CHAPTER 9

Integrating evidence on the determinants of productivity

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Abstract

There is mounting theoretical and empirical evidence on determinants of productivity growth. However, the empirical findings provide policy makers with limited guidance to determine which of the correlates truly matter in determining growth rates and productivity levels. This paper reviews and characterizes the different empirical approaches that exist to date and proposes an analytical scheme that helps to study productivity growth in a more integrated framework. Within this framework, existing results from the empirical literature can be evaluated and new directions for future work can be identified.

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9.1 INTRODUCTION

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The cumulative body of knowledge concerning productivity growth and its determinants is vast. From a theoretical perspective, investment in the search for new knowledge is seen as a key determinant of productivity. However, the theories vary over how the allocation of such investment is determined, and how or how much such investment affects productivity levels or growth rates. The empirical evidence provides a quantification of the contribution of production factors to growth. In addition, there is evidence on the correlation between output and a large collection of variables. However, the various strands of the empirical literature have little in common and do not provide policy makers with much guidance on which of the many correlates truly matter in determining productivity levels and growth rates.

In this chapter we will briefly review and characterise what is known about productivity growth, innovation and their determinants. The various strands of the traditional empirical literature will be discussed in light of various theories, and some recent empirical results will be presented. Next, this chapter will place the various analytical schemes used to understand productivity growth in a more integrated framework that allows one to determine which factors are exogenous and which may be influenced through policy. Within this framework, results from the literature at the micro-, sectoral, or macro- levels can be evaluated, and new directions for empirical work can be identified. More speculatively, the chapter ends with an attempt to rank the quantitative importance of the various underlying determinants of productivity that can be influenced by policy.

The bottom line of this chapter for policy makers is that the possibilities for improving productivity growth through better policy are not limited by historically achieved productivity gains at a national level, but by the trajectory of advances to be achieved in the future by the world's best. To place limits on rosy expectations of policy outcomes, this chapter will posit an international productivity frontier with a growth rate that has historic precedent. In the long run, it is quite unlikely that total factor productivity (TFP) in a small country can grow faster than the rate for the global frontier. At the same time, substantial and unexploited possibilities to catch up can exist that can be substantially larger than those identified in macro-oriented research. This chapter will then disentangle the means by which firms in the economy can move towards the frontier.

9.2 EMPIRICAL EVIDENCE ON PRODUCTIVITY

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The branches of the theoretical literature each have their own method for making sense of empirical evidence on output, inputs, and growth. Models of economic growth that have been developed typically describe the process by which an economy saves and invests resources from current income in order to generate a stock that produces a flow of productive services in the future. In the traditional models (cf. Solow, 1956; Swan, 1956) growth is in the long-run exogenously limited. In contrast, endogenous growth models allow for a lasting influence of asset stocks on growth (e.g., Aghion and Howitt, 1998; Barro and Sala-i-Martin, 1995). Intermediate positions are taken by the semi-endogenous growth models (cf. Jones, 1995).

These growth models often underlie growth accounting exercises (see Section 9.2.1). With minor modifications, the standard empirical method for estimating the effect of R&D spending on growth can be used to retrieve estimates of the parameters of endogenous or semi-endogenous growth models. In this manner, the contribution of human capital formation, R&D activity, and capital accumulation to growth may be calculated (see, e.g., Jones and Williams, 1998). The growth literature also underlies empirical efforts at identifying the determinants and evolution of cross-country differences in growth and welfare (see Sections 9.2.2 and 9.2.3). The micro-based innovation models (see Reinganum, 1982, for an early example), are able to explain a host of interesting factors influencing growth, such as the effects of entry barriers, or the supply of high-quality workers in local labour markets. Finally, the firm-demographics models can provide estimates of the contribution of firm-turnover and of within-firm growth to sectoral or aggregate growth (see, e.g., Bartelsman and Doms, 2000).

9.3 GROWTH ACCOUNTING

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Elsewhere in this volume, comparisons of total factor productivity (TFP) and labour productivity growth are made for recent periods and various countries, including the Netherlands. We refer to Chapter 2 for tables showing the contributions of capital, labour and TFP to output growth in the Netherlands. The theory underlying the growth accounting framework is rather simple. In an economy populated by a cost-minimizing representative firm, output is produced by employing the services of various productive inputs. A firm hiring factors of production will do so until the marginal cost of that factor equals the marginal revenue from selling output. In the accounting framework, all revenue is accounted for as payments for factor inputs. Under these conditions, the growth rate of output equals a weighted average of the growth rates of factor inputs plus the growth unaccounted for, or TFP.

Growth accounting thus provides an historical analysis that attributes total output growth to various factors of production that are explicitly purchased. For cross-country comparisons, the method assumes that each country is populated by one representative firm that makes decisions regarding the level of productive inputs. As measurement becomes better, and the list of inputs broader through inclusion of R&D, other innovative activity, investment in ‘intangibles’, etc, the measured TFP growth will decline. Total factor productivity (TFP) thus remains the measure of our ignorance, that part of growth that is unaccounted for by explicit resource expenditures by firms.

The good news is that growth accounting indeed accounts for most of output growth. For policy makers, the bad news is that it does not aid much in explaining, e.g., *why* investment in ICT is higher in the U.S. than in E.U. countries.

9.4 CROSS-COUNTRY GROWTH EMPIRICS: CONVERGENCE

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A second class of empirical studies takes as a starting point the observed differences in growth rates over time and across countries. A seminal paper in the field is Baumol (1986) who showed the existence of a negative correlation between growth and initial income in a small cross-section of countries for a long time span. This result was seen as consistent with the neoclassical notion of convergence and evidence for a shrinking cross-sectional distribution of per capita income over time. This paper has provoked a wide range of studies assessing the existence of convergence (see Islam, 2003; and Abreu et al., 2003 for recent surveys). This literature has studied convergence at different levels of spatial aggregation (e.g., countries versus states; e.g. Barro and Sala-i-Martin, 1995), at different level of sectoral aggregation (e.g., Dollar and Wolff, 1993), for different samples of countries and for different time-spans. The literature has also emphasised the important differences between what is known as β-convergence and σ-convergence. The former convergence concept looks for a negative relationship between per capita income or productivity and its subsequent growth rate whereas the latter concept looks for a declining cross-sectional dispersion of per capita income or productivity.

The existing literature on the issue is by far too large and diffuse to properly characterise in this chapter. With the aim of this chapter in mind, though, a few important notions are worth mentioning. First, an assessment of productivity determinants or developments requires the analysis of GDP per hour worked or total factor productivity, instead of the fairly widely used measure of GDP per capita. Second, analyses at detailed levels of sectoral aggregation are preferable over aggregate analyses. At detailed levels of aggregation, production processes are less heterogeneous and productivity developments are more likely to capture real technological progress instead of changes in, for example, the production mix. Third, panel approaches are preferable (provided that sufficiently long time series of sectoral indicators are available) since those allow to (i) control for variation over time and (ii) allow for controlling for unobserved heterogeneity across countries.

Building on these notions, we will try to characterise the existing literature by an own empirical analysis on a sub-aggregate level in which we study the determinants of sectoral labour productivity growth.[2] This analysis is in many respects exemplary for the huge body of empirical evidence that exists to date. For some reviews of the empirical literature, we refer to Barro and Sala-i-Martin (1995), Islam (2003), OECD (2003b) and Temple (1999). The analysis is performed for the Total Economy (TET), the aggregate sector Total Industry TIN) as well as the sub-sectors agriculture (AGR), mining and quarrying (MID), manufacturing (MAN), services (SOC), electricity/gas and water (EGW), and construction (CST).

The analysis proceeds in three steps. We first describe the evolution of labour- and total factor productivity over time across the OECD countries by showing the evolution of the cross-sectional distribution of productivity (Section 9.2.1). As a second step, we perform an unconditional β-convergence analysis (Section 9.2.2). In the final step, we aim at identifying determinants of productivity levels (Section 9.3).

[2] Similar results for total factor productivity are available upon request.

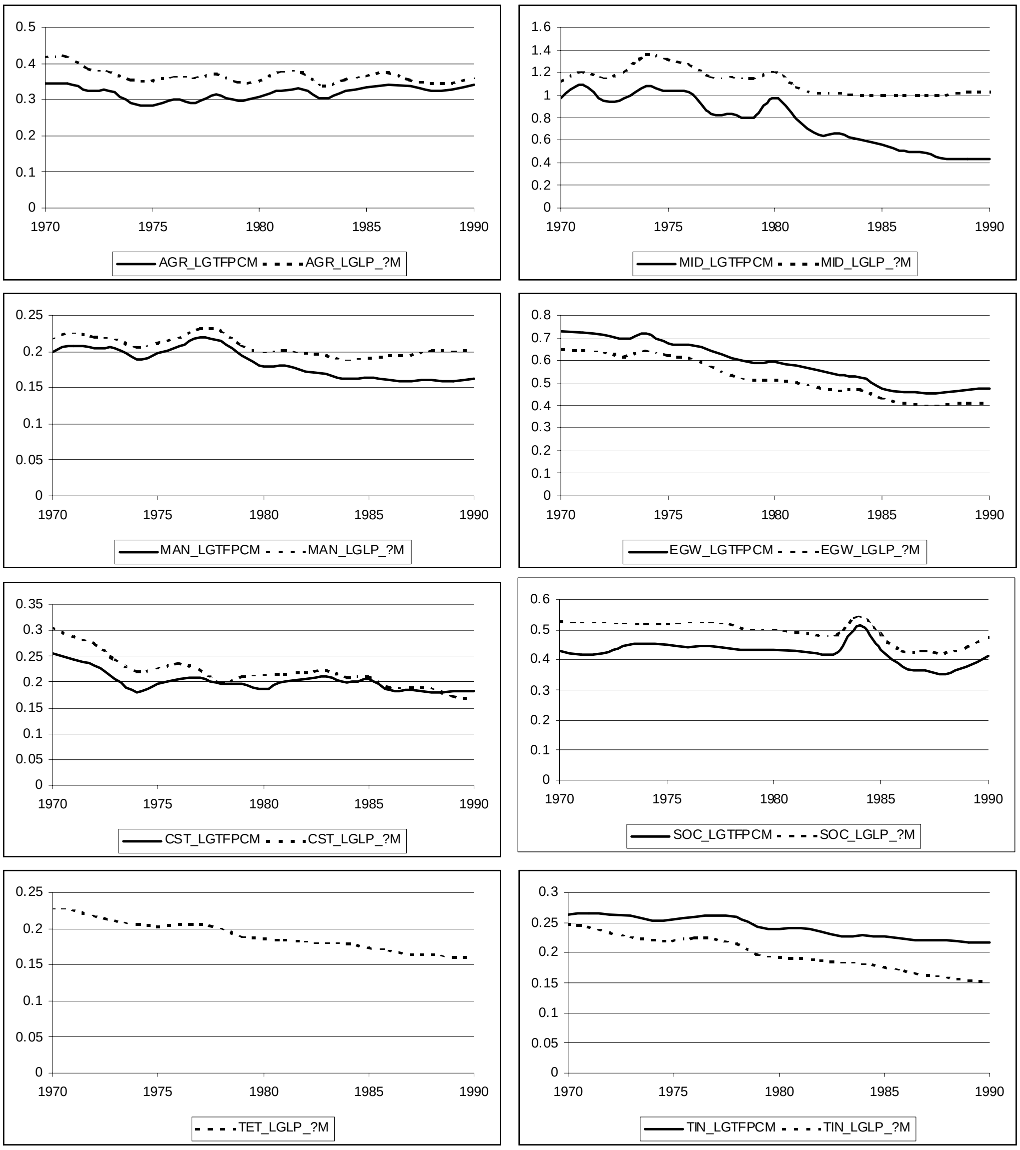
This analysis extends the seminal analysis by Bernard and Jones (1996) in three directions. First, we consider a longer time span, namely 1960-1995. Second, we perform a pooled cross-section analysis of β-convergence (cross-sectional results are available upon request). Finally, we do not restrict attention to an analysis of unconditional β-convergence, but also perform a conditional β-convergence.

Describing cross-sectional productivity developments: σ*-convergence*

Our first descriptive step in the analysis is to describe the evolution of the distribution of sectoral productivity growth in a cross-section of countries, better known in the literature as an analysis of σ-convergence. Figures 9.1a-9.1f contain the development over time of the standard deviation of the natural logarithm of labour productivity and total factor productivity taken over a cross-section of countries for the specified sectors. A declining standard deviation points at convergence of productivity levels and vice versa.[3]

Figure 9.1a – 1h: Standard deviation of labour- and total factor productivity

[3] Alternative (though less commonly used) measures for σ-convergence exist and can give rise to different conclusions regarding convergence (see Dalgaard and Vastrup, 2001).



The results illustrate three important conclusions:

- at the aggregate level (total economy and total industry) there is evidence for convergence (viz. a declining standard deviation of the log of productivity);
- convergence is by no means absolute; even for a fairly homogeneous set of OECD countries, substantial variation in cross-sectional variation persist;

- at a more detailed sectoral level, with the exception of construction and electricity, gas and water, the evidence of convergence is very weak.

These results are in line with other studies in the literature. Taking a more micro-perspective at productivity developments, they also should not come as a big surprise. There are important and persistent differences across countries, sectors and industries that are expected to show up in productivity differences. Furthermore, relative positions in industries can quickly change, as a result of technological breakthroughs, entry, exit and relocation of firms.

Unconditional β-*convergence*

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A necessary (though not sufficient) condition for σ-convergence is that the initial productivity level and the subsequent growth rate of productivity are negatively correlated. This is known as β-convergence. Table 9.1 reveals the results of a panel regression analysis (cf. Islam, 1995) of the growth rate of labour productivity over the period 1960-1995 for the sectors under consideration, using 5-year periods. These results reveal that with the exception of social services (and to a lesser extent mining and quarrying), there is statistically significant evidence of β-convergence. Confronting this evidence with the lack of σ-convergence in, for example, the agricultural sector and manufacturing clearly reveals the relevance of countries changing relative positions (better known as regression towards the mean in the convergence literature).

Table 9.1: Labour productivity – panel analysis 5-year intervals 1960-1995

	AGR	MID	MAN	EGW	CST	SOC	TET	TIN
Constant	0.1794	0.2384	0.1787	0.2293	0.3954	0.071	0.2917	0.2744
	4.04	2.24	3.63	4.07	6.10	1.46	8.30	8.2
log Initial productivity	–0.0146	–0.0171	–0.0144	–0.0171	–0.0377	–0.0061	–0.0263	–0.0243
	–3.12	–1.78	–2.98	–3.42	–5.94	–1.29	–7.68	–7.49
adjusted R^2	0.10	0.03	0.09	0.12	0.31	0.01	0.43	0.43
Number of observations	77	64	76	76	76	71	77	73
F-statistic	9.71	3.17	8.86	11.67	35.34	1.65	58.96	56.04

Note: White t-statistics are reported below the estimated coefficient

9.5 CROSS-COUNTRY GROWTH EMPIRICS: FINDING PRODUCTIVITY DETERMINANTS

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Implicit in the previous analyses was the assumption that all countries converge to the same steady state. As already hinted at before, the empirical literature on convergence clearly reveals that this is an heroic assumption (e.g., Islam, 1995). As a first step, one can estimate the regression equations in Table 9.1 with fixed effects. Such an analysis indeed reveals that there is a substantial amount of heterogeneity present. The problem with such an exercise, though, is that is provides no insights into the determinants of the country-specific steady states. The specification of the country-specific steady states is the issue to which we turn next.

9.5.1 The growth accounting counterpart

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The last subsection concluded that there are important differences in the steady-state productivity levels to which countries converge. A most relevant question then, of course, is what determines those steady state differences. The early theoretical literature on this stayed close to the production function framework underlying the growth accounting literature. The cross-section growth empirical counterpart of this is the seminal work by Mankiw et al. (1992). They empirically test the neoclassical growth model. In a typical neoclassical growth regression, growth positively depends on the savings rate (resulting in physical capital accumulation) and negatively on employment growth (plus depreciation and exogenous technological progress). Extended versions of the model also allow a role for enrolment rates in education (resulting in human capital accumulation). At a detailed sectoral level, information on human capital is however not readily available. An empirical application of this framework to the previously described sample of sectors and countries can be found in Table 9.2.

Table 9.2: Conditional convergence labour productivity – panel analysis 5-year intervals 1960-1995

	AGR	MID	MAN	EGW	CST	SOC	TET	TIN
Constant	0.0113	0.2339	0.1169	0.2258	0.2869	0.0113	0.1373	0.2087
	0.17	1.72	2.20	3.56	3.97	0.19	3.91	5.68
Initial productivity	–0.0046	–0.0136	–0.0122	–0.0217	–0.0304	–0.0051	–0.0144	–0.0206
	–0.72	–1.26	–2.21	–4.01	–4.82	–1.00	–4.05	–5.19
Log investment share	–0.0263	0.0467	0.0003	–0.0061	–0.0033	–0.0011	0.0107	0.0017
	–2.40	2.89	0.03	–0.63	–0.55	–0.25	1.70	0.23
log(n+g+delta)	–0.0095	–0.0073	–0.0121	–0.0154	–0.0082	–0.0177	–0.0161	–0.0102
	–2.45	–0.50	–3.77	–2.36	–1.88	–2.35	–4.64	–4.52
Adjusted R^2	0.24	0.19	0.19	0.28	0.34	0.09	0.51	0.54
Number of observations	63	49	67	63	63	61	69	67
F-statistic	7.46	4.69	6.23	9.03	11.51	3.00	24.99	26.85

Note: White t-statistics are reported below the estimated coefficient

9.5.2 Barro regressions

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Expanding on the previous class of cross-country growth regressions, the literature has gone several steps further in trying to characterise the steady state of countries/sectors. Partly due to the open-ended character of endogenous growth theories that has – bluntly stated – revealed that almost anything can matter in explaining growth and productivity differences, a plethora of proxies for ‘anything that can matter’ has been tried. The class of regression analyses using this approach is known as Barro regressions (after Barro, 1991).

This literature has often been accused of testing without theorizing. Although this critique is to some extent valid, it also needs to be acknowledged that the theory provides little guidance on the correct specification of a model that can be tested empirically. Given the open-ended character of the theory, some new methodologies have been developed that can yield some guidance in determining the factors that are empirically found to be relevant. These methodologies have revealed that at a macro-level, variables exist that can be argued to provide reasonably robust explanations for variations in growth rates (e.g., Sala-i-Martin, 1997; Florax et al., 2002; and Beugelsdijk et al., 2004).[4]

It is beyond the scope of this chapter to provide a complete description of all variables that have been analysed (see, for example, Temple, 1999; Durlauf and Quah, 1999). The traditional growth enhancing factors that have extensively been analysed are innovation (e.g., Griliches, 1992; Jones and Williams, 1998), human capital (e.g., Benhabib and Spiegel, 1994; King and Levine, 1994) and equipment capital (e.g., Temple, 1998). In the remainder of this section we turn more extensively to the less intensively studied factors such as the financial system, product market competition and labour market flexibility.

Financial System

Financial systems play a role in the growth process because they are important to the provision of funding for capital accumulation and for the diffusion of new technologies. The microeconomic rationale for financial systems is based largely on the existence of frictions in the trading system. In a world in which writing, issuing and enforcing contracts consume resources, and in which information is asymmetric and its acquisition is costly, properly functioning financial systems can reduce these information- and transaction costs. In the process, savers and investors are brought together more efficiently, and ultimately economic growth is affected.

OECD (2001a) examines the role of financial systems in resource allocation and growth. It provides evidence suggesting that legal and regulatory framework conditions for financial systems, and particularly their enforcement and transparency, support innovation and investments in new enterprises. Evidence is also presented of significant correlations between financial development and productivity growth.

Banking System and Equity Markets

The financial system affects capital accumulation by altering savings rate or by reallocating resources among different investments projects. It also serves in the monitoring of investments

[4] In the growth accounting method, with its emphasis on the role of factor prices, the relationship between productivity improvements and many of the institutionally related variables is less direct. It is thought that the ‘framework’ conditions affect productivity and innovations by forcing managers to speed up the adoption of new technologies and by inducing firms to increase R&D investments in order to acquire a lead over their competitors. Flexibility of the labour market reduces the costs of adjusting resources in a case of technological success or failure. However, in the growth accounting method, with its assumptions of profit maximization by a representative firm, there is no role for such a mechanism.

to reduce the risk that resources are mismanaged. The establishment of banks that can monitor investments for groups of investors reduces the duplication of monitoring costs. Besides reducing the costs of acquiring information ex ante, financial intermediaries may also mitigate the information acquisition and enforcement costs of monitoring firm managers and exerting corporate control ex post, after financing activity.

Levine and Zervos (1998) investigate whether well-functioning stock markets and banks promote long-run economic growth. Well-functioning banks spur technological innovation by identifying and funding those entrepreneurs with the best chances of successfully implementing innovative products. The empirical results confirm the hypothesis that stock market liquidity and banking sector development both positively and robustly predict growth, capital accumulation, and productivity improvements.

Levine (1998) examines the relationship between the legal system and banking development and traces this connection through to long-run rates of per capita GDP growth, capital stock growth, and productivity growth. The evidence shows that the component of banking development associated with national legal characteristics is positively and robustly correlated with productivity growth.

Rajan and Zingales (1998) examine whether financial development facilitates economics growth by reducing the costs of external financing to firms. They find that the sectors that are relatively more in the need of external financing develop faster in countries with better financial systems.

Venture Capital

One important impediment to entry for new innovative firms is the lack of financing. Start-ups obviously have no track record, and often very little collateral, which makes it difficult for them to obtain bank loans or other forms of debt financing. The main source of financing for innovative start-ups is therefore equity capital, provided by venture capitalists.

Kortum and Lerner (1998) investigate the influence of venture capital on patented inventions in the United States across 20 industries over three decades (1965-1992). The authors find that the amount of venture capital activity in an industry significantly increases its rate of patenting. The estimates suggest that venture capital accounts for about 15% of industrial innovations.

OECD (2001b) in one of the chapters discusses the importance of venture capital in financing new innovative firms. It also suggests that the degree of development of venture capital investment depends among other factors on the existence of well-functioning equity markets that facilitate sale of assets. These 'new' equity markets provide an exit mechanism that allows entrepreneurs and investors in early stage risky project to be compensated for their efforts.

Product and Labour Market Regulations

Product market regulations affect productivity improvements and innovations by forcing managers to speed up the adoption of new technologies and by inducing firms to increase R&D investments in order to acquire a lead over their competitors.

OECD (2002) presents empirical evidence on the role that policy and institutional settings, in both product and labour markets, play for productivity and firm dynamics. It exploits firm-level data for ten OECD countries and industry level data for a broader set of countries, together with a set of indicators of regulation and institutional settings in product and labour markets. Industry productivity is negatively affected by strict product market regulations. Likewise, high hiring and firing costs seem to hinder productivity. Moreover burdensome regulations on entrepreneurial activity as well as high costs of adjusting the workforce seem to negatively affect the entry of new small firms.

OECD (2003a) looks at the scope and depth of regulatory reforms in OECD countries and tries to relate them to growth outcomes. The authors find evidence that reforms promoting private governance and competition tend to boost productivity.

9.6 EVIDENCE FROM CONVERGENCE WITH PRODUCTIVITY FRONTIER

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In the empirical analysis in the three previous sections, we have used average productivity across firms to characterise the gap between initial productivity and the steady state productivity. Crucial in the analysis is the notion that countries converge to their own steady state. From a technology diffusion point of view, the approach that countries converge to their own steady states and that technology is a pure public good has several flaws. In an alternative view, technology gaps between a country and a leader country are driving technological change. And even more precisely, technology of the best performing firm in the leader country matters for the potential for technology to diffuse instead of average productivity. Taking a catching-up perspective on productivity growth, our measure of average productivity and its distance to steady-state productivity has some evident flaws.

In this section, we will describe some empirical evidence on technology gaps. In addition to average productivity gaps that are widely available (see, for example, Chapter 2), we will also show evidence on productivity at the frontier captured by the productivity of the top firms in an industry. In this subsection, we will proxy this by productivity of the top quartile of firms in a given sector. We restrict attention to a descriptive analysis, since the lack of information for many countries on the distribution of productivity across firms within an industry prevents a sensible regression analysis expanding on the analysis in Sections 9.2 and 9.3 at this stage. Still, the information is informative and provides some first view on more extensive information that will become available in the future and that – as we will argue in the sequel – will be important for understanding productivity differences and their evolution over time.

Looking at average productivity in sectors, two key results stand out (cf. Chapter 2 in this volume). First, sectoral leaderships are not restricted to the USA. Although the USA has the lead in many sectors, this is not true for all sectors (especially not if we control appropriately for differences in hours worked which are relatively high in the USA). Second, the productivity gap on average ranges from 0 to 20%.

One step further, we can look at the ratio between productivity of the top-quartile in a sector and average productivity in that sector. The countries for which we have information on the distribution of labour productivity within sectors are Finland (FIN), France (FRA), the United Kingdom (GBR), the Netherlands (NLD) and the USA (USA). The sectors covered are given in Table 9.3a. The results reveal that this ratio is relatively high in the USA with the top-quartile firms outperforming the average with a factor 1.8 – 2.5. The ratio is lowest in the Netherlands with the top-quartile outperforming the average with a factor 1.4 – 2.0. Finland and the United Kingdom are somewhere in between these two extremes whereas the situation in France strongly resembles that in the Netherlands.

Table 9.3a. Top-quartile labour productivity relative to average in 1992

Top quartile relative to average productivity	FIN	FRA	GBR	NLD	USA
Food products, beverages and tobacco	2.35	1.88	2.24	1.96	2.47
Textiles, textile products, leather and footwear	1.84	1.92	1.82	1.74	2.54
Wood and products	2.05	1.53	2.00	1.41	2.13
Pulp, paper, paper products, printing and publishing	2.02	1.70	1.85	1.54	2.01
Chemical, rubber, plastics and fuel products	2.29		2.19	1.84	2.13
Other non-metallic mineral products	2.18	1.69	1.96	1.83	2.07
Basic metals	2.38		1.99	1.58	2.08
Fabricated metal products	1.71		1.67	1.46	1.84
Machinery and equipment	1.93	1.66	1.85	1.50	1.99
Transport equipment	1.72	1.61	1.73	1.52	2.04
Other manufacturing	1.77	1.64	1.83	1.59	1.91
Unweighted average	2.02	1.70	1.92	1.63	2.11
Unweighted average (balanced)	1.99	1.70	1.91	1.64	2.14

Combining the information on average (relative) productivity and top versus average productivity in a country provides evidence on (i) the gap between the most productive firms in the countries under consideration and the (ii) the gap between average productivity in a country/sector and the top productivity in the world in that sector. It turns out that productivity in the top-quartile of firms in each sector is highest in the USA (details available upon request).[5] Furthermore, we can determine the average productivity in a country relative to the technology frontier proxied by the productivity of the top quartile in the leader country of the world (viz. the USA). This information is contained in Table 9.3b. It is this gap that is in our view the most

[5] Note that because of lack of data at a sectoral level we were unable to control for differences in hours worked. Macro-information on hours worked is available from the GGDC Total Economy Database 2003 (University of Groningen and the Conference Board). Hours worked per worker are 1799, 1676, 1552, 1653 and 1397 for the USA, Finland, France, United Kingdom and the Netherlands, respectively. Using these to correct, for example, the unweighted average productivity, we find relative productivity levels of 0.33, 0.48, 0.34 and 0.50 for Finland, France, United Kingdom and the Netherlands, respectively. See also OECD, 2003b, and De Groot et al., 2003, for similar exercises decomposing GDP per capita in differences in GDP per worker, participation and number of hours worked.

relevant empirical proxy for the potential of countries to catch up. It is evident that this gap is much larger than suggested on the basis of average productivity (of about 0-20%). The average Dutch firms perform only at 40% of their leading US counterparts. Clearly a huge potential for catching up is still available.

Table 9.3b: Average productivity relative to the top-quartile productivity in the USA

Average productivity relative to top quartile USA	FIN	FRA	GBR	NLD	USA
Food products, beverages and tobacco	0.24	0.30	0.24	0.30	0.40
Textiles, textile products, leather and footwear	0.25	0.40	0.28	0.32	0.39
Wood and products	0.40	0.42	0.13	0.39	0.47
Pulp, paper, paper products, printing and publishing	0.39	0.39	0.34	0.40	0.50
Chemical, rubber, plastics and fuel products	0.26	0.39	0.26	0.47	0.47
Other non-metallic mineral products	0.38	0.60	0.32	0.45	0.48
Basic metals	0.37	0.34		0.44	0.48
Fabricated metal products	0.40	0.43		0.39	0.54
Machinery and equipment	0.27	0.39	0.21	0.35	0.50
Transport equipment	0.31	0.40	0.34	0.35	0.49
Other manufacturing	0.31	0.38	0.65	0.44	0.52
Unweighted average	0.33	0.40	0.31	0.39	0.47
Unweighted average (balanced)	0.31	0.41	0.31	0.39	0.47

9.7 RESOURCE REALLOCATION AND AGGREGATE PRODUCTIVITY

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The heterogeneity in productivity across firms within an industry, as shown above, not only points to an increased potential for productivity improvements for the average firm. They also point to the importance of differences in firm size and changes in firm size for determination of aggregate productivity. Aggregate productivity growth is a weighted average of firm-level productivity, with appropriate adjustments for contribution of firm entry and exit. If firms with higher than average productivity increase in size, this adds to aggregate productivity. Likewise, if less than average productivity firms shrink and/or exit the industry, aggregate productivity increases. The effect on the aggregate of productivity growth within a particular firm depends on the size of the firm. The aggregation rules can be used to decompose aggregate productivity growth into the contributions of with-firm growth, resource reallocation and firm entry and exit.[6]

[6] Subtle differences in the decomposition may change the interpretation of the components as well as the numerical magnitudes. For example, the effect of entry depends on whether one considers entrants to 'replace' average incumbents, in which case the contribution of entry often is negative, or whether entrants replace 'exiters', in which case the contribution usually turns out positive. Over longer periods, surviving entrants invariably provide a positive contribution to productivity, regardless of method of computation.

The OECD growth study (2003b) provides evidence on the decomposition of productivity growth for the same countries for which the productivity distribution were displayed in Table 9.3b above. Although exact results depend on the time period under review, the industries selected, and the productivity measure considered, it is found that within-firm growth does not come close to explaining all productivity changes in the aggregate. In all cases, resource reallocation, either through changes in size of continuing firms or through the exit and entry process, is seen to contribute substantially to aggregate growth.

The decompositions provide an interesting view of how individual firms and the market-driven resource movements affect productivity. However, it is less clear how this process can be affected by underlying determinants. Resource reallocation does not necessarily have to be in the 'right' direction to improve the aggregate.

9.8 INTEGRATING THE EVIDENCE: A ROUGH SKETCH FOR A MODEL

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After this overview of scattered empirical and theoretical evidence on productivity determinants, it will be evident that a framework is needed that can integrate the disparate empirical findings and the features of the underlying theoretical models. In recent papers, some of the aspects of the above-mentioned theoretical approaches have been combined. For example, Klette and Kortum (2002) integrate a firm demographics model with features of a macroeconomic growth model and Acemoglu et al. (2002) combine features of micro-based innovation models with firm demographics. In the present chapter, a plausible 'accounting' model is presented that combines all the features. It is an accounting model, because not all the relevant features are endogenised and solved for in a general equilibrium setting. Instead, certain features are considered exogenous and the effects can be explored in alternate scenarios.

The accounting framework used is in a sense ad-hoc, but fits with many of the features of current theoretical models and with stylised facts from recent empirical work. The framework hosts the following features:

- Heterogeneity among firms in productivity and innovation strategies
- Resource reallocation between firms
- A global technology frontier
- Innovation and adoption of technology
- Global and local spillovers of knowledge
- Embodied and disembodied technology

The framework can be used to decompose productivity into contributions of primary factor inputs to output growth (growth accounting), but also to decompose overall productivity growth into the contribution of resource reallocation and within-firm productivity gains. Finally, the framework can be used to assess how changes in exogenous parameters affect the distance to the frontier and the speed at which the frontier is approached.

9.8.1 Firm-level choices and market interactions

While productivity levels and growth rates may be computed for countries and sectors of the economy, productivity is the result of micro-level decisions to convert inputs into output of goods and services. The basic unit of analysis of this framework will thus be a firm, although conceptually other units such as non-profit institutions, where decisions are made over inputs, and outputs are covered as well. The firms in an economy are heterogeneous in many dimensions: location, product mix, factor intensity, composition of workforce, size, productivity, and innovation strategy, to name a few. In the simple framework described below, firms may vary in size, productivity, and innovation strategy.

The characteristic of firms most important for studying productivity growth is the strategy followed to improve their own productivity. Following notions that are common in economic literature, there are firms that continuously attempt to be near, or on, the technology frontier through innovative investments, while there are also firms that improve their productivity by purchasing, installing and learning to use technology embodied in capital goods.[7] Finally, there are firms that operate at a distance from the frontier and employ perfectly known technologies. We label them, respectively, innovators, adopters, and followers.

In the accounting framework, the innovators need to undertake innovative activities (conduct R&D, employ highly skilled workers, experiment with business practices) in order to increase the stock of knowledge that improves TFP in their own productive activities. The efficacy of the innovative activities is boosted through spillovers of their own knowledge stock, and from the stock available to firms at the frontier. The spillover parameter could be positive, as existing knowledge makes the work of researchers and innovators easier. Theoretically this 'standing on giants shoulders' effect could be outweighed by a negative 'depletion of technological opportunities' effect.[8] The crucial aspect of innovation is that the profitability of the expenditure on innovative activity depends not only on technological success, but also on leveraging the fixed cost of the innovation through increases in scale of production.

Adopter firms may employ some innovative activity to be able to use new technology embodied in capital goods. The firms purchase capital goods until expected costs and benefits are equal at the margin. The firms can improve TFP by adding 'innovative effort' in the process of learning best how to use the technology embodied in the capital. By doing so, the firms are able to converge towards the technology frontier, or at least to the productivity level of the innovators. Because the increase in TFP is associated with the innovative use of technology embodied in the capital, the firms are not able to leverage the investment through increased size, to the extent that innovative firms can leverage fixed costs of increasing their knowledge stock.

Finally, there are 'follower' firms that generate output and profit by employing labour and capital in well-known and well-understood production processes. These firms do not invest in uncertain innovative activities and have less variability in TFP and profitability than do innovators and adopters. TFP growth does take place, as knowledge diffuses, patents expire,

[7] Jovanovic and Nyarko (1996), Gerschenkron (1952), Acemoglu et al. (2002), to name a few.
[8] See Romer (2001), Kortum (1997), and Jones and Williams (1998).

education levels increase, etc. In the accounting model this is accomplished by assuming a diffusion duration that makes productivity growth a function of the level of the productivity gap between followers and adopters.

The choice of innovation strategy is not the only behaviour attributed to firms in the framework. Firms have the choice to exit the market altogether, and potential entrants may decide to enter the market. Further, the firms have the choice, given the demand curve they face, of the level of resources to apply to production.

The demand curve facing a firm depends not only on the price-quality characteristics of its products, which reflects its productivity, but also on the supply conditions at other firms in the market. A successful innovator will potentially be able to supply a larger share of the market if it is able to mobilise productive resources rapidly. Innovators that are not successful in generating a good technological outcome quickly shrink, and/or exit the market. Adopter firms have much smaller swings in technological success or failure, much smaller variation in productivity, and thus have smaller potential shifts in market shares.

A full general equilibrium model could show the conditions under which firms or potential entrants would decide to follow one of the strategies. Also, a model could show how, dependant on technological outcomes, resources in the economy would be added to or shifted away from firms, with firm exit at the extreme. Also, the decisions of firms on how much to spend on innovative activity and how much on capital and other primary inputs, would be determined by cost and benefit at the margin, taking into account actions of other firms and exogenous conditions. Such a general equilibrium model is complex, because firms must take into account not only the dynamics effects of their own actions but also how their actions affect their competitors, etc. Even simple versions of such models quickly run into computational bounds.[9] Such a model does not exist at present, but the relevant behavioural descriptions of the firms' choices, as described above, will provide guidance in tracking the mechanism driving the effects of various determinants of productivity.

With the simple breakdown of firms by innovation strategy, and a description of how firms' decisions interact with the demand side to determine resource allocation, a description will be given of the paths through which the various factors affect growth. These factors include traditional growth accounting items, but also factors such as the quality of the banking system, land use regulations, etc. It should be emphasised that the ultimate source of productivity growth is innovative activity, but that in a world with heterogeneous firms, aggregate productivity may change owing to movements of firms towards the frontier, and shifts in resources between firms. Further, the resource reallocation may itself affect firm-level decisions with regard to innovative activity.

9.8.2 Qualitative effects of productivity determinants

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In presenting the qualitative effects of underlying drivers of productivity, their role in determining the choice by firms of their innovation strategy is first presented. Next, the firms'

[9] See Pakes and Mcguire (2001) or Peeters (2002).

expenditures on factor inputs and innovative activities are linked to the underlying drivers. With these links in place, a method for quantification of the contribution of the various drivers to (potential) growth is given.

9.8.3 Choice of innovation strategy

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Table 9.4 marks the factors affecting the choice of a firm at the margin between being and innovator or an adopter, and the choice at the margin between being an adopter or follower. The choice depends on expected value of profits for firms engaging in each strategy. At the margin the innovators are more profitable if the cost of innovation is lower, if the chance of being technologically successful is higher, and if it is easier to leverage technological success with increased size. The latter depends on ease of resource reallocation and the speed with which customers can switch between suppliers.

Table 9.4: The choice of innovation strategy

	Adopters vs. Innovators	Followers vs. Adopters
The cost of innovative activity		
Private and public R&D	X	X
Human capital	X	X
Foreign R&D spillovers	X	
Venture capital	X	
Chance of technological success		
Private and public R&D	X	
Human capital	X	
Foreign R&D spillovers	X	
Resource reallocation		
Cost of adjusting resources with technological success/failure		
Labour-market Flexibility	X	
Banking system	X	X
Equity markets	X	X
Sensitivity of customers to price/quality		
Product-market regulations	X	

The costs of innovation will depend on the price of human capital and the efficacy with which it is used. The price will decrease with increased supply of skilled researchers, all else being equal. The efficacy of the human capital input depends on spillovers from past knowledge. The spillovers may vary according to whether the knowledge was developed in-house, by partners in networks, or in firms in value chain, or with public funding. The cost of attracting funds for such risky activities is reduced with the availability of venture capital.

The chance of technological success rises with the research efforts expended by a firm. Per unit of own innovative input, the chance of success and the relative improvement in TFP, if the innovative activity is successful, depends on the available knowledge stock and spillovers, as well as on the quality of the researchers and their effort. For innovators, the size of the improvement resulting from research success is high, but the chance of achieving the breakthrough rather small. For adopters applying innovative activity to make use of technology embodied in capital, the risks are smaller, as is the size of the resulting productivity improvement.

Finally, the choice between being an innovator or adopter depends on the speed with which a technologically successful firm can spread the fixed costs of innovation over higher production volume. This depends, in turn, on the speed with which the firm can mobilise resources (capital and labour, and new production locations), and on the sensitivity of customers to differences in price-quality characteristics among competing suppliers. Resource reallocation becomes less costly with increases in flexibility of employment protection legislation (EPL). On the other hand, if it becomes difficult to hire and fire workers, firms more readily choose to engage in 'smooth' upgrading of technology rather than to risk a disruptive change. Furthermore, firms have more reason to train workers in-house because the expected period over which the costs are amortised increases. Strong EPL, thus shifts the balance from innovator to adopter. Resource reallocation also is aided by a well function banking system and the possibility to finance changes in corporate ownership.

The choice between being an adopter of technology and a follower also depends on the costs of innovation and resource reallocation. For adopters, productivity advances are achieved by adding complementary human capital, in order to learn how to employ the purchased technology. The outcomes of this innovative effort is not very uncertain. Nonetheless, most of the learning costs will need to be made again if the firm attempts to increase its size because the innovation is not non-rival in production to the same extent as it is for innovators. For this reason, reallocation of resources is not as important. A good banking system is important in order to provide the resources to purchase the capital with embodied technology, and proper incentives (e.g., corporate governance) need to be in place to improve the efficiency of the complementary innovative activities.

9.8.4 Within-firm innovative activity, capital accumulation and growth

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In growth accounting, which is an appropriate analytical tool at the firm level, output growth can be decomposed into the contribution of capital deepening, innovative capital and innovation. A remaining residual describes the growth arriving as manna from heaven. In growth accounting, contributions can be calculated only for those factors where input decisions are made by the 'decision-making unit' under study. The contribution of capital deepening comes through a firms' purchases of capital goods, the innovative capital contribution depends on the quality of the purchased capital (e.g. ICT capital) and the innovative expenditures needed to learn how to use it well, while the contribution of innovation is often proxied by weighting the growth of the available knowledge stock with the expenditure share on own-R&D. Many of the possible determinants of aggregate productivity are external to the firm but affect the firm's decisions, and thereby within-firm productivity growth. These links are marked in Table 9.5, showing when a determinant affects the contributing factor to within-firm growth.

The columns of Table 9.5 are related to the innovation strategies chosen by a firm, as displayed in Table 9.4. The residual accrues to the followers and its magnitude is related to the size of the TFP gap from the followers to the adopting firms. For followers, TFP growth thus comes about as knowledge about production processes and products becomes fully diffused.[10] Innovators actively build a knowledge stock and continue to invest in innovative activity in an attempt to stay at or near the productivity frontier. Adopters and innovators actively make use of existing technology by purchasing capital and applying it in an innovative manner. This innovative capital deepening may increase TFP, as complementary innovative inputs help close the gap to more productive firms. All three types of firms may increase labour productivity through traditional capital deepening.

The marks in the rows of Table 9.5 show how the factors underlying within-firm output growth contribute to the growth accounting components, such as innovative activity. The first set of rows are the 'own inputs' under direct control by the firm. ICT capital is taken to be an innovative input. This relates to the possibilities to use ICT to innovate in business processes and other methods for transacting with customers and suppliers. Of course, ICT capital may also just be used as a traditional machine, with little or no 'knowledge' component.

The second set of rows are determinants external to the firm, and possibly related to policy instruments. For example, a mark in the column 'innovative activity' for the row showing public R&D, means that a higher stock of public R&D knowledge will increase expenditures on innovative activity for innovative firms. For the firm, the costs and benefits of an extra unit of innovative input need to be weighed at the margin. This is affected by costs of innovative inputs, effectiveness of activity, spillovers, chance of technological success and magnitude of improvement if successful, and the leverage applied to outcome through resource reallocation. Some of the determinants operate through lowering the costs of innovative activity, e.g. a higher supply of skilled workers. Other determinants affect innovative activity indirectly, through the increased potential profitability of a successful innovation brought about by increased resource reallocation, e.g., property rights, or strong competition policy.

[10] It is assumed that policy has no direct influence on the rate of catch-up or on the number of years of lag to the frontier for follower firms. Of course, policy will affect the choice of a firm's innovation strategy, and thus the number of followers.

Table 9.5: Factors underlying within-firm output growth

	TFP growth			Capital deepening
	Residual	Innovative activity	K/L + innovation	K/L
OWN INPUTS				
R&D		X		
ICT capital		X	X	
Non-ICT capital				X
Skilled workers		X	X	
EXTERNAL DETERMINANTS				
Innovation				
Public R&D	X	X		
Foreign R&D spillovers	X	X		
Firm co-operation and knowledge flows in clusters		X		
Embodied technology flows (i.e. ICT)			X	
Human capital				
Participation		X	X	
Skill upgrading		X	X	
Financial system				
Venture capital		X		
Equity markets			X	X
Banking system			X	X
Corporate governance		X	X	
Product market competition				
Property rights		X		
Ease of entry		X		
Regulation in markets for goods and services		X		
Labour market flexibility				
Labour market regulation (firing and hiring)		X		
Wage bargaining system			X	X
Property market				
Town and planning regulation		X		

For innovators and adopters, the amount of exploration and learning applied together with new capital, determines the amount of productive advance a firm makes, beyond that embodied in the equipment. The underlying factors that matter here are the costs and availability of human capital. Further, financing must be available for the not so risky innovation and for the capital deepening itself. Good corporate governance plays a role in driving managers to put in the effort to add innovative value to the purchased capital.

Most of the determinants in the table operate in a manner similar to that described for Table 9.4. A well functioning venture capital system allows firms to undertake risky innovative projects. Some underlying factors require further explanation. For example, the wage bargaining system may affect growth through a few channels. At the most elementary level, market power of unions may increase the wage rental ratio and result in an inefficiently high capital-labour ratio. Under the assumption that technology is embodied in capital, output per hour will increase through this channel. Further, the market power of unions may result in firms attempting to close out labour through innovating with a bias against labour (Caballero and Hammour, 1998). Alternatively, it has been argued that bargaining between workers and firms, with government involvement, may lead to paths with low wage growth. This in turn reduces capital investment and increases the age of the capital stock, which results in low productivity growth. Some evidence for the Netherlands (Bartelsman, 2000) points out that such wage moderation actually serves as a means to reduce opportunistic behaviour of unions following innovation and capital investment. This mitigates the hold-up problem that would have reduced innovative activities and investment.

9.9 QUANTIFICATION OF THE UNDERLYING DETERMINANTS OF GROWTH

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Neither traditional growth accounting, nor the cross-country growth regressions, provide much guidance in calculating how a change in, for example, property rights, will affect growth. With growth accounting, by construction, labour productivity growth equals the contribution of capital deepening plus the contribution of knowledge intensity growth plus the residual. All external factors ‘compete’ to contribute to this residual.

The empirical evidence on the role of various institutional settings, such as the regulatory environment or the quality of the banking system, usually depends on quantifying the institutional setting in an index, and regressing growth in a panel of countries, sectors, and/or time on the index. This evidence does not capture the path or mechanism through which the institutional setting affects growth. The regressions reflect a reduced form of a more complete model. The parameter estimated in such standard regression specifications coincides with a partial derivative of aggregate output growth with respect to the underlying factor, all else being equal. Because the ‘all else’ factors also vary by country and over time, the parameter estimated cannot be translated directly into appropriate unknown model parameters. In cross-country regressions, it is very difficult to assess the relative importance of the determinants, and no allowance is made for the indirect effect of the determinant on own inputs.

An important advantage of the model sketched out in this paragraph is that one can generate growth scenarios for different values of, for example, the availability of venture capital, and then conduct growth accounting for each scenario. Under the different scenarios, output growth will vary, as will the contribution of capital deepening, innovative activity, and the residual. Further, the different scenarios will also provide different decompositions of aggregate productivity into the contributions of within-firm growth and resource reallocation. The magnitudes of the effect of various determinants could be based on model calibration, using known moments in the sectoral country time series on outputs and inputs as well as the regression parameters from the empirical literature. In other words, one would search over the parameter space of the model such that the parameters estimated from data generated by the model match the empirical results from the literature. Because such a calibration exercise effort has not been made yet, no exact quantifications can be made. Instead, a verbal example will be provided of how a policy change will affect the outcomes of the model paths of output and productivity. In the next paragraph, the example of a reduction of hiring and firing costs brought about through appropriate changes in policy is considered.

The long-run growth rate of the innovators does not change, even with changes in the allocation of research activity, and remains equal to the growth rate of the global frontier. What does change, is the share of firms choosing to be innovators, because lower resource adjustment costs improves the ability to exploit opportunities if the innovation is successful and reduces costs of shrinking the firm when the innovation fails. In the short run, productivity growth will be boosted as more firms move closer to the global frontier and as resources are able to shift more rapidly to firms that have higher productivity. In the long run, average productivity levels will be higher, and more firms will be closer to the global frontier than before the policy change. Further, aggregate productivity will be higher for firms grouped by innovation strategy because the better firms are able to gain greater output shares.

The contribution to growth from resource reallocation, both through entry and exit and between existing firms, increases. Within-firm growth may actually decline in the long run, because the catch-up effect is reduced with more firms being closer to the frontier, on balance.

On balance, the policy change has only transitory productivity growth effects, but provides a long-run path of output that is produced closer to the global productivity frontier, providing permanent welfare gains.

9.10 CONCLUSION

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The determinants of productivity differences and the evolution of productivity over time has in the past decades been intensively studied in both the theoretical as well as the empirical literature. This literature has provided a plethora of theoretical and empirical approaches. An overall integrating framework is lacking. In this chapter, we have identified (i) heterogeneity of firms within sectors, (ii) entry and exit of firms, (iii) the institutional context within which firms operate, (iv) the concept of a world technology frontier, (v) local within and between sector knowledge spillovers and global spillovers, (vi) embodied versus disembodied technology and

(vii) innovation as opposed to adoption as key elements in both the theoretical as well as the empirical literature that should be part of an integrating framework. A first attempt to develop such a framework was presented, with an emphasis on qualitative aspects. Future work will be devoted to refining and especially calibrating the framework.

APPENDIX *Data*

Our main data source is the International Sectoral Data Base from the OECD (version 1998). This database contains information on GDP in constant dollars, the investment ratio, the number of employees, a simple construct of total factor productivity (as an index[11]), capital stocks, etc. Information on human capital is taken from De la Fuente and Doménech (based on Barro and Lee, but corrected for several inconsistencies). Institutional indicators were obtained from Barro and Lee (1994), Nickell and Nunziata (2001) and Kaufman et al. (2002). Data on productivity of the average firm and the top quantile of firms were compiled by the OECD firm-level study (Bartelsman and Barnes, 2001; Bartelsman et al., 2003; OECD 2003b). Details are available upon request from the authors.

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