is ln(MFP). Selected by SBC.

Lag order	*(1,1,0,0,1)*	*DOLS*	*(0,0,2,2,1)*	*(2,0,1,0,1)*	*DOLS*
Model	*MIN1*	*MIN2*	*MIN3*	*MIN4*	*MIN5*
roadug2	1.218 ***	0.806 ***		-	-
	(0.171)	(0.094)			
I3ug2	-	-	0.820 ***	-	-
			(0.086)		
ci5ioug	-	-		0.076 *	0.102 ***
				(0.038)	(0.028)
ITdigi	-	-		-0.007	-0.041 *
				(0.022)	(0.022)
disputes	-0.025 **	-0.055 ***	-0.052 ***	-0.065 **	-0.130 ***
	(0.012)	(0.006)	(0.007)	(0.028)	(0.031)
minexpprice	-0.413 ***	-0.233 ***	-0.259 ***	-	-
	(0.103)	(0.072)	(0.054)		
dubai	-0.029	-0.091 *	-0.076 ***	-0.239 ***	-0.267 ***
	(0.062)	(0.042)	(0.029)	(0.053)	(0.032)
constant	1.062 *	2.584 ***	2.541 ***	5.484 ***	5.957 ***
	(0.592)	(0.346)	(0.303)	(0.269)	(0.186)
opgaph11	-	-	-	2.521	1.412 ***
				(0.721)	(0.572)
ECM(-1)	-0.422 ***	-	-	-0.403 ***	-
	(0.113)			(0.085)	
Test statistics					
No. of observations	28	26	27	27	26
Time period	75-76 to 2002-03	77-78 to 2002-03	76-77 to 2002-03	76-77 to 2002-03	75-76 to 2002-03
Bounds test	12.462	-	14.266	1.565	-
Long run forcing?	No[a]	-	No[b]	Yes	-
R^2	0.985	-	0.989	0.980	-
Std. error of reg.	0.020	-	0.018	0.025	-
DW ‘d’ stat .	1.798	2.373	2.406	1.973	1.936
Durbin’s ‘h’ stat .	0.669	-	-	-	-
	(0.504)				
Serial correlation	0.013	-	1.999	0.008	-
	(0.909)		(0.177)	(0.930)	
Functional form	1.495	-	2.081	0.309	-
	(0.236)		(0.168)	(0.586)	
Normality	0.548	-	0.217	1.119	-
	(0.760)		(0.897)	(0.572)	
Hetero.	0.093	-	0.141	0.159	-
	(0.763)		(0.710)	(0.694)	
AIC (SBC)	66(61)	-	66(59)	57(51)	-
ADF test	-	-3.234	-	-	-3.655

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistic for roadug2 of 7.180. [b] F-statistic for I3ug2 of 7.180.

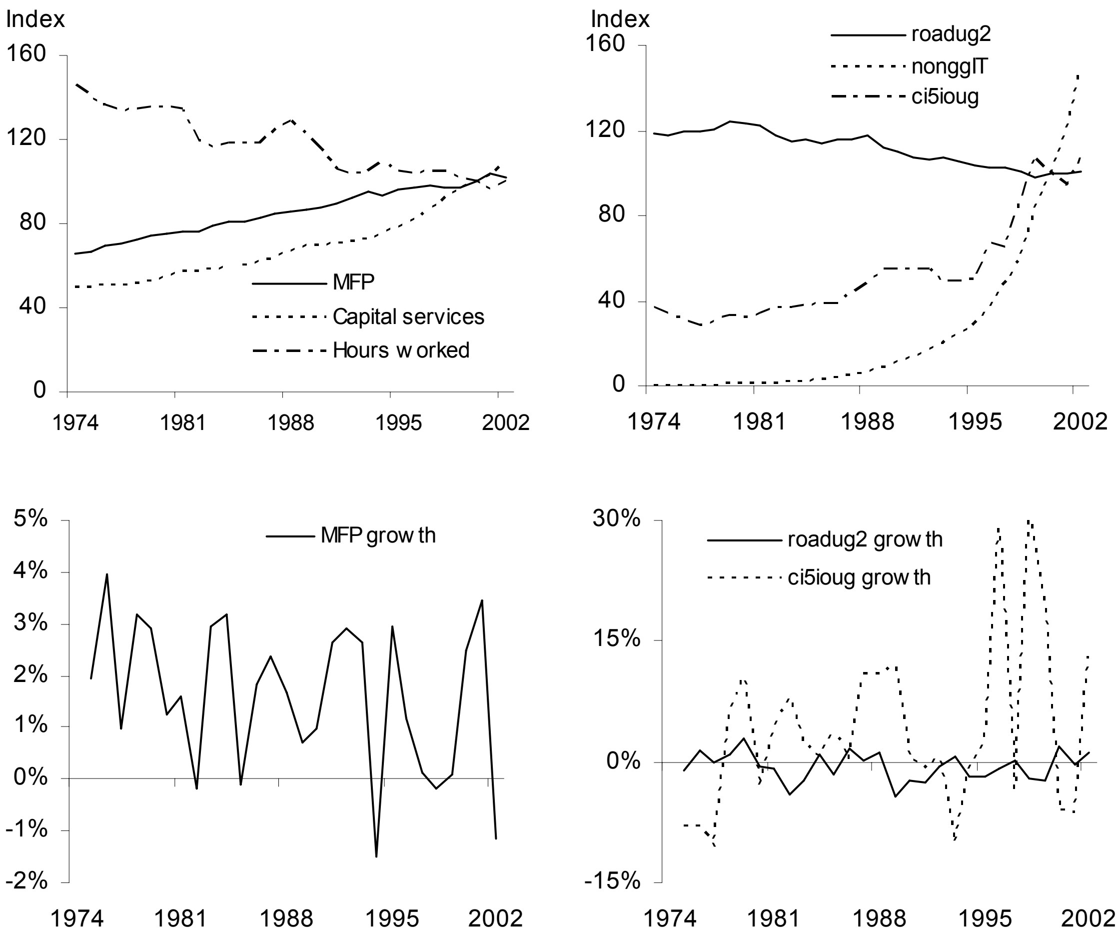
Source: Authors’ estimates.

F.3 Manufacturing (MAN)

Data description

Figure F.6 presents the trends in the main variables for Manufacturing. MFP and capital services have increased over the sample, while hours worked has declined. The service provided by usage-adjusted road infrastructure has declined. IT and communication infrastructure services increased strongly.

Figure F.6 **Trends in key variables for Manufacturing**
Index 2000-01 = 100; Percentage growth



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Results including road infrastructure

This section tests the effect of different measures of road infrastructure services on industry MFP under different specifications of the control variable set. Each initial variable set is specified as to be a plausible model for the explanation of industry MFP. The specification of the initial set of control variables can make a difference to whether the final model includes the key variables of interest or whether they test out.

There are insufficient observations to include all potential influences on manufacturing MFP for which there are data. A single test down procedure cannot be run. Therefore, a set of tests is undertaken.

The specification of the initial variable sets include a core set of explanatory variables in implementing a general-to-specific test down procedure. The core set includes road infrastructure ('roads' or 'roadug2'), communication infrastructure ('ci5ioug'), and private IT capital comprising computers and software ('nonggIT').

Regression results are tested for sensitivity to the inclusion or exclusion of combinations of a scale control, time trend, and control for the effect of the business cycle (denoted as models 'a' to 'f').

Control variables include industry own-financed R&D knowledge stock ('rown_o'), foreign business knowledge stock ('rfbteio'), inter-industry knowledge stock ('rext_t'), effective rates of assistance ('era'), energy prices ('dubai'), the number of working days lost due to industrial disputes ('disputes'), trade openness ('tiopente'), and an intercept.

The proportion of manufacturing employed with post-secondary school qualifications and the non-business knowledge stock were tested under various specifications, but their coefficients were always negative and, therefore, these variables were not included in the regressions which follow.

Road infrastructure with no usage adjustment

Table F.5 sets out the initial variable sets for regressions including 'roads' and 'ci5ioug' (models MAN1a to MAN1f).

Table F.5 **General-to-specific initial variable set for Manufacturing with 'roads'**

Model	*MAN1a*	*MAN1b*	*MAN1c*	*MAN1d*	*MAN1e*	*MAN1f*
roads	x	x	x	x	x	x
ci5	x	x	x	x	x	x
nonggIT	x	x	x	x	x	-
rown_o	x	x	x	x	x	x
rfbteio	x	x	x	x	x	x
rext_t	x	x	x	x	x	x
ToT	x	x	x	x	x	x
tiopente	x	x	x	x	x	x
dubai	x	x	x	x	x	-
intercept	x	x	x	x	x	x
trend	x	-	x	x	x	x
opgaph11 (fixed)	x	x	-	x	-	-
opgaph11	-	-	-	-	-	x
inpxadj2 [a]	x	x	x	-	-	x

[a] Combined input services index. Does not include road infrastructure, communication infrastructure, computers & software, or R&D capital. Significance of inpxadj2 sensitivity tested to separate scale controls for hours worked (hrs) and capital excluding road infrastructure and computers and software (otrcapi3).

Road infrastructure is highly significant in models MAN1b, MAN1c, MAN1e and MAN1f (table F.6). The signs on communication infrastructure and private IT capital are negative where they remain in the final model.

The main problems with these results are:

- the estimated economic magnitude of the coefficient on 'roads' is implausible
- the magnitude of the coefficient on 'inpxadj2' implies a failure of the CRS assumption that is far too large
- the bounds test generally does not provide a clear rejection of the null hypothesis that the variables do not form a long-run co-integrating relationship
- none of the models pass the forcing tests for all variables.

On the other hand, the suite of standard statistical tests do not suggest significant problems with the models, and the estimated coefficients on the control variables are of the expected signs and are estimated reasonably well.

The main purpose of showing the full set of results is to demonstrate that the choice of variables to include in the test procedure can influence final models.

Table F.6 **Effects on Manufacturing MFP with 'roads'**

Dependent variable is ln(MFP). Selected by SBC. Maximum lag equals one.

Lag order	*(1,1,0,0,1,0,1)*	*(1,1,0,0,0,1, 0,1)*	*(0,0,0,0,1,1)*	*(0,0,1,1,0,1, 0)*	*(0,0,1,1,1)*	*(0,1,1,1,0,0, 1,1)*
Model	*MAN1a*	*MAN1b*	*MAN1c*	*MAN1d*	*MAN1e*	*MAN1f*
roads	0.661	1.066 **	1.609 ***	-	0.647 ***	1.975 ***
	(0.483)	(0.431)	(0.433)		(0.182)	(0.294)
ci5ioug	-	-	-0.099 ***	-0.025	-0.098 ***	-0.094 ***
			(0.021)	(0.017)	(0.015)	(0.014)
nonggIT	-	-0.078 ***	-	-0.005	-	-
		(0.020)		(0.025)		
rown_o	0.062 **	0.051 **	0.074 ***	0.040 **	-	0.092 ***
	(0.026)	(0.020)	(0.025)	(0.016)		(0.016)
rfbteio	0.114 ***	0.176 ***	-	0.109 ***	-0.078	-
	(0.036)	(0.038)		(0.036)	(0.056)	
rext_t	0.132 *	0.133 **	-0.100	0.112 **	-	-0.176 ***
	(0.062)	(0.050)	(0.060)	(0.040)		(0.049)
ToT	0.177 **	0.188 ***	0.150 **	-	-	0.224 ***
	(0.066)	(0.055)	(0.058)			(0.038)
tiopente	0.191 ***	0.162 ***	-	-	-0.147 ***	0.072 *
	(0.057)	(0.043)			(0.045)	(0.034)
dubai	-	-	-	0.011	-	-
				(0.007)		
intercept	1.705	-0.509	-1.903	3.513 ***	2.421 ***	-3.144 ***
	(1.835)	(1.735)	(1.793)	(0.283)	(0.690)	(1.230)
time trend	-0.015 **	-	0.010 ***	0.000	0.021 ***	0.010 ***
	(0.005)		(0.004)	(0.005)	(0.002)	(0.003)
opgaph11	0.651 ***	0.587 ***	0.608 ***	0.256 ***	-	0.496 ***
	(0.140)	(0.105)	(0.143)	(0.053)		(0.083)
inpxadj2	-0.594 ***	-0.575 ***	-0.289 ***	-	-	-0.479 ***
	(0.148)	(0.117)	(0.080)			(0.056)
ECM(-1)	-0.651 ***	-0.682 ***	-	-	-	-
	(0.107)	(0.090)				

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Table F.6 **(continued)**

Model	*MAN1a*	*MAN1b*	*MAN1c*	*MAN1d*	*MAN1e*	*MAN1f*
Test statistics						
No. of observations	28	28	28	28	28	27
Time period	75-02	75-02	75-02	75-02	75-02	76-02
Step 1 test	2.944	4.036	2.083	0.695	0.442	3.895
Long run forcing?	No	No	No	No	No	No
R^2	0.999	0.999	0.997	0.999	0.997	0.999
Std. error of reg.	0.005	0.004	0.008	0.006	0.009	0.004
DW ‘d’ stat .	2.584	2.590	2.574	2.656	2.240	2.145
Durbin’s ‘h’ stat	-1.873	-1.772	-	-	-	-
	(0.061)	(0.076)				
Serial correlation	1.934	1.713	1.824	2.643	0.357	0.164
	(0.188)	(0.213)	(0.195)	(0.125)	(0.557)	(0.694)
Functional form	6.074	0.054	0.000	1.795	0.203	1.054
	(0.028)	(0.820)	(0.994)	(0.200)	(0.657)	(0.327)
Normality	3.820	2.112	0.410	0.388	0.043	0.984
	(0.148)	(0.348)	(0.814)	(0.824)	(0.979)	(0.611)
Hetero.	1.037	0.010	0.163	0.381	1.417	0.215
	(0.318)	(0.921)	(0.689)	(0.542)	(0.245)	(0.647)
AIC (SBC)	106(97)	110(101)	91(85)	98(90)	89(83)	106(96)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2.

Source: Authors’ estimates.

Road infrastructure adjusted by value added shares

The next set of regression results incorporate road infrastructure adjusted by value added shares ‘roadug2’. The initial variable sets are specified in table F.7.

Table F.7 **General-to-specific initial variable set for Manufacturing with ‘roadug2’**

Model	*MAN2a*	*MAN2b*	*MAN2c*	*MAN2d*	*MAN2e*	*MAN2f*
roadug2	x	x	x	x	x	x
ci5ioug	x	x	x	x	x	x
nongglT	x	x	x	x	x	-
rown_o	x	x	x	x	x	x
rfbteio	x	x	x	x	x	x
rext_t	x	x	x	x	x	x
era	x	x	x	x	x	x
dubai	x	x	x	x	x	x
disputes	x	x	x	x	x	x
intercept	x	x	x	x	x	x
trend	x	-	x	x	x	x
opgaph11 (fixed)	x	x	-	x	-	-
opgaph11	-	-	-	-	-	x
inpxadj2[a]	x	x	x	-	-	x

[a] Combined input services index. Does not include road infrastructure, communication infrastructure, computers & software, or R&D capital.

Usage-adjusted road infrastructure is economically very significant in explaining manufacturing MFP in models MAN2a to MAN2c and to MAN2f (table F.8). It tests out of models MAN2d and MAN2e that do not include the scale control variable ‘inpxadj2’.

However, ‘roadug2’ strongly fails the forcing test for each model where it survived a test down procedure. Therefore, little confidence can be taken from the estimated magnitude of the effect of roads on productivity as the forcing tests calls into question the direction of causation. The usage adjustment drives any apparent significance. In the case of manufacturing, non-usage adjusted road infrastructure is also highly significant in some models, but, again, road infrastructure failed the forcing tests.

Communication infrastructure is insignificant in these tests. The R&D variables are significant and signed as expected. The scale control variable suggests decreasing returns to scale.

Table F.8 **Effects on Manufacturing MFP with 'roadug2'**

Dependent variable is ln(MFP). Selected by SBC. Maximum lag equals one.

Lag order	*(0,1,0,0,0,1, 1,0)*	*(0,0,0,0,0,1, 1,0,0)*	*(0,0,0,1,0,1, 0,0)*	*(0,0,0,0,0,1, 1,1)*	*(0,0,0,0,1,0, 0,0)*	*(0,1,0,1,0,0, 1,0,1,0)*
Model	*MAN2a*	*MAN2b*	*MAN2c*	*MAN2d*	*MAN2e*	*MAN2f*
roadug2	0.498 ***	0.344 ***	0.543 ***	-	-	0.278 **
	(0.104)	(0.106)	(0.173)			(0.106)
ci5ioug	-	-0.006	-0.000	-0.020	-	-0.018
		(0.011)	(0.023)	(0.015)		(0.013)
nonggIT	-0.057 ***	-	-	-0.047	-0.108 ***	-
	(0.019)			(0.032)	(0.037)	
rown_o	0.075 ***	0.088 ***	0.079 ***	0.065 ***	0.093 ***	0.101 ***
	(0.013)	(0.017)	(0.025)	(0.021)	(0.028)	(0.023)
rfbteio	0.147 ***	0.136 ***	0.117 ***	0.134 ***	0.221 ***	0.142 ***
	(0.023)	(0.014)	(0.041)	(0.040)	(0.046)	(0.022)
rext_t	0.093 ***	0.098 ***	0.079	0.126 ***	0.226 ***	0.156 ***
	(0.027)	(0.011)	(0.051)	(0.044)	(0.049)	(0.038)
era	0.043	0.033 ***	-	0.056 ***	0.089 ***	0.029 *
	(0.012)	(0.010)		(0.019)	(0.022)	(0.013)
dubai	0.007	0.014 ***	0.012	0.019 **	0.024 **	0.022 ***
	(0.004)	(0.004)	(0.010)	(0.007)	(0.010)	(0.007)
disputes	-	-0.006 **	-0.006	-	-0.008 *	-0.004
		(0.003)	(0.005)		(0.005)	(0.003)
intercept	1.743 ***	2.510 ***	2.111 ***	2.706 ***	1.690 ***	2.924 ***
	(0.413)	(0.414)	(0.642)	(0.464)	(0.455)	(0.470)
time trend	0.017 ***	-	0.001	0.012 *	0.015	-0.006
	(0.004)		(0.007)	(0.007)	(0.010)	(0.005)
opgaph11	0.292 ***	0.239 ***	-	0.257 ***	-	0.389 ***
	(0.048)	(0.044)		(0.054)		(0.083)
inpxadj2	-0.300 ***	-0.240 ***	-0.287 ***	-	-	-0.293 ***
	(0.050)	(0.056)	(0.097)			(0.566)
Test statistics						
No. of observations	28	28	28	28	28	27
Time period	75-02	75-02	75-02	75-02	75-02	76-02
Step 1 test	2.073	6.495	3.947	5.999	6.924	5.331
Long run forcing?	No[a]	No[b]	No[c]	No[d]	No[e]	No[f]
R^2	0.999	0.999	0.998	0.999	0.998	0.999
Std. error of reg.	0.004	0.004	0.008	0.006	0.008	0.004
DW 'd' stat .	2.781	2.329	2.623	2.627	2.496	2.799
Serial correlation	3.121	0.550	1.940	2.516	1.460	2.784
	(0.101)	(0.470)	(0.184)	(0.135)	(0.243)	(0.126)
Functional form	0.074	3.198	1.820	0.528	0.210	0.032
	(0.790)	(0.095)	(0.197)	(0.479)	(0.653)	(0.862)

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Table F.8 **(continued)**

Lag order	*(0,1,0,0,0,1, 1,0)*	*(0,0,0,0,0,1, 1,0,0)*	*(0,0,0,1,0,1, 0,0)*	*(0,0,0,0,0,1, 1,1)*	*(0,0,0,0,1,0, 0,0)*	*(0,1,0,1,0,0, 1,0,1,0)*
Model	*MAN2a*	*MAN2b*	*MAN2c*	*MAN2d*	*MAN2e*	*MAN2f*
Normality	0.158	1.101	2.216	0.864	0.740	1.210
	(0.924)	(0.577)	(0.330)	(0.649)	(0.691)	(0.546)
Hetero.	0.006	0.019	1.845	0.035	0.346	0.014
	(0.939)	(0.891)	(0.186)	(0.852)	(0.561)	(0.906)
AIC (SBC)	112(103)	108(99)	92(84)	100(92)	90(84)	106(95)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. **a** F-statistics for roadug2, rext_t and dubai of 6.511, 4.843 and 9.923, respectively. **b** F-statistics for roadug2, ci5ioug, rown_o, era and dubai of 4.441, 5.116, 5.032, 4.294 and 6.491, respectively. **c** F-statistics for roadug2 and dubai of 12.591 and 8.689, respectively. **d** F-statistics for rext_t, era and dubai of 5.452, 6.454 and 4.504, respectively. **e** F-statistic for era of 6.804. **f** F-statistics for opgaph11, roadug2, era and dubai of 13.484, 7.790, 10.819 and 4.072, respectively.

Source: Authors' estimates.

Increased maximum lags and the effect of digitisation

This section presents results from two types of tests: specification of a higher order autoregressive distributed lag (ARDL) with a necessitated reduction in the scope of the control variables (models MAN3a to MAN3c); and tests of time varying effects related to digitisation (models MAN4a to MAN4c). The initial variable sets are presented in table F.9.

Like the previous tests, while the specification of the initial variable sets are all reasonable specifications of a potential model explaining manufacturing MFP, none of the eventual models are fully satisfactory.

Table F.9 **Variable sets for Manufacturing with 'roads'**

Model	*MAN3a*	*MAN3b*	*MAN3c*	*MAN4a*	*MAN4b*	*MAN4c*
roads	x	x	x	-	-	x
ci5ioug	x	x	x	x	x	-
nonggIT	x	x	x	x	x	x
ITdigi[b]	-	-	-	x	x	x
rown_o (t)	x	x	x	x	x	-
rown_o (t-1)	-	-	-	-	-	x
rfbtdioch	-	-	-	x	x	x
rext_t	-	-	-	x	x	-
era	x	x	x	x	x	x
intercept	x	x	x	x	x	x
trend	x	-	x	x	x	x
opgaph11	x	x	-	x	x	x
inpxadj2[a]	x	-	-	x	x	x
hrs	-	x	-	-	-	-

[a] Combined input services index. Does not include road infrastructure, communication infrastructure, computers and software, or an estimate of R&D capital. [b] For Manufacturing a smoothed version of this variable was used, where a smooth increase in 'digi' up to 1990 (where data are available) is assumed (rather than 0 prior to 1990).

Additional dynamics, but fewer controls

Road infrastructure is highly significant in models MAN3a to MAN3c that were specified as ARDL(2,2) models (table F.10). Communication infrastructure is negative signed in all three models, while private IT capital is positive and highly significant. A coefficient of 0.03 for own-industry R&D represents a gross rate of return of roughly 20 to 25 per cent. Industry protection is signed as expected — unlike some of the earlier results.

The bounds test rejects the null of no long-run relationship for each model. However, various variables fail the forcing tests. The models are statistically acceptable in other respects, although the degree of negative serial correlation in model MAN3c could be of concern.

Table F.10 **Increased lags and digitisation**

Dependent variable is ln(MFP). Selected by SBC.

Lag order	*(0,0,0,0,0,2)*	*(0,0,0,0,0,2)*	*(1,0,0,2,0,2)*	*(0,1,0,1,1,1,0, 0,0)*	*(0,0,0,0,1,1)*	*(0,0,2,1,2)*
Model	*MAN3a*	*MAN3b*	*MAN3c*	*MAN4a*	*MAN4b*	*MAN4c*
roads	0.577 ***	0.707 ***	0.550 ***	-	-	-
	(0.213)	(0.202)	(0.189)			
ci5ioug	-0.086 ***	-0.101 ***	-0.086 ***	0.080 **	-	-
	(0.015)	(0.014)	(0.013)	(0.034)		
nonggIT	0.089 ***	0.106 ***	0.129 ***	-0.077 **	0.021 *	0.040 ***
	(0.019)	(0.018)	(0.022)	(0.032)	(0.011)	(0.005)
ITdigi[g]	-	-	-	-0.042 ***	-0.015 ***	-0.042 **
				(0.008)	(0.003)	(0.018)
rown_o	0.027	0.033 **	0.031 *	-	0.047 ***	-
	(0.015)	(0.014)	(0.016)		(0.012)	
rfbtdioch	-	-	-	0.542 ***	0.193 ***	0.139 ***
				(0.107)	(0.054)	(0.049)
rext_t	-	-	-	0.206 ***	0.071 **	-
				(0.047)	(0.032)	
manedu	-	-	-	0.292 **	-	-
				(0.104)		
era	-0.054 **	-0.059 ***	-0.070 ***	-0.057 **	-	-0.137 ***
	(0.020)	(0.018)	(0.020)	(0.026)		(0.066)
ToT	-	-	-	0.180 ***	-	-
				(0.040)		
intercept	3.198 ***	2.751 ***	2.908 ***	3.215 ***	4.952 ***	6.180 ***
	(0.762)	(0.710)	(0.714)	(0.702)	(0.238)	(0.519)
time trend	-0.013 *	-0.020 ***	-0.025 ***	-	-	-
	(0.007)	(0.007)	(0.008)			
opgaph11	0.359 ***	0.384 ***	0.275 ***	0.413 ***	0.371 ***	0.428 ***
	(0.053)	(0.048)	(0.052)	(0.052)	(0.067)	(0.064)
inpxadj2	-0.157 ***	-	-	-0.396 ***	-0.237 ***	-0.232 ***
	(0.046)			(0.063)	(0.047)	(0.047)
hrs	-	-0.139 ***	-	-	-	-
		(0.032)				
ECM(-1)	-	-	-1.173 ***	-	-	-
			(0.128)			
Test statistics						
No. of observations	27	27	27	27	28	27
Time period	76-02	76-02	76-02	76-02	75-02	76-02
Step 1 test	5.640	4.877	5.038	4.243	5.481	4.674
Long run forcing?	No[a]	No[b]	No[c]	No[d]	No[e]	No[f]
R^2	0.999	0.999	0.999	0.999	0.998	0.998
Std. error of reg.	0.005	0.005	0.005	0.005	0.007	0.007
DW ‘d’ stat .	2.279	2.359	2.772	2.463	2.189	2.368
Serial correlation	0.356	0.648	4.261	1.722	0.235	0.631
	(0.560)	(0.433)	(0.060)	(0.216)	(0.634)	(0.440)

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Table F.10 **(continued)**

Lag order	*(0,0,0,0,0,2)*	*(0,0,0,0,0,2)*	*(1,0,0,2,0,2)*	*(0,1,0,1, 1,1,0,0)*	*(0,0,0,0,1,1)*	*(0,0,2,1,2)*
Model	*MAN3a*	*MAN3b*	*MAN3c*	*MAN4a*	*MAN4b*	*MAN4c*
Functional form	1.862	0.492	0.797	0.057	0.067	0.371
	(0.193)	(0.494)	(0.388)	(0.815)	(0.799)	(0.552)
Normality	0.373	0.810	1.356	1.001	2.245	0.513
	(0.830)	(0.667)	(0.508)	(0.606)	(0.326)	(0.774)
Hetero.	1.916	0.322	0.441	1.838	0.999	2.979
	(0.179)	(0.576)	(0.512)	(0.187)	(0.327)	(0.097)
AIC (SBC)	98(91)	101(94)	98(90)	103(93)	95(89)	94(86)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistics for rown_o and era of 4.944 and 4.156, respectively. [b] F-statistics for rown_o and era of 6.344 and 4.036, respectively. [c] F-statistics for nonggIT, rown_o and era of 5.175, 7.242 and 4.654, respectively. [d] F-statistics for rfbtdioch, era and ToT of 3.913, 5.360 and 5.651, respectively. [e] F-statistics for ITdigi, rfbtdioch and rext_t of 5.147, 3.892 and 4.059, respectively. [f] F-statistic for ITdigi of 9.385. [g] For Manufacturing a smoothed version of this variable was used, where a smooth increase in 'digi' up to 1990 (where data are available) is assumed (rather than 0 prior to 1990).

Source: Authors' estimates.

Conditioned time varying effects of infrastructure

Models MAN4a to MAN4c test whether the effect of IT capital is partly dependent on the digitisation of the telecommunications network. Market sector results found evidence that the effect of IT capital did depend on digitisation. Road infrastructure is included in the initial variable set of model MAN4c only, although it tests out. Model 4c also includes own-industry R&D lagged one period in the initial variable set as it fails the forcing tests in models MAN4a and MAN4b. The primary communication infrastructure variable was intentionally excluded from the test procedure for model MAN4c and the model was specified as an ARDL(2,2) model. The model does allow for a potential effect of communication infrastructure through digitisation of the copper network in conjunction with IT capital.

The effect of 'ITdigi' is negative and significant in each of the models. In other respects, the models differ substantially. Communication infrastructure has a positive and economically and statistically significant effect in model MAN4a, but it tests out of model MAN4b. In model MAN4a, IT capital is negative, but it is positive in MAN4b and MAN4c. All of the control variables are signed as expected and are significant, but they suggest that quite different models can be used to explain industry MFP.

The bounds test rejects the null of no long-run relationship for each model. However, no model clearly passes all forcing tests, but are statistically acceptable in other respects. Information criteria select model MAN4a as the best fitting model.

Other tests were undertaken incorporating a relationship between digitisation and the industry's private conventional capital 'otrcapdg'. Various specifications did not produce a significant result.

Alternative construction for digitisation and estimation strategies

The motivation for the first two tests of this section were as follows.

- *Model MAN5a*: to test the same construction of 'ITdigi' as used in most industry tests; that is, to assume that in 1989 the proportion of digitised lines was zero. The variables 'ci5ioug', and 'manedu' tested out of the model.
- *Model MAN5b*: in model MAN5a, terms of trade very strongly failed the forcing test, so the test was re-run without it. This resulted in industry protection testing out. The variables 'ci5ioug', and 'manedu' also tested out of this model.

These models provide some evidence of a positive impact of IT capital. However, the effect in the 1990s is declining (a negative coefficient on 'ITdigi'). Communications infrastructure is not significant in either model. The R&D variables are signed as expected, are of reasonable magnitudes and are estimated well. A point estimate of 0.048 implies a gross return to industry R&D of roughly 30 to 35 per cent.

The null hypothesis of no long-run co-integrating relationship is rejected for both models. Overall, model MAN5b is a decent model (table F.11), but with a number of the forcing tests indeterminate.

A number of alternative estimation strategies were tested to see if the results of model MAN5b could be supported. Model MAN6 was estimated using OLS with a residual-based co-integration test (table F.11). The same set of variables were included, but the tested down model is very different. Fully modified ordinary least squares (FMOLS) estimation produced the same tested down model as model MAN6 and nearly equivalent results. DOLS estimation resulted in the coefficient on industry protection being substantially more negative and significant, but otherwise very similar results.

Table F.11 **Tests of an alternative construction for 'ITdigi' and estimation strategies**

Dependent variable is ln(MFP). Selected by SBC.

Lag order	*(0,0,0,1,1,1,0,0)*	*(0,0,0,0,1,1,)*	*OLS*
Model	*MAN5a*	*MAN5b*	*MAN6*
ci5ioug	-	-	-0.046 ***
			(0.014)
nonggIT	0.011	0.019 *	0.060 ***
	(0.008)	(0.010)	(0.003)
ITdigi	-0.020 ***	-0.014 ***	-0.013 **
	(0.006)	(0.003)	(0.005)
rown_o	0.027 *	0.048 ***	-
	(0.014)	(0.012)	
rfbtdioch	0.287 ***	0.202 ***	-
	(0.056)	(0.053)	
rext_t	0.065 **	0.069 **	-
	(0.023)	(0.031)	
era	-0.035 *	-	-0.055 ***
	(0.018)		(0.018)
ToT	0.111 ***	-	-
	(0.031)		
intercept	5.175 ***	5.064 ***	5.489 ***
	(0.246)	(0.227)	(0.247)
opgaph11	0.392 ***	0.380 ***	0.320 ***
	(0.052)	(0.065)	(0.061)
inpxadj2	-0.342 ***	-0.261 ***	-0.138 **
	(0.047)	(0.046)	(0.050)
Test statistics			
No. of observations	28	28	28
Time period	75-76 to 02-03	75-76 to 02-03	75-76 to 02-03
Step 1 test	7.445	7.388	na
Long run forcing?	No[a]	?[b]	na
R^2	0.999	0.998	0.998
Std. error of reg.	0.005	0.007	0.007
DW 'd' stat .	2.803	2.181	2.271
Serial correlation	4.755	0.202	0.489
	(0.047)	(0.659)	(0.493)
Functional form	0.221	0.247	1.994
	(0.646)	(0.625)	(0.173)
Normality	0.679	2.065	0.177
	(0.712)	(0.356)	(0.915)
Hetero.	0.001	0.349	0.149
	(0.979)	(0.560)	(0.702)
AIC (SBC)	104(96)	96(90)	96(91)
ADF co-integration test			-5.206[c]

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistics for ITdigi2, rfbtdioch and tot of 4.5, 4.2 and 19.4, respectively. [b] F-statistics for ITdigi, rfbtdioch, and rext_t indeterminate at 3.7, 4.1 and 3.3, respectively. [c] Presence of unit root rejected.

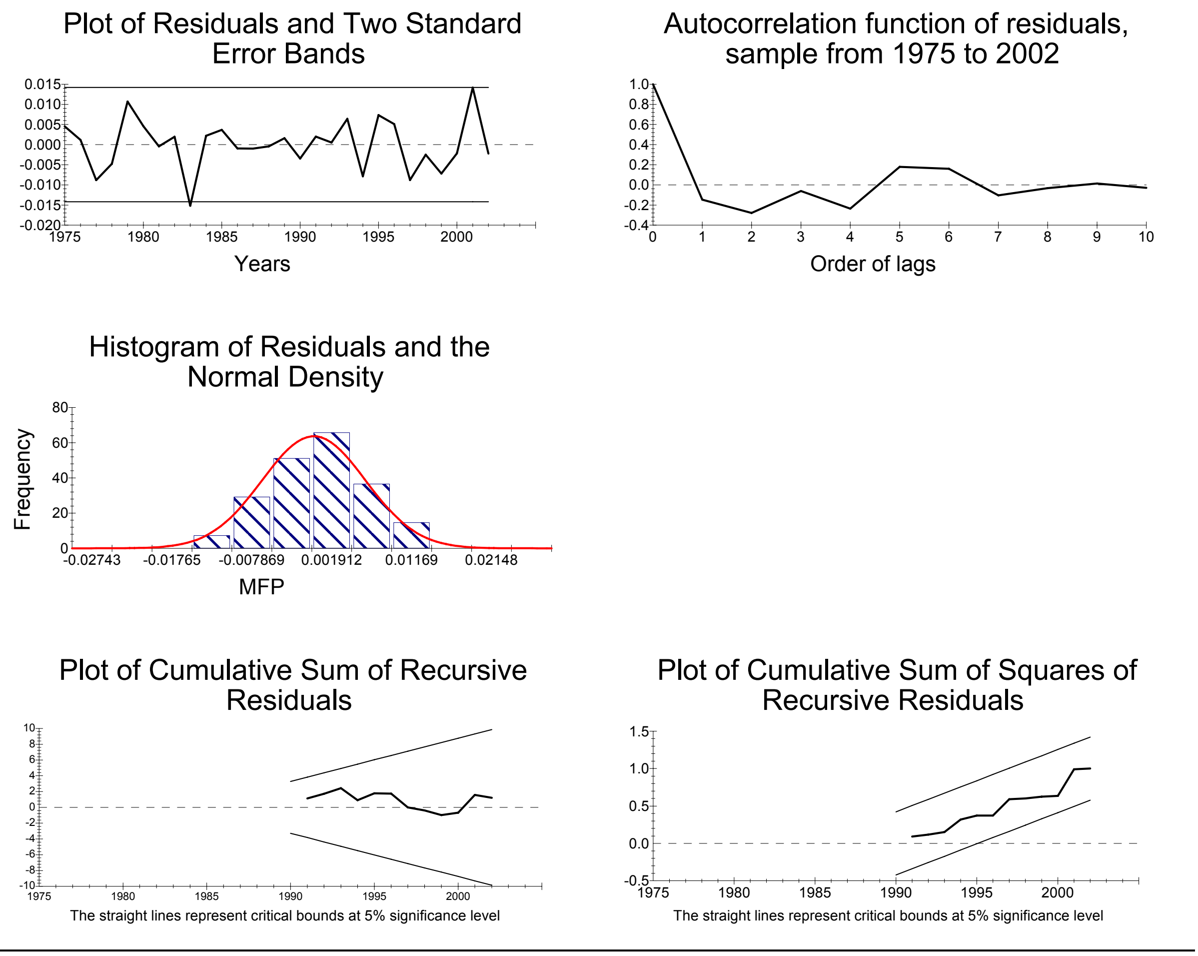
Source: Authors' estimates.

The negative coefficient on communication infrastructure only occurs with the inclusion of the input-output usage adjustment (‘ci5ioug’). When no usage adjustment is applied, communication infrastructure tests out of the models (the signs, magnitudes and statistical significance of the other variables are largely unaffected).

These final tests support a positive excess effect of IT capital, but do not support a positive effect of communication infrastructure or digitisation.

The residuals of model MAN6 and stability of the model are acceptable (figure F.7).

Figure F.7 **Post-estimation tests for model MAN6**



Data source: Authors’ estimates.

Summary

A positive effect of IT capital

A number of different models provide support for a positive effect of IT capital, and these are the models considered to be the better models. However, these models do not support a positive effect of communication infrastructure or digitisation (in conjunction with either the industry's other capital or IT capital).

More than one co-integrating vector?

While the results provide insights into some of the factors that have influenced manufacturing MFP, no single model is fully satisfactory.

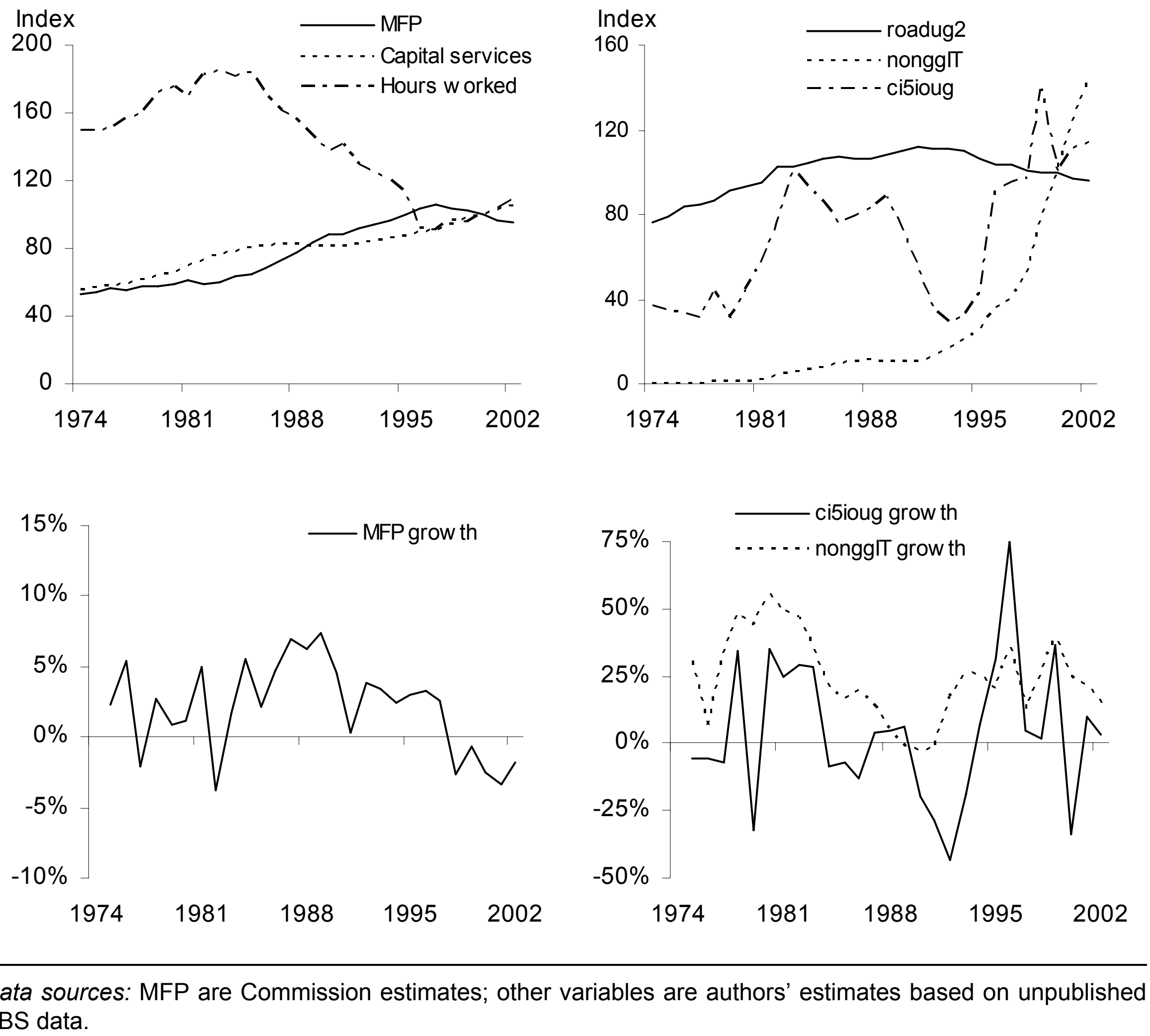
One possible reason for this may be a failure of the assumption of a single co-integrating vector. The ARDL approach to co-integration analysis has the advantage that variables can be I(0), I(1) or a mixture. This is useful because unit root testing often does not give a definitive indication of the order of integration, and alternative estimation methods crucially rely on the analyst knowing the time series properties of the data. However, as discussed in appendix J, the method does assume the existence of a single co-integrating vector. A VAR(ECM) modelling framework might be useful in future work.

F.4 Electricity, gas & water (EGW)

Data description

Figure F.8 presents the trends in the main variables for Electricity, gas & water. Hours worked declined sharply from the mid-1980s. Private IT capital and communication infrastructure services have grown strongly with substantial variation in growth rates.

Figure F.8 **Trends in key variables for Electricity, gas & water**
Index 2000-01 = 100; Percentage growth



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Results

Initial results

The first test includes a maximum allowable lag of three periods (model EGW1 of table F.12). The short-run effect of 'roadug2' in the ECM is highly negative (not shown), but the long-run coefficient is positive and extremely economically significant.

However, model EGW1 is strongly rejected. The economical and statistical significance of road infrastructure is dependent on both the usage adjustment and the specification of an ARDL order of at least (2,2). This means that there are fewer controls in the test procedure, and the ones that survive strongly fail the forcing tests. The bounds test does not reject the null hypothesis that the variables do not form a long-run relationship. The ECM term is not significant also indicating the absence of a co-integrating long-run relationship. Alternative cycle controls were not significant. The statistical significance of the results were sensitive to the inclusion of a trend term.

The test procedure for model EGW2 reduced the maximum lag to one and increased the number of controls. The test procedure successively tested the effects of the infrastructure variables 'I3', 'I3ug2', 'roads' and 'roadug2'. Each was highly insignificant.

The model provides support for a positive and significant effect of communication infrastructure and a small negative effect of private IT capital. An interaction term between communication infrastructure and IT capital was insignificant, as were slope shift terms for IT capital.

The control for changes in human capital 'QALI' was not statistically significant. Dropping it has only a very small effect on the model (model EGW3).

Results for models EGW2 and EGW3 are sensitive to the inclusion of the two trend shifts at 1984 ('trnd1984') and 1995 ('trnd1995'). Trend terms are often included in regressions to control for unexplained influences on output. The positive coefficient between 1984 and 1995 is likely to be picking up the substantial reforms undertaken in this industry, including regulatory, governance and ownership of government business enterprises.

Table F.12 **Effects on Electricity, gas & water MFP**

Dependent variable is ln(MFP). Selected by SBC.

Lag order	*(1,2,0,0)*	*(0,0,0,0,1,1,1)*	*(0,0,0,1,1,1)*	*(0,0,0,0,0)*	*First differenced*
Model	*EGW1*	*EGW2*[a]	*EGW3*	*EGW4*	*EGW5*
roadug2	2.264 ** (1.013)	-	-	-	-
otrcapdg	-	-	-	0.157 *** (0.012)	-
ci5ioug	0.122 (0.085)	0.073 *** (0.012)	0.083 *** (0.010)	0.017 (0.015)	0.033 ** (0.013)
ITdigi	-	-	-	-0.176 *** (0.017)	-
nonggIT	-0.237 ** (0.087)	-0.018 *** (0.005)	-0.015 *** (0.005)	-	-0.099 *** (0.021)
QALI	-	0.208 (0.126)	-	0.908 *** (0.180)	0.356 ** (0.170)
era	-	-0.080 *** (0.025)	-0.057 ** (0.022)	-	-
centbrg	-	0.019 * (0.010)	0.023 ** (0.010)	-	-0.037 *** (0.013)
disputes	-	0.035 *** (0.008)	0.038 *** (0.008)	-	-
intercept	-6.763 (4.485)	3.053 *** (0.440)	3.715 *** (0.190)	0.116 (0.725)	0.043 *** (0.007)
trend	0.038 * (0.021)	-	-	-	-
trnd1984	-	0.050 *** (0.005)	0.056 *** (0.003)	0.018 *** (0.006)	-
trnd1995	-	-0.070 *** (0.005)	-0.073 *** (0.005)	-	-0.011 *** (0.002)
opgaph11	-	-	-	-	0.472 *** (0.131)
ECM(-1)	-0.198 (0.116)	-	-	-	-
Test statistics					
No. of observations	26	28	28	28	27
Time period	77-02	75-02	75-02	75-02	76-02
Step 1 test	2.773	5.740	4.864	10.116	-
Long run forcing?	No[b]	No[c]	No[d]	Yes	-
R^2	0.996	0.999	0.999	0.996	0.850
Std. error of reg.	0.017	0.010	0.011	0.017	0.015
DW ‘d’ stat .	2.113	2.544	2.374	1.934	2.247
Durbin’s ‘h’ stat.	-0.357 (0.721)	-	-	-	-

(continued on next page)

Table F.12 **(continued)**

Lag order	*(1,2,0,0)*	*(0,0,0,0,1,1,1)*	*(0,0,0,1,1,1)*	*(0,0,0,0,0)*	*First differenced*
Model	*EGW1*	*EGW2*[a]	*EGW3*	*EGW4*	*EGW5*
Serial correlation	0.117 (0.737)	1.713 (0.210)	0.742 (0.402)	0.008 (0.929)	0.866 (0.364)
Functional form	0.791 (0.386)	0.225 (0.642)	0.001 (0.979)	0.817 (0.376)	0.250 (0.623)
Normality	0.220 (0.896)	0.984 (0.612)	1.312 (0.519)	0.434 (0.805)	0.741 (0.690)
Hetero.	1.831 (0.189)	0.009 (0.924)	0.008 (0.929)	0.138 (0.713)	4.589 (0.042)
AIC (SBC)	66(61)	84(76)	83(76)	72(68)	72(67)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] Variables that tested out were roadug2/l3ug2/roads, ITdigi, and otrcapdg. If slope shifts on nonggIT were included in the test procedure, they also tested out. Results were not sensitive to the dropping of opgaph11. [b] F-statistics for nonggIT and ci5ioug of 8.175 and 12.882, respectively. [c] F-statistics for nonggIT and disputes of 8.266 and 4.934, respectively. [d] F-statistics for nonggIT and disputes of 7.182 and 4.019, respectively.

Source: Authors' estimates.

The reforms had positive static efficiency effects, but were also expected to have positive dynamic efficiency effects, such as through regulatory reforms putting in place the institutions for market development, and increased pressures for good performance resulting in innovation.

The negative coefficient post-1995 offsets the 1984 shift and suggests that the identified variables in the model provide an adequate explanation of MFP.

It should be noted that the 'disputes' variable is based on economywide industrial disputes and not industry-specific disputes — a separate time series for EGW was not available from official ABS collections. Possible interpretations of the positive coefficient on industrial disputes are discussed in section F.5 on the construction industry.

An increasing capital share

Additional terms were entered into the test procedures above to allow the elasticity/income shares on total capital services 'ksrv' and labour inputs 'hrs' to change. The terms were economically and statistically insignificant.

A simpler model that passes all tests

While the bounds test rejects the null of no long-run relationship, the forcing tests for 'nonggIT' and 'disputes' fail in both models EGW2 and EGW3. They also failed under various other specifications that produced similar results to these models.

Dropping 'nonggIT' and 'disputes' from the initial variable set and re-testing down gives model EGW4. The selected model is a static model as it does not include any lags in the regressors or a lagged dependent variable. The variables that tested out were 'trend', 'trnd1995', 'era' and 'centbrg'.

The bounds test for model EGW4 strongly rejects the null of no long-run relationship and the forcing tests all pass. The statistical properties of the model are acceptable.

The model points towards a positive effect of the digitisation of the copper network on the marginal product of the industry's private conventional or 'other' capital. However, the effect of IT capital conditioned on digitisation is negative. The coefficient on communication infrastructure is positive, but estimated poorly with confidence intervals easily taking in an elasticity not significantly different from zero. The model also points to a very large positive effect of increases in human capital in the market sector.

There are a number of concerns with this model. The estimates for 'otrcapdg' and 'ITdigi' are possibly estimated 'too' precisely. It seems unlikely that any model specification for EGW would ever be able to estimate the effects of these variables so precisely, given the aggregation of sub-industries and the known major changes in the industry. The model is sensitive to the inclusion of both variables. If either is dropped, the remaining variable is not statistically significant, nor are the other variables in the model.

Another concern is the strength of the estimated effect of increases in human capital in the market sector 'QALI'. The mechanisms that would drive such a result are not immediately obvious. It is possible that industry-specific human capital changes are highly correlated with the broader market sector, and that changes in EGW human capital have in fact had a very substantial impact on industry productivity. However, when an industry-specific educational attainment variable was included in the test procedures, the sign on the variable was always negative (statistical significance depended on the particular model specification).

The 'QALI' attempts to take into account changes in human capital beyond those reflected by changes in educational attainment measured as the proportion of those employed with post-secondary school qualifications. The data that goes into the market sector measure is probably also of significantly better quality than the industry-specific educational attainment measure that was constructed for this study.

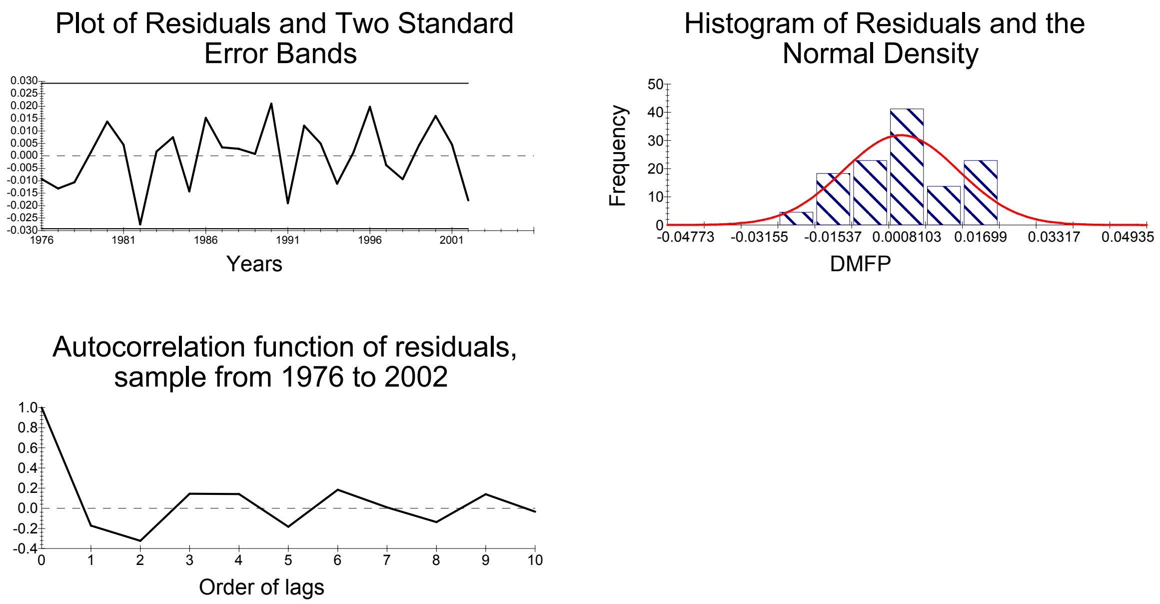
It could be that there is substantial industry investment in training that is not reflected in the educational attainment data based on qualifications.

A reasonable model from first differencing

First differencing produces results that do not support an effect of digitisation on either private conventional capital or IT capital (model EGW5). The effect of communication infrastructure is positive and significant, consistent with models EGW1 to EGW3. IT capital is estimated to have had a negative effect on industry productivity. The test down procedure included IT capital slope shifts at 1986 and 1995, as well as the variables ‘otrcapdg’, ‘ITdigi’, ‘era’, ‘roads’, and ‘trnd1984’.

A general-to-specific procedure resulted in a statistically acceptable model (see the statistical tests in the table and the tests in figure F.9) that produced coefficient magnitudes and signs that are plausible. There is an ‘uncontrolled for’ decline in the industry productivity growth rate from 1995. The estimated magnitude of the effect of ‘QALI’ is more in line with market sector estimates and the estimates for some other industries.

Figure F.9 **Post-estimation tests for model EGW5**



Data source: Authors’ estimates.

Summary

The results do not shed any light on the significance of the potential excess and free input effect of road infrastructure on industry productivity.

The results point towards a positive excess effect of communication infrastructure and a negative effect of IT capital.

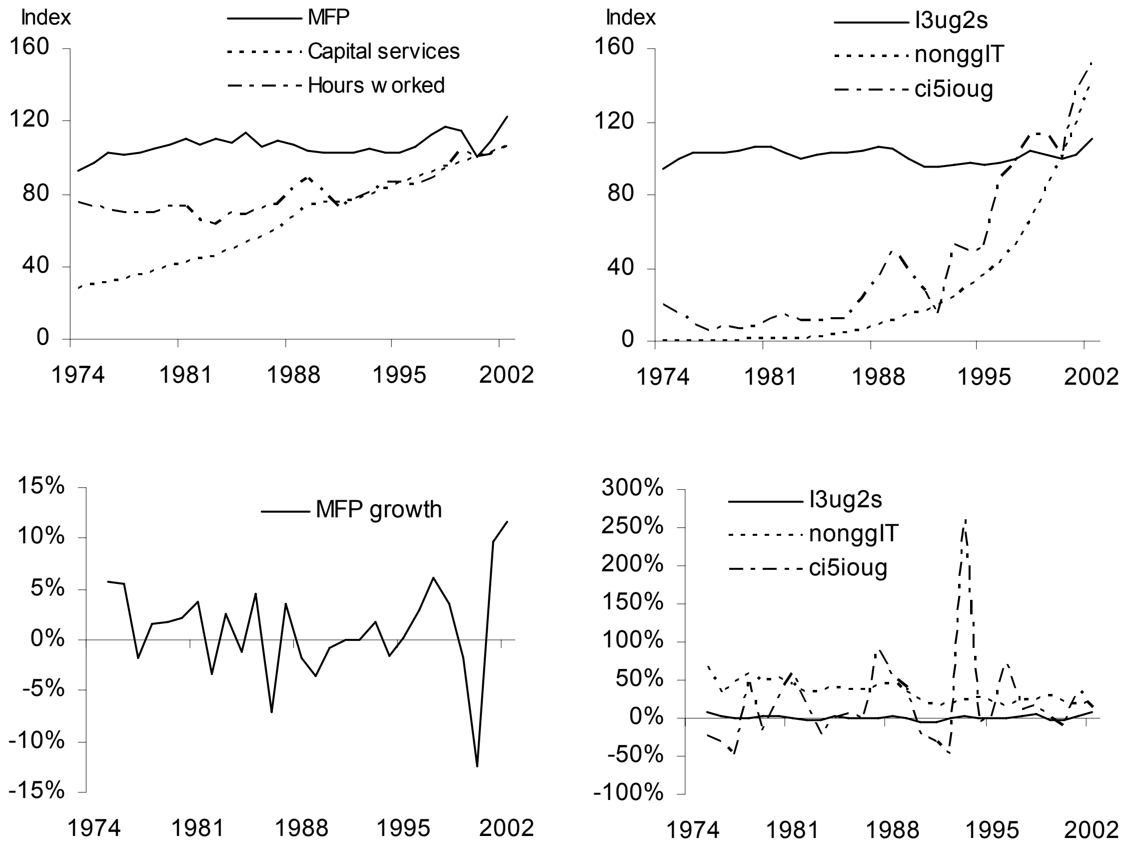
While there is some evidence of digitisation having impacts on the industry in conjunction with other forms of capital from model EGW4, and this model passes both the bounds and forcing tests and is statistically acceptable in other respects, the evidence is not considered robust.

F.5 Construction (CON)

Data description

Figure F.10 presents the trends in the main variables for Construction. Compared with other industries, growth in MFP over the period has been weak. Capital services has increased much more rapidly than hours worked. IT capital and communication infrastructure services have grown strongly.

Figure F.10 **Trends in key variables for Construction**
Index 2000-01 = 100; Percentage growth



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Results

The regression results in this section do not include either general government or road infrastructure. Tests of these variables resulted in the same unrealistically large or insignificant coefficients as for other industries. Therefore the tests below focus on other infrastructure variables.

The first two models (models CON1 and CON2) are the result of general-to-specific test down procedures (table F.13). The variables 'otrcapdg' or 'ksrvdg', 'ci5ioug', 'centbrg', 'ci5iodg' and a linear trend tested out of model CON1. The variables 'union', 'ci5ioug', 'otrcapdg', 'ITdigi', and 'nonggIT' tested out of model CON2. A time trend was not included in the initial variable set for model CON2.

Model CON3 uses the three key surviving explanatory variables of models CON1 and CON2, but richer dynamics were allowed for by increasing the maximum lag length to two periods. Other variables were not included in the test procedure. The test procedure was also run with the cycle variable 'opgaph11', but the use of 'ACCI' produced a better model. Both the SBC and AIC produced the same lag order of (0,0,2,0).

The tests produce acceptable results

The models all pass the bounds test indicating that the variables form long-run co-integrating relationships for the explanation of MFP. Only model CON3 does not clearly pass the forcing tests with the test for 'ITdigi' being indeterminate.

The coefficient on 'ITdigi' is positive and significant in both models CON1 and CON3. The effect of IT capital on the industry's productivity appears to have been enhanced by the digitisation of the copper network.

Industrial disputes is positive and significant in all models. One explanation for this is that Australian strikes have tended to be relatively short. For example, between 1988 and 1999 around 60 to 90 per cent of working days lost were in disputes of less than 5 days (ABS Cat. no. 6322.0). In the short-run, firms are able to maintain output, or at least have output fall less than input costs (their wage bill), such that there is a positive contemporaneous relationship between the number of disputes and productivity. The first differenced terms from the error correction representations are positive and significant in both models. For model CON3, the selected model included two lags of 'disputes' with the period (t-2) being the most significant economically and statistically.

While it is plausible that there is a positive relationship between productivity and industrial disputes contemporaneously, the regression coefficients are meant to be interpreted as long-run effects. A possible explanation for the estimated positive long-run effect is that industrial disputes may have altered investment plans and organisational practices by increasing the relative price of labour leading to, for example, more rapid or extensive up-take of new technologies.

Table F.13 **Effects on Construction MFP**

Standard errors in brackets. Selected by SBC.

Lag order	*(1,0,2)*	*(1,0,0)*	*(0,0,2,0)*
Model	*CON1*	*CON2*	*CON3*
ITdigi	0.027 ***	-	0.017 **
	(0.006)		(0.007)
disputes	0.064 ***	0.043 ***	0.052 ***
	(0.014)	(0.013)	(0.009)
centbrg	-	-0.045 ***	-0.017
		(0.013)	(0.012)
intercept	4.338 ***	4.743 ***	4.524 ***
	(0.068)	(0.083)	(0.095)
syddmmy	-0.096 **	-0.065 *	-0.096 ***
	(0.035)	(0.036)	(0.020)
opgaph11	0.557 ***	0.754 ***	-
	(0.179)	(0.224)	
ACCI	-	-	0.001 ***
			(0.000)
ECM(-1)	-0.617 ***	-0.521 ***	-
	(0.117)	(0.107)	
Test statistics			
No. of observations	27	27	26
Time period	76-02	76-02	77-02
Step 1 test	7.679	5.194	5.491
Long run forcing?	Y	Y	?[a]
R^2	0.869	0.842	0.829
Std. Error of Reg.	0.020	0.021	0.024
DW ‘d’ stat .	2.248	2.160	2.289
Durbin’s ‘h’ stat.	-0.810	0.499	-
	(0.418)	(0.618)	
Serial correlation	0.656	0.213	0.480
	(0.428)	(0.650)	(0.498)
Functional form	0.160	0.223	0.038
	(0.694)	(0.642)	(0.848)
Normality	0.115	0.202	1.104
	(0.944)	(0.904)	(0.576)
Hetero.	3.125	0.028	0.313
	(0.089)	(0.868)	(0.581)
AIC (SBC)	63(58)	63(59)	57(52)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistic for ITdigi indeterminate at 3.627.

Source: Authors’ estimates.

Another possible explanation is that the process of settling industrial disputes led to employers and employees agreeing to work arrangements that improved productivity with a lagged effect. Although the bounds test supports a 'long-run' relationship, the effects are likely to better interpreted as explaining an effect observed over the time period under study (1976-77 to 2002-03), rather than being an accurate measure of a 'long-run' effect.

The period included significant change in the industrial relations system. In model CON2, after holding the number of industrial disputes constant, the degree to which agreements are centrally determined is negative and significant. This model suggests that industrial reforms promoting enterprise level agreements have had a positive impact on industry MFP. However, the index is not significant in the other models. The index is a national index rather than industry-specific, so it may be introducing a degree of measurement error if the timing or pattern of the move towards more flexible agreement setting in the construction industry differed substantially to the national average.

A dummy variable for the construction boom and contraction associated with the Sydney 2000 Olympics ('syddmmy') was negative and significant. The dummy included the years 1999-00, 2000-01 and 2001-02.

The statistical properties of all models are acceptable.

F.6 Wholesale trade (WT)

Data description

Major trends and influences

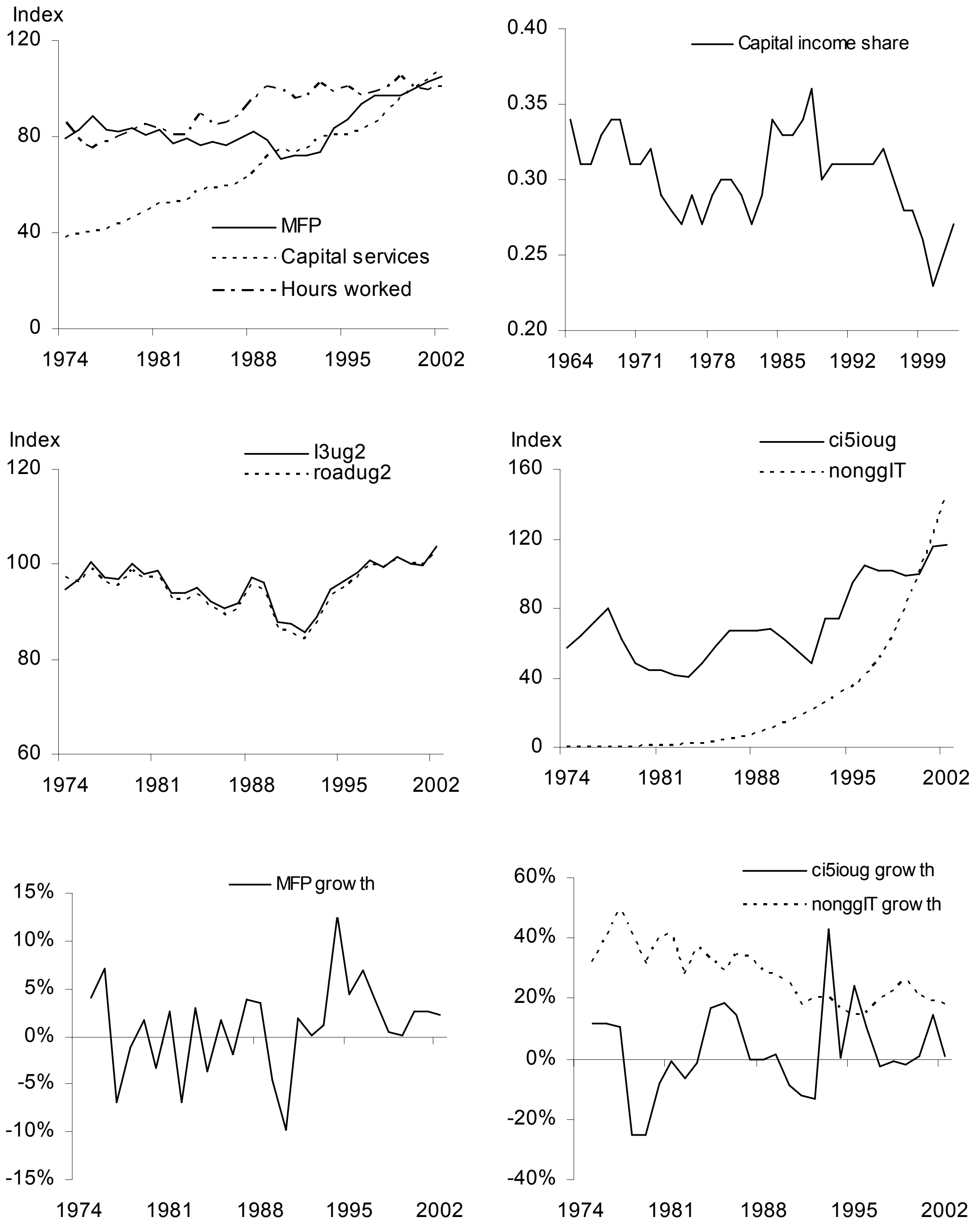
MFP growth was flat to negative up until the early 1990s. It then increased rapidly and posted very strong growth through the mid-1990s before returning to more modest growth rates (figure F.11).

The 1990s acceleration in wholesaling productivity is attributed primarily to increases in competition and the costs of holding inventories that drove the adoption of technologies enabling a faster flow-through of goods and reductions in warehousing costs (see box F.2).

The technologies are reported to have reduced the labour content of distribution. However, capital's share of income does not show any significant increase in the 1990s (top right-hand-side panel). The capital share declined from the mid-1960s, increased in the mid to late 1980s, then declined again. To the extent there are changing income shares, annual changes in shares are reflected in the MFP index through the weights used to aggregate the growth rates of different inputs.

Figure F.11 **Trends in key variables for Wholesale trade**

Index 2000-01 = 100; Percentage growth



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Box F.2 Productivity trends and drivers and enablers of change in Wholesale trade

Trends in wholesaling

- The proportion of industry gross product, at 1991-92, for basic materials wholesaling, machinery and motor vehicle wholesaling, and personal and household good wholesaling were 32, 37.5 and 30.5 per cent, respectively. The strongest acceleration in output in the 1990s was in basic materials.
- Labour productivity growth accelerated in the 1990s for both basic materials and machinery and motor vehicle wholesaling. It declined for personal and household good wholesaling.
- MFP estimates at the subdivision level are not available. However, indicators suggest that basic materials and machinery and motor vehicles wholesaling were the drivers of MFP growth at the divisional level.

Drivers and enablers of change

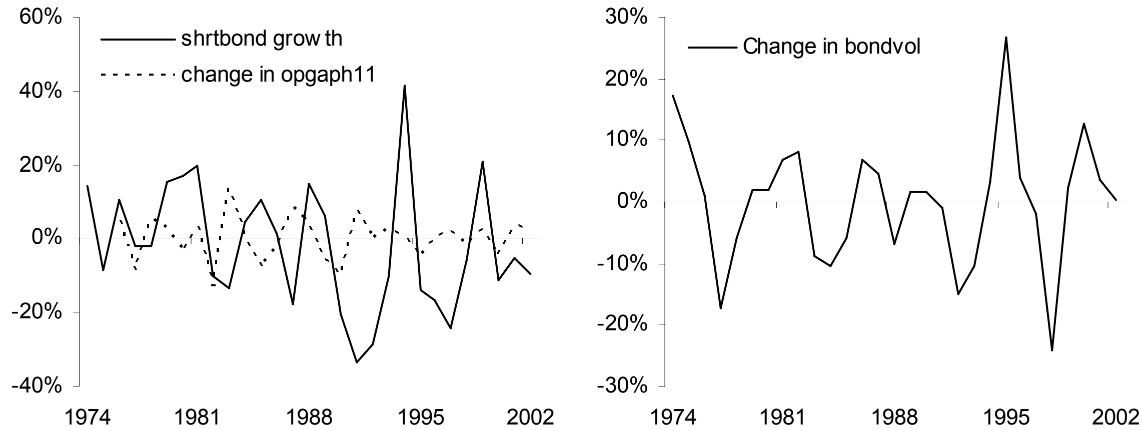
- In the 1980s, high-rise warehouses essentially acted as storage facilities, and, with prevailing high interest rates, the costs of holding inventory were high.
- In the 1990s, the trend to centralisation of warehousing facilities continued, but distribution became increasingly concerned with the rapid flow-through of goods. Technologies allowing real time transmission of information and inventory control, particularly the adoption of product numbering and scanning, enabled major changes to the wholesaling business. There was a noticeable decline in the stocks to sales ratio held by private businesses through the 1990s. While stock levels may fluctuate with changes in the business cycle, inventory to sales ratios declined steadily during the 1990s.
- Industry consultations supported the idea that technological changes during the 1990s enhanced productivity through their impact on inter and intra-organisational relationships, reduced per unit storage costs, and reductions in the labour content of distribution. Improvements in accuracy and reduced paper shuffling, handling, storage and errors (and stock returns) allowed further reductions in labour.
- Industrial relations changes in the 1990s promoted greater flexibility in work arrangements, for example, in hardware and timber wholesaling.
- Wholesalers now tend to contract out the transport of goods to dedicated carriers who can achieve greater economies of scale. Where transportation is outsourced, there may be some decline in measured labour and capital in wholesale activities (relative to output) and an increase in the transport and storage sector. Where warehouse operations are outsourced to third parties the activity remains, for statistical purposes, within the wholesale sector.
- Industry consultations stressed the importance of competition for industry productivity. In the absence of strong competition, it is unlikely that the technologies, changes in management structures and firm organisation and outsourcing would have been implemented to the same extent. Lack of competition reduces incentives to implement, or even be aware of, best practice processes.

Source: Johnston et al. (2000).

Business cycle and shocks

Johnston et al. (2000) noted that the output of Wholesale trade is sensitive to economywide demand shocks and to interest rates. High interest rates increase the cost of storing inventories in warehouses. Otto (1999) found that the terms of trade and interest rate spreads were significant sources of economywide demand shocks. Therefore, a number of variables related to these findings are tested in the regressions (figure F.12).

Figure F.12 **Cycle and shock measures, 1974-75 to 2002-03[a]**



[a] The output gap measure ‘opgaph11’ is constructed with a Hendersen 11 term moving average applied to industry gross value added (GVA) in order to derive a measure of potential output. The gap measure is the growth rate in actual GVA less the growth rate in potential output. The measure ‘shrtbond growth’ is the growth in the yield for a spliced series of 2-3 year Commonwealth bonds. The ‘bondvol’ measure is the change in the average of three prior periods change in ‘shrtbond’.

Data source: MFP data are Commission estimates; opgaph11, shrtbond and bondvol data are authors’ estimates based on ABS national account data and RBA data.

Regression results

Results excluding road and general government infrastructure

The first set of tests does not include either a road or general government infrastructure variable.

Models WT1 and WT2 are the result of a test down procedure that included the variables ‘ci5ioug’, ‘centbrg’, ‘tiopen’ and ‘wtedu’ in addition to those ‘surviving’ variables indicated in table F.14. The variables ‘era’, ‘tiopen’ and ‘centbrg’ were included to capture changes in the operating environment in terms of competitive pressures and industrial relations. Model WT1 also included the variable ‘shrtbond’ as a control for changes in the costs of holding inventories. The variable 'yrbond' was also tested as it is based on the longer end of the yield curve.

In model WT1, the cost of capital variable (whether 'shrtbond' as shown or 'yrbond') was unexpectedly positively signed. It is possible that the bond yields are picking-up a correlation with the business cycle, but a specific cycle control was included 'opgaph11'. However, the bond yields have a number of fairly sharp movements that may be closely correlated with the business cycle, but which are not fully captured by the 'smoothed' output gap measure. Possibly related, significant changes in bond volatility may be closely related to periods of significant changes in economic disruption with low productivity firms exiting, thereby raising average productivity — the 'cleansing effect' of economic downturns.

Increases in the costs of holding inventories could be expected to have short-run negative impacts, which might be offset by investments in the medium to longer term that improve productivity. The effect of some of the significant changes in the costs of holding inventories experienced in the 1970s, 1980s and 1990s should be reflected in the composition of the capital services measures. Therefore, the yield curve measures were not included in the test down procedures for model WT2.

The effect of IT capital conditioned on digitisation of the copper network was very strong and significant under many different variations of models WT1 and WT2. The effect of private conventional capital 'otrcap' conditioned on digitisation was consistently negative. The latter results suggest that changes in the organisation of economic activity enabled by digitisation and IT capital working in conjunction, may have had a disruptive effect on the marginal product of the pre-existing private capital stock of the industry.

Models WT3 to WT5 result from different initial variable sets and an increase in the maximum number of lags.

Table F.14 **Effects on Wholesale trade MFP, no road infrastructure**[a]

Dependent variable is ln(MFP). Selected by SBC. Maximum lag equals one.

Lag order	*(0,0,0,0,0,1)*	*(0,1,1,0)*	*(0,0,0,0,0,0)*	*(1,2,1,2,1)*	*(0,0,2,2)*	*FD*
Model	*WT1*	*WT2*	*WT3*	*WT4*	*WT5*	*WT6*[a]
otrcapdg	-0.082 *** (0.015)	-0.268 *** (0.064)	-0.093 *** (0.028)	-0.176 *** (0.061)	-	-0.108 ** (0.046)
nongglT	-	-	-0.058 *** (0.009)	-	-	-
ci5ioug	-	-	-	0.065 * (0.034)	0.134 *** (0.036)	-
ITdigi	0.159 *** (0.015)	0.232 *** (0.051)	0.093 *** (0.026)	0.201 *** (0.047)	0.104 *** (0.012)	0.144 ** (0.060)
wtedu	-	-	0.201 (0.142)	-	1.116 *** (0.346)	0.293 ** (0.109)
era	-0.304 *** (0.054)	-0.273 *** (0.093)	-0.294 *** (0.082)	-	-	-0.254 *** (0.077)
dubai	-0.046 *** (0.014)	-	-	-	-	-
shrtbond	0.218 *** (0.032)	-	-	-	-	-
dbondvol	-	-	-	0.235 *** (0.090)	-	-
intercept	5.610 *** (0.378)	6.267 *** (0.608)	5.309 *** (0.825)	4.261 *** (0.147)	-0.813 (1.520)	-0.022 ** (0.008)
time trend	-0.023 *** (0.002)	-0.014 *** (0.003)	-	-0.009 *** (0.002)	-0.024 *** (0.005)	-
opgaph11	0.707 *** (0.106)	-	-	0.942 ** (0.325)	-	0.543 *** (0.102)
ACCI	-	-	0.001 *** (0.000)	-	-	-
ECM(-1)	-	-	-	-0.628 *** (0.137)	-	-
Test statistics						
No. of observations	28	28	28	27	27	27
Time period	75-76 – 02-03	75-76 – 02-03	75-76 – 02-03	76-77 – 02-03	76-77 – 02-03	76-77 – 02-03
Step 1 test	1.770	2.984	2.310	5.259	3.411	-
LRF test passes?	No[b]	Yes	No[c]	Yes	Yes	-
R^2	0.983	0.941	0.948	0.992	0.942	0.697
Std. error of reg.	0.017	0.031	0.029	0.014	0.033	0.029
DW 'd' stat .	2.376	2.160	1.699	2.654	2.092	1.859
Durbin's 'h' stat.	-	-	-	-2.419 (0.016)	-	-
Serial correlation	0.889 (0.358)	0.194 (0.664)	0.474 (0.499)	3.552 (0.084)	0.077 (0.784)	0.001 (0.975)
Functional form	1.750 (0.202)	4.035 (0.058)	3.597 (0.072)	0.442 (0.519)	1.082 (0.313)	2.689 (0.117)

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Table F.14 **(continued)**

Normality	0.918	0.880	0.358	2.199	2.081	1.314
	(0.632)	(0.644)	(0.836)	(0.333)	(0.353)	(0.518)
Hetero.	0.335	1.162	0.093	1.472	0.128	1.298
	(0.568)	(0.291)	(0.763)	(0.236)	(0.724)	(0.265)
AIC (SBC)	70(64)	55(50)	57(52)	72(63)	50(45)	55(51)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] The variables that tested out were dubai, nonggIT and ci5ioug. [b] F-statistics for era and shrtbond of 3.342 and 3.319, respectively. [c] F-statistics for nonggIT and wtedu of 4.186 and 4.266, respectively.

Source: Authors' estimates.

The main results for the ARDL models WT3 to WT5 were as follows.

- Consistent with models WT1 and WT2, the effect of 'otrcap' in conjunction with digitisation, where included, is negative. This points towards disruption/substitution effects.
- Private IT capital is negative in model WT3, and insignificant in the other models.
- Consistent with models WT1 and WT2, the conditioning of the effect of IT capital on digitisation is strongly positive and significant in all models whether or not 'nonggIT' or 'ci5ioug' is in the models, and irrespective of other alterations to the models.
- Together, the results suggest that it is the network related effects of information and communications technology that were important to improving industry performance. The nature of the network effects are related to organisational and coordination improvements (as discussed in box F.2).

The F-statistic for the bounds test is below the lower bound critical value for each of the models, except WT4, suggesting that the variables do not form a long-run co-integrating relationship, and that other estimation strategies should be used to test the relationships.

The data generating process might be characterised by a trend stationary process or a near trend stationary process, or an I(0) process with breaks. The Dickey-Fuller and Dickey-Fuller GLS univariate tests for MFP do not reject I(1) against a trend stationary alternative. However, the Zivot-Andrews test does reject I(1) against an I(0) alternative with a single break in trend at 1986. Conflicting results for other variables were also obtained.

Given the bounds test results, model WT6 was estimated in first differences. If variables are I(1), then differencing will result in stationary variables.

The variables ‘dubai’, ‘nonggIT’ and ‘ci5ioug’ tested out of the model. To control for cost of capital shocks, each of the variables ‘dbondvol’, ‘shrtbond’ and ‘yrbond’ were iteratively included in the test down variable set. Each was significant, but positively signed, and were dropped for the final model. Dropping them did not alter the results for the remaining variables.

Consistent with the ARDL results, differencing produced negative and significant coefficients on ‘otrcapdg’ and ‘era’, and positive and significant coefficients on ‘ITdigi’ and ‘wtedu’. The differenced model is statistically acceptable.

Results including road infrastructure

A large number of ARDL regressions were run to test the effect of road infrastructure on industry MFP. The main result was the same as for most other industries. If road infrastructure is usage adjusted by value added shares, then the estimated elasticity is highly statistically significant and economically very significant (models WTR1 to WTR3 in table F.15). However, it is the usage adjustment that is driving the significance. When tests are run with a road infrastructure measure that is not usage adjusted, then it tests out in all circumstances.

Given concerns about the road infrastructure variable, the earlier results are preferred for communications infrastructure and the effects of digitisation.

Table F.15 **Effects on Wholesale trade MFP, long run coefficients**
Dependent variable is ln(MFP)

Selection criteria	*SBC*	*AIC*	*SBC*	*SBC*
Lag order	*(0,0,0,1,2)*	*(1,0,1,1,2)*	*(0,0,0,0,0,1,1)*	*(0,2,1,2,2,2)*
Model	*WTR1*	*WTR1*	*WTR2*	*WTR3*
dva	-	-	0.332 *** (0.102)	-
yrbond	-	-	0.119 *** (0.039)	-
bondvol	-	-	-	-0.252 ** (0.098)
roadug2	1.108 *** (0.128)	1.017 *** (0.116)	0.449 ** (0.195)	0.835 *** (0.212)
ci5ioug	0.115 ** (0.042)	0.109 *** (0.035)	0.061 ** (0.023)	-0.020 (0.025)
nonggIT	-0.071 *** (0.022)	-0.083 *** (0.016)	-0.143 *** (0.036)	-0.377 *** (0.099)
nongs95	-	-	0.032 *** (0.008)	-
nonggIT*ci5ioug (interaction)	-	-	-	0.079 ** (0.027)
dubai	0.056 ** (0.024)	0.052 ** (0.020)	-	-
intercept	-1.688 *** (0.443)	-1.325 *** (0.401)	0.854 (0.729)	0.537 (0.994)
time trend	0.022 *** (0.006)	0.027 *** (0.005)	0.041 *** (0.011)	0.011 (0.009)
ECM(-1)	-	-1.205 *** (0.117)	-	-
Test statistics				
No. of observations	26	27	27	27
Time period	77-02	76-02	76-02	76-02
Step 1 test	2.313	-	0.958	4.703
Long-run forcing?	No[a]	-	No[b]	No[c]
R^2	0.984	0.986	0.986	0.994
Std. error of reg.	0.017	0.017	0.016	0.013
DW ‘d’ stat .	2.222	2.123	2.412	2.365
Durbin’s ‘h’ stat.	-	-0.403 (0.687)	-	-
Serial correlation	0.676 (0.423)	0.517 (0.483)	0.844 (0.372)	1.012 (0.338)
Functional form	2.077 (0.169)	1.147 (0.301)	0.682 (0.421)	0.000 (0.996)

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Table F.15 **(continued)**

Selection criteria	*SBC*	*AIC*	*SBC*	*SBC*
Lag order	*(0,0,0,1,2)*	*(1,0,1,1,2)*	*(0,0,0,0,0,1,1)*	*(0,2,1,2,2,2)*
Model	*WTR1*	*WTR1*	*WTR2*	*WTR3*
Normality	0.537	1.471	1.800	2.983
	(0.764)	(0.479)	(0.407)	(0.225)
Hetero.	0.786	0.002	1.239	1.180
	(0.384)	(0.965)	(0.276)	(0.288)
AIC (SBC)	65(59)	67(60)	69(62)	74(64)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistics for ci5ioug and dubai of 3.277 and 4.244, respectively. [b] F-statistics for yrbond and ci5ioug of 5.553 and 3.949, respectively. [c] F-statistics for roadug2, ci5ioug and nongglT*ci5ioug of 4.168, 5.538 and 11.589, respectively.

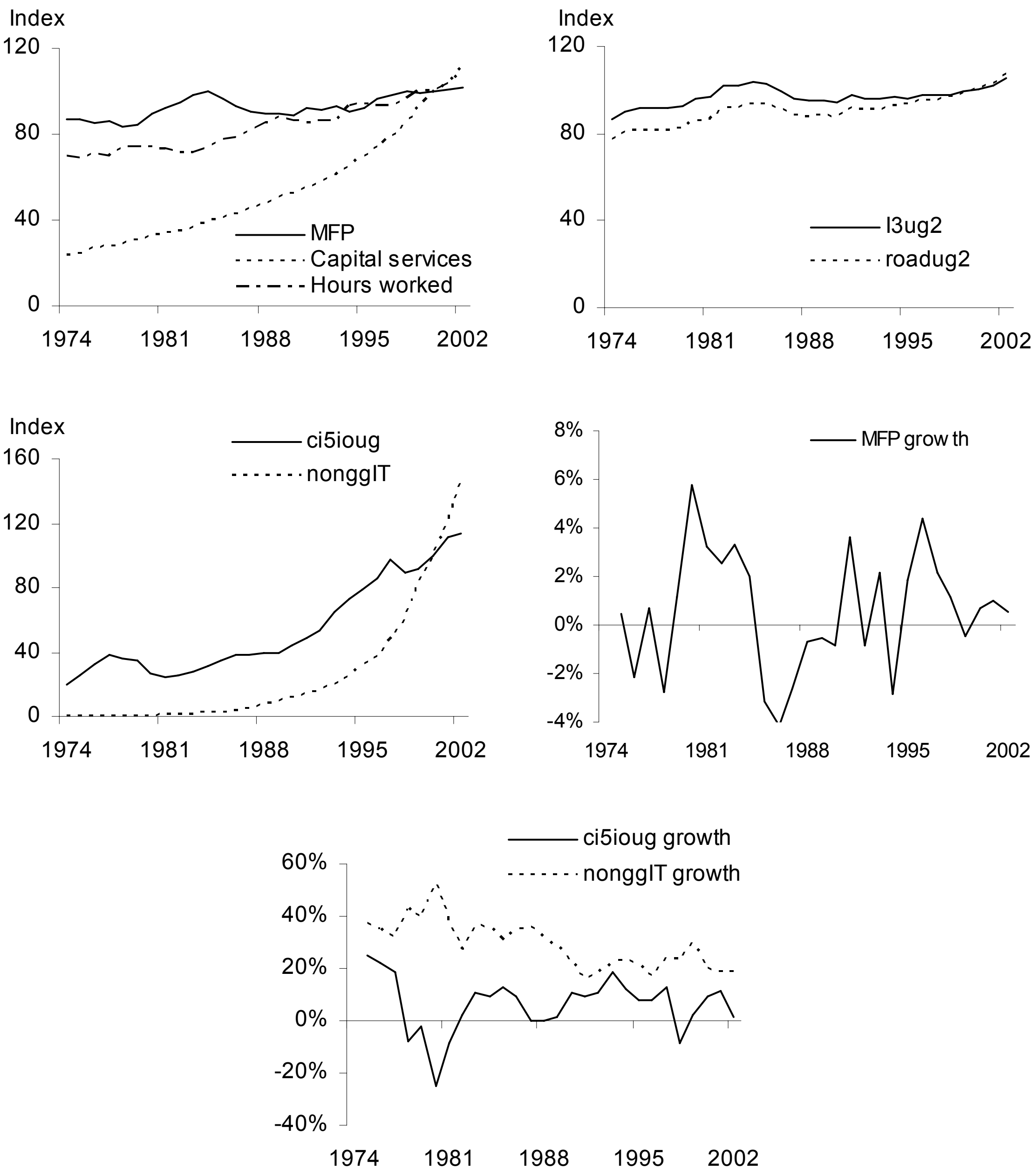
Source: Authors' estimates.

F.7 Retail trade (RT)

Data description

Figure F.13 presents the trends in the main variables for Retail trade.

Figure F.13 **Trends in key variables for Retail trade**
Index 2000-01 = 100; Percentage growth



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Results

Models RT1 and RT2 test the significance of general government and road infrastructure, respectively. Similar to other industries, the tests produce very large elasticity estimates for these types of infrastructure when the measures are constructed with a usage adjustment (table F.16). Without the usage adjustment, the variables are not significant.

The first test without the inclusion of road or general government infrastructure resulted in the variables 'ci5ioug', 'centbrg' and 'opgaph11' testing out of the model (model RT3). The coefficient on private IT capital was positive and highly significant and there is support for a further positive effect of IT capital conditioned on digitisation of the copper network. However, the very large economic magnitude of these coefficients and the coefficient on education were of concern. The bounds test did not reject the null, but other tests indicated that the model was statistically adequate.

Model RT4 tested the effect of digitisation on the industry's 'other' capital, as well as introducing slope shifts for IT capital (given some of the findings for other industries). The variables 'trend', 'ITdigi', 'rtedu' and 'opgaph11' tested out.

While the effect of 'otrcapdg' was positive and significant, the regression produced the unexpected result of a highly negative and significant effect of communication infrastructure. The estimated elasticity for IT capital was much lower than in model RT4, and slope shifts at 1986-87 and 1995-96 were statistically significant. The bounds test rejected the null, but the forcing tests for 'ci5ioug' and 'nonggIT' were indeterminate. These results matched closely model RT2, but with the exclusion of road infrastructure.

There does not appear to be a plausible argument why communication infrastructure would have had a negative impact on MFP. Therefore, the test procedure of model RT4 was re-run with communication infrastructure excluded. The model tested down to the same set of variables and the estimated elasticities for the remaining variables were very similar (model RT5). Digitisation of the copper network continued to have a modest positive effect on industry MFP.

As no single model passed both the bounds test and each of the forcing tests, a number of alternative estimation strategies were tested. First differencing did not produce acceptable results. OLS estimation in levels generally supported a positive and significant coefficient for IT capital of around 0.06, with a shift down in that coefficient of the same order of magnitude at 1986-87, followed by a large increase in the coefficient conditioned on digitisation. Communication infrastructure and other capital conditioned on digitisation were not significant. The residuals of the models displayed a high degree of positive serial correlation.

Table F.16 **Effects on Retail trade MFP, long run coefficients**

Dependent variable is ln(MFP). Selected by SBC.

Lag order	*(3,2,0,0,0)*	*(1,0,0,1,0,0,1)*	*(1,0,0,1)*	*(0,1,2,0,1,1)*	*(1,0,1,0,1)*	*FMOLS*
Model	*RT1*	*RT2*	*RT3*	*RT4*	*RT5*	*RT6*[e]
CPI	-0.476 ***	-	-	-	-	-
	(0.117)					
l3ug2	0.756 ***	-	-	-	-	-
	(0.128)					
roadug2	-	0.468 ***	-	-	-	-
		(0.149)				
otrcapdg	-	0.025 ***	-	0.039 ***	0.026 **	-0.011
		(0.009)		(0.007)	(0.012)	(0.013)
ci5ioug	0.058	-0.074 *	-	-0.128 ***	-	-
	(0.056)	(0.038)		(0.033)		
nongglT	0.213 ***	0.038 ***	0.251 **	0.059 ***	0.069 ***	0.059 ***
	(0.062)	(0.009)	(0.095)	(0.004)	(0.009)	(0.006)
nongs85	-	-0.051 ***	-	-0.072 ***	-0.121 ***	-0.093 ***
		(0.015)		(0.009)	(0.018)	(0.010)
nongs95	-	0.016 ***	-	0.019 ***	0.027 ***	-
		(0.005)		(0.004)	(0.007)	
ITdigi	-	-	0.125 ***	-	-	0.053 ***
			(0.037)			(0.012)
rtedu	-	-	0.849 ***	-	-	-
			(0.290)			
intercept	3.172 ***	2.659 ***	2.373 *	4.984 ***	4.658 ***	4.563 ***
	(0.886)	(0.722)	(1.356)	(0.112)	(0.041)	(0.008)
time trend	-0.034 **	-	-0.103 ***	-	-	-
	(0.015)		(0.034)			
opgaph11	-	0.327 ***	-	-	0.553 *	-
		(0.168)			(0.309)	
ECM(-1)	-1.012 ***	-0.787 ***	-0.437 ***	-	-0.534 ***	-
	(0.180)	(0.103)	(0.111)		(0.086)	
Test statistics						
No. of observations	26	27	28	27	27	27
Time period	77-02	76-02	75-02	76-02	76-02	76-02
Step 1 test	2.320	6.331	3.435	6.029	2.560	-
Long run forcing?	No[f]	No[a]	?[b]	?[c]	No[d]	-
R^2	0.964	0.980	0.914	0.977	0.964	-
Std. Error of Reg.	0.014	0.010	0.019	0.011	0.013	-
DW ‘d’ stat .	2.395	2.654	1.791	2.174	2.525	-
Durbin’s ‘h’ stat.	-	-2.008	0.685	-	-1.525	-
		(0.045)	(0.493)		(0.127)	

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Table F.16 **(continued)**

Lag order	*(3,2,0,0,0)*	*(1,0,0,1,0,0,1)*	*(1,0,0,1)*	*(0,1,2,0,1,1)*	*(1,0,1,0,1)*	*FMOLS*
Model	*RT1*	*RT2*	*RT3*	*RT4*	*RT5*	*RT6*[e]
Serial correlation	2.232 (0.157)	4.775 (0.207)	0.284 (0.600)	0.958 (0.343)	1.980 (0.177)	-
Functional form	3.372 (0.088)	1.742 (0.207)	0.694 (0.415)	0.314 (0.583)	0.197 (0.663)	-
Normality	0.638 (0.727)	1.216 (0.544)	1.320 (0.517)	2.794 (0.247)	0.318 (0.853)	-
Hetero.	0.307 (0.585)	4.541 (0.043)	0.001 (0.971)	0.130 (0.721)	7.865 (0.010)	-
AIC (SBC)	71(64)	81(74)	68(63)	79(72)	75(69)	-

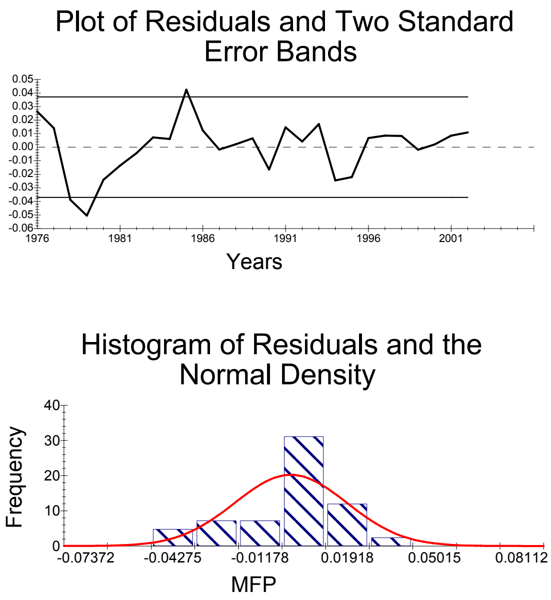
*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistic for nongglT and nongs85 of 6.734 and 3.188, respectively. [b] F-statistic for ITdigi indeterminate at 4.235. [c] F-statistics for ci5ioug and nongglT of 2.649 and 3.805, respectively. [d] F-statistic for nongglT of 9.641. [e] Estimated with FMOLS using Bartlett weights and a truncation lag of one with the assumption that at least one of the regressors has a drift. The results were not sensitive to other specifications and assumptions. [f] F-statistics for CPI, l3ug2 and ci5ioug of 14.116, 2.994 and 3.146, respectively.

Source: Authors' estimates.

Models were also estimated with FMOLS under various specifications of the lag length and assumptions about the time series properties of the data. The pattern of a positive effect of IT capital and a significant reduction in the elasticity in the mid-1980s, followed by a large positive effect conditioned on digitisation, held in all tests (model RT6).

Model RT6 displays a high degree of positive serial correlation following FMOLS estimation with the correlogram indicating a coefficient of almost +0.4 after one period (figure F.14). As the model is re-estimated by successively shortening the sample, beginning with dropping the earliest observations first, the residuals of the model become better behaved. For example, if the sample is restricted to 1984-85 to 2002-03, then the coefficients and standard errors on 'otrcapdg' and 'ITdigi' are -0.016 (0.007) and +0.074 (0.007), and the correlogram indicates that there is no serial correlation in the residuals.

Figure F.14 **Post-estimation tests for model RT6, 1976-77 to 2002-03**



Data source: Authors' estimates.

Summary

Johnston et al. (2000) noted a number of factors that may have had an impact on retail productivity — competition; rationalisation (capturing economies of scale); technological change being biased against labour; supply-chain integration; regulated hours worked (at least on labour productivity); and expansion of low labour productivity sub-industries.

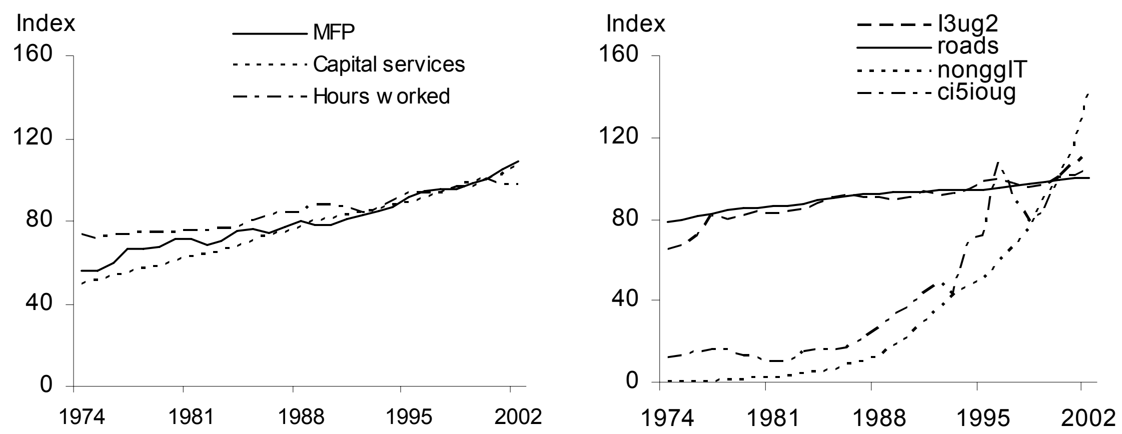
While the models cannot capture the 'richness' of findings based on case study approaches, the results do support varying effects from technological change. The results support an effect of IT capital that has varied substantially over time. There is evidence that digitisation has had effects on Retail trade, but the different model specifications point to different channels. Models RT4 and RT5 suggest a positive effect in conjunction with the industry's conventional capital. Model RT6 favours a positive effect together with IT capital.

F.8 Transport & storage (TS)

Data description

Figure F.15 presents the trends in the main variables for Transport & storage. The pattern of growth for MFP, capital services and labour inputs is similar. For some other industries, the series show distinctly different patterns (for example, hours worked declining from the mid-1970s). For TS, capital services has grown appreciably faster, but the overall impression, compared with some industries, is of steady-state growth.

Figure F.15 **Trends in key variables for Transport & storage**
Index 2000-01 = 100



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Unit root testing indicated that most variables were likely non-stationary, although Zivot-Andrews tests sometimes rejected I(1) behaviour in favour of an I(0) process with a single break in the mid-1980s (table F.17). The non-usage adjusted variable 'roads' tested as I(1) to I(2) (see the unit root tests for the market sector in appendix G).

Table F.17 **Unit root test[a] findings for Transport & storage, 1974-75 to 2002-03**

Critical values of 5 per cent used for tests.

	No breaks	*Zivot-Andrews: single break*	*Additive/Innovational Outlier Clemente, Montanes & Reyes tests*
MFP	I(1)	I(1) rejected against I(0) with break in trend with min. t-stat. at 1986	Innov. outlier/Add. outlier single/ double break tests do not reject I(1)
Road infrastructure (roadug2)	I(0) with drift – I(1)	I(1) rejected against I(0) with break in trend with min. t-stat. at 1978	Innov. outlier/Add. outlier single/ double break tests do not reject I(1)
Communications infrastructure (ci5ioug)	I(1)	I(1)	Innov. outlier/Add. outlier single/ double break tests do not reject I(1)
Private IT capital (nonggIT)	I(0) with drift – I(1)	I(1)	Innov. outlier single and double break tests reject I(1). Add. outlier tests do not
Industry human capital (tsedu)	I(0) trend stationary	I(1) rejected in favour of break in intercept & trend with min. t-stat at 1985	Innov. outlier/Add. outlier single/ double break tests do not reject I(1)

Source: Authors' estimates.

Results

Models were estimated with both the inclusion and exclusion of road infrastructure. Regressions using the ARDL approach to co-integration analysis were supplemented with alternative estimation strategies in response to unsatisfactory results.

Background to the tests

When the ABS constructs industry capital stocks it allocates Australia's public road infrastructure assets to the industry Transport & storage. As the industry's capital services measure used to construct MFP already contains public road infrastructure, the interpretation of the estimated elasticity is therefore an excess interpretation (that does not include the free input effect).

It might be expected that the excess return for this industry would be zero or possibly negative, representing a very large asset 'parked' on the accounts of the industry, but with external effects 'realised' by other market sector industries.

Regressions tested both usage-adjusted and non-adjusted road infrastructure measures. The maximum allowable lag length and the inclusion of specific controls varied by test.

The results from two regressions using the usage-adjusted road infrastructure variable 'roadug2' are presented in table F.18. Model TSR1 trades off a rich set of controls for additional dynamics with a maximum allowable lag length of three lags. It includes only the primary variables of interest and a time trend. A range of shock and cycle variables were tested to improve the model, including: 'opgaph11'; 'yrbond'; 'shrtbond'; 'totgdsvl'; 'bondvol'; and 'CPI'.

Model TSR2 reduces the maximum allowable lag in order to increase the set of control variables. Variables that tested out of the model are listed in the table notes.

Neither model TSR1 or TSR2 passed both the bounds test and all the long-run forcing tests. Therefore, a general-to-specific test down procedure was performed using standard OLS estimation (model TSR3). Controls variables are signed as expected. The residuals of the model do not contain a unit root lending some support to the interpretation that the variables form a co-integrating relationship (figure F.16).

Results including road or general government infrastructure

The coefficient on road infrastructure is very economically and statistically significant in each of models TSR1 to TSR3. However, these results should be rejected. While the bounds test rejects the null for model TSR1, 'roadug2' fails the forcing test. The bounds test is indeterminate for model TSR2.

Models were estimated using the variable 'roads' that is not usage adjusted. A number of different specifications were estimated constrained by the same trade-off between dynamics and the richness of the initial variable set. With a maximum allowable lag of three periods, and testing various definitions and combinations of a trend, cycle and scale control term, a model could not be generated with road infrastructure positive and significant. Reducing the allowable lags to one period and including a set of control variables in a test down procedure did not produce satisfactory models, and the estimated elasticities for 'roads' contained very large standard errors. This strongly suggests that it is the usage adjustment alone that is driving significance in models TSR1 to TSR3.

The same pattern of results apply to tests of the effects of general government infrastructure. Regressions were run with the variables 'I3ug2' (models TSR4 and TSR5) and 'I3'. Model TSR4 contains a broader set of controls, while TSR5 contains richer dynamics. Usage-adjusted general government infrastructure is highly significant, just like the results for usage-adjusted road infrastructure. However, dropping the usage adjustment in tests of 'I3' resulted in general government infrastructure being insignificant in explaining industry MFP.

Table F.18 Effects on Transport & storage MFP, with road infrastructure

Dependent variable is ln(MFP).

Selection criteria	*AIC/SBC*	*SBC*		*SBC*	*SBC*
Max. lag	*3*	*1*		*1*	*3*
Lag order	*(3,0,0,1)*	*(0,1,1,0,0,0)*	*OLS*	*(0,0,1,1,1,0,0,0)*	*(2,2,2,0)*
Model	*TSR1*	*TSR2*[a]	*TSR3*[b]	*TSR4*[f]	*TSR5*
roadug2	1.031 *** (0.473)	0.747 *** (0.074)	-	-	-
roads	-	-	1.147 *** (0.463)	-	-
l3ug2	-	-	-	0.722 *** (0.085)	0.781 *** (0.100)
ci5ioug	0.054 (0.051)	0.032 *** (0.010)	0.096 *** (0.027)	-	-
nongglT	-0.077 ** (0.027)	-0.050 *** (0.009)	0.012 * (0.006)	0.000 (0.010)	0.016 *** (0.005)
nongs86	-	-	-	0.016 *** (0.005)	
nongs95	-	-	-	0.011 *** (0.003)	
ITdigi	-	-	-	-	0.037 *** (0.002)
tsedu	-	-	-	0.137 * (0.071)	-
era	-	-	-0.125 ** (0.049)	-	-
tiopen	-	0.084 * (0.046)	0.189 *** (0.074)	0.252 *** (0.054)	-
centbrg	-	-	-0.032 *** (0.010)	-0.010 * (0.006)	-
dubai	-	0.022 *** (0.007)	-	-	-
intercept	-0.632 (2.067)	0.195 (0.312)	-0.372 (1.791)	-0.583 (0.594)	0.788 * (0.440)
Time trend	0.020 (0.009)	0.018 *** (0.003)	-0.028 ** (0.011)	-	-
opgaph11	-	0.577 *** (0.109)	0.571 *** (0.138)	-	0.553 *** (0.162)
ECM(-1)	-0.562 *** (0.194)	-	-	-	-1.115 *** (0.176)
Test statistics					
No. of observations	26	28	28	28	26
Time period	77-02	75-02	75-02	75-02	77-02
Step 1 test	5.479	3.146	-	1.525	6.022
Long run forcing?	No[c]	No[d]	-	No[g]	Yes
R^2	0.993	0.998	0.992	0.997	0.998

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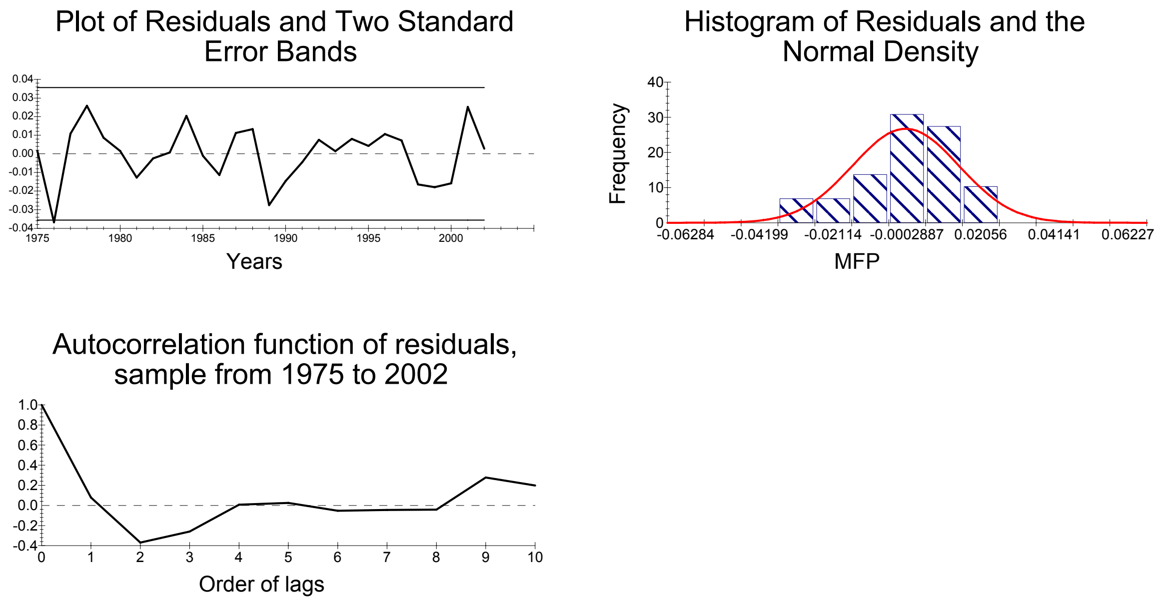
Table F.18 **(continued)**

Selection criteria	*AIC/SBC*	*SBC*		*SBC*	*SBC*
Max. lag	*3*	*1*		*1*	*3*
Lag order	*(3,0,0,1)*	*(0,1,1,0,0,0)*	*OLS*	*(0,0,1,1,1,0,0,0)*	*(2,2,2,0)*
Model	*TSR1*	*TSR2*[a]	*TSR3*[b]	*TSR4*[f]	*TSR5*
Std. Error of Reg.	0.015	0.009	0.018	0.012	0.008
DW ‘d’ stat .	1.935	2.173	1.840	2.458	2.108
Serial correlation	0.016	0.224	0.140	1.547	0.092
	(0.901)	(0.642)	(0.712)	(0.232)	(0.766)
Functional form	0.016	1.029	0.365	0.107	4.652
	(0.901)	(0.325)	(0.554)	(0.748)	(0.049)
Normality	1.918	1.182	1.023	0.463	0.174
	(0.383)	(0.554)	(0.599)	(0.793)	(0.917)
Hetero.	0.061	0.008	0.470	0.369	4.481
	(0.807)	(0.928)	(0.499)	(0.549)	(0.045)
AIC (SBC)	69(63)	87(80)	70(64)	81(74)	83(76)
ADF test of residuals	-	-	-5.548[e]	-	-

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] Variables that tested out were otrcapdg, ITdigi, nongs86, tsedu and ci5ioug. [b] Variables that tested out were nongs86, nongs95, tsedu, and era. [c] F-statistic for roadug2 of 5.911. [d] F-statistic for ci5ioug of 5.139. [e] Augmented Dickey-Fuller test. The null of no co-integrating relationship is rejected. [f] Variables that tested out were ci5ioug, otrcapdg ITdigi, and era. [g] F-statistics for I3ug2 and tsedu of 3.472 and 4.437, respectively.

Source: Authors’ estimates.

Figure F.16 **Post-estimation tests for model TSR3**



Data source: Authors' estimates.

Results excluding road and general government infrastructure

Different initial variable sets were established for the tests of models that excluded road and general government infrastructure. All models were estimated as ARDL (1,1) or (2,2) models and selected by SBC. None of the selected models included a lagged dependent variable (table F.19).

For model TS1, 'ci5ioug', 'ITdigi', 'centbrg', and 'opgaph11' tested out of the models. It was thought that the cost of holding materials and goods might be a factor influencing investment and productivity in the industry and, therefore, various measures of the cost of capital were tested, including changes in two to three year bond yields 'dshrtbond'. A slope shift term on IT capital was also tested at 1992 and was not significant.

The cost of capital measures were not significant and were dropped from the initial variable set for model TS2. The variables 'ci5ioug', 'ITdigi', 'centbrg' and 'opgaph11' tested out. Compared with model TS1, IT capital becomes significant, while the industry-specific education measure becomes statistically insignificant.

As models TS1 and TS2 did not clearly reject the null hypothesis of no long-run relationship, the specification of models TS3 to TS6 tested the introduction of additional dynamics and/or allowed for parameter change in the intercept and/or the coefficient on IT capital.

Model TS3 allowed the intercept to shift. The variables 'tiopen', 'ci5ioug', 'opgaph11' and 'tsedu' tested out. The magnitude of the effects for 'otrcapdg' and 'nonggIT' are increased and IT capital conditioned on digitisation becomes highly significant.

Model TS4 introduced slope shift terms for IT capital at 1986, 1992 and 1995. The variables 'tsedu', 'era', 'opgaph11', and a time trend tested out. The shift at 1986 ('nongs86') was negative and significant, while the other slope shifts tested out.

The conditioning of IT capital on digitisation continued to result in a positive and highly significant effect. Overall, the model points to a significant increase in the effect of IT capital on productivity in the 1990s resulting from complementarity between IT capital and digital transmission.

The F-statistic from the long-run forcing test for centralised bargaining is indeterminate in models TS3 and TS4, while all other variables pass the test. Dropping 'centbrg' from model TS4 and re-testing down resulted in model TS5. The variables 'era', 'tsedu', 'nongs92', a linear time trend, and 'opgaph11' tested out.

Tests of the inclusion of 'ci5ioug' with 'nonggIT' and an interaction term did not produce significant results.

Model TS5 is the preferred ARDL model overall as signs accord with expectations, it incorporates adequate controls for other sources of influences on MFP, the F-statistic for rejecting the null in the bounds test is not far outside 5 per cent, and only the variable 'tiopen' is marginally indeterminate in the forcing tests.

Table F.19 **Effects on Transport & storage MFP, no road infrastructure**

Dependent variable is ln(MFP). Selected by SBC. Model TS6 estimated by OLS

Lag order	*(0,0,0,0,0,0,0)*	*(0,0,0,0,0,0)*	*(0,0,0,0,0,1)*	*(0,0,0,0,0,0,1)*	*(0,0,1,0,0,0,1)*	*OLS*
Model	*TS1*	*TS2*	*TS3*	*TS4*	*TS5*	*TS6*[a]
ci5ioug	-	-	-	0.047 *	0.108 ***	-
				(0.025)	(0.035)	
otrcapdg	-0.041 **	-0.037 **	-0.108 ***	-0.115 ***	-0.096 ***	-0.026 *
	(0.017)	(0.017)	(0.037)	(0.037)	(0.028)	(0.014)
nonggIT	0.015	0.021 **	0.063 ***	0.066 ***	0.050 ***	0.051 ***
	(0.011)	(0.010)	(0.008)	(0.006)	(0.010)	(0.008)
nongs86	-	-	-	-0.020 **	-0.025 **	-0.015 *
				(0.010)	(0.011)	(0.008)
ITdigi	-	-	0.109 **	0.148 ***	0.097 ***	-
			(0.050)	(0.040)	(0.027)	
tsedu	0.230 *	0.219	-	-	-	-
	(0.128)	(0.130)				
era	-0.178 ***	-0.178 ***	-0.138 *	-	-	-0.166 ***
	(0.059)	(0.060)	(0.074)			(0.053)
tiopen	0.533 ***	0.409 ***	-	-	0.280 **	0.201 **
	(0.131)	(0.097)			(0.131)	(0.090)
centbrg	-	-	0.044 *	0.034 *	-	-0.020 ***
			(0.021)	(0.017)		(0.008)
dshrtbond	-0.055	-	-	-	-	-
	(0.040)					
intercept	2.046 **	2.615 ***	4.764 ***	3.859 ***	2.736 ***	4.502 ***
	(0.975)	(0.903)	(0.489)	(0.118)	(0.588)	(0.552)
shift1986	-	-	-0.043 *	-	-	-
			(0.022)			
opgaph11	-	-	-	-	-	0.497 ***
						(0.151)
Test statistics						
No. of observations	28	28	27	28	27	28
Time period	75-02	75-02	76-02	75-02	76-02	75-02
Step 1 test	2.231	3.016	3.229	2.752	3.401	-
Long run forcing?	No[b]	No[c]	?[d]	?[e]	?[f]	-
R^2	0.983	0.982	0.987	0.989	0.987	0.990
Std. error of reg.	0.025	0.025	0.021	0.021	0.021	0.020

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Table F.19 **(continued)**

Lag order	*(0,0,0,0,0,0,0)*	*(0,0,0,0,0,0)*	*(0,0,0,0,0,1)*	*(0,0,0,0,0,0,1)*	*(0,0,1,0,0,0,1)*	*OLS*
Model	*TS1*	*TS2*	*TS3*	*TS4*	*TS5*	*TS6*[a]
DW 'd' stat .	1.791	1.705	1.919	2.139	1.990	1.675
Serial correlation	0.052	0.168	0.113	0.111	0.124	0.633
	(0.822)	(0.686)	(0.740)	(0.743)	(0.730)	(0.436)
Functional form	0.265	0.296	2.062	0.223	1.341	1.083
	(0.613)	(0.592)	(0.168)	(0.642)	(0.263)	(0.311)
Normality	1.632	1.480	0.101	0.172	0.699	0.833
	(0.442)	(0.477)	(0.951)	(0.918)	(0.705)	(0.659)
Hetero.	2.199	1.417	2.083	2.451	4.424	2.777
	(0.150)	(0.245)	(0.161)	(0.130)	(0.046)	(0.108)
AIC (SBC)	61(56)	61(57)	62(57)	66(60)	62(56)	67(62)
ADF test of residuals	-	-	-	-	-	-5.465[g]

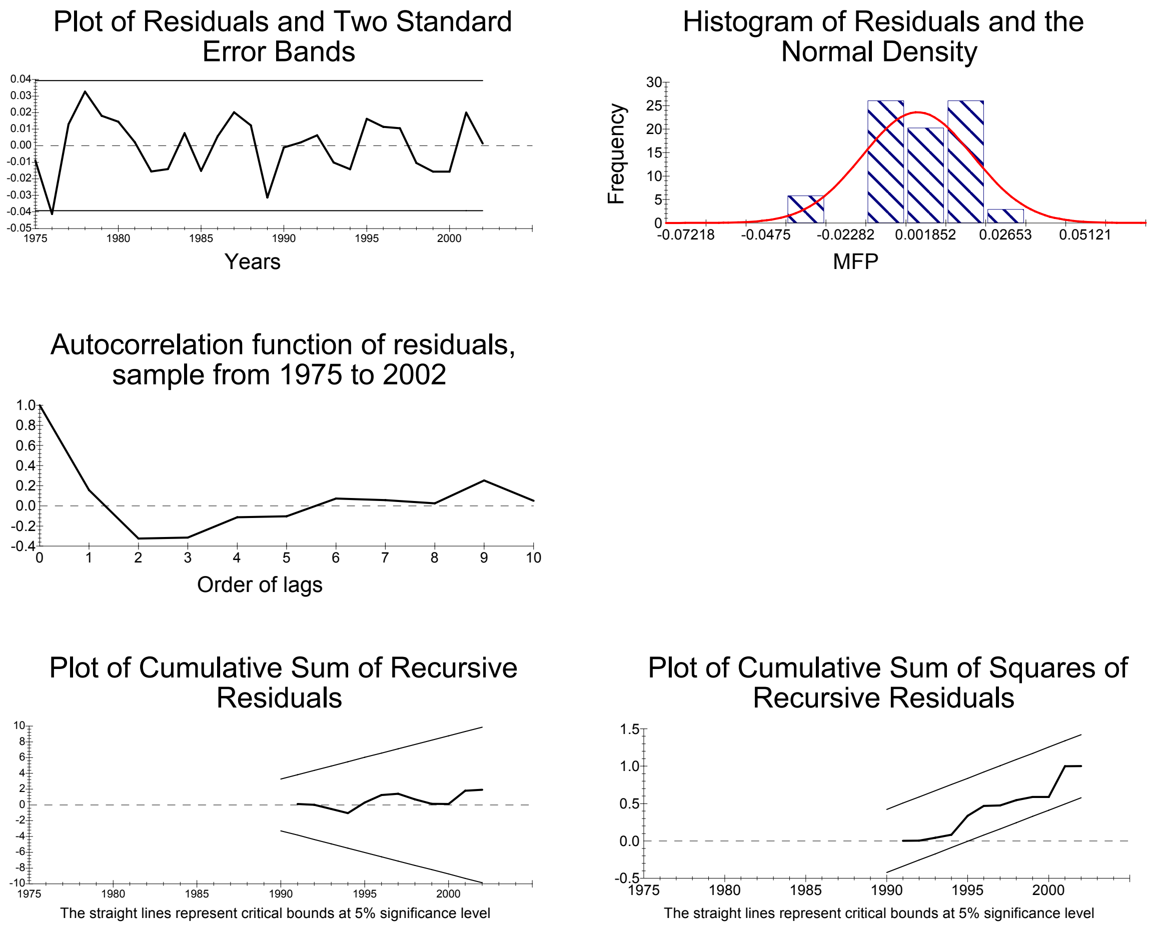
*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] Variables that tested out were a human capital control (tsedu or QALI), scale controls (hrs, ksrv or inptxadj), ci5ioug, ITdigi, and a linear trend term. [b] F-statistics for dshrtbond, tsedu and tiopen of 3.210, 3.221 and 6.726, respectively. [c] F-statistics for tsedu and tiopen of 3.914 and 3.729, respectively. [d] F-statistic for centbrg of 3.013. [e] F-statistic for centbrg of 3.461. [f] F-statistic for tiopen of 2.751. [g] Augmented Dickey-Fuller test. The null of no co-integrating relationship is rejected.

Source: Authors' estimates.

The bounds test for the models in table F.19 did not provide a clear rejection of the hypothesis that the variables do not form a long-run co-integrating relationship. Therefore, a number of alternative estimation strategies were pursued.

- *First differencing*: first differenced models produced results that, while the signs and magnitudes of variables were reasonable, the standard errors of the estimates were very wide on all variables.
- *OLS in levels*: model TS6 in table F.19 was estimated with OLS with tests of the residuals rejecting the presence of a unit root. The absence of a unit root, if the variables are non-stationary, provides support for a co-integrating relationship. The statistical tests for the model and the tests in figure F.17 produce acceptable results, except that the distribution of the residuals could be more 'normal'.
  - IT capital had a positive impact on industry MFP. The process of digitisation appears to have lowered the marginal product of the industry's 'other' capital. These results are supported by the results for models TS3 to TS5. There is also evidence from the ARDL models that digitisation increased the effect of IT capital on industry MFP.

Figure F.17 **Post-estimation tests for model TS6**



Data source: Authors' estimates.

Summary

The regressions are unable to provide an estimate of the economic magnitude of the effect of road infrastructure, or general government infrastructure more broadly, on the industry's MFP performance.

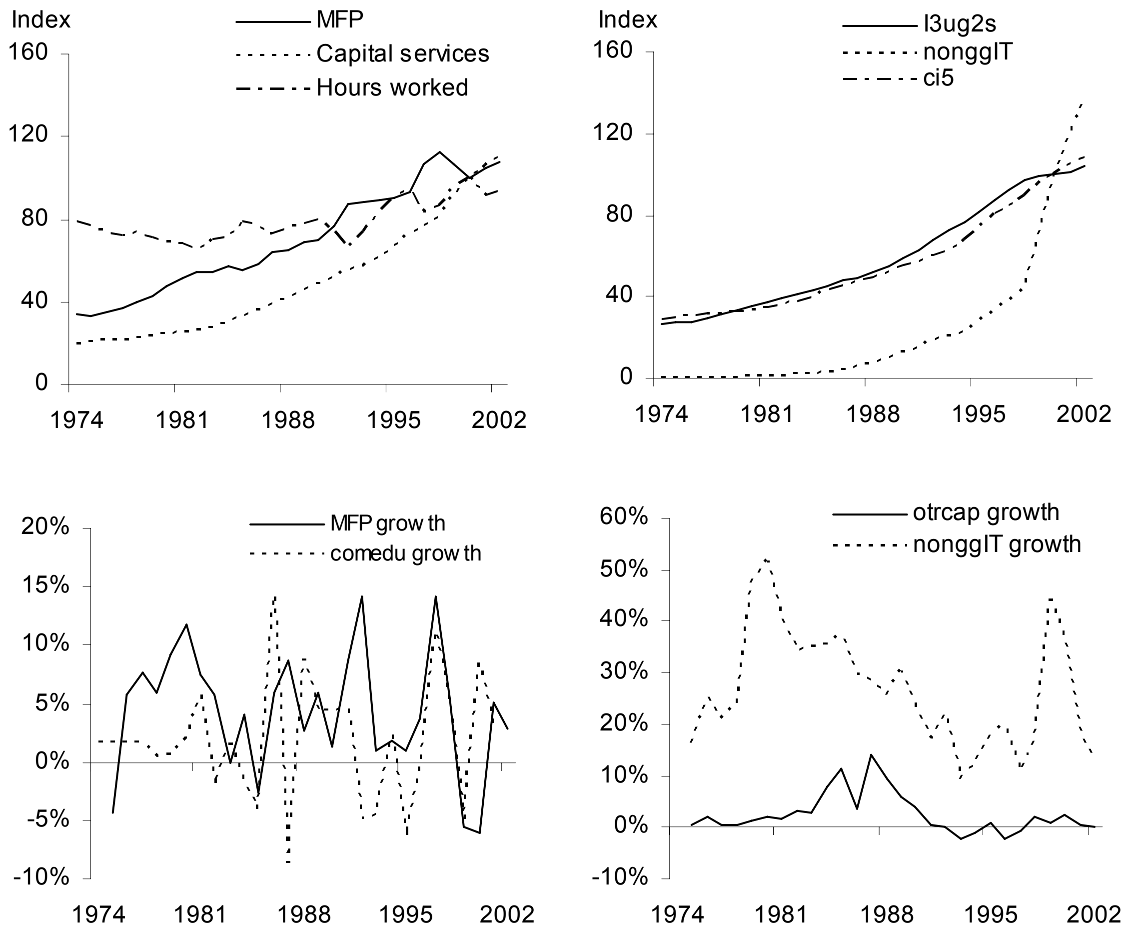
Digitisation of the telecommunications network and the significant increase in the network's capacity to transmit information appears to be part of a process that resulted in significant impacts on the industry's capital. Complementary effects appear to dominate for IT capital, thereby increasing its marginal product. Disruptive effects appear stronger for other private capital.

F.9 Communication services (COM)

Data description

Figure F.18 presents the trends in the main variables for Communication services.

Figure F.18 **Trends in key variables for Communication services**
Index 2000-01 = 100; Percentage growth



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

Unit root testing rejected I(2) (table F.20). Most tests pointed towards I(1), although some tests favoured I(0) with structural break(s). For MFP, dfuller rejects I(2), but dfgls only rejects I(2) if against I(1) with a trend term — suggesting that the growth rates are stationary around a deterministic trend.

Table F.20 **Unit root test findings for Communication services, 1974-75 to 2002-03**

Critical values of 5 per cent used for tests.

	No breaks[a]	*Zivot-Andrews: single break*[b]	*Additive/Innovational Outlier Clemente, Montanes & Reyes tests*
MFP	I(2) rejected against I(1) with trend	I(1) not rejected. I(2) rejected against I(1) with break in trend at 1991	Additive outlier/Innovational outlier tests do not reject I(1). I(2) rejected against I(1) with breaks at 1984 and 1996
nonggIT	I(1)	I(1) not rejected	Additive outlier tests do not reject I(1). Double break Innovational outlier test rejects I(1) with breaks at 1977 and 1997
comedu	I(1) rejected against trend stationary process	I(1) not rejected	Single/Double break Additive outlier/Innovational outlier tests do not reject I(1)

Source: Authors' estimates.

Results excluding general government and road infrastructure

Tests of usage-adjusted general government or road infrastructure resulted in the same unrealistically large coefficients as for other industries. Non-usage adjusted measures were not significant. Therefore, the tests below focus on detecting the effect of digitisation and IT capital.

Model COM1 tests whether the effect of digitisation increased the marginal product of the industry's entire capital services 'ksrv' (table F.21). As there is some overlap between 'ksrv' and other forms of capital re-entered as explanatory variables, model COM2 tests the interaction between digitisation and the industry's own 'other' capital. The effect of IT capital and education is also investigated in the models. A number of variables consistently tested out of the models, including: 'ITdigi'; an interaction term between 'nonggIT' and 'ci5' when both were included; a dummy for the Y2K bug under various constructions; and a linear time trend. The allowable maximum lag and lag order selection criteria differs across the models.

The main results from models COM1 and COM2 are as follows.

- The digitisation of the copper network appears to have increased the marginal product of the industry's capital stock.
- The industry's IT capital has had a positive excess effect on productivity. The effect is declining slowly. It is possible that the significance of the trend decline

in the effect of IT capital ‘nongtrnd’ is picking up a persistent error in the quality adjustment methods used to construct the IT capital services index, rather than a trend decline in the marginal product of IT capital as such.

- The increase in the proportion of employed with post-secondary school qualifications appears to have had an important positive effect on industry productivity, although it is not particularly well estimated in some regressions and it is sensitive to the inclusion of the trend decline in the elasticity of IT capital.

The models do not provide a clear rejection of the null hypothesis of no long-run co-integrating relationship between the variables. If education is dropped from model COM2a, then its bounds test F-statistic increases to 3.837 and is indeterminate.

The failure of the bounds test to provide a clear acceptance or rejection of the null, suggests that the long-run properties of the models need to be further investigated using other estimation strategies. A model was estimated using FMOLS. FMOLS is sensitive to the requirement that the dependent variable and regressors are I(1), as tended to be favoured by the unit root tests in table F.20.

The FMOLS results provide support for the direction and the magnitude of effects found in models COM1 and COM2. IT capital and rising human capital had large, positive effects on industry MFP. Digitisation of the copper network increased the marginal product of the industry’s own ‘other’ capital. The construction of ‘otrcapdg’ conditions the effect of other capital on the share of access lines digitised and the elasticity must be evaluated at different values. From 1998-99, the share of access lines is 100 per cent, so the elasticity is just the estimated coefficient as presented in the tables. For values between 1990-91 and 1998-99, the economic magnitude of the elasticity is less than the presented coefficient.

Table F.21 **Effects on Communication services MFP**

Standard errors in brackets.

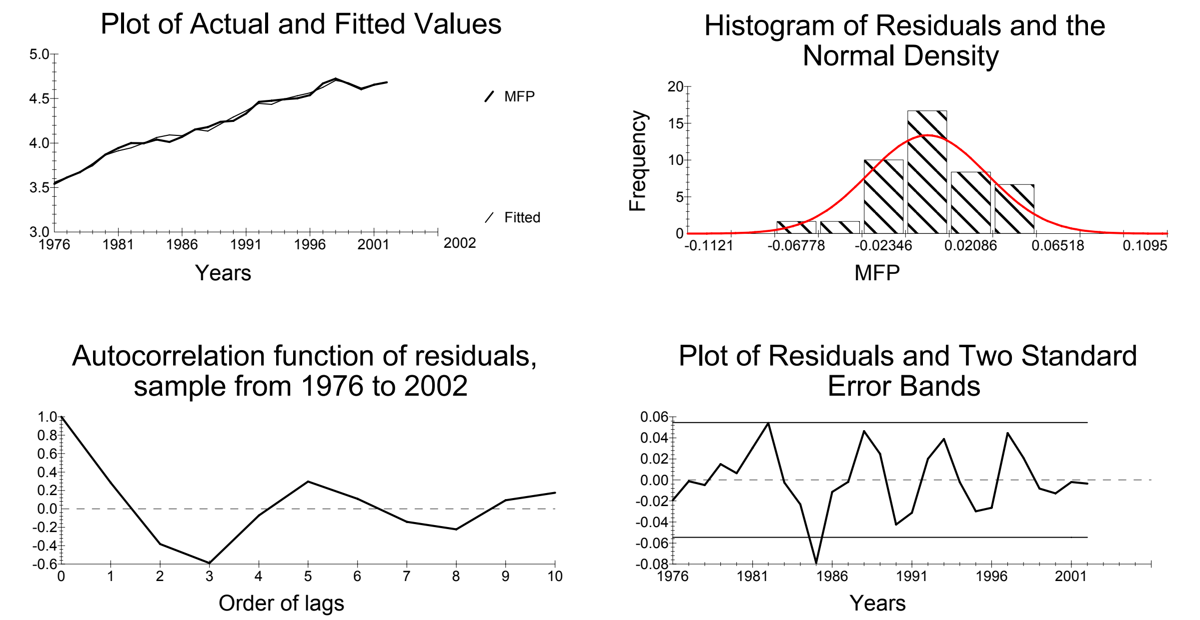
Lag order	*(2,0,0,0,0)*	*(2,1,0,1,0)*	*(1,1,0,1,0)*	*(2,1,0,0,0)*	*(1,1,1,1,0)*	*-*
Max. lag	*2*	*2*	*1*	*2*	*1*	
Selection	*SBC*	*AIC*	*SBC*	*SBC*	*AIC*	*FM OLS*[d]
Model	*COM1a*	*COM1b*	*COM1c*	*COM2a*	*COM2b*	*COM3*
ksrvdg	0.120 ***	0.134 ***	0.154 ***	-	-	-
	(0.016)	(0.017)	(0.023)			
otrcapdg	-	-	-	0.112 ***	0.132 ***	0.083 ***
				(0.014)	(0.020)	(0.017)
nongglT	0.224 ***	0.247 ***	0.267 ***	0.218 ***	0.259 ***	0.241 ***
	(0.016)	(0.020)	(0.027)	(0.015)	(0.034)	(0.020)
nongtrnd[e]	-0.006 ***	-0.007 ***	-0.009 ***	-0.005 ***	-0.007 ***	-0.007 ***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
comedu	0.234	0.278 *	0.469 **	0.192	0.408 *	0.323 **
	(0.168)	(0.160)	(0.204)	(0.148)	(0.209)	0.127)
intercept	2.915 ***	2.757 ***	1.986 **	3.089 ***	2.189 **	2.539 ***
	(0.727)	(0.687)	(0.884)	(0.642)	(0.912)	(0.551)
opgaph11	1.252 **	0.790	1.129 *	0.911 *	1.278 *	1.174 ***
	(0.514)	(0.492)	(0.555)	(0.470)	(0.661)	(0.317)
ECM(-1)	-0.879 ***	-0.898 ***	-0.669 ***	-0.965 ***	-0.678 ***	-
	(0.169)	(0.177)	(0.147)	(0.178)	(0.165)	
Test statistics						
No. of observations	27	27	28	27	26	27
Time period	76-02	76-02	75-02	76-02	77-02	76-02
Step 1 test	2.500	2.500	3.325	2.845	3.412	-
Long run forcing?	?[a]	?[a]	?[b]	Y	?[c]	-
R^2	0.995	0.996	0.996	0.996	0.995	-
Std. Error of Reg.	0.029	0.028	0.030	0.029	0.030	-
DW ‘d’ stat .	2.143	2.090	1.562	2.135	1.615	-
Durbin’s ‘h’ stat.	-	-	1.849	-	1.820	-
			(0.065)		(0.069)	
Serial correlation	0.244	0.113	1.535	0.197	1.198	-
	(0.627)	(0.741)	(0.231)	(0.662)	(0.291)	
Functional form	0.214	0.075	0.061	0.283	0.170	-
	(0.649)	(0.787)	(0.807)	(0.601)	(0.685)	
Normality	5.764	12.468	2.490	10.303	5.672	-
	(0.056)	(0.002)	(0.288)	(0.006)	(0.059)	
Hetero.	0.001	0.030	0.118	0.000	0.006	-
	(0.976)	(0.863)	(0.734)	(0.992)	(0.937)	
AIC (SBC)	54(48)	55(48)	55(49)	54(48)	50(44)	-

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. **a** F-statistic for comedu indeterminate at 2.983. **b** F-statistic for nongtrnd indeterminate at 3.500. **c** F-statistic for nongtrnd of 3.472. **d** Estimated with Phillips and Hansen (1990) Fully Modified OLS. Bartlett lag windows used with lags between two and five. The results were not sensitive to the number of lags used or to the inclusion of the cycle variable which is not I(1). Assumed drift in at least one variable. **e** Mean trend value over the sample is 21.5.

Source: Authors’ estimates.

The statistical properties of models COM1 and COM2 are reasonable, except for the failure of the normality tests. The residuals of model COM3 show residual autocorrelation (figure F.19). As the sample is shortened by dropping the earliest observations, the presence of residual autocorrelation diminishes. The coefficients on 'otrcapdg' and 'nonggIT' remains highly significant, but after 1985 education is no longer significant.

Figure F.19 **Post-estimation tests for model COM3 with estimated FMOLS**



Data source: Authors' estimates.

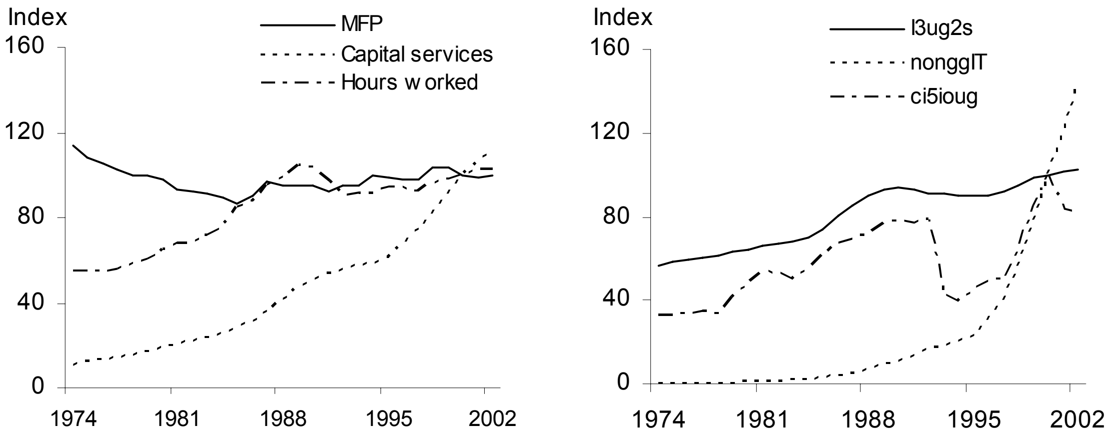
F.10 Finance & insurance (FIN)

Data description

Figure F.20 presents the trends in the main variables for Finance & insurance. MFP decreased until the mid-1980s, than began to increase. Capital services have increased very strongly.

Figure F.20 **Trends in key variables for Finance & insurance**

Index 2000-01 = 100



Data sources: MFP are Commission estimates; other variables are authors' estimates based on unpublished ABS data.

The unit root tests without breaks indicate that the variables are of an order less than I(2) (table F.22). MFP, private IT capital, and private IT capital conditioned on digitisation appear characterised by a drift. The Zivot-Andrews tests indicate that a number of the variables are level stationary I(0) with a break in intercept. The innovational outlier tests point to structural breaks in the early to mid-1980s and then again in the early to mid-1990s.

Table F.22 **Unit root test findings for Finance & insurance, 1974-75 to 2002-03**

Critical values of 5 per cent used for tests.

	No breaks [a]	*Zivot-Andrews: single break* [b]	*Innovational Outlier tests*
MFP	I(0) with drift or I(1) with trend	I(2) rejected against I(1) with trend break and min. t-stat at 1987	Single and double break Innov. outlier tests reject I(2) with breaks at 1984 & 90
Communications infrastructure (ci5ioug)	I(1)	I(1) rejected against I(0) with intercept break and min. t-stat at 1993	Single break Innov. outlier rejects I(2) with break at 1992. Double break Innov. outlier rejects I(2) with breaks at 1992 & 95
Private IT capital (nonggIT)	I(0) with drift, but very sensitive to specific test	Break in trend and intercept tests indicate I(2)	Single break Innov. outlier tests indicates I(2). Double break test indicates I(0) with breaks at 1982 and 94.
IT capital and digitisation (ITdigi)	I(0) with drift, but very sensitive to specific test	Break in intercept indicates I(0) with min. t-stat at 1993	Single and double break tests do not reject I(2)
Education (finedu)	I(1)	Break in intercept indicates I(0) with min. t-stat at 1996	Single and double break tests do not reject I(2) with breaks at 1992 & 96

Source: Authors' estimates.

Results

Tests of usage-adjusted general government or road infrastructure resulted in the same unrealistically large coefficients as for other industries. Non-usage adjusted measures were not significant. Therefore, the tests below focus on detecting the effect of communication infrastructure.

Table F.23 presents results based on the ARDL co-integration technique and table F.24 presents results based on other estimation strategies (first differencing, standard OLS in levels and FMOLS). The strategies were investigated as some of the ARDL models did not pass bounds and/or forcing tests, or, where they did, there was some other aspect to the model that was not entirely satisfactory. All of the selected ARDL models are dynamic models.

From the regressions undertaken, the key results are as follows.

- IT capital had a significant negative effect on industry productivity, but its elasticity increased markedly post-1985. Overall, there is solid evidence of substantial variation in the effect of IT capital.
- There is evidence of a positive effect of communication infrastructure both directly and, more robustly, through the interaction between digitisation and the industry's other capital.
- There is no evidence of a significant positive effect in the interaction between the industry's IT capital and digitisation of the copper network.
- Increases in the quality of labour appear to have had a very economically significant positive impact on industry productivity.

These results hold under different model specifications/variable sets and estimation strategies. However, the magnitude of the estimated effects vary substantially.

There is no single preferred ARDL model. Models FIN2 and FIN6 pass both the bounds and forcing tests, but the degree of negative serial correlation in model FIN6 is a concern. FIN2 contains only other capital and IT capital with the model indicating that the elasticity on IT capital may have become positive post-1985. Models FIN1 and FIN3 to FIN5 do not pass the bounds or all of the forcing tests, but are statistically adequate otherwise. Information criteria select model FIN3.

To capture changes in the effect of IT capital, the models include slope shifts. A different approach is to choose different functional forms for the variable. For example, if a squared term is entered for 'nonggIT' (not shown), then the primary coefficient is negative and significant at around -0.080 (depending on the model) and the squared term is positive and significant at around +0.004. Conditioning the effect of IT capital on its own level would be one way of picking up various possible network effects as IT became increasingly diffused throughout the economy. Modelling the effect as a quadratic or higher polynomial runs into the problem that the effects can continue to increase or decrease indefinitely. Other functional forms could be chosen that bound the effect to avoid this problem (such as allowing the effect of IT capital to change over time governed by a logit function or modelling the effect of IT capital within a 'smooth transition' framework).

The regression results provide reasonably robust evidence that Finance & insurance has struggled to realise significant productivity improvements from IT capital. The problem does not appear related to the digitisation of the copper network, possibly because the industry is fairly concentrated and major players in the industry made significant use of dedicated high speed lines throughout most of the 1980s. Those 'private' lines are not captured in the digitisation variables.

Table F.23 **Effects on Finance & insurance MFP**

Standard errors in brackets. Selected by SBC.

Lag order	*(1,0,0,0,0)*	*(1,0,1,1)*	*(1,0,0,0,1,0,0,0)*	*(1,0,0,0)*	*(1,0,0,0,1,0)*	*(2,1,0,1,0)*
Model	*FIN1*[g]	*FIN2*[c]	*FIN3*	*FIN4*[d]	*FIN5*	*FIN6*
otrcapdg	0.081 *	0.011 *	0.060 ***	0.128 ***	0.028 ***	0.037 ***
	(0.040)	(0.006)	(0.011)	(0.029)	(0.006)	(0.005)
ci5ioug	0.134 *	-	0.046 **	0.076 *	0.032 **	-
	(0.066)		(0.019)	(0.038)	(0.015)	
nonggIT	-0.204 **	-0.053 ***	-0.068 ***	-	-0.083 ***	-0.032 **
	(0.094)	(0.006)	(0.005)		(0.008)	(0.014)
nongs85	-	0.064 ***	0.074 ***	-	0.042 ***	0.052 ***
		(0.009)	(0.008)		(0.009)	(0.005)
nongs89	-	-	-0.031 ***	-	-	-
			(0.007)			
nongs92	-	-	-0.011 **	-	-	-
			(0.005)			
nongs95	-	-	-0.009 **	-	-	-
			(0.004)			
ITdigi[h]	-0.074 *	-	-	-0.134 ***	-	-
	(0.036)			(0.038)		
QALI	-	-	-	-	0.448 ***	0.363 ***
					(0.128)	(0.081)
intercept	3.299 ***	4.509 ***	4.357 ***	4.723 ***	2.488 ***	3.213 ***
	(0.599)	(0.017)	(0.072)	(0.122)	(0.566)	(0.363)
trend	0.049	-	-	-0.050 ***	-	-0.016 ***
	(0.029)			(0.012)		(0.005)
trendsq	-	-	-	0.001 ***	-	-
				(0.000)		
opgaph11	2.234 ***	0.894 ***	0.951 ***	1.468 ***	0.727 ***	0.393 ***
	(0.779)	(0.224)	(0.153)	(0.494)	(0.164)	(0.095)
ECM(-1)	-0.356 ***	-0.679 ***	-0.691 ***	-0.506 ***	-0.802 ***	-1.103 ***
	(0.106)	(0.103)	(0.075)	(0.138)	(0.107)	(0.112)
Test statistics						
No. of observations	28	28	28	28	28	27
Time period	75-02	75-02	75-02	75-02	75-02	76-02
Step 1 test	3.321	4.499	2.796	2.859	2.479	5.826
Long run forcing?	No[a]	Yes	No[b]	No[e]	No[f]	Yes
R^2	0.939	0.964	0.985	0.940	0.943	0.984
Std. Error of Reg.	0.015	0.012	0.008	0.015	0.010	0.008
DW ‘d’ stat .	2.291	1.924	2.859	2.110	2.204	2.857
Durbin’s ‘h’ stat.	-0.928	0.239	-2.475	-0.428	-0.655	-
	(0.353)	(0.811)	(0.013)	(0.668)	(0.512)	
Serial correlation	0.848	0.004	5.662	0.127	0.337	6.336
	(0.369)	(0.951)	(0.030)	(0.726)	(0.569)	(0.024)
Functional form	0.551	0.016	0.053	1.124	0.067	0.455
	(0.467)	(0.901)	(0.821)	(0.302)	(0.798)	(0.510)

(continued on next page)

Table F.23 **(continued)**

Lag order	*(1,0,0,0,0)*	*(1,0,1,1)*	*(1,0,0,0,1,0, 0,0)*	*(1,0,0,0)*	*(1,0,0,0,1,0)*	*(2,1,0,1,0)*
Model	*FIN1*[g]	*FIN2*[c]	*FIN3*	*FIN4*[d]	*FIN5*	*FIN6*
Normality	1.768	1.098	2.231	1.736	6.563	1.237
	(0.413)	(0.578)	(0.328)	(0.420)	(0.038)	(0.539)
Hetero.	16.398	0.000	0.123	15.072	0.032	0.162
	(0.000)	(0.999)	(0.729)	(0.001)	(0.860)	(0.690)
AIC (SBC)	75(69)	82(77)	92(84)	75(70)	85(79)	89(82)

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The bounds test related to the step 1 F-statistic and the long-run forcing test are described in appendix J. The other statistical tests are described in table E.2. [a] F-statistic for ci5ioug of 7.544. [b] F-statistics for otrcapdg, ci5ioug and nongs89 of 8.103, 8.234, and 14.621, respectively. [c] Variables that tested out were a linear time trend, ci5ioug, ITdigi, and finedu. A single slope shift at 1985 for IT capital was included in the test procedure. [d] Variables that tested out were nonggIT, finedu and ITdigi. [e] F-statistics for otrcapdg, ci5ioug and ITdigi of 4.914, 10.434 and 3.761, respectively. [f] F-statistics ci5ioug and nonggIT of 4.396 and 3.952, respectively. [g] Industry-specific education variable tested out. [h] For Finance & insurance a smoothed version of this variable was used, where a smooth increase in ‘digi’ up to 1990 (where data are available) is assumed (rather than 0 prior to 1990).

Source: Authors’ estimates.

The first differenced results support the direction of the effects from the ARDL models and the instability in the IT capital coefficient (table F.24). FIN8 is preferred over FIN7 as it does not include a trend term and it includes a control for human capital. The trend term was included to test whether there was an unexplained trend increase or decline in the productivity growth rate following the inclusion of the quadratic trend term in model FIN4. A variable deletion test for the IT variables in model FIN8 indicated that they are jointly highly significant.

OLS and FMOLS results provide support for the significance of the effects of digitisation, communication infrastructure and IT capital (models FIN9 and FIN10).

Table F.24 **Alternative estimation strategies for Finance & insurance**[a]

Standard errors in brackets. Selected by SBC.

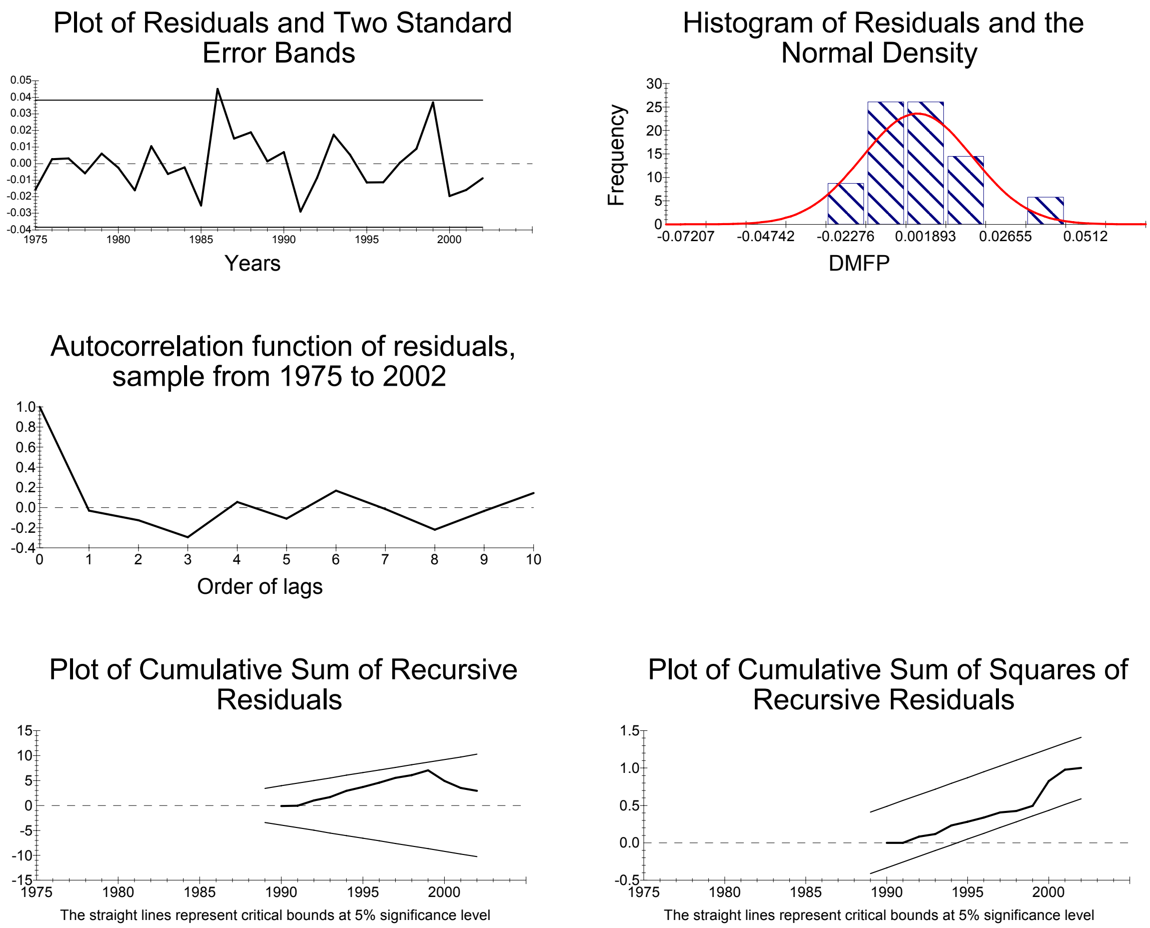
Estimation strategy	*First Differenced*	*First Differenced*	*OLS*	*FM OLS*
Model	*FIN7*[c]	*FIN8*	*FIN9*[b]	*FIN10*[a]
otrcapdg	0.116 ***	0.052 **	0.038 ***	0.036 ***
	(0.039)	(0.022)	(0.007)	(0.004)
ci5ioug	0.054 *	0.037	0.037 *	0.048 ***
	(0.026)	(0.027)	(0.018)	(0.012)
nonggIT	-	-0.081	-0.091 ***	-0.089 ***
		(0.053)	(0.009)	(0.006)
nongs85	-	0.032	0.037 ***	0.038 ***
		(0.025)	(0.011)	(0.007)
nongs89	-0.021 **	-0.021 **	-	-
	(0.010)	(0.010)		
ITdigi[e]	-0.108 *	-	-	-
	(0.052)			
QALI	-	0.473 **	0.451 ***	0.416 ***
		(0.215)	(0.161)	(0.104)
intercept	-0.055 ***	-0.002	2.454 ***	2.562 ***
	(0.014)	(0.017)	(0.712)	(0.459)
trend	0.002 ***	-	-	-
	(0.000)			
opgaph11	0.541 ***	0.504 ***	0.545 ***	0.534 ***
	(0.100)	(0.099)	(0.126)	(0.081)
Test statistics				
No. of observations	28	28	29	28
Time period	75-02	75-02	74-02	75-02
R^2	0.685	0.713	0.941	-
Std. Error of Reg.	0.019	0.019	0.016	-
DW ‘d’ stat .	2.020	1.827	1.869	-
Serial correlation	0.022	0.042	0.040	-
	(0.883)	(0.840)	(0.844)	
Functional form	1.203	0.078	0.158	-
	(0.286)	(0.783)	(0.695)	
Normality	3.075	1.522	37.656	-
	(0.215)	(0.467)	(0.000)	
Hetero.	0.236	1.256	1.120	-
	(0.631)	(0.273)	(0.299)	
AIC (SBC)	68(63)	68(63)	76(71)	-
ADF test of residuals	-	-	-4.211[d]	-

*** statistical significance at 1 per cent or greater. ** statistical significance at 5 per cent or greater. * statistical significance at 10 per cent or greater. Standard errors are in brackets. The other statistical tests are described in table E.2. [a] Trended case using Bartlett weights and truncation lag equal to one. Results not sensitive to longer lag window. [b] A linear time trend and ITdigi tested out of the model. The industry-specific education variable was negatively signed and was replaced with the economywide QALI variable. [c] nonggIT, nongs85 and finedu tested out of the model. [d] Augmented Dickey-Fuller. The null of no co-integrating relationship is rejected. [e] For Finance & insurance a smoothed version of this variable was used, where a smooth increase in ‘digi’ up to 1990 (where data are available) is assumed (rather than 0 prior to 1990).

Source: Authors’ estimates.

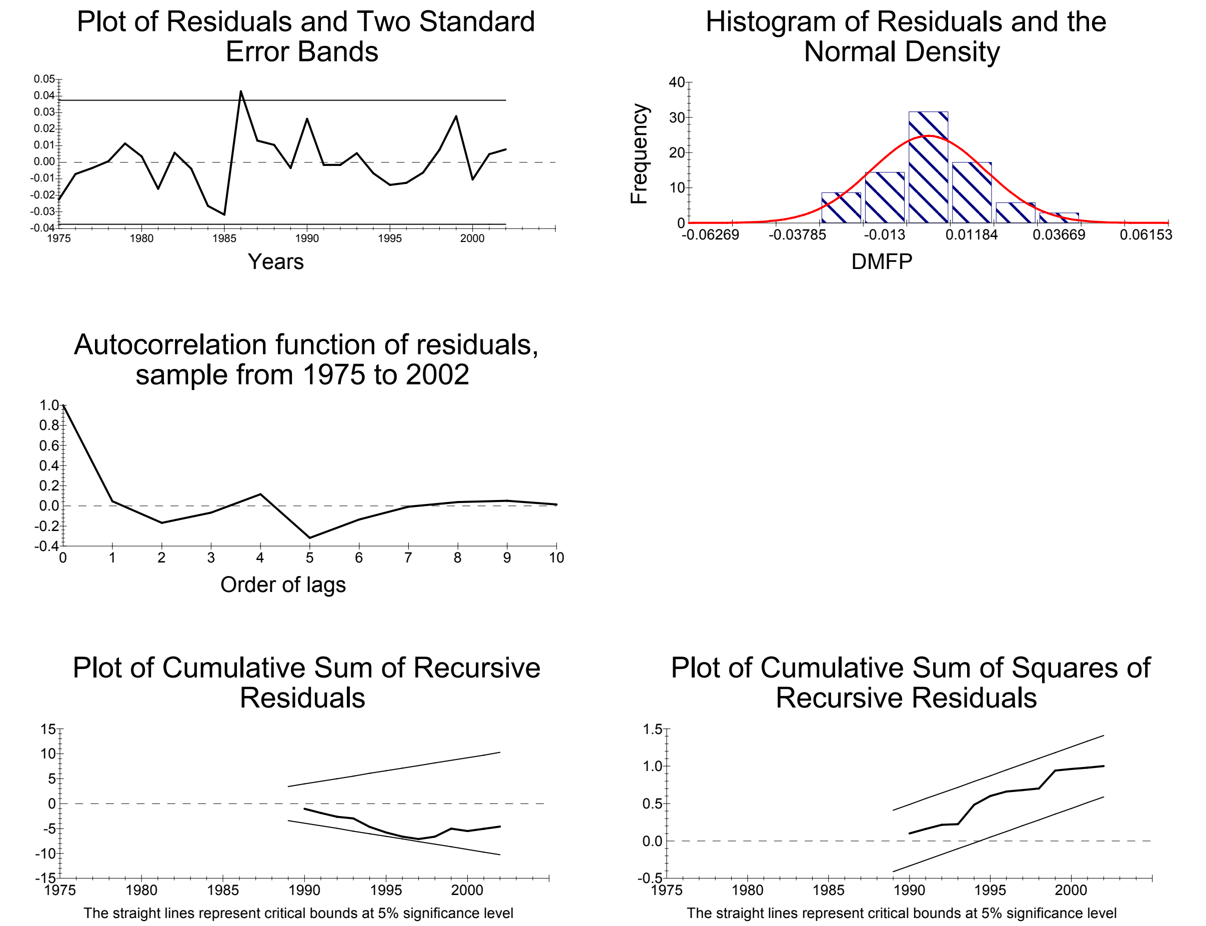
The statistical tests in table F.24 and the tests below do not indicate any major problem with the first differenced models FIN7 (figure F.21) and FIN8 (figure F.22). The distribution of the residuals in FIN8 conform better to the 'normality' requirement, compared with models FIN7, FIN9 and FIN10.

Figure F.21 **Post-estimation tests for model FIN7**



Data source: Authors' estimates.

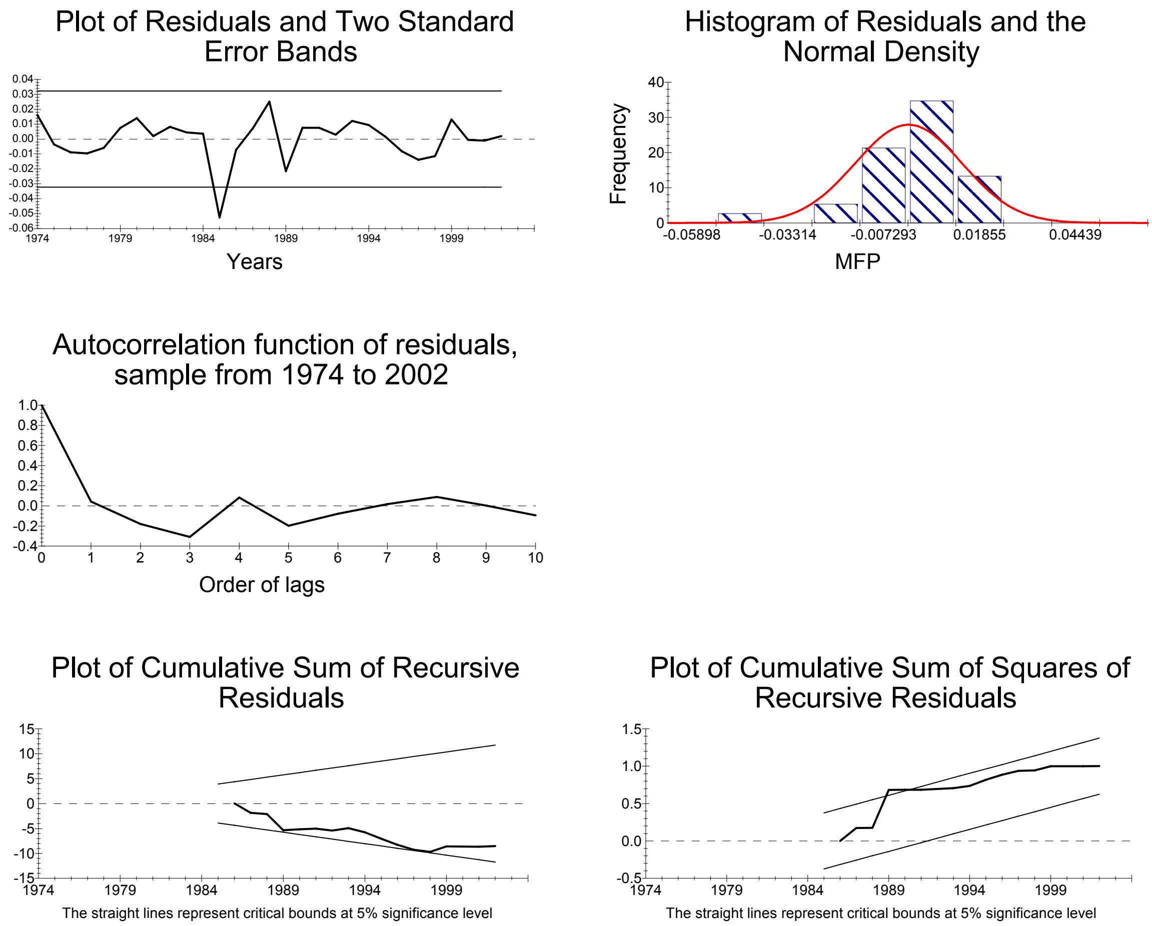
Figure F.22 **Post-estimation tests for model FIN8**



Data source: Authors' estimates.

The CUSUM tests indicate that the parameters of the model are stable for model FIN9 (figure F.23). If 'nongs84' is used rather than 'nongs85', then the CUSUM tests results improve with the test statistic staying more solidly within the 5 per cent critical value bounds for both tests.

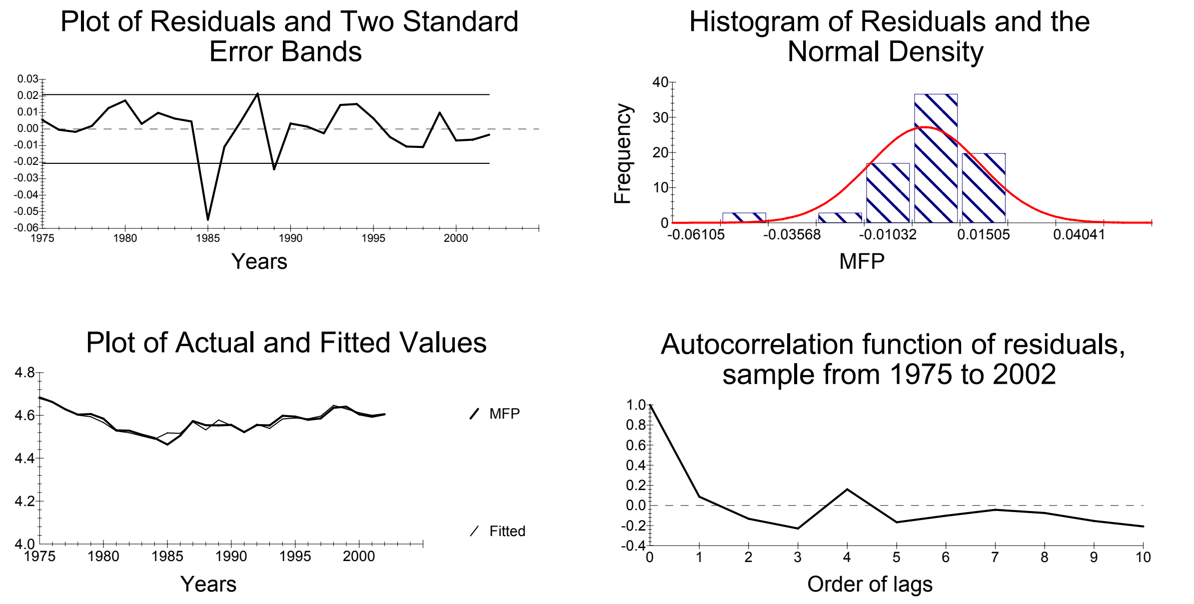
Figure F.23 **Post-estimation tests for model FIN9**



Data source: Authors' estimates.

The residuals of model FIN10 appear satisfactory (figure F.24).

Figure F.24 **Post-estimation tests for model FIN10 estimated with FMOLS**



Data source: Authors' estimates.

F.11 Summary of findings at the industry level

For most industries, the results suggest broadly similar relationships between infrastructure and productivity to those found at the market sector level. However, as expected, the extent of the effect varies by industry. The industry results are also subject to similar, but more acute, estimation difficulties. Market sector models are estimated with greater precision as evidenced by model fit criteria. One reason for this is that market sector data are viewed as being of higher quality.

The risks of data mining are more substantial for some of the industry results, although the appendixes provide a great deal of information on tests undertaken, which should provide a fair reflection of the robustness of the results.

Despite the problems, the industry results in this study do contribute to the growing Australia literature on industry productivity. Other studies have also encountered significant problems when working with industry data.

Elasticities from preferred industry models

The elasticities have been selected from the large number of regressions detailed above. The acceptance criteria for the models are the same as those used for market sector (see appendix E).

Except in a couple of instances, robust estimates of the effect of road infrastructure and communication infrastructure could not be obtained within the same test down procedure (which was also the case for the market sector).

Excluding road infrastructure

The results from the preferred industry models containing communication infrastructure (table F.25) provide some evidence in support of the results from the preferred market sector models (table E.16). However, the results for particular infrastructure variables vary considerably across industries. This would be expected as a result of industry specific effects but may also be due to measurement issues and the significant difficulties in modelling industry MFP.

In line with the market sector results, communications infrastructure had a positive effect on industry MFP (for those industries where it survived the test down procedure). The industry results range from 0.03 to 0.10 (with the results from the market sector MFP models about mid-range at 0.05). The industries in this range are Transport & storage, Manufacturing, Wholesale trade and Electricity, gas & water (from largest to smallest effect).[2] For Construction, Retail trade and Finance & insurance the variable tested out (although there were some reasonable models for Finance & insurance that also had a positive coefficient on communication infrastructure within this range). For Communication services, re-entering communication capital services did not provide evidence of an excess effect.

The preferred industry models also provide some support for the market sector results of the effect of digitisation interacted with IT capital. (See appendix E for further discussion of the method of modelling this effect.) For five of the seven industries for which the preferred model included this variable, digitisation enhanced the effect of IT capital on MFP (as was the case for the market sector). The exceptions are Mining and Manufacturing, for which the effect was negative (suggesting disruption effects). However, all the positive industry results were considerably larger than those for the market sector — with an industry range of 0.027 to 0.201 compared with a market sector range of 0.006 to 0.015. The largest positive effects were for Wholesale trade and Transport & storage.

The results for the interaction between other private industry capital and digitisation (a variable not included in the preferred market sector models) varied by industry. Digitisation increased the marginal product of other private capital for Communication services and Finance & insurance (complementary effects) but reduced it for Wholesale trade, Retail trade and Transport & storage (disruption/substitution effects).[3]

Alternative methods of modelling digitisation, tested for the market sector, were not tested at the industry level.

Including road infrastructure

The industry models including road infrastructure did not meet the model acceptance criteria, in particular, the bounds and forcing tests, or did not meet them as well as the equivalent models without road infrastructure. The coefficients on road infrastructure were either very large (and considerably larger than those for the market sector) or not statistically significant. In all cases except Manufacturing, the statistical significance of the road infrastructure measure was driven by the usage adjustment — only in Manufacturing was the unadjusted roads measure significant and even this model was not fully satisfactory.

2 For Agriculture, forestry & fishing and Mining the communications coefficient was not statistically significant.

3 The coefficient was also negative for Mining, but was not statistically significant.

Results for some industry models including road infrastructure are presented in table F.26. However, the road infrastructure coefficients are implausibly large (or 'stratospheric' as Gramlich (1994) described similar results in other empirical studies of infrastructure) — even allowing for their interpretation as including a 'free' input effect as well as any 'excess' effect (for industries other than Transport & storage). The magnitude (and in some cases sign) of the communication infrastructure coefficient in these models also changed considerably (compared with those from models without road infrastructure). The results from table F.25 are substantially better.

Table F.25 **Preferred industry MFP regressions without general government infrastructure or road infrastructure**

Industry	*AG*	*MIN*	*MAN*	*EGW*	*CON*	*WT*	*RT*	*TS*	*COM*	*FIN*
Model	*AGS1*	*MIN5*	*MAN4a*	*EGW5*	*CON1*	*WT4*	*RT6*	*TS6*	*COM2a*	*FIN6*[d]
Communication infrastructure[e]	0.097[j] (0.072)	0.102 (0.028)	0.080 (0.034)	0.033 (0.013)	-	0.065 (0.034)	-	0.108 (0.035)	-	-
Industry 'private' IT capital[f]	-	-	-0.077 (0.032)	-0.099 (0.021)	-	-	0.059 (0.006)	0.050 (0.010)	0.218 (0.015)	-0.032 (0.014)
Industry 'private' IT conditioned on digitisation[c]	0.063 (0.018)	-0.041 (0.022)	-0.042 (0.008)	-	0.027 (0.006)	0.201 (0.047)	0.053 (0.012)	0.097 (0.027)	-	-
IT trend[g]	-	-	-	-	-	-	-	-	-0.005 (0.001)	-
IT slope shift (1985 or 1986)[h]	-	-	-	-	-	-	-0.093 (0.010)	-0.025 (0.011)	-	0.052 (0.005)
Industry 'other' private capital conditioned on digitisation[i]	-	-	-	-	-	-0.176 (0.061)	-0.011[j] (0.013)	-0.096 (0.028)	0.112 (0.014)	0.037 (0.005)
Acceptance criteria[a]										
Statistically acceptable?	Yes	Yes	Yes	Yes	Yes	Yes	Yes[k]	Yes	Yes	Yes
Passes bounds test?[b]	Yes	na	Yes	na	Yes	Yes	na	Ind.	< l.b.c.v.[l]	Yes
Any clear long-run forcing test failures?	No	na	Yes	na	No	No	na	No	No	No
Other sources of growth controlled?	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Yes	Yes	Yes
Plausible magnitudes and signs?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

'-' tested out or not included in model. **na** Test not applicable. **a** The bounds test and long-run forcing tests are described in appendix J and the other statistical tests are described in appendix E. **b** Test returns F-statistic below lower bound critical value '< l.b.c.v.', or indeterminate 'Ind.'. **c** Variable is industry ITdigi. For Finance & insurance and Manufacturing a smoothed version of this variable was used, where a smooth increase in 'digi' up to 1990 (where data are available) is assumed (rather than 0 prior to 1990). **d** While this is the preferred model on the acceptance criteria there a number of other reasonable models that have a coefficient on ci5ioug of >+0.03 and statistically significant. **e** All results based on input-output adjusted communication infrastructure 'ci5ioug'. **f** Variable is industry 'nonggIT'. **g** Variable is 'nongtrnd'. **h** Variable is 'nongs85' or 'nongs86'. **i** Variable is industry 'otrcapdg'. **j** Not significant. **k** Estimated with fully modified OLS. High degree of 1st order serial correlation that disappears as estimation restricted to more recent data. When estimation is based on the sample 1984-85 to 2002-03, the residuals are white and the coefficient and standard errors for 'otrcapdg' and 'ITdigi' are -0.016 (0.007) and 0.074 (0.007), respectively. **l** As the bounds test was below the lower bound critical value, FMOLS was also used to estimate the model. The direction of effects were the same, and the magnitude.

Source: Authors' estimates.

Table F.26 **Selected industry MFP regressions including road infrastructure**

Industry *Model*	*AG* *AG11*	*MIN* *MIN2*	*MAN* *MAN3c*	*EGW* *EGW1*	*WT* *WTR2*	*RT* *RT2*	*TS* *TSR2*
Road infrastructure[c]	0.852 (0.039)	0.806 (0.094)	0.550 (0.189)	2.264 (1.013)	0.449 (0.195)	0.468 (0.149)	0.747 (0.074)
Communication infrastructure[d]	-0.025[l] (0.016)	-	-0.086 (0.013)	0.122[l] (0.085)	0.061 (0.023)	-0.074 (0.038)	0.032 (0.010)
Industry ‘private’ IT capital[e]	-	-	0.129 (0.022)	-0.237 (0.087)	-0.143 (0.036)	0.038 (0.009)	-0.050 (0.009)
Industry ‘private’ IT capital conditioned on digitisation[f]	-	-	-	-	-	-	-
IT slope shift 1985[i]	-	-	-	-	-	-0.051 (0.015)	-
IT slope shift 1995[j]	-	-	-	-	0.032 (0.008)	0.016 (0.005)	-
Industry ‘other’ private capital conditioned on digitisation[k]	-		-	-	-	0.025 (0.009)	-
Acceptance criteria[a]							
Statistically acceptable?	Yes	Yes	Partial[g]	Yes	Yes	Partial	Yes
Passes bounds test?[b]	Yes	na	Yes	No	No	Yes	No
Any clear long-run forcing test failures?[h]	No	na	Yes	Yes	Yes	Yes	Yes
Other sources of growth controlled?	Yes	Yes	Yes	No	Yes	Yes	Yes
Plausible magnitudes and signs?	Partial	Partial	No	No	Partial	Partial	Partial

‘-‘ tested out or not included in model. **na** Test not applicable. [a] The bounds test and long-run forcing tests are described in appendix J and the other statistical tests are described in appendix E. [b] Test returns F-statistic below lower bound critical value ‘< l.b.c.v.’, or indeterminate ‘Ind.’. [c] Variable is ‘roadug2’ except for MAN, which uses roads. [d] Variable is ‘ci5ioug’. [e] Variable is ‘nonggIT’. [f] Variable is ‘ITdigi’. For Manufacturing a smoothed version of this variable was used, where a smooth increase in ‘digi’ up to 1990 (where data are available) is assumed (rather than 0 prior to 1990). [g] High negative serial correlation. [h] See relevant industry sections above for further details. [i] Variable is ‘nongs85’. [j] Variable is ‘nongs95’. [k] Variable is ‘otrcapdg’. [l] Not significant.

Source: Authors’ estimates

Gross returns at the industry level

While the level of estimated elasticity is informative, it is often of more interest to derive the rate of return to infrastructure. Some of the criticisms of Aschauer (1989a) and similar studies are based on the implausibility of the rates of return — the rates of return making the size of the effect more obvious than the actual elasticities.

It should be noted that, even aside from any imprecision in estimation, the rates of return presented in this paper should be interpreted as indicative. A rate of return on capital (as conceived in the economics literature) generally measures the additional output generated from an increase in capital — by multiplying the output elasticity (from an estimated production function) by the observed ratio of output to capital. However, the rates of return presented in this paper are based on MFP elasticities rather than output elasticities. Nevertheless, even though they are conceptually different, estimated MFP and output elasticities are likely to be quite similar in magnitude.[4] Consequently, the MFP-based rates of return presented here are likely to be close approximations to output-based rates of return.

The indicative rates of return at the industry level are listed in table F.27 (based on the elasticities from table F.25 and F.26). Again, the possible returns to road infrastructure cover a wide band (but a narrower band than at the market sector level). Evaluated at the mean intensity for the period 1974-75 to 2002-03, the return to road infrastructure across industries ranges from 2 to 84 per cent. The industries with the highest returns are Manufacturing and Electricity, gas & water.

The possible returns to communication infrastructure cover a narrower band than those to road infrastructure (as was the case for the market sector).[5] Evaluated at the mean intensity for the period 1974-75 to 2002-03, the return to communications infrastructure (in models not including road infrastructure[6]) range from -2 to 24 per cent — a range that takes in zero (no effect) in all cases. There is little variation across industries, except for Manufacturing that has the highest rate of return

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[4] These elasticities will differ to the extent that the assumptions used in the construction of MFP estimates (constant returns to scale and factors paid according to their marginal products) do not hold.

[5] The caveats about the rate of return calculation for the market sector also apply at the industry level.

[6] As noted above, robust estimates of the effect of road infrastructure and communication infrastructure could not be obtained within the same test down procedure — in the models with both road and communication infrastructure the rates of return on the latter are lower for most industries.

(around double that of other industries) and Electricity, gas & water with the lowest rate of return (close to zero).

Table F.27 **Implied gross rates of return[a] to infrastructure from the industry models**

Rate of return band based on minus or plus two standard errors, per cent

			Rate of return		
Infrastructure type	*Model*	*Elasticity (Std. error)*	*1974-75 to 2002-03*	*1974-75 to 1988-89*	*1989-90 to 2002-03*
		Models including communications infrastructure[c]			
Comm. infrastructure					
Ag., forestry & fishing	AGS1	0.097 (0.072)	-2 to 11	-2 to 12	-2 to 9
Mining	MIN5	0.102 (0.028)	2 to 8	2 to 8	2 to 9
Manufacturing	MAN4c	0.080 (0.034)	2 to 24	2 to 29	2 to 19
Electricity, gas & water	EGW5	0.033 (0.013)	0 to 2	0 to 2	0 to 2
Wholesale trade	WT4	0.065 (0.034)	0 to 8	0 to 10	0 to 7
Transport & storage	TS6	0.108 (0.035)	2 to 10	2 to 10	2 to 9
		Models including road infrastructure and communications infrastructure[b]			
Comm. infrastructure[d]					
Ag., forestry & fishing	AG11	-0.025 (0.016)	-2 to 0	-3 to 0	-2 to 0
Manufacturing	MAN3c	-0.086 (0.013)	-18 to -10	-22 to -12	-15 to -8
Electricity, gas & water	EGW1	0.065 (0.034)	-1 to 9	-2 to 10	-1 to 8
Wholesale trade	WTR2	0.061 (0.023)	1 to 7	1 to 8	1 to 6
Retail trade	RT2	-0.074 (0.038)	-9 to 0	-11 to 0	-8 to 0
Transport & storage	TSR2	0.032 (0.010)	1 to 3	1 to 3	1 to 3
Road infrastructure[e]					
Ag., forestry & fishing	AG11	0.852 (0.039)	19 to 23	17 to 21	21 to 25
Mining	MIN2	0.806 (0.094)	19 to 31	14 to 22	25 to 41
Manufacturing	MAN3c	0.550 (0.189)	16 to 84	15 to 79	17 to 90
Electricity, gas & water	EGW1	2.264 (1.013)	4 to 75	3 to 62	5 to 88
Wholesale trade	WTR2	0.449 (0.195)	2 to 30	2 to 26	2 to 34
Retail trade	RT2	0.468 (0.149)	6 to 27	5 to 24	7 to 31
Transport & storage	TSR2	0.747 (0.074)	19 to 29	16 to 23	24 to 35

[a] The rates of returns for communication infrastructure are only indicative. They use the average of the simple sum of productive capital stocks of several asset types in chain volume terms — productive capital stocks are not strictly additive and the addition will also be less accurate the further away from the base year (2001-02). [b] Communication infrastructure tested out of the Mining model MIN2. [c] Communication infrastructure tested out of the models for Construction, Communication services, Finance & insurance and Retail trade. [d] Road and communication infrastructure both tested out of the models for Construction, Communication services and Finance & insurance. [e] Usage-adjusted road infrastructure 'roadug2' for all industries except for Manufacturing, which uses 'roads'.

Source: Authors' estimates.

Comparison with other studies

Comparisons with other studies are not straightforward because of the different approaches taken, different time periods and the varying amounts of information reported. For example, it is not possible to directly compare the elasticities and rates of returns from cost function studies with those of production function studies.[7]

Public infrastructure

For Australian industry studies, the range of elasticity estimates for public infrastructure is very wide — -0.26 to 3.50 across all industries. The range for most individual industries is similarly wide and there is no real pattern in terms of which industries have the largest/smallest effects (see table A.3 for further details). The preferred industry estimates in this paper again fit within this range (at the positive end) and are also implausible in magnitude (table F.28). Only Paul (2003) reports comparable rates of returns. His point estimates are below the confidence intervals for the preferred models in this paper for Agriculture, Mining and Transport, storage & communication, at the bottom of the confidence interval for Manufacturing and just above the confidence interval for Wholesale & retail trade.

As discussed earlier, this study does not take account of average capacity utilisation changes or congestion. Previous studies also omitted these potentially important factors. This study has also shown that the industry results for road infrastructure are driven by the usage adjustment factor. A value-added adjustment factor breaks the requirement that inputs and outputs be measured independently. As such, the large elasticities in this and previous studies cannot be interpreted as intended — that is, that changes in road infrastructure causes productivity growth.

[7] It is possible to derive the primal (output-side) measure from the cost function but these measures will still only be comparable if the assumption of constant returns to scale holds.

Table F.28 **Comparison of public infrastructure[a] industry models**

Rate of return band based on minus or plus two standard errors, per cent

Industry	Model – this study	*Elasticity (standard error)* This study	Otto & Voss (1994a)[d]	Paul (2003)[c]	Range of other studies	*Rate of return Point estimate (range)* This study 1974-75 to 2002-03	Paul (2003)[b] 1968-69 to 1995-96
Ag., forestry & fishing	AG11	0.852 (0.039)	0.41 (0.673)	0.94 (0.26)	0.28 – 1.72	21 (19 to 23)	6.1
Mining	MIN2	0.806 (0.094)	2.04 (0.589)	1.27 (0.68)	1.07 – 2.04	25 (19 to 31)	7.4
Manu-facturing	MAN3c	0.550 (0.189)	0.27 (0.157)	0.68 (0.17)	-0.26 – 1.39	50 (16 to 84)	16.8
Electricity, gas & water	EGW1	2.264 (1.013)				39 (4 to 75)	
Wholesale trade	WTR2	0.449 (0.195)	0.24 (0.135) [WRT]	1.15 (0.17) [WRT]	-0.15 – 2.85 [WRT]	16 (2 to 30)	31.3 [WRT]
Retail trade	RT2	0.468 (0.149)				17 (6 to 27)	
Transport & storage	TSR2	0.747 (0.074)	-0.24 (0.161) [TSC]	1.23 (0.45) [TSC]	-0.24 – 3.50 [TSC]	24 (19 to 29)	9.2 [TSC]

WRT = Wholesale and retail trade; TSC = Transport, storage and communications. [a] For results from this study, usage-adjusted road infrastructure 'roadug2' for all industries except Manufacturing, which use 'roads'. Paul (2003) uses net general government capital stock. Otto and Voss (1994a) uses gross general government capital stock. [b] Paul (2003) does not report by industry the rate of return calculated by the same method he used for the market sector (that is, dividing marginal benefit by marginal cost). However, the marginal output benefit he reports is equivalent to the rates of return method used for the calculations in this paper. [c] Primal measures derived from cost function approach. [d] Restricted increasing returns to scale specification for capital productivity. MFP specification not reported but coefficients were reported not to be stable between specifications. Otto and Voss (1994a) noted that at the sectoral level their results were generally poor.

Source: Authors' estimates; Paul (2003); Otto and Voss (1994a); table A.3.

Communication infrastructure

There appear to be no studies that provide enough information to make direct comparisons of results of the effect of communications infrastructure (as defined in this paper[8]). The US study by Nadiri and Nandi (2001) used a cost function approach rather than the production function approach used in this study. While both this study and Nadiri and Nandi (2001) find positive spillovers from communication infrastructure, the different approaches taken mean the magnitudes of the results are not directly comparable.

8 Communication network infrastructure rather than information and (tele)communication technology capital in general.

However, it is possible to make some broad comparisons. While cost and output elasticities are not directly comparable (except under the assumption of constant returns to scale, which is not likely to hold for all industries), it is possible to look for patterns across industries (table F.29). Nadiri and Nandi (2001) found positive spillovers for all industries examined and relatively high marginal cost benefits in the service industries (such as Wholesale & retail trade and Finance & insurance), which they suggest is a reflection of the high information intensities of these industries. This industry pattern is not as apparent in the preferred models in this paper — for Retail trade and Finance & insurance, for example, communication infrastructure was not statistically significant. The imprecision of the preferred model estimates also mean that the rate of return bands for most industries include zero (or no effect). However, communication infrastructure was statistically significant for Wholesale trade and there are other acceptable Finance & insurance models (see tables F.23 and F.24).[9]

For the effect of digitisation there are also few direct comparisons available. However, the generally positive estimates for the interaction between digitisation and IT capital found in this paper accord with the results of Barker et al. (2006) — that digitisation of telecommunications infrastructure improved the productivity impact of increases in the penetration of personal computers.

Assuming communication infrastructure plays broadly the same role in influencing productivity as in the United States, it might be expected that estimated returns in Australia would be somewhat higher if Australia lags the United States in the completion of major networks or the significant upgrading of those networks.

9 In addition, there is a positive effect of digitisation of the copper network in Wholesale trade and Retail trade (and other industries such as Agriculture and Transport & storage).

Table F.29 **Comparison of communication infrastructure industry models**

Rate of return band based on minus or plus two standard errors, per cent

		Elasticity (standard error)		*Rate of return Point estimate (range)*	
		This study[a]	*Nadiri & Nandi (2001)*[b]	*This study*[a]	*Nadiri & Nandi (2001)*[c]
Industry	*Model - this study*	*output-side elasticity*	*cost-side elasticity*	*1974-75 to 2002-03*	*1950 to 1991*
Ag., forestry & fishing	AGS1	0.097 (0.072)	-0.0107	4 (-2 to 11)	0.70
Mining	MIN5	0.102 (0.028)	-0.0121 to -0.0096	5 (2 to 8)	0.42
Manufacturing	MAN4c	0.080 (0.034)	-0.0125 to -0.0087	13 (2 to 24)	5.97
Electricity, gas & water	EGW5	0.033 (0.013)	-0.0107 to -0.0101	1 (0 to 2)	0.52
Wholesale trade	WT4	0.065 (0.034)	-0.0081 [WRT]	4 (0 to 8)	1.84 [WRT]
Transport & storage	TS6	0.108 (0.035)	-0.0101	6 (2 to 10)	0.67

WRT = Wholesale and retail trade. [a] Communication infrastructure tested out of the models in this study for Construction, Communication services, Finance & insurance and Retail trade. The rates of returns for communication infrastructure are only indicative. They use the average of the simple sum of productive capital stocks of several asset types in chain volume terms — productive capital stocks are not strictly additive and the addition will also be less accurate the further away from the base year (2001-02). [b] Elasticity is range across a number of sub-industries. Not directly comparable with output-side elasticity unless constant returns to scale holds, in which case the output-side elasticity is the negative of the cost elasticity. [c] Marginal cost benefit is aggregation of sub-industries — Nadiri and Nandi industry codes 1, 2-5, 7-27, 6, 32, 28-29, 34, respectively. Not directly comparable with rate of return from this study.

Source: Authors' estimates; Nadiri and Nandi (2001).

G Unit root and break tests

As discussed in appendix J, the adopted approach to co-integration analysis accommodates variables that are I(0), I(1) or a mixture of I(0) and I(1). The procedure does not require prior knowledge of the order of integration of the variables. However, the strategy is not valid for I(2) variables and certain models are estimated with alternative estimation strategies that require knowledge of the order of integration of the variables. Therefore, this appendix presents the results of univariate unit root tests at the level of the market sector (table G.1). Tests are undertaken with and without structural breaks.

The key results of the unit root tests are as follows.

- Tests that do not include structural breaks indicate that the variables are generally I(1). Some variables test as I(0) with a drift. The knowledge stocks may be more of a problem as the unit root tests indicate they could be I(2).
- Introducing various forms of breaks into the testing results in significant uncertainty concerning the true order of integration of many variables.

The variables are non-stationary

Multifactor productivity (MFP), labour productivity, public infrastructure, road infrastructure, communication infrastructure, and industry protection all test as I(1) using the Augmented Dickey-Fuller and Dickey-Fuller generalised least squares tests. Private IT capital and education test as I(0) with a drift or I(1).

Table G.1 **Unit root tests for the market sector, 1968-69/1974-75 to 2002-03**

Critical values of 5 per cent used for tests. Only breaks significant at 10 per cent or greater are shown for innovational outlier tests.

	Rho(ρ)[a]	*ln(X)*[b]	*Zivot-Andrews: single break in trend*[c]	*Innovational outliers: single structural break in mean*[d]	*Innovational outliers: two structural breaks in mean*[d]
MFP	0.984	I(1)	I(1), 1980	I(1)	I(1)
Labour productivity	0.997	I(1)	I(1), 1980	I(1)	I(1), 1977 & 89
Public infrastructure (I3)	0.902	I(1)	I(1), 1994	I(1)	I(0), 1982 & 97
Public infrastructure (I3ug2s)	0.864	I(1)	I(1), 1991	I(1)	I(0), 1982 & 96
Road infrastructure (roads)	0.954	I(1)-I(2)	I(2), 1996	I(2)	I(0), 1982 & 95
Road infrastructure (roadug2)	0.945	I(1)	I(1), 1980[f]	I(1)	I(1)-I(2), 1981 & 85
Comm. infrastructure (ci5)	1.020	I(1) with drift	I(2), 1994	I(2)	I(2), 1984 & 95
Comm. infrastructure (ci5ioug)	1.027	I(1)	I(1), 1996	I(1), 1995	I(1), 1979 & 95
Private IT capital (nonggIT)	0.972	I(0) with drift	I(2), 1981	I(2), 1980	I(2), 1979 & 84
Education (edu)	0.912	I(0) with drift	I(1), 1993[g]	I(0)	I(0), 1992 & 95
Industry protection (era)	1.030	I(1)	I(1), 1996	I(1), 1986	I(1), 1986 & 92
Australian bus. R&D (rbus15of)	1.033	I(2)	I(0), 1992[h]	At least I(2)	At least I(2)
Foreign gross R&D (rfg15_te)	0.982	I(0) with drift or I(2)	At least I(2)	I(1), 1993[e]	I(1), 1981 & 89

Detailed definitions are provided in table 3.3 for infrastructure variables and in table E.1 for other variables. Years are financial years beginning 1 July of year specified. [a] Coefficient from a regression of the variable on its lagged value and an intercept. [b] The unit root tests included the Augmented Dickey-Fuller and the Dickey-Fuller generalised least squares tests. The selection of the lag length was undertaken using a combination of inspection of the correlogram, a testing down procedure and test statistics. [c] Zivot and Andrews (1992). Null is a unit root process with drift. The alternative hypothesis is a trend stationary process with a one-time break in trend. Year of minimum t-statistic shown. [d] Clemente et al. (1998) innovational outlier tests with single and double structural breaks. [e] Dickey-Fuller tests indicate the stock of foreign gross R&D is I(0) with a drift if the sample is restricted to 1974-75 onwards. If earlier data is included in the test, then foreign gross R&D tests as I(2). The initial observation for almost all models in the paper is between 1974-75 and 1976-77. [f] Zivot-Andrews single break in intercept test indicates I(0) with minimum t-statistic at 1991. [g] Zivot-Andrews single break in intercept test indicates I(0) with minimum t-statistic at 1992. [h] Result is for break in intercept test. Break in trend test results in an order of at least I(2).

Source: Authors' estimates.

Potential problems with I(2) variables

Testing indicated that the domestic business knowledge stock is likely to be I(2). Depending on the particular test, the stock of foreign gross R&D, private IT capital and non-usage adjusted communication infrastructure also tested as I(2). This means that the growth rate of these variables are not stationary for the period under observation. Visual inspection of the growth rates supports the formal tests.

The autoregressive distributed lag co-integration procedure outlined in appendix J, and common alternative approaches, are not valid for variables of I(2). However, unit root tests often have low power, and tests that incorporate immediate or gradual breaks can indicate a lower order. Given the uncertainty about the true order of integration of the variables, one can proceed as if they are I(1). The knowledge stocks do not survive test down procedures under many specifications.

If the variables are indeed I(2), then their behaviour in the regressions should be very unstable. For example, parameter estimates should be sensitive to the time period included in the regressions (see Haldrup (1998) for a discussion of co-integration in the context of I(2) variables).

If the variables could be observed over a substantially longer time period, it is very likely that their growth rates would be stationary.

H Scale and capacity utilisation

This appendix provides further background on the modelling issues related to scale and capacity utilisation that were identified in chapter 4.

H.1 Scale

Conventional measures of multifactor productivity (MFP) (as estimated by the ABS and the Commission) assume constant returns to scale (CRS) and that each input factor is paid its marginal product.

ABS Cat. no. 5216.0 notes that "The approach adopted by the ABS has been founded on neo-classical economic theory. It is based on a translog production function in conjunction with two assumptions: (i) there are zero economies of scale; and (ii) the marginal products of capital and labour are equal to their respective real market prices." The first assumption of constant returns to scale ensures the output factor elasticities sum to unity. Together with the second assumption this makes the output factor elasticities equal to the factor income shares, which are observable.

However, if the assumption of CRS is not correct (that is, there are decreasing or increasing returns to scale) then the scale effects will be captured in the conventional MFP measure.[1] This may bias the estimation of the parameters of interest in the modelling using a MFP equation.

For the market sector, because public capital is already included in the capital stock used by the ABS, the CRS assumption in the calculation of MFP applies to all inputs. For the individual industries, this is the case only for that part of public capital allocated to that industry (which for most industries is zero or a small proportion of total capital) — therefore the assumption is CRS for private inputs.

As discussed in chapter 4, it is possible to allow for an error in the CRS assumption arriving at estimating equation (4.4d)

$$mfp_t = y - \beta_1 k_t - \beta_2 l_t - \beta_3 g_t - \beta_4 c_t - (1-\varepsilon) s_t = a + \lambda t + \gamma g_t + \alpha c_t + \theta_i x_i$$

[1] The MFP measure will therefore not be a pure measure of technological changes. For further discussion of this issue see Fox (2005).

$$mfp_t = a + \lambda t + \gamma g_t + \alpha c_t + \theta_i x_i + (\varepsilon - 1)s_t$$

where s_t represents a scale control variable. The term ε is the true scale technology $\varepsilon = \beta_1 + \beta_2 + \beta_3 + \beta_4$ and may be less than, equal to, or greater than one. If the true technology is CRS, then $(\varepsilon - 1)$ evaluates to zero. If the true technology is increasing returns, then $(\varepsilon > 1)$ and a positive coefficient is obtained on the scale control when equation (4.4d) is estimated. A negative coefficient results if the true technology is decreasing returns.

The measure for s_t can be a conventional capital services index (k). IC (1995) included both conventional capital and a separate hours worked measure to control for possible scale effects. Alternatively, a combined input services index can be used (for example, Otto and Voss 1994a). This has the advantage of saving degrees of freedom and may control better for any possible scale effects not derived from physical capital. The regression results presented in this paper were sensitivity tested to these alternative approaches.

A number of Australian infrastructure and productivity studies have examined the issue of scale, with varying results (see box H.1).

Box H.1 **Treatment of scale in empirical studies**

Australian productivity studies including infrastructure have produced varying results on the issue of scale.

IC (1995, p. QB.40) noted that when estimating an unrestricted production function the capital contribution to output growth tended to fall and the productivity contribution rise. This was taken as suggesting decreasing returns to scale across conventional capital and labour inputs.

It is possible to relax the implicit assumption of constant returns to scale by reintroducing the input variables on the right-hand side of the MFP estimating equation. This approach has been followed in some Australian studies.

IC (1995, p. QB.40) used this approach at the sectoral level and found that manufacturing and 'other services' (covering Electricity, gas & water, Transport, storage & communications, and Recreation & personal services in aggregate) exhibited evidence of increasing returns to labour and capital and mining exhibited decreasing returns. They considered the evidence of slight decreasing returns to labour and capital (a negative coefficient on the reintroduced capital stock variable) in Mining to be consistent with the idea of diminishing returns to a fixed ore body — as more inputs are applied to a given ore body proportional increases in inputs will contribute less than

(continued on next page)

Box H.1 **(continued)**

proportionately to output (p. QB.35). For ‘other services’, they note that the result of increasing returns to scale may not apply to the industries individually — it may be plausible, for example, for electricity and rail but less likely for recreational and personal services (p. QB.38).

Paul (2003, p. 454) used a translog cost function approach to examine the effect of public infrastructure in Australia from 1968-69 to 1995-96. He found CRS at the aggregate level and in Manufacturing, Construction and Recreation & personal services (with a cost elasticity with respect to output not statistically different from 1) but found scale economies in production in Agriculture, Mining, Wholesale & retail trade (from 1981 to 1996) and Transport, storage & communication (from 1991 to 1996).

Otto and Voss (1994a) examined the effect of public infrastructure on ‘private sector’ productivity in Australia. Starting from a generalised Cobb-Douglas form of production technology, they tested for the case of restricted increasing returns to scale (RIRS) (with CRS over private inputs and increasing returns to scale over public capital) and CRS (over all inputs — that is, decreasing returns to scale over private inputs for a given level of public capital because of congestion in the use of public services). They found weak evidence against CRS and some support for RIRS at the aggregate level. The industry results were generally poor.

Aschauer (1989a), on which Otto and Voss (1994a) based their approach, did not reject CRS at the aggregate level for the US. He provided arguments why RIRS and CRS each might be reasonable. Economies of scale are the reason for public provision of some capital so RIRS might be reasonable. Congestion in the use of public capital may mean increasing returns to scale may be inappropriate and CRS over all factors might be appropriate.

Connolly and Fox (2006) derived their regressions from a Cobb-Douglas production function (and calculated MFP using the standard growth accounting framework assuming CRS and output elasticities equal to factor shares of income), rather than alternative functional forms. This was on the grounds that “… previous studies in Australia and elsewhere have found that the CES [constant elasticity of substitution] or translog functional forms produce results virtually identical to those using a Cobb-Douglas functional form” (p. 52). They reported results from regressions that imposed CRS but also noted that “when constant returns to scale are not imposed some of the estimated output elasticities are implausible” (p. 54).

Song (2002) in an empirical study of public capital and private production in Australia found that the restriction of constant returns to scale over private inputs (labour and private capital) and public inputs was valid. Valadkhani (2003) in an empirical analysis of aggregate labour productivity tested for constant returns to scale assumption and found that it could not be rejected.

H.2 Capacity utilisation, business cycle and technical progress

The specification of equation (4.4b) in chapter 4 assumes that inputs are fully employed. The construction of the capital service indexes and labour input index does not recognise business cycle or shock effects on the capacity utilisation of the. Therefore, as discussed in chapter 4, a cycle term and a stochastic error term are also added to the estimating equation (4.4d)

$$mfp_t = a + \lambda t + \pi m_t + \gamma g_t + \alpha c_t + \theta_i x_i + (\varepsilon - 1)s_t + \mu_t$$

where m_t is the control for the business cycle and μ_t is the error term.

MFP growth is generally regarded as pro-cyclical. During economic downturns there is a tendency to hoard inputs. With a decline in outputs, capacity utilisation and MFP decline. During the following economic expansion, the growth rate in outputs is initially met by increasing capacity utilisation and not a rise in inputs, increasing measured MFP.

A number of studies have examined this issue empirically, including the following.

- Otto (1999) found that roughly 70 per cent of the variance of MFP is due to technology shocks and 30 per cent to demand shocks. Demand shocks explain almost all of the variation in capacity utilisation. He proxied capacity utilisation by information from the ACCI-Westpac surveys, which is based on asking managers whether they are working at a satisfactorily full rate of operation. He tested a range of variables designed to capture non-technological shocks affecting the Australian economy. The terms of trade and an indicator of the interest rate spread appeared significant and robust.
- Economic downturns and periods of structural change can have a ‘cleansing effect’ where the least productive firms exit industries and firms adopt up-to-date technologies in order to survive (Malley and Muscatelli 1999). Average firm productivity increases. Based on evidence from US manufacturing industries, Malley et al. (2000) found that recessions can enhance productivity through reorganisation and restructuring effects, if the recessions are not too deep.
- Fare et al. (2001) found that New Zealand manufacturing MFP growth was counter-cyclical over the period 1986 to 1996. In these manufacturing studies, the cleansing effect appears strong enough to offset capacity utilisation effects resulting in MFP growth being counter-cyclical. In contrast, the authors found that Australian manufacturing MFP growth was pro-cyclical.

- Fox (2005) stated that "… the empirical observation of pro-cyclical productivity growth can, in some models, be explained by increasing returns to scale". Fox used a variety of tests to separate New Zealand industry and market sector total factor productivity (TFP) growth into contributions from technical progress and returns to scale over the time period 1988-2002. He stated that the results were not statistically satisfactory for several industries, and were quite sensitive to the model used. Notwithstanding, the results from different methods provided a consistent picture and indicated that returns to scale were either constant or increasing, and very little of TFP growth over the period in New Zealand was explained by technical progress.

The specific cycle measures tested in this paper are discussed in appendix D.

I Correlations between productivity and infrastructure

This appendix provides further background on the trends in infrastructure and productivity and the correlation between them.

It should be noted that these correlations are based on the data used in the modelling exercise and do not include any ABS revisions to these data since November 2003. The data therefore differ from the most recent multifactor productivity (MFP) data presented in chapter 3. Revisions to the ABS National Accounts methodology in 2004-05 mainly resulted in changes to the levels rather than significant changes in growth rate patterns (see ABS 2005). However, of the ten industries examined in this paper the most significant changes to the growth rate patterns were in Finance & insurance and Retail trade — over the period 1974-75 the average growth was revised from -0.5 to 0.5 per cent a year for Finance & insurance and from 0.6 to 0.9 per cent a year for Retail trade.

I.1 Productivity growth compared with growth in infrastructure services

At the level of the market sector, there is no clear relationship between productivity growth rates and growth rates in unadjusted road and communication infrastructure services. There is some evidence of a positive relationship between productivity growth rates and growth rates in the infrastructure measures that have been adjusted by a value-added based usage factor (figure I.1). However, because the usage adjustment is based on value added there is some lack of independence between the measures of MFP and infrastructure.

Figure I.1 **Plots of market sector productivity and infrastructure services growth rates, 1975-76 to 2002-03**

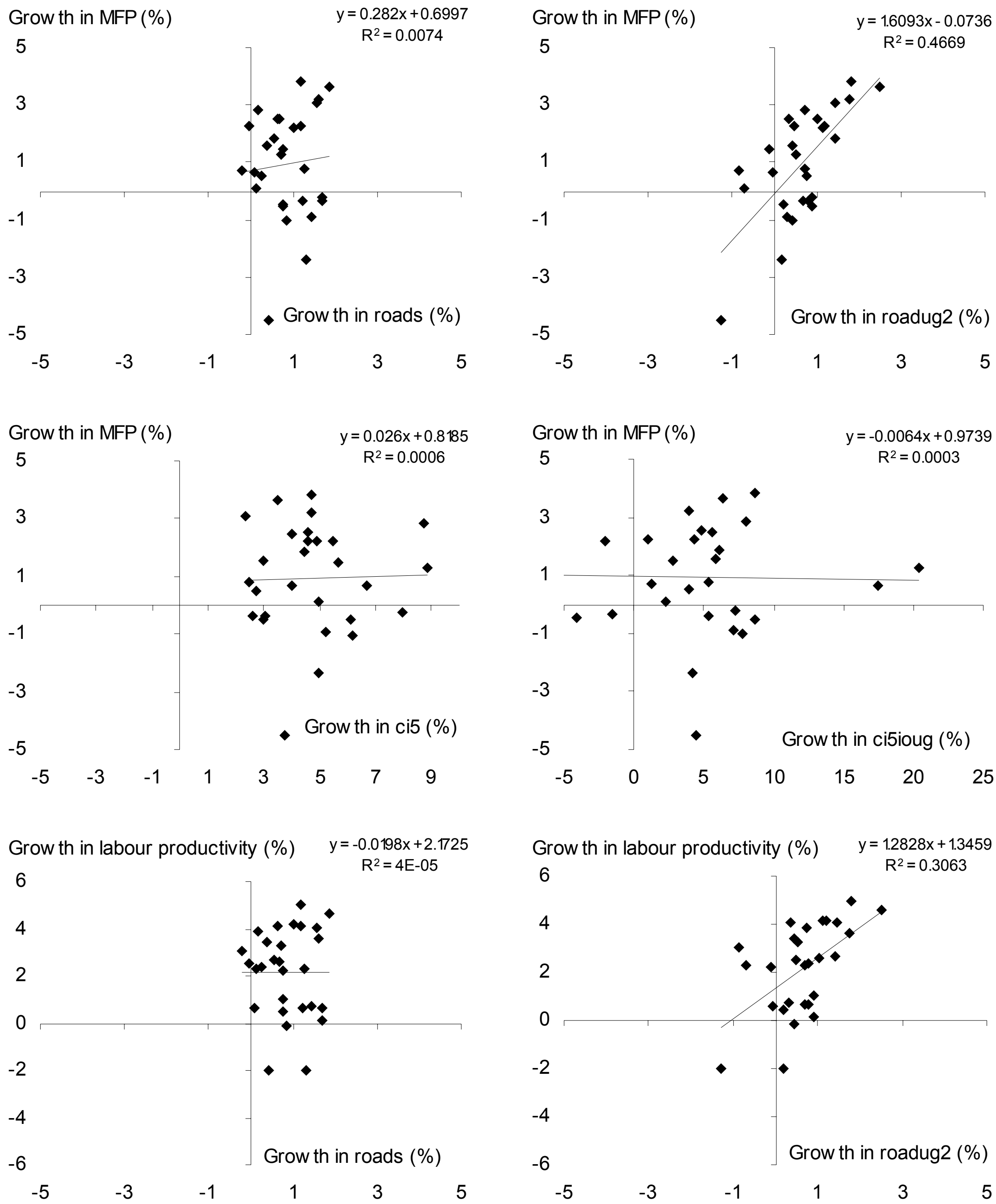

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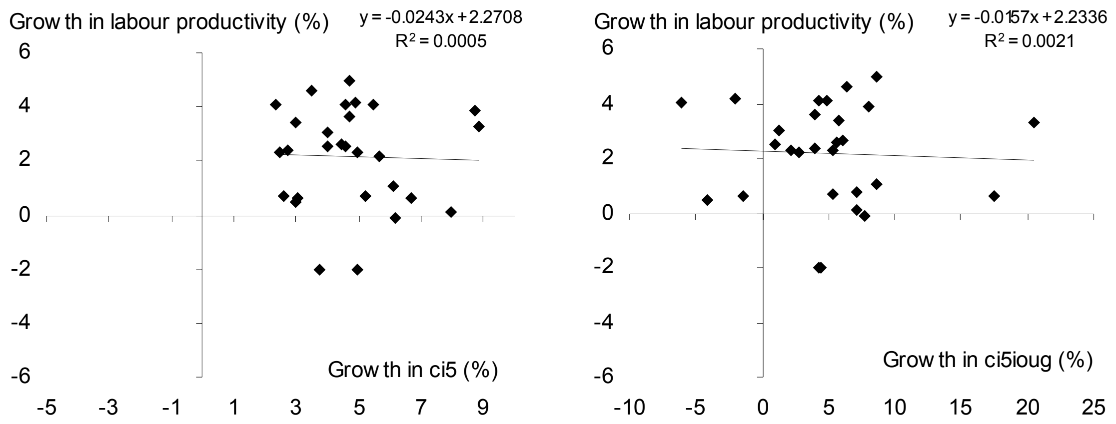
Figure I.1 **(continued)**



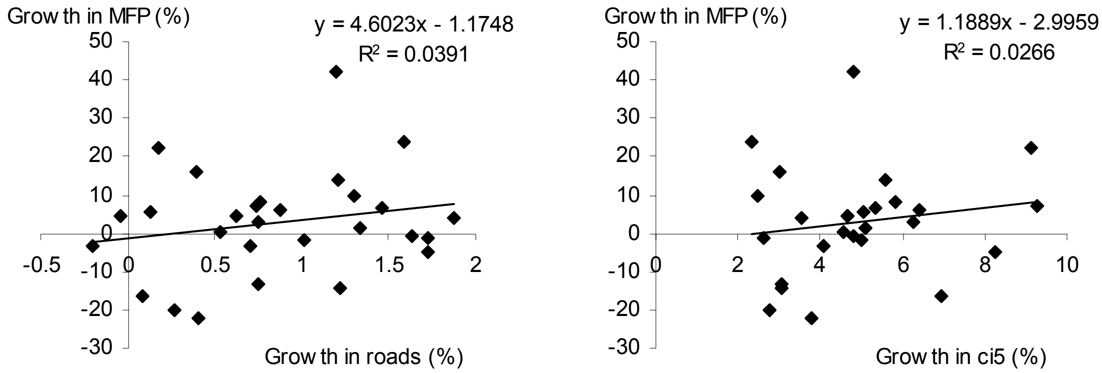
Data source: Authors' estimates.

The industry focus in this paper covers ten of the industries included in the ABS's market sector. It should be noted that productivity estimates are less accurate at the industry level than at the aggregate level.[1] Figure I.2 shows the relationship between MFP growth and growth in infrastructure measures. Again, there is no clear relationship between MFP growth rates and growth rates in unadjusted road and communication infrastructure services. Further discussion on individual industries is provided in appendix F.

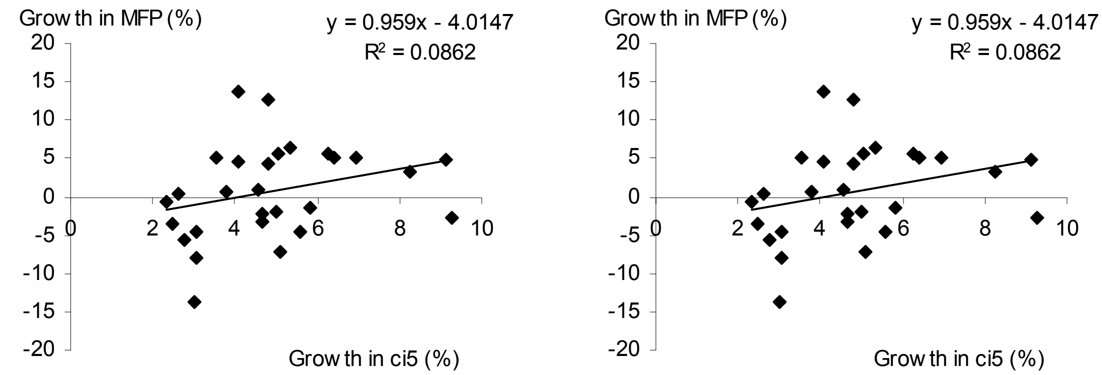
[1] Any bias in use of a value-added basis of measurement, rather than gross output, is more severe at the industry level (Cobbold 2003). There is uncertainty about the industry allocation of hours worked. And there may be issues about the precision of estimates of industry output (Zheng 2005). Services outputs present more severe measurement challenges, especially where there are changes in quality to take into account.

Figure I.2 **Plots of industry productivity and infrastructure services growth rates, 1975-76 to 2002-03**

Agriculture, forestry & fishing



Mining



Manufacturing

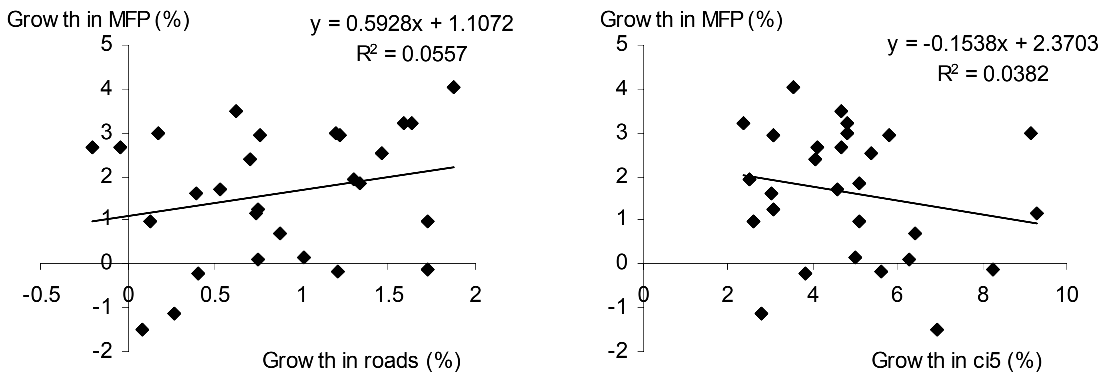


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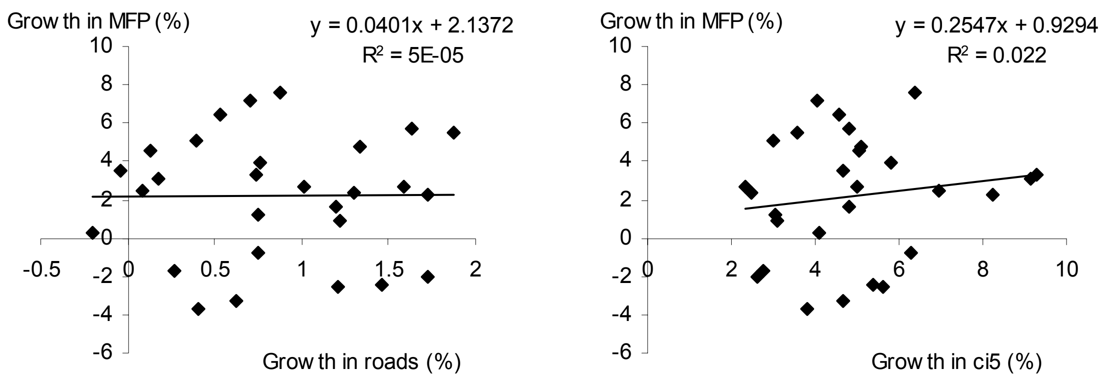
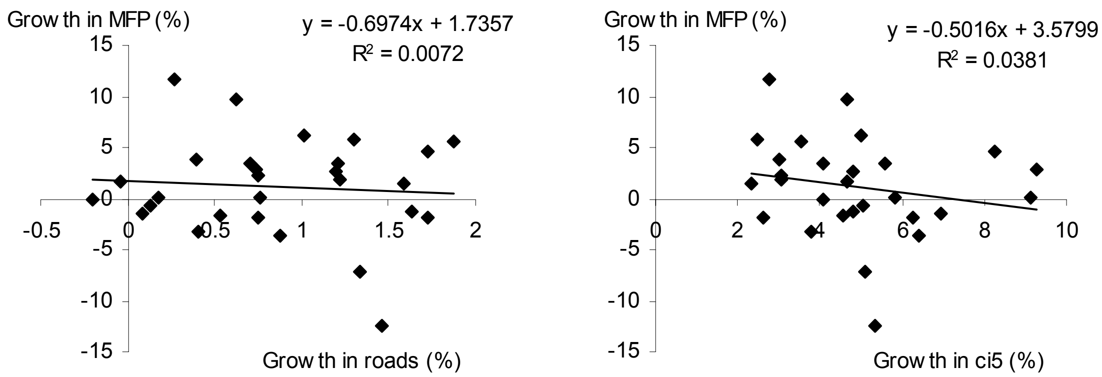
Figure I.2 **(continued)**

Electricity, gas & water



Construction



Wholesale trade

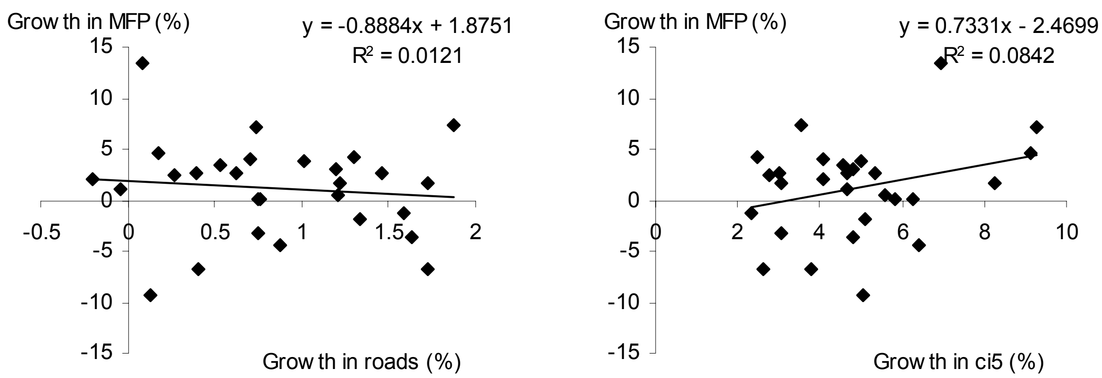


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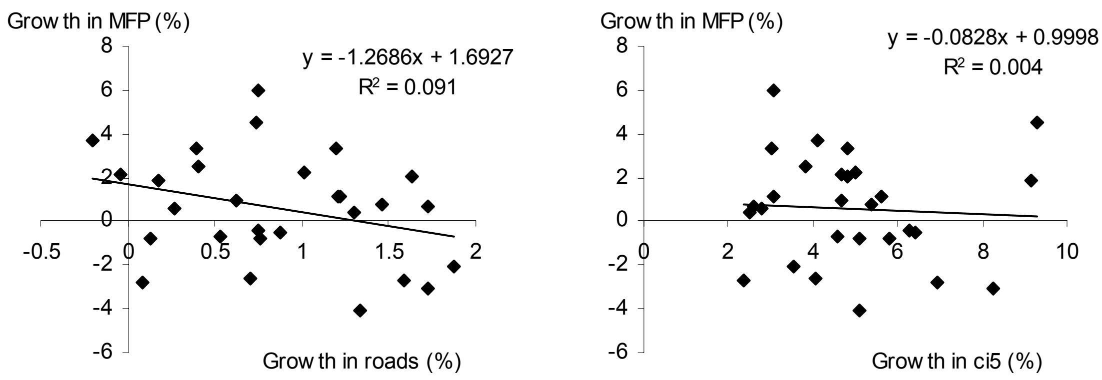
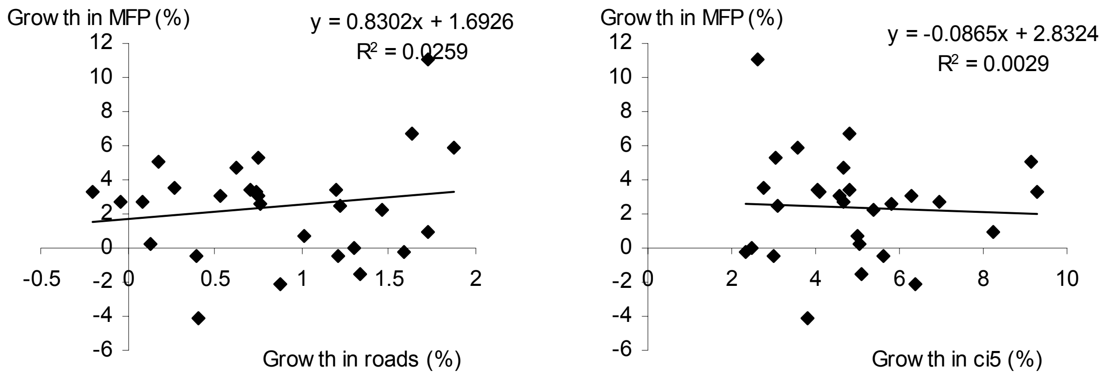
Figure I.2 **(continued)**

Retail trade



Transport & storage



Communication services

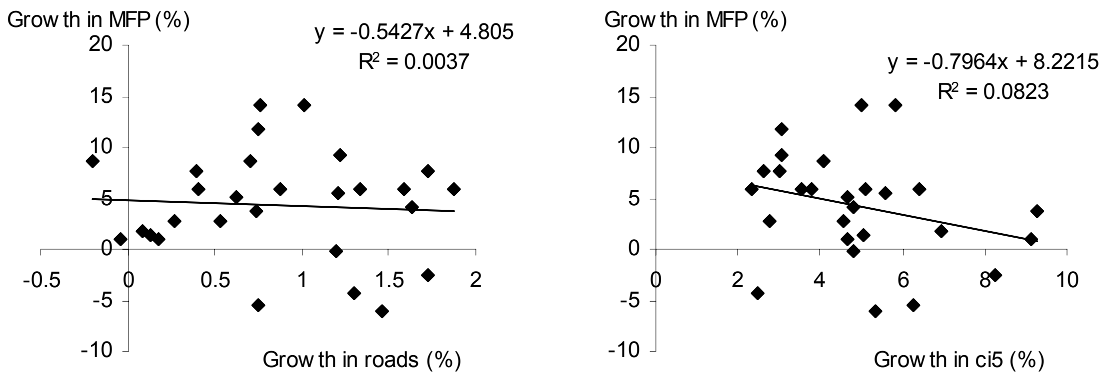


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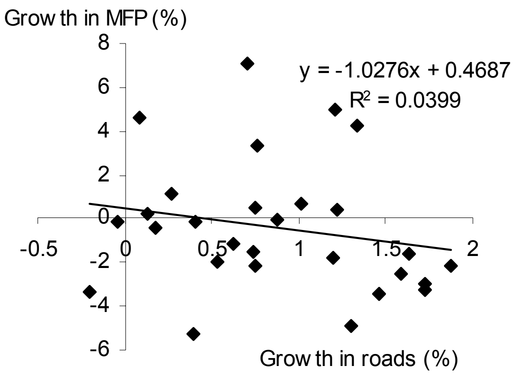
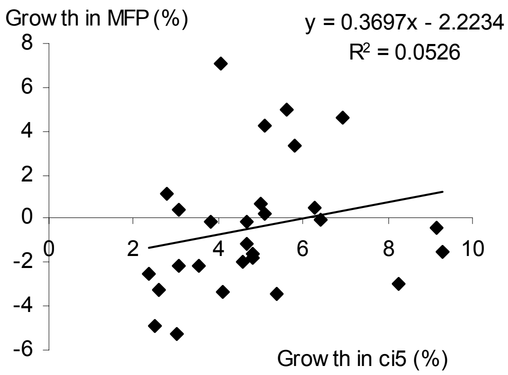
Figure I.2 **(continued)**

Finance & insurance





Data source: Authors' estimates.

J Estimation strategy

The purpose of this appendix is the elaborate on the estimation strategy outlined in chapter 4.

The market sector and industry models were specified as general Autoregressive Distributed Lag (ARDL) models following Pesaran and Shin (1999). Pesaran and Shin show how the ARDL model can be used for co-integration analysis.

Step 1: Bounds test

For estimation purposes, an unrestricted error correction model is specified

$$\Delta mfp_t = \alpha_0 + \alpha_1 mfp_{t-1} + \alpha_2 x_{t-1} + \sum_{i=1}^{p-1} \delta \Delta mfp_{t-i} + \sum_{i=1}^{p-1} \phi \Delta x_{t-i} + u_t \qquad \text{(J.1)}$$

where *mfp* represents multifactor productivity, α_0 is a constant, and *x* represents the variables of interest and control variables (public infrastructure, IT capital, communications infrastructure, and possibly education, industry protection, trade openness and other controls).

The choice of *t* determines the number of lagged differenced variables included in the model. It is constrained by the trade-off between the number of explanatory variables and the number of available observations.

The joint null hypothesis is that the long-run coefficients are individually and jointly equal to zero:

$$H_o : \alpha_1 = \alpha_2 = 0$$

If this hypothesis cannot be rejected, then the variables do not form a long-run co-integrating relationship. Rejection is against the alternative hypothesis that the long-run coefficients are both non-zero

$$H_1 : \alpha_1 \neq 0; \alpha_2 \neq 0$$

The error correction model is first estimated without the inclusion of the lagged levels of the variables. A variable addition test is then undertaken with the

F-statistic obtained testing the null hypothesis. Under the null, the statistic has a non-standard distribution irrespective of whether the variables are I(0) or I(1). The critical values for the bounds test were computed in Pesaran et al. (1996) and re-produced in Pesaran and Pesaran (1997). Different assumptions about the deterministics of the model (for example, whether or not an intercept and time trend is included) require the use of different critical values tables.[1]

If the computed F-statistic is below the lower band critical value (l.b.c.v.), then the null is conclusively not rejected — the variables are not jointly significantly different from zero and they do not form a long-run relationship. If the F-statistic is above the upper band critical value (u.b.c.v.), then the null is conclusively rejected in favour of the existence of a long-run relationship. If the F-statistic falls between the lower and upper critical values, then the outcomes of the test are inconclusive. This means that other approaches to testing the existence of a long-run co-integrating relationship have to be relied upon.

The bounds test assumes the existence of a single co-integrating relationship which may not be the case. Pesaran and Pesaran (1997) recommend undertaking a series of 'long-run forcing' tests. Each of the explanatory variables is iteratively treated as the dependent variable and the bounds test is undertaken. If the tests fail to reject the null hypothesis, but the relationship of interest passes the test, then this indicates that the explanatory variables are the long-run forcing variables for the explanation of the dependent variable. Belke and Polleit (2005) interpret failure of the long-run forcing test as evidence of a spurious regression in the sense that the analyst cannot be confident that the model is capturing the intended direction of causation.

Pesaran et al. (1999) extend the bounds testing procedure in a Vector Autoregressive/Error Correction Method (VAR/ECM) framework. Testing of the number of co-integrating vectors is explicitly undertaken. The bounds test is still only valid in the presence of a single long-run co-integrating relationship.

Step 2: Obtaining the long-run coefficient estimates

Having confirmed the existence of a long-run relationship, the long-run parameters are obtained by estimating the following general ARDL(*p*,*m*) model

$$mfp_t = \alpha_0 + \lambda_t + \sum_{i=1}^{p} \phi_i mfp_{t-i} + \sum_{i=0}^{m} \delta_i x_{t-i} + u_t \qquad \text{(J.2)}$$

The number of regressions estimated is $(p+1)^k$ where p is the maximum number of lags of the dependent variable, m is the maximum number of lags of the explanatory

[1] See appendix E for a discussion of critical values for small samples.

variables, m is set equal to p, and k is the number of variables in the equation. For example, if the model contains six explanatory variables (excluding the intercept and trend if present) and two lags, then $(2+1)^6 = 729$ regressions are computed.

Selection criteria are used to determine which models have the best fit. In the above case, the selected model would contain zero, one or two lags of the dependent and explanatory variables, and the number of lags may be different for each variable. The Akaike Information Criterion (AIC) tends to select models with a higher lag order, while the Schwarz Bayesian Criterion (SBC) selects models of a lower lag order (a more 'parsimonious' model, as the model's score is more heavily penalised for the inclusion of additional regressors compared with the AIC). The two estimators have similar small sample properties, with some preference towards the SBC, since it is a consistent model selection criterion, while the AIC is not. While the consistency property will not guarantee the selection of the true model in such a small sample, the limited number of observations means that there is a preference for preserving degrees of freedom by selecting the most parsimonious model suggested by the standard model selection criteria. Most model results in this paper are from models selected by the SBC.

The long-run coefficient for explanatory variable x_1 is calculated as the sum of the coefficients on it and its lags divided by one minus the sum of the coefficients on the lagged dependent variable.

$$\alpha_1 = \frac{\sum_{i=0}^{m} \delta_i x_1}{(1 - \sum_{i=1}^{p} \phi_i)}$$

If the selected model contains zero lags of the lagged dependent variable, then the long-run coefficient is simply the sum of the coefficients for the explanatory variable (the same as in the finite distributed lag model case).

The procedure has a number of advantages compared with alternative co-integration analysis techniques.

- It can provide a robust estimate of the long-run relationship between variables irrespective of the order of integration of the underlying regressors: the regressors can be either I(1) or I(0), or fractionally integrated, and the procedure does not require prior knowledge of the true order of integration (that is, pre-testing of unit roots is not required). This is useful as correct identification of the order of integration of a series can be difficult due to the relatively low power of many unit root tests.

- The step 1 bounds test gives a clear indication of the rejection or not of the null of no co-integrating relationship when the test statistic falls above the upper bound or below the lower bound.
- The procedure can result in a model with sufficient lags to capture the data generating process in a general-to-specific modelling framework (subject to the constraint of the number of available observations combined with the number of explanatory variables). It can avoid ad hoc specification of the lag structure of the model.
  - Most models in this paper are specified in a way that gives greater weight to limiting the risk of omitted variable bias compared with fully specified dynamics. This approach was taken because the capital service measures are based on an accumulation of past expenditures and the ARDL (1,1) specification can accommodate substantial transition paths following shocks.
- Selection of the optimal lag order can eliminate potential endogeneity bias.
- An intercept, time trend, and business cycle variable can be included in the estimated models.

An error correction representation

Where the selected ARDL lag order includes a lagged dependent variable, results are also presented based on a 'restricted' ECM

$$\Delta mfp_t = \Delta x_t + \Phi[\alpha_o + \alpha_1 x_{t-1} - mfp_{t-1}] + \mu_t \qquad \text{(J.3)}$$

where Φ is the error correction term, is negatively signed, and has a value usually between zero and negative one. The static long-run solution is separated from the short-run dynamics of the model. Specified in this way, a restriction is imposed that the long-run multiplier is unity. A coefficient of, say, -0.2 implies a relatively slow adjustment back to equilibrium with 20 per cent of the disequilibrium distance recovered in the following year (with annual data). A coefficient of -0.9 implies that almost all of the shock is recovered in the following year. A coefficient of -1.3 implies a process of over-shooting or over-correcting in the return to equilibrium.

Encompassing models and non-nested tests

Most of the modelling results presented are the outcomes of a tightly specified general-to-specific test down procedure.

The choice of the initial set of variables to include in testing procedures faced a trade-off between the following considerations:

- the default inclusion of one or more of a public or road infrastructure variable, a communication infrastructure variable, and an IT capital variable
- a desire to investigate interactions between certain variables
- a desire to control for other influences on productivity
- a possible need to include controls for the business cycle and a linear time trend
- a desire to specify as general a specification as possible incorporating dynamics.

The relatively limited number of available time series observations meant that a single encompassing model could not be specified. Selection of the preferred models was done on the basis of expected signs, plausible economic magnitudes, the statistical properties of the models, and overall model fit determined by information criteria.

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