Population Distribution and Telecommunication Costs

Staff Research Paper

Peter Cribbett

The views expressed in this paper are those of the staff involved and do not necessarily reflect those of the Productivity Commission. Appropriate citation in indicated overleaf.

August 2000

ISBN 1 74037 013 9

Inquiries:
Media and Publications
Productivity Commission
Locked Bag 2
Collins Street East Post Office
Melbourne Vic 8003

Tel: (03) 9653 2244
Fax: (03) 9653 2303
Email: maps@pc.gov.au

An appropriate citation for this paper is:

Cribbett, P. 2000, *Population Distribution and Telecommunication Costs*, Productivity Commission Staff Research Paper, AusInfo, Canberra, August.

The Productivity Commission

The Productivity Commission, an independent Commonwealth agency, is the Government's principal review and advisory body on microeconomic policy and regulation. It conducts public inquiries and research into a broad range of economic and social issues affecting the welfare of Australians.

The Commission's independence is underpinned by an Act of Parliament. Its processes and outputs are open to public scrutiny and are driven by concern for the wellbeing of the community as a whole.

Information on the Productivity Commission, its publications and its current work program can be found on the World Wide Web at www.pc.gov.au or by contacting Media and Publications on (03) 9653 2244.

Preface

In March and December 1999, the Commission published international benchmarking studies comparing Australia’s telecommunications prices and regulatory arrangements with those in a number of other OECD countries. These studies noted that an important influence on costs, and potentially on price differences between countries, is line density. Line density distributions are influenced by the distribution of population.

In this study, differences in population distribution, between Australia and several countries and US States, are examined to gauge their impact on average telecommunication line costs.

Acknowledgments

The study was conducted in the Economic Infrastructure Branch, as part of the Productivity Commission's program of research into the performance of Australia's economic infrastructure industries.

The paper has benefited from the cooperation of Telstra and the Australian Communications Authority (ACA). In particular, John de Ridder and Steven Owens (Telstra) and Neill Whitehead and Bernadette Tan (ACA) are thanked for their assistance, comments and helpful discussions.

Dr Dan Alger of Economics Incorporated is also to be thanked for kindly providing extensive background data and estimates from the Alger and Leung (1999) study.

The paper was written and researched by Peter Cribbett assisted by Dr Yimin Zhao.

Contents

APPENDICES

Abbreviations

ABS	Australian Bureau of Statistics
ACA	Australian Communications Authority
ACCC	Australian Competition and Consumer Commission
BCPM	Benchmark Cost Proxy Model
BIE	Bureau of Industry Economics
CBG	Census Block Group (US Census Bureau)
CD	Collector district (Australian Bureau of Statistics)
CDF	Cumulative distribution function
ESA	Exchange Service Area
FCC	Federal Communications Commission (US)
GLS	Generalised Least Squares
FGLS	Feasible Generalised Least Squares
HAI	Hatfield Associates Incorporated (HAI Consulting)
ITU	International Telecommunications Union
LPP	Line per person
NUSC	Net Universal Service Cost
PC	Productivity Commission
PDF	Probability density function
RLI	Reporting Level Indicator
SLA	Statistical Local Area (Australian Bureau of Statistics)
USO	Universal Service Obligation

Key points

- The average cost of providing local telephone service is increased in Australia, because it has a relatively large proportion of its population (and hence lines) in areas with low population densities.
- Previous benchmarking by the Commission indicated that Finland has lower prices than Australia. This new study suggests that this is not the result of cost advantages due to a more favourable population distribution.
- Depending on assumptions about the cost of providing each line, average line costs in low-density areas of Australia of less than about 2 lines per square kilometre were found to be between 6 and 10 times the average cost per line in the rest of Australia.
- Similarly, low density areas are estimated to account for some 25 per cent of the total cost of providing local telephone service, despite having only about 5 per cent of the total number of lines. This compares with a 10 per cent cost share for the equivalent low-density areas in Washington State and 5 per cent for those areas in California.

Reasons for undertaking the study

- This study was undertaken to examine the extent to which price differences in international comparisons can be attributed to differences in the distribution of population, therefore providing insights into the importance of other factors such as industry and regulatory performance.
- This work is in support of the Commission's ongoing program of benchmarking the performance of Australia's economic infrastructure. It follows on from two international benchmarking studies of telecommunications prices.
- The research addresses a weakness in the general understanding of the influence of widely accepted economies related to the geographic intensity of service provision on overall costs when there are significant differences in the way population, and hence telephone lines, are distributed.

Previous studies

- In the past, researchers examining the influence of population and line distribution on cross-country differences in telecommunication line costs have, for the most part, used data too highly aggregated for the purpose.
- Moreover, the data used has generally been obtained from various sources with no attempt to ensure comparability.
- Also, researchers have ignored that the number of telephone lines per head of population varies with population density.

Approach

- Average line costs for Australia, New Zealand, Finland and the US States of Alaska, California, Oregon and Washington were estimated using line density distributions (the proportions of lines in various line density categories) and a common cost function (average cost per line as a function of line density)
  - line density distributions were derived from population distributions and estimates of lines per person, taking into account the variation in lines per person with population density.
- Population density distributions for each country and US State were 'normalised' to a consistent level of aggregation. This adjustment was necessary because population density distribution estimates are highly sensitive to the level of data aggregation used.
- Readily available cost functions were augmented to provide greater information on the relative costs per line in low-density areas using information provided by Telstra and the Australian Communications Authority.

1 Introduction

Telecommunication services play a vital role in the Australian economy. They are used in the production of virtually every good and service — and their role continues to increase. Technological innovations in telecommunications are facilitating better information management and lowering the transaction costs of business. Hence, price reductions in these services, to the extent that they reflect more efficient resource usage, are likely to yield economy-wide benefits.

Recently, the Productivity Commission (PC) undertook two international benchmarking studies comparing the prices of telecommunications services in Australia with several other developed countries (PC 1999a,b). The studies noted as one potential source of high prices, low productivity. Another, strong financial performance, where that performance is based on a deleterious exercise of market power.

It was also acknowledged that there are other factors associated with a carrier's operating environment, over which a carrier has limited control, which may affect prices.

Perhaps most important among these other environmental factors, are differences in the way in which populations, and hence lines, are distributed in each country — that is, differences in line densities.

There has been little argument about the relevance of these differences when comparisons are made within a country.[1] However, the magnitude of the impact of these differences on cross-country comparisons of telecommunication prices has been the subject of continuing debate (for contrasting views see, for example, NECG 1999, Ovum 1998, BIE 1995, Ergas, Ralph and Sivakumar 1990).

1 Telecommunication cost studies show, unambiguously, that one of the most important factors in explaining cost differences between different locales within a country is line density. See, for example, Alger and Leung (1999), NECG (1999), Gabel and Kennet (1994), Guldmann (1991).

1.1 Purpose

The aim of this study is to provide information on the influence of line density on cross-country price comparisons by estimating the differences in average line costs that can be attributed solely to differences in the way populations (and hence lines) are distributed.

To isolate the effect of line density on average line costs, the influence of other factors on cost was held constant. That said, there are many other influences on line costs (see box 1.1). Hence, the results of this study should not be interpreted as representing all the cost differences between countries that are beyond the control of carriers.

Box 1.1 **Other factors influencing telecommunications costs**

Line densities are not the sole determinant of average line costs. Costs may differ between countries for many other reasons. Other factors that affect the costs of laying or maintaining lines include those attributable to:

- geology, geography and climate — for example, terrain, soil type, depth to bedrock, vegetation, and water levels;
- regulation — for example, local government requirements that lines be laid underground; and
- input costs — for example, relatively high labour or capital costs.

In addition, line density is only a proxy for average line length — the average amount of cable required to link a subscriber to their local exchange. The exact configuration of subscribers varies between areas with the same line density, affecting average costs.

Another factor, for which line density is only a partial proxy, is the number of lines connected to each exchange. This affects average line costs — with fewer lines connected to an exchange average line costs are higher. In any country, the average numbers of lines connected to an exchange tends to fall with a fall in line density. Nevertheless, for different exchange service areas having the same broad line density the numbers of lines connected to each exchange varies significantly.

Line costs, at a particular line density, were defined as the typical (average) costs of efficiently providing the relevant customers with basic local telephony services. The costs include all the associated infrastructure costs of providing the basic services to meet forecast demands at customer locations, the cost of meeting those demands and billing. This includes the costs associated with the network elements (loop, switching, transport and signalling), facilities and associated operations.[2]

[2] This also includes a market reflective rate of return on assets required to provide the services.

1.2 Recent studies

Ovum (1998) and Alger and Leung (1999) are two recent studies that addressed the issue of the impact of cross-country differences in population density, and hence line density, on international price comparisons. These studies are outlined and reviewed in appendix A.

The Ovum study is topical. It was cited by the Australian Competition and Consumer Commission (ACCC) in a recent telecommunications access determination.

The Ovum study was similar to a number of other studies, in that the line density issue was addressed in passing (for example, Ergas, Ralph and Sivakumar 1990, NECG 1999). As outlined in appendix A, the analysis was relatively brief and the results equivocal. Hence, it did not strongly support a conclusion that adjustments for differences in line density were not required when comparing Australian access charges with those prevailing in the US and UK.

Alger and Leung (1999) was the only study identified, that was singularly devoted to the subject. The authors estimated the average line costs in five countries — Australia, New Zealand, Sweden, the United Kingdom and the United States. Their study took a broadly similar approach to this study.

Relatively disaggregated census data was used for each country, the population data being used to estimate line density distributions. Weighted average costs for each country were then estimated using cost results for a number of US States obtained from a US engineering cost model.

Although the study was a significant advance on previous work, it did not identify or address an issue related to the comparability of census data. Differences in the level of aggregation used for different census data significantly affect density estimates and hence average line cost estimates. Consequently, for comparisons between countries to be valid, the same levels of aggregation must be used. Where levels are not the same between countries, some 'normalising' adjustments are required.

1.3 Scope

Three countries and four US States were included in this study — Australia, Finland, New Zealand, Alaska, California, Oregon and Washington State. The choice of countries (and US States) was partly motivated by data availability and cost. Finland was chosen because it was the country that had the lowest overall prices in the Productivity Commission's benchmarking studies.

1.4 Consultation

Telstra and the Australian Communications Authority (ACA) were kept up-to-date with the progress of the study and both provided data. The ACA provided raw output from their Universal Service Obligation (USO) cost model — the Net Universal Service Cost (NUSC) model. Telstra also provided cost data from a USO related study they had commissioned. In addition, they provided extensive data on line numbers by wire-centre along with concordance data matching this data to Australian Bureau of Statistics (ABS) census data.

Dr Dan Alger of Economics Incorporated provided extensive background data and estimates from the Alger and Leung (1999) study. Dr Daniel Kelly of HAI Consulting Incorporated provided the results of model runs for all US States from the HAI model version 5.0a.

1.5 Refereeing

Drafts of the chapters and appendixes were refereed by Dr Tim Fry (Monash University), and Dr Philippa Dee, Dr Patrick Jomini and Chris Chan (Productivity Commission).

2 Research method

The aim of this study was to estimate the differences in average line costs that may be attributed to differences in the way populations, and hence telephone lines, are distributed.

Average line costs were estimated using line density distributions (the proportions of lines in various line density categories) and a cost function (average cost per line as a function of line density). The average cost per line for a country was estimated as a weighted sum of the costs per line for each line density category, using the proportion of lines falling in the density categories as the weights.

That is, average line costs were estimated by:

$$AC = \sum_{i=1}^{T} \phi_i C_i \qquad 2.1$$

Where *AC* is the estimate of the average line cost for a country, ϕ_i is the proportion of lines in a particular line density category *i*, C_i is the average line cost for that density category, and *T* is the number of density categories.

In order to isolate cost differences solely attributable to differences in the way populations are distributed, a common cost function was used.[1] Consequently, areas with the same density were assigned the same cost per line.

2.1 Cost functions

Line costs vary significantly with line density. Moreover, estimates of average line costs, for any given density, also vary significantly.

BCPM and HAI cost schedules

The cost schedules used for this study were all based on two schedules provided by Telstra. These schedules were based on cost estimates obtained from the US

1 Other factors influencing costs are outlined in box 1.1.

Benchmark Cost Proxy Model (BCPM) and the Hatfield Associates Incorporated (HAI) cost model, respectively (see box 2.1).

Box 2.1 **The BCPM and HAI 'forward-looking' cost models**

The cost schedules used in this study are based on results from the US Benchmark Cost Proxy Model (BCPM) and the Hatfield Associates Incorporated (HAI or Hatfield) model. These engineering models are used to estimate the total average cost (per line) of providing basic local telephony services in nine line density categories. They use very detailed data (on customer locations and demands, topography, soil conditions and climate) as a basis for designing a network capable of serving existing customers at least cost.

The US models were developed for use by protagonists in US regulatory hearings on access charges and universal service subsidy payments. The BCPM model was financed by incumbent carriers (and produces higher cost estimates). The HAI model was financed by entrants.

More recently, the US Federal Communications Commission (FCC) developed its own model, the Hybrid Cost Proxy Model (HCPM). Costs estimated with this model fall in between those of the protagonists' models. However, the structure and cost estimates of the HCPM are closer to those of the HAI model.

The results of the models are provided in various forms — for example, by individual US Census Block Group, Block or wire centre. Results are also aggregated into average line cost within a density range (for example, the average cost per line of Census Block Groups with line densities between 0 to 5 lines per square mile — that is, 0 to 1.93 lines per square kilometre).

Telstra provided aggregated cost schedules, which they claim are typical of the relationship between cost and line density. They are based on the aggregated averages for five US States (Florida, Georgia, Maryland, Missouri and Montana) and are consistent with BCPM and HAI cost schedules obtained from other sources.

These and other cost models provide differing estimates of the levels of costs, and of the cost relativities between the high- and low-density areas.[2] This variation and uncertainty about the exact shape of the relationship between cost and line density, motivated the decision to try several different cost schedules.

The BCPM and HAI engineering models have been used extensively in US regulatory hearings (at both State and Federal levels) to determine appropriate interconnect prices and universal service subsidies. Both are designed to estimate

2 For example, the BCPM cost results are about 25 per cent higher than the HAI results for the low-density areas, but more than 200 per cent higher for high-density areas. Similarly, the HAI estimates suggest average line costs in a low-density area (0 to 2 lines per square kilometre) are about 20 times greater than in a high-density area (4000 or more lines per square kilometre); the BCPM estimates suggest a difference of less than 8 times.

‘forward-looking’ costs — that is, to estimate the long-run monthly per line cost of providing local telephony services with least-cost technologies.

The BCPM and HAI cost schedules provide estimates of the total average cost (per line) of providing basic local telephony services in nine line density categories.

Adjustments to the BCPM and HAI cost schedules

The lowest density category for the BCPM and HAI cost schedules is 0 to 5 lines per square mile (0 to 1.93 lines per square kilometre). The proportion of lines falling within this category has an important influence on country-wide average line costs, and hence comparisons.

Accordingly, more information was added on cost relativities within this range. Cost data was provided by Telstra and the Australian Communications Authority (ACA).

The Telstra and ACA data provided estimates of ‘forward-looking’ costs at low densities (based on Australian conditions).[3] These were used to estimate the relative average costs of lines in various partitions of the 0 to 1.93 square kilometre category.[4] The results of this analysis were ‘spliced’ into the BCPM and HAI schedules — replacing the lowest density category with two categories.[5] Ten augmented cost schedules were produced in the process (see appendix B for details).

2.2 Line density distributions

The line density distributions were imputed from population density distributions, and information on the relationship between population and line density.[6]

3 The costs had been estimated to assist in assessing the magnitude of the universal service obligation (USO). Telstra’s results were based on a study that estimated the ‘forward looking’ line costs for 40 wire centres in low-density areas. The ACA results were from their engineering model (similar in design to the HAI model). This model was used to estimate the costs in 6122 low line-density areas.

4 Analysis of the Telstra cost data provided relative cost estimates for two categories — 0 to 0.1 and 0.1 to 1.93 lines per square kilometre. Analysis of the ACA data provided relative cost estimates for the 0 to 0.2 and 0.2 to 1.93 lines per square kilometre ranges.

5 Thus, the resulting schedules had ten density categories.

6 Comparable cross-country data on line density distributions were unobtainable. Hence, the Australian relationship between population and line density was used.

The population density distributions were constructed using census data from Australia, Finland, New Zealand and four US States — Alaska, California, Oregon and Washington.

Population density distributions for each country (and US State) were estimated as the cumulative proportion of population at or below a given population density (see appendix B).[7]

Reporting levels

Each country provides census data at a number of reporting levels (or levels of aggregation). At a particular reporting level, a country is divided into a number of distinct geographic areas. For each of these areas (or statistical reporting units), the number of people in the area (population count) and its size (in square kilometres) are provided.

The population density associated with the area (at a particular reporting level) was estimated as the number of persons per square kilometre (population count divided by area size).

At the base, or lowest reporting level, a country is divided into the largest number of distinct areas. Higher reporting levels are constructed by joining base reporting units together to create larger reporting units. For the US States, the second lowest reporting level was used,[8] the Census Block Group (CBG), and for Australia, Finland and New Zealand the two lowest reporting levels were used (see appendix B).

Adjustment issues

Estimates of a country's population density distribution vary systematically with the level of aggregation used. If larger reporting units are used (a higher reporting level), estimated densities tend to be lower (see box 2.2).[9]

7 These are referred to as cumulative distribution functions (CDFs) of population density.

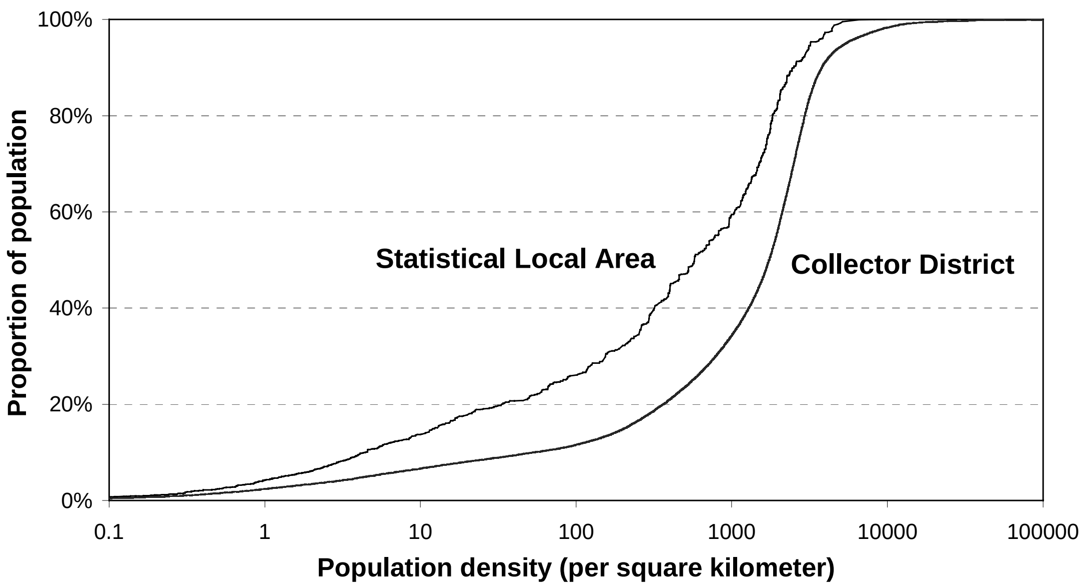
8 The lowest level of aggregation in the US, the base reporting level, is the census block level.

9 Estimated densities will tend to be lower over most but not all of the range of the distribution.

Box 2.2 **Different reporting levels yield different population density estimates**

The figure below illustrates the impact on estimates of population density and its distribution when different sized census areas are used. The cumulative distribution functions (CDFs) for population densities in Australia presented in the figure were derived from 1996 census data provided at the base reporting level — the collector district (CD) — and the next level up — the statistical local area (SLA). Population densities were calculated for each level by dividing the population count in each census area (CD or SLA reporting unit) by its size in square kilometres.

Australia — Cumulative distribution of population densities



The horizontal axis represents population density per square kilometre. The vertical axis represents the proportion of the total population living in CD or SLA reporting units at or below that level of population density.

The reporting level used significantly influences results. For example, at the 20 per cent level (that is, with 20 per cent of the population at or below that population density level), the population density estimates are 11 times greater using CD data compared with SLA data. Estimates of line density distributions and hence costs are affected. For illustrative purposes, average costs per line for Australia were estimated using cost data from the HAI model and line density estimates based on each distribution estimate. The estimate based on the SLA data was 50 per cent higher than that based on the CD data.

Note: A logarithmic scale has been used for the population densities. There were 34 259 collector districts and 1321 statistical local areas. Due to the large number of observations, the plot based on collector districts appears to be smooth.

It was important to ensure that the reporting levels used ‘matched’ each other. If they had not, systematic errors would have been introduced.[10] Therefore, a common reporting level was selected — the US CBG level.[11] Population density estimates were then adjusted so that they would correspond to this reporting level.[12]

However, none of the reporting levels used in Australia, Finland or New Zealand match the US CBG level. Thus, a preliminary step in the adjustment process was to construct a ‘reporting level indicator’ (RLI) to measure the extent to which these reporting levels differ from the US CBG level.

This RLI was used to adjust each country’s population data so it would correspond with data reported at the CBG level.

An indicator (or index) was required because none of the ‘units’ used for reporting levels, in any of the countries, were well defined. A particular reporting level comprises a number of observations or ‘units’, each having an area in square kilometres and population count for that area. The size of these areas and the corresponding number of persons included within an area, at a given reporting level, vary substantially.[13]

The adjustment involved estimating density distributions for each country at two reporting levels — one being the closest reporting level above, and the other below the CBG level.[14] The adjusted distribution was derived as a weighted average of these two distributions.[15] See appendix B for details of the adjustments.

10 ‘Match’ in terms of being at a similar level of aggregation. That is, when comparing countries, the areas used for each census observation should be broadly similar, across the countries, in locales with similar population densities — when the same level of aggregation is being used.

11 The CBG level is the second lowest reporting level used in the US — the lowest level being the census block. The CBG level was chosen because, as already noted, the BCPM and HAI cost schedules are based on results reported at that level.

12 If the cost function had been based on data provided at a different reporting level, then the common reporting level would have had to match that level. The CBG level appeared to be a good choice because data at this level provides a high degree of detail, making the resulting cost comparisons more accurate. Also, if data from an even lower level of aggregation were used, the results may have been less accurate due to the discrete nature of the fundamental units, persons.

13 The area size of each observation is influenced by local population density and many other factors. As density increases, reporting units from a particular reporting level tend to be smaller in area. That said, at any density there is still a considerable variation in area size.

14 The numerical value of the reporting level indicator was used to determine whether a reporting level from another country was above or below the CBG level.

15 For technical reasons, explained in the appendix, a weighted harmonic mean was used. The weightings were based on the numerical values provided by the reporting level indicator.

Population densities were then converted to line densities using a concordance function based on Australian data.[16] The concordance function provided the number of lines per person for a given population density.[17]

2.3 Cost estimates

Finally, average line cost estimates, for each country and US State, were obtained using the line density distributions and cost schedules. The line density distributions provided the proportions of lines falling in each of the ten line density categories. With this information, the weighted average line cost for each country was estimated using equation 2.1.

16 As part of the sensitivity analysis, population densities were also converted to line densities using country- and State-wide averages of lines per person, which were obtained from ITU (1998) and FCC (1999), respectively.

17 The concordance function was based on data provided by Telstra on the numbers of lines in and sizes of Australian exchange service areas (see appendix B). As part of the adjustment, the line densities provided by the concordance function were scaled to preserve each country's overall ratio of lines per person.

3 Population and line density distributions

Graphical representations of each country and US State's population and line density distributions are presented in this chapter. They provide a sense of where particular distributional differences between countries may influence overall line cost and whether a country is likely to have higher average line costs.

3.1 Population distributions

Population density distributions (CDFs) were constructed from census data for Australia, Finland, New Zealand and four US States — Alaska, California, Oregon and Washington. The CDFs represent the cumulative proportion of population at or below a given population density.

Estimates of a country's population density CDF vary significantly depending on the level of aggregation used. Accordingly, as outlined in chapter 2, census data from each country was adjusted to make the resulting CDFs consistent with the US Census Block Group (CBG) level of aggregation.[1]

In addition to CDFs, probability density functions (PDFs) of population density were also estimated.[2] A PDF provides an estimate of the concentration (probability density) of population at a particular population density — the area under a PDF curve, between two population densities, provides an estimate of the proportion of population living in areas within that range of densities.[3]

1 See appendix B for details of this adjustment.

2 The PDFs were estimated using kernel density estimation. Silverman (1986) and Tapia and Thompson (1978) describe this technique. An estimated PDF is similar to a histogram. Technically, the integral of a PDF is the associated CDF of the underlying distribution.

3 The 'probability' in PDF refers to the likelihood that a person chosen at random from the population is located within a given population density range. The function, therefore, provides the probability density. A logarithmic scale is used in the figures; hence the PDFs are of the logarithm of population (and line) density.

Broad comparisons

Over a large range of population densities, Australia's population is distributed in a very similar way to New Zealand, Washington and Oregon. For all the countries and US States compared, most of the population is located in areas with between 100 to 10 000 persons per square kilometre (see figures 3.1 and 3.2 and table 3.1).

California differs significantly from Australia, having 93 per cent of its population in areas with more than 100 persons per square kilometre, compared with 80 per cent for Australia. Moreover, only 0.2 per cent of its population is in areas with less than one person per square kilometre, compared with 2.8 per cent in Australia.[4] Also, as figures 3.1 and 3.2 illustrate, California's population is concentrated at higher densities and its CDF is always to the right of Australia's.[5]

Table 3.1 **Population distributions**
(per cent)

Population density range (persons per square kilometre)	*Australia*	*New Zealand*	*Finland*	*California*	*Alaska*	*Oregon*	*Washington*
0 to 1	2.8	1.5	0.7	0.2	12.8	1.6	0.7
1 to 100	16.9	14.9	43.8	6.6	27.0	23.1	16.8
100 to 10 000	79.3	83.6	55.3	87.6	59.8	75.1	81.9
10 000 plus	1.0	0.0	0.2	5.6	0.4	0.2	0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

4 In this way, California, with its high concentration of population in large and medium sized cities, is probably much more similar to some European countries.

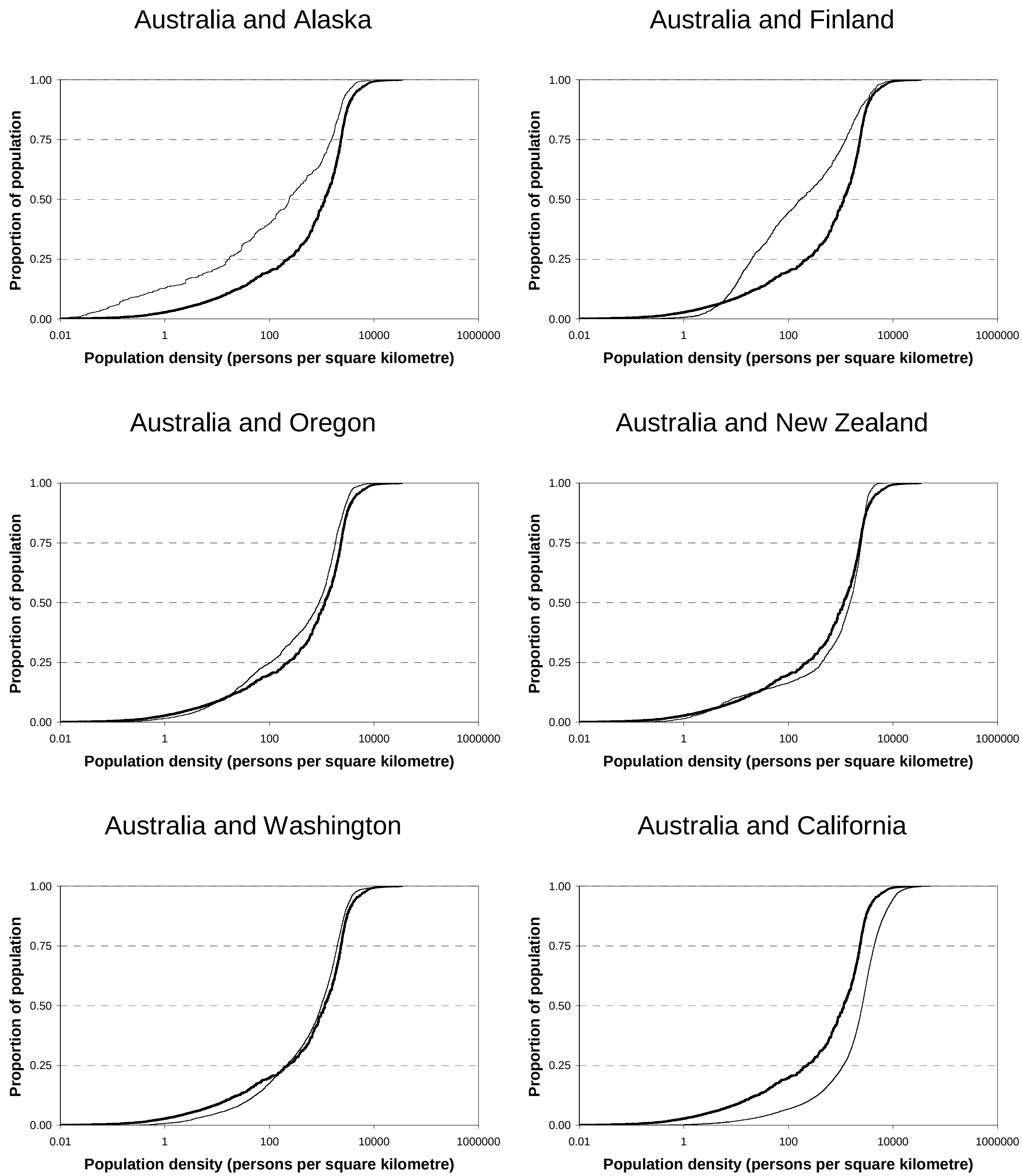
5 If this pattern persists when line CDFs are compared, then Australia's average line costs will be estimated as being higher than California's — almost regardless of the line density cost function used.

If one country's line CDF is always to the left of another's, then, for any reasonable cost function, its average line costs must be higher. The reasonable cost function is one consistent with the economies of density prevailing in telecommunications (a cost function with decreasing average costs).

With decreasing average line costs and country A's line CDF to the left of country B's, then at any percentile the lines in A will be at a lower density than the lines in the corresponding percentile in B. Because the lines in B are at a higher density, they, on average, will cost less. Consequently, the average costs of A's lines must be higher than B's when taken across the whole country.

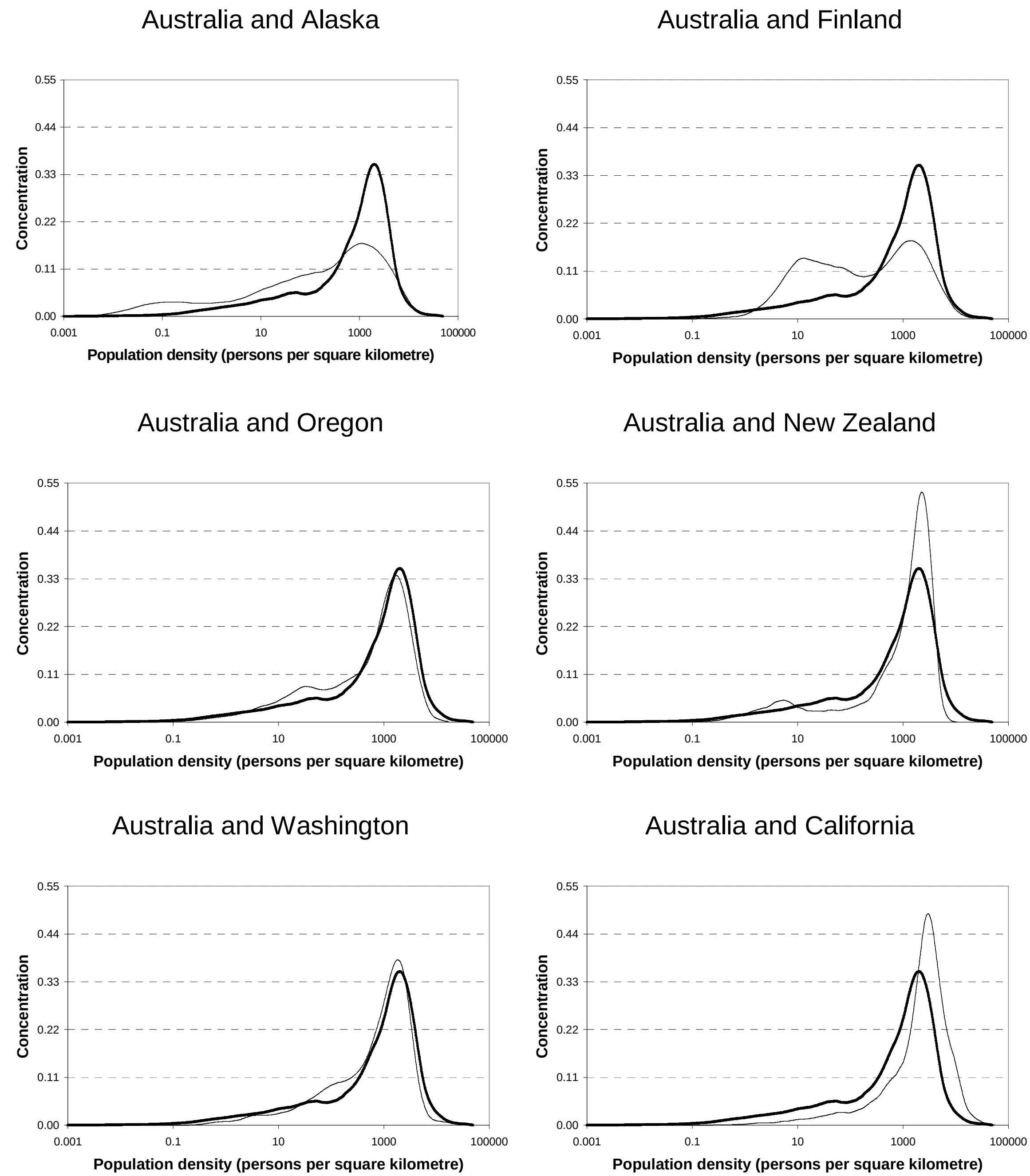
The above is subject to the general proviso that all non-line density factors are held constant.

Figure 3.1 **Population density — cumulative distribution functions**



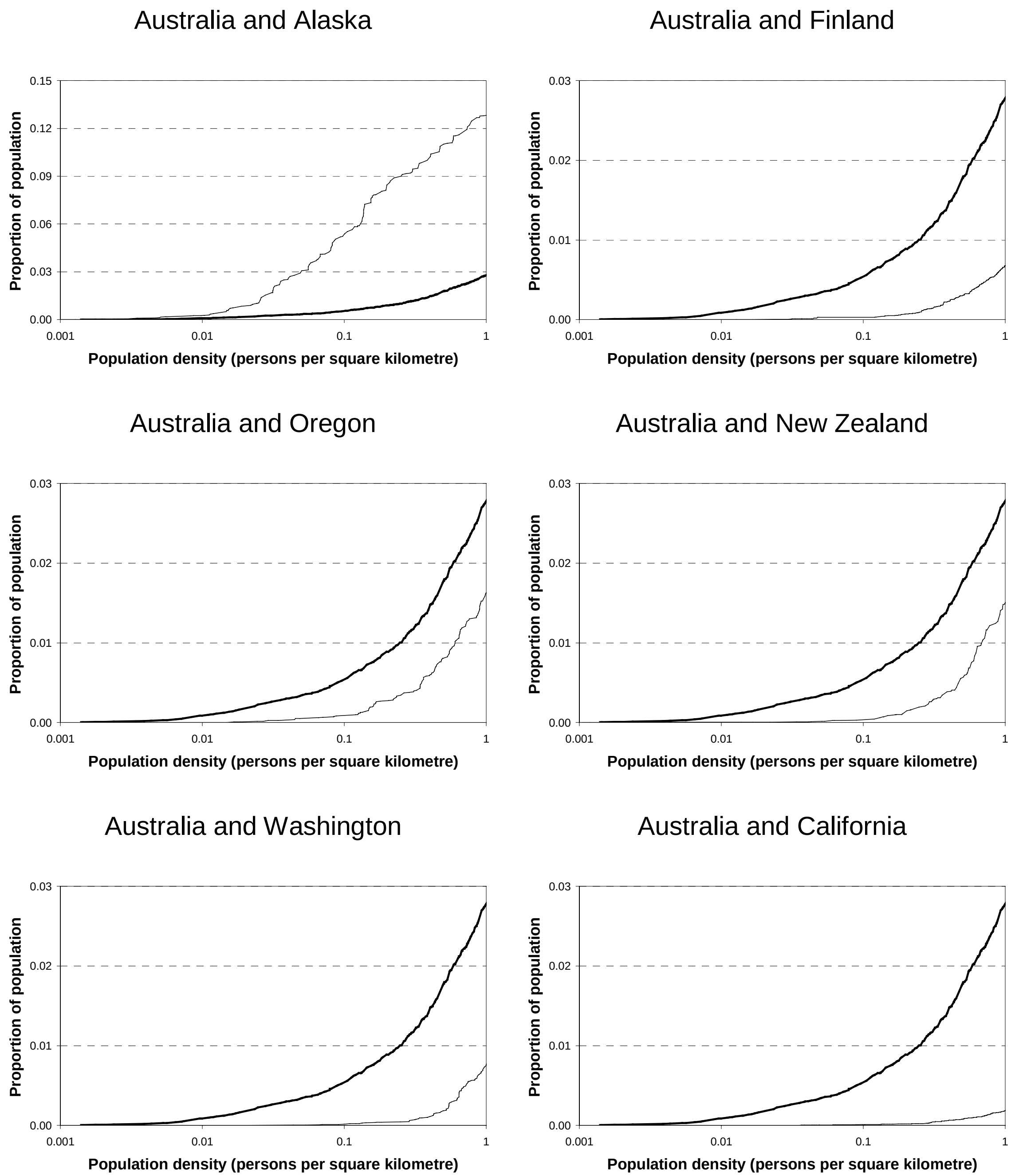
Note The darker line represents Australia's cumulative distribution function (CDF). Each country's CDF represents the proportion of total population at or below a given population density.

Figure 3.2 **Population density — probability density functions**



Note The darker line represents Australia's probability density function (PDF). Each country's PDF represents the concentration (or probability density) of population at that population density. The area under a PDF curve, between two population densities, represents the proportion of population within that range.

Figure 3.3 **Population density — cumulative distribution functions in low-density areas**



Note Australia is the darker line. Note the scale change in the chart comparing Australia to Alaska. Alaska has 12.8 per cent of its population in areas with a population density below one person per square kilometre.

Finland and Alaska also differ significantly from Australia. Both have a less pronounced concentration of population in the 100 to 10 000 persons per square kilometre range and a relatively greater concentration in the 1 to 100 range.[6] Alaska is also dramatically different from the others, having 12.8 per cent of its population in areas with densities of less than one person per square kilometre.

Low density comparisons

Australia has relatively more of its population in low-density areas than any of the other countries or US States compared, Alaska excepted. See table 3.2 and figure 3.3.

Table 3.2 **Total population in low density areas**
(per cent)

Population density range (persons per square kilometre)	*Australia*	*New Zealand*	*Finland*	*California*	*Alaska*	*Oregon*	*Washington*
0 to 0.1	0.526	0.028	0.031	0.009	5.248	0.082	0.012
0.1 to 0.2	0.361	0.078	0.040	0.008	3.236	0.185	0.029
0.2 to 0.4	0.526	0.279	0.156	0.042	1.541	0.322	0.061
0.4 to 1.0	1.367	1.104	0.451	0.124	2.822	1.033	0.660
Total	2.781	1.489	0.677	0.184	12.847	1.622	0.761

A higher concentration of population at these low densities can also mean more lines at low densities and higher average line costs.

3.2 Line distributions

The population density distributions presented in the previous section were used to impute line density distributions.

A concordance function that provided the number of lines per person as a function of population density was used to convert population densities to line densities. This function was estimated using Australian data provided by Telstra. The numbers of lines per person ranged from an average of 0.24 in areas below 0.01 persons per square kilometre, to 0.76 persons per square kilometre in areas with more than 10 000 persons per square kilometre.[7]

6 Both are located at high latitudes and this is likely to influence the type and distribution of economic activity and employment, and, hence, population.

7 See appendix B for a description of the data used and the estimation of the concordance function.

These initial line density estimates were then adjusted so they would be consistent with each country or US State's average lines per person.[8] The country- and US State-wide average lines per person are presented in table 3.3.

Table 3.3 **Country- and US State-wide average lines per person**

Country	*Lines per person*	*US State*	*Lines per person*
Australia	0.5188	Alaska	0.6529
Finland	0.5490	California	0.6668
New Zealand	0.4992	Oregon	0.6236
US	0.6399	Washington	0.6245

Note Country-wide lines per person from *World Telecommunications Development Report, Universal Access*, International Telecommunications Union, March 1998. US State-wide estimates of lines per person based on US Census Bureau 1999 and US Federal Communications Commission 1999 — see appendix B.

Source: International Telecommunications Union 1998, US Census Bureau 1999, US Federal Communications Commission 1999, Appendix B.

Broad comparisons

Over a large range of line densities, the estimated distribution of Australia's lines is very similar to the estimated distribution of lines in New Zealand, Washington and Oregon. See figures 3.4 and 3.5 and table 3.4.

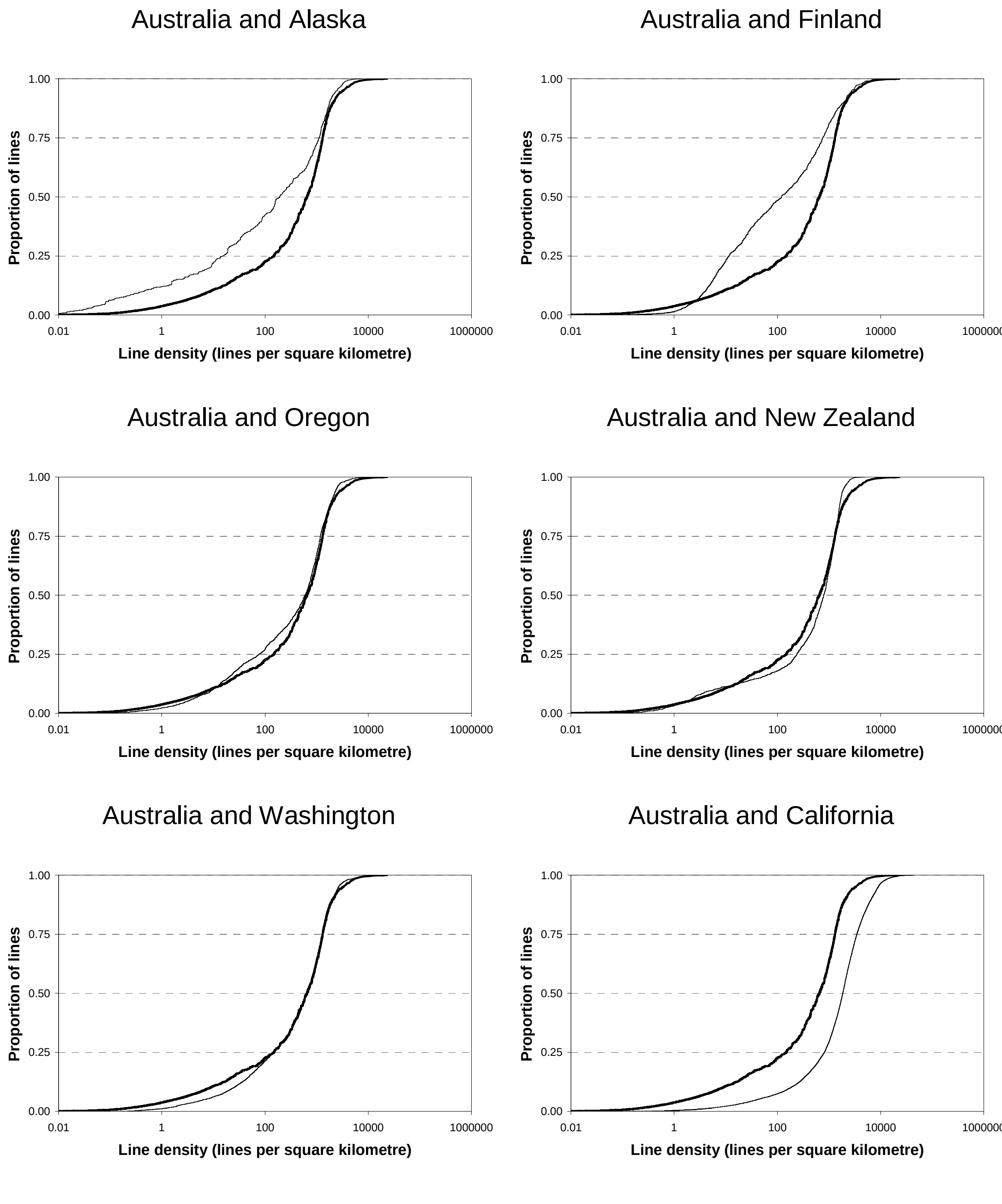
The most significant differences between the population density distributions and the inferred line density distributions are the:

- leftward shift of the distributions — due to the number of lines per person for each country and US State being less than one; and
- reduction in magnitude of differences between the distributions at low densities — due to the concordance function adjustments which resulted in relatively fewer lines per person, and hence smaller differences, at low densities compared with higher densities.

The leftward shift also means that the density ranges for lines cannot be compared directly with the population density ranges. For example, the population density range for Australia of 0 to 1 person per square kilometre corresponds to line densities between 0 and 0.6 lines per square kilometre. With each country and US State having a different average of lines per person, the same population density ranges are unlikely to correspond to the same line density ranges.

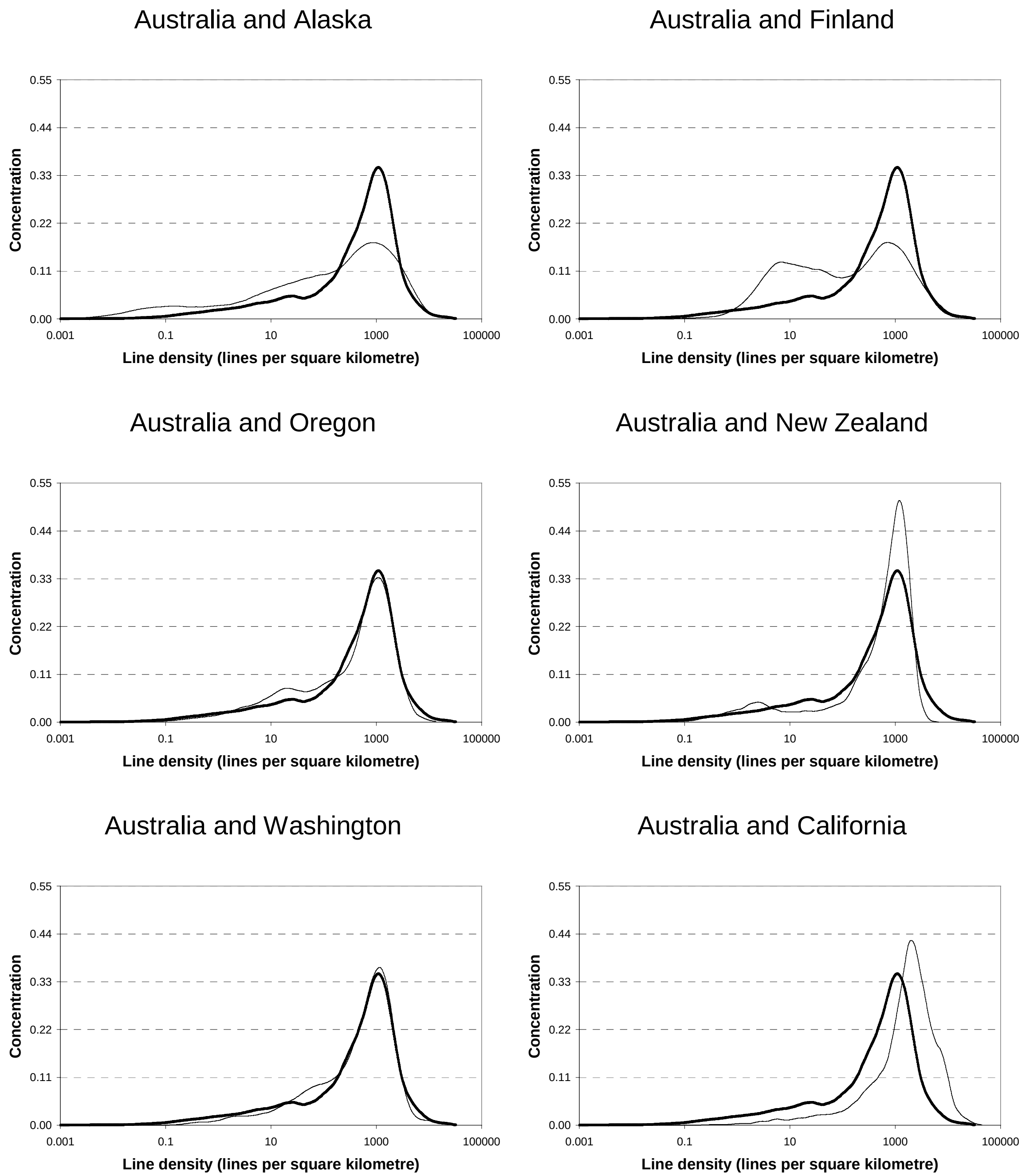
8 See chapter 2 and appendix B for a more detailed explanation of these adjustments.

Figure 3.4 **Line density — cumulative distribution functions**



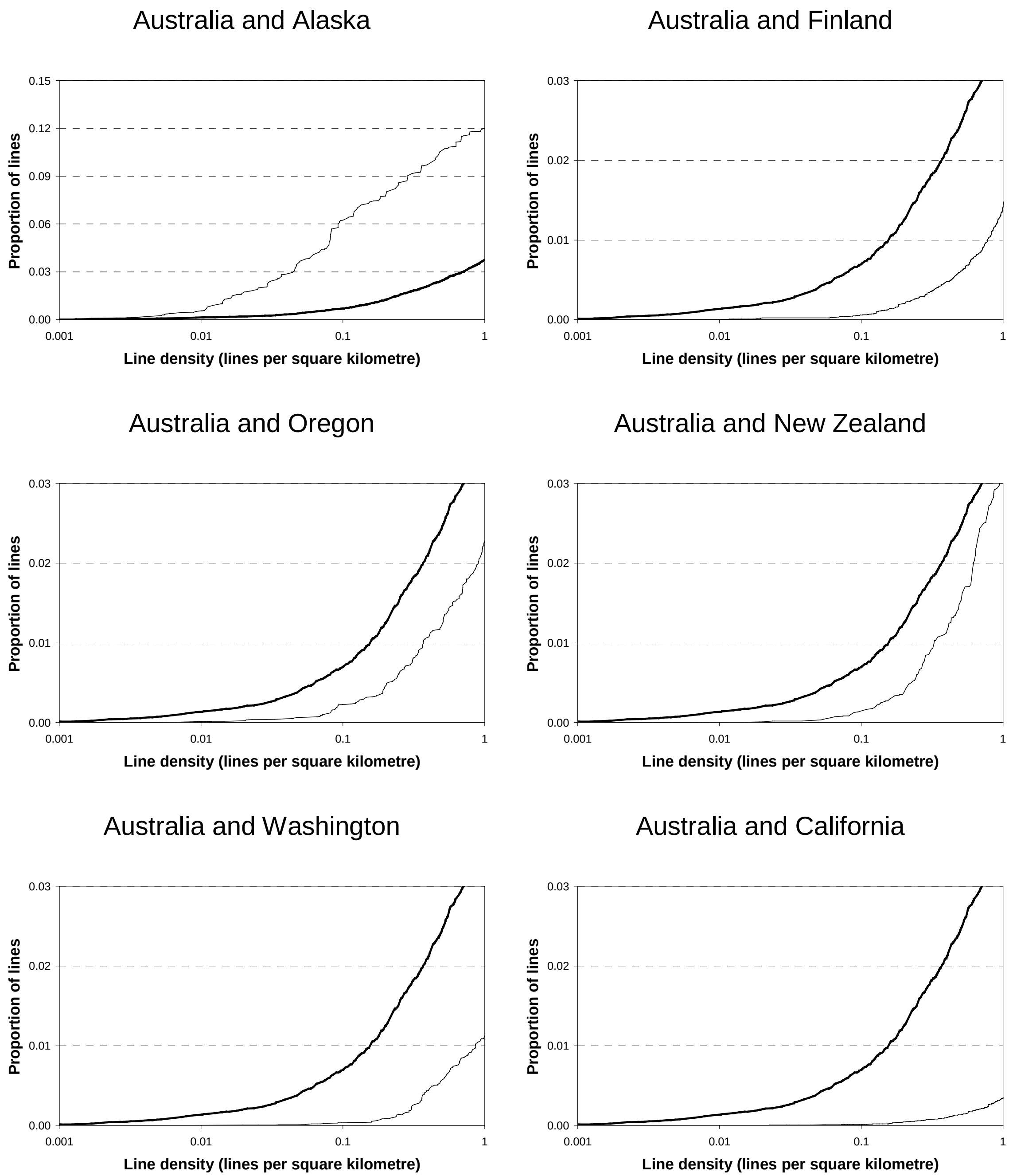
Note The darker line represents Australia's cumulative distribution function (CDF). Each country's CDF represents the proportion of total population at or below a given population density.

Figure 3.5 **Line density — probability density functions**



Note The darker line represents Australia's probability density function (PDF). Each country's PDF represents the concentration (or probability density) of population at that population density. The area under a PDF curve, between two population densities, represents the proportion of population within that range.

Figure 3.6 **Line density — cumulative distribution functions in low-density areas**



Note The darker line represents Australia.

The leftward shift (of the line CDF from the population CDF) also means there are proportionately more lines per square kilometre in areas with low line density.

Table 3.4 **Distribution of total lines**

(per cent)

Line density range (lines per square kilometre)	*Australia*	*New Zealand*	*Finland*	*California*	*Alaska*	*Oregon*	*Washington*
0 to 1	3.7	3.3	1.4	0.3	11.9	2.3	1.1
1 to 100	18.8	14.6	47.1	7.1	30.4	24.8	20.2
100 to 10 000	76.9	82.1	51.2	89.0	57.7	72.9	78.1
10 000 plus	0.5	0.0	0.3	3.5	0.0	0.0	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Australia's imputed line density distribution (CDF) is always to the right of California's imputed line density CDF. For reasons outlined earlier, this means that the estimated average line cost for Australia must be higher.[9]

The estimated line density distribution for Alaska differs dramatically from Australia's and from all the other countries and US States — although there are some similarities with Finland over medium line density ranges.

Box 3.1 **The actual distribution of line densities in Alaska**

The estimates for Alaska, like the other countries and US States, are based on an Australian concordance relationship between population densities and the average number of lines per person. For Alaska, this relationship breaks down.

Using the Australian relationship, Alaska is estimated to have proportionately more lines in low density areas than the others. Consequently, it is also estimated to have by far the highest average line costs (see chapter 4).

In reality, Alaska has very few lines in lower density areas, and is estimated as having the lowest State-wide average line costs of all US States (see Alger and Leung 1999, appendix A.3 table 3.1). All of Alaska's lines are contained in an area of 509 square kilometres — only 0.01 per cent of Alaska's area.

Alaska is unusual, in climate, in its small sparsely distributed population (600 000 which includes a relatively large indigenous population) and in having vast underdeveloped and inhospitable regions. Given this anomaly, the average State-wide cost estimates for Alaska are overstated.

This anomaly highlights the unreliability of population based estimates where a country or State's pattern of telephone penetration is atypical.

9 As long as a reasonable line density cost function is used to estimate the costs for both countries (other factors held constant). See footnote 5.

However, the estimates of Alaska's line distribution do not accord with the actual distribution of Alaska's lines (see box 3.1). Consequently, these estimates (and later cost estimates) should only be interpreted as estimates of what Alaska's line distribution (and average line costs) would be *if* Alaska followed the Australian line density – population density pattern.

Bearing this in mind, the CDF and PDF estimates for Alaska and Finland suggest both have a relatively greater concentration of lines in the 1 to 100 lines per square kilometre range when compared with the others. In its estimated distribution, Alaska retains this dramatic difference at low densities. The estimates are that 12 per cent of lines are located in areas with less than one line per square kilometre.

Low-density comparisons

Based on the estimates of line density distributions, Australia has relatively more of its lines in low-density areas, particularly at very low densities, than any of the other countries or US States, Alaska excepted.[10] See table 3.5 and figure 3.6.

Table 3.5 **Distribution of total lines in low density areas**
(per cent)

Line density range (persons per square kilometre)	*Australia*	*New Zealand*	*Finland*	*California*	*Alaska*	*Oregon*	*Washington*
0 to 0.1	0.697	0.134	0.058	0.013	6.239	0.225	0.034
0.1 to 0.2	0.553	0.221	0.141	0.030	1.519	0.224	0.048
0.2 to 0.4	0.847	0.767	0.279	0.057	1.963	0.606	0.351
0.4 to 1.0	1.642	2.158	0.941	0.244	2.217	1.202	0.676
Total	3.739	3.280	1.418	0.343	11.938	2.257	1.109

The relatively greater proportion of lines at these very low densities suggests that Australia should have a higher country-wide average line cost than those countries or US States it is otherwise similar to — New Zealand, Washington and Oregon — if all other factors which might affect costs are held constant.

In contrast, Finland has proportionately many more lines in medium line density areas. This may be expected to offset the higher costs of the additional lines Australia has at the lowest densities to some extent.[11]

10 And, as already noted, the line distribution estimates for Alaska are quite inaccurate; they grossly exaggerate the existence of lines at lower densities.

11 The extent to which Finland's proportionately greater number of lines in medium density areas offsets the greater concentration of lines at low densities in Australia will depend on the shape of the cost function used.

4 Line cost estimates

Estimates of differences in line costs (between three countries and four US States) are presented in this chapter. These differences are solely attributable to differences in the way their populations, and hence lines, are distributed.

Line density distributions presented in chapter 3 and cost schedules described below were used in the estimation process. Estimates obtained using other related cost schedules can be found in appendix C.

4.1 Estimates of relative line costs

As outlined in chapter 2 and appendix B, average country- or US State-wide line costs were estimated as a weighted average cost. The weights used were the proportion of lines in a line density category and the costs used were the average line cost associated with that category.

Details of the cost schedules used to estimate average line costs are presented in table 4.1. Their use should not be interpreted as endorsement of being more representative of Australian or US cost conditions than the other cost schedules constructed and used in the study. They are indicative only. The two cost schedules presented in table 4.1 were chosen from a larger set examined (five BCPM and five HAI adjusted schedules) simply because they represent the median cases.[1]

These adjusted cost schedules are designated as BCPM (Telstra 1) and HAI (Telstra 1). The 'Telstra 1' signifies that the original BCPM or HAI schedule was modified using regression results obtained from cost data provided by Telstra using method 1 (see appendix B).[2]

---

1 Indeed, the shape of line density cost functions is likely to vary between countries, due to a variety of local influences not accounted for in the simplified cost function. For example, as discussed later, although some of the other adjusted schedules may be more consistent with US conditions, it may be argued that the HAI ACA 1 adjusted schedule may be more representative of Australian conditions.

The cost schedules comprise estimates of average line cost by line density category based on results from the BCPM and HAI engineering cost models (see chapter 2).

2 Two different methods were used to adjust the original schedules.

As noted in chapter 2, the density categories are based on imperial units because the BCPM and HAI schedules are from the US.

Table 4.1 **BCPM and HAI adjusted cost schedules**
($US per month per line)

Density categories		*BCPM (Telstra 1)*	*HAI (Telstra 1)*
(lines per square mile)	(lines per square kilometre)		
0 to 0.39	0 to 0.1	372.99	300.29
0.39 to 5	0.1 to 1.93	158.90	127.93
5 to 100	1.93 to 38.58	63.41	40.61
100 to 200	38.58 to 77.16	39.30	22.37
200 to 650	77.16 to 250.76	33.23	17.44
650 to 850	250.76 to 327.92	31.50	14.44
850 to 2550	327.92 to 983.76	28.56	12.01
2550 to 5000	983.76 to 1928.94	26.91	10.03
5000 to 10 000	1928.94 to 3857.88	23.80	9.15
10 000 and above	3857.88 and above	20.66	6.37

Note The last eight rows of the schedules are the original BCPM and HAI schedules provided by Telstra. The first two rows are estimates based on Telstra data that have been used to replace cost estimates for the 0 to 5 lines per square mile range in the original schedules.

Source: BCPM and HAI schedules provided by Telstra. Author’s adjustments based on Telstra provided data.

The most notable difference between the two schedules is their general shape. There are proportionately greater cost differences within the HAI (adjusted) schedule between the highest and lowest density categories.

Another difference is that the BCPM cost estimates are always higher than the HAI estimates. This difference, as noted in chapter 2, is possibly explained by the origins of the models. Each was developed for use in US regulatory hearings on access charges — the BCPM funded by incumbents, the HAI by entrants.[3]

Estimates of the proportions of lines in each of these cost schedule categories are presented in table 4.2. The estimates were constructed from the line density distributions reported in chapter 3.

Country- and State-wide average line cost index estimates were calculated using the two cost schedules in table 4.1 and the line density distributions in table 4.2. The costs were estimated as weighted averages using equation 2.1, chapter 2. All factors that might affect costs, other than line density, were held constant in deriving these estimates. The results are presented in table 4.3.

3 What is surprising, however, is the magnitude of the difference in cost estimates between the competing models (given that both models were attempting to estimate costs for the same US States).

Table 4.2 **Distributions of line density by cost schedule category**

(per cent)

	Country or State						
Cost schedule categories (lines per square kilometre)	*Australia*	*New Zealand*	*Finland*	*California*	*Alaska*	*Oregon*	*Washington*
0 to 0.1	0.70	0.13	0.06	0.01	6.24	0.22	0.03
0.1 to 0.2	0.55	0.22	0.14	0.03	1.52	0.22	0.05
0.1 to 1.93	3.92	5.07	4.09	0.62	7.03	3.07	2.04
1.93 to 38.58	12.20	9.22	35.00	4.08	19.20	17.49	10.77
38.58 to 77.16	2.81	2.40	6.51	1.90	4.79	4.06	6.06
77.16 to 250.76	10.40	8.71	11.18	5.33	14.26	11.42	12.20
250.76 to 327.92	4.26	3.32	3.88	2.25	2.62	3.14	3.92
327.92 to 983.76	27.80	30.26	19.64	14.68	16.08	26.78	28.13
983.76 to 1928.94	25.97	35.78	9.61	22.81	19.83	23.42	25.36
1928.94 to 3857.88	7.62	4.85	7.35	26.31	7.42	8.73	9.36
3857.88 and above	3.76	0.04	2.54	21.97	1.01	1.44	2.08
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Note The line density distributions were estimated from each country's population census data. Population densities were converted to line densities based on a line–population density relationship estimated from Australian data (Telstra's Exchange Service Area data). Comprehensive detail on the method of estimating the line density distributions is provided in appendix B.

Table 4.3 **Indexes of country- and State-wide average line costs**

Australia normalised to 100

Country or State	*Average country- or State-wide line density (lines per square kilometre)*	*Index of average line cost*	
		BCPM (Telstra 1)	*HAI (Telstra 1)*
Alaska	0.3	167	203
Finland	9.1	115	123
Australia	1.2	100	100
Oregon	8.1	98	96
New Zealand	6.5	96	93
Washington	20.3	87	80
California	53.2	69	53

Note The method of estimating country- and US State-wide average line costs is described in appendix B. The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The BCPM and HAI based cost schedules were adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. All factors that might affect costs, other than line density, held constant.

These indexes of average line costs suggest that Australia has a cost disadvantage sourced in its population, and hence line distribution when compared with New Zealand, Washington, Oregon and California. The source of the cost disadvantage is

Australia's relatively larger proportion of its population and lines in low-density areas.[4]

That is, Australia has relatively more of its population in very low-density areas than all the other countries and US States included in the study, except for Alaska.

Alaska has the highest *estimated* costs because a relatively large proportion of its population is located in both medium- and low-density areas. This, in turn, meant that a very large proportion of its lines were estimated as being in medium- and low-density areas. However, Alaska has few lines located in low population density areas (see box 3.1).[5] Consequently, the following estimates for Alaska are estimates of what average line costs would be *if* Alaska had a line–population distribution pattern similar to Australia.

Finland appears to have higher costs (based on line density alone) because a larger proportion of its population is in medium density areas. In this way it has some similarities to Alaska — although these similarities are more apparent when the two distributions are compared visually (see chapter 3, figures 3.1 and 3.2).

Finland was identified as being one of two countries with the lowest telecommunications prices in two recent international benchmarking studies (PC 1999a,b).[6] A finding in this study that average line costs in Finland are likely to be higher than those in Australia, suggests that lower Finnish prices cannot be attributed to differences in population distribution.

Comparing all the countries and US States together, most of the estimated differences in average line cost could be sourced to differences in the proportion of lines in low-density areas (see tables 4.4 and 4.5). This is evidenced by a correlation between the per cent of lines within this density range and the 'overall' average line cost, using the BCPM or HAI adjusted schedules, of 0.96.[7]

4 Nevertheless, it should be noted that there are other factors which may differ between them (see box 1.1). These other factors are not accounted for in this study, and they could offset or reinforce this disadvantage in particular cases.

5 As discussed in chapter 3, even though Alaska's population is widely dispersed, the total area served by lines is only 509 square kilometres. This means that Alaska has few, if any, lines in low-density areas. In fact, HAI estimates based on actual line data suggests that Alaska is the US State with the lowest average line costs.

6 The other country with low telecommunications prices was Sweden.

7 This is equivalent to an R-squared of 0.92 or an adjusted R-squared of 0.91.

Table 4.4 Indexes of line costs using the adjusted BCPM cost schedule

Low density — 0 to 1.93 lines per square kilometre

Country or State	*Per cent of lines in low density areas*	*Index of average line cost*		
		Low density areas[a]	*Remaining areas*[b]	*Overall*
Finland	4.29	396	103	115
Australia	5.17	459	80	100
Oregon	3.52	422	86	98
New Zealand	5.43	402	78	96
Washington	2.12	397	80	87
California	0.66	399	66	69

Note The method of estimating country- and US State-wide average line costs is described in appendix B. The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The BCPM based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. All factors that might affect costs, other than line density, held constant. **a** Low-density areas are those with line densities between 0 and 1.93 lines per square kilometre (0 and 5 lines per square mile). **b** Remaining areas are those with more than 1.93 lines per square kilometre.

Table 4.5 Relative line costs using the adjusted HAI cost schedule

Low density — 0 to 1.93 lines per square kilometre

Country or State	*Per cent of lines in low density areas*	*Index of average line cost*		
		Low density areas[a]	*Remaining areas*[b]	*Overall*
Finland	4.29	574	103	123
Australia	5.17	666	69	100
Oregon	3.52	612	77	96
New Zealand	5.43	582	65	93
Washington	2.12	576	69	80
California	0.66	578	50	53

Note The method of estimating country- and US State-wide average line costs is outlined in appendix B. The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The HAI based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. All factors that might affect costs, other than line density, held constant. **a** Low-density areas are those with line densities between 0 and 1.93 lines per square kilometre (0 and 5 lines per square mile). **b** Remaining areas are those with more than 1.93 lines per square kilometre.

Based on the estimates obtained using the BCPM Telstra 1 cost schedule, the share of Australia's line costs in very low density areas (0 to 1.93 lines per square kilometre) is 24 per cent of total country-wide line costs, despite these areas having only about 5 per cent of the total number of lines. This compares with a 10 per cent cost share for these very low-density areas in Washington State and 4 per cent for the same areas in California (see table C.17).

With the adjusted HAI Telstra 1 cost schedule, the share of Australia's line costs in very low density areas (0 to 1.93 lines per square kilometre) is estimated as 34 per cent of country-wide line costs which compares with 15 per cent for Washington State and 7 per cent for California (see table C.18).

4.2 Some qualifications

To some extent, the study's results are sensitive to the way the:

- cost schedules were constructed;
- population density distributions adjusted; and
- line density distributions estimated.

Moreover, it is important to emphasise that this study estimates cost differences solely attributable to differences in the way that populations, and hence lines, are distributed. Other factors that might affect costs are held constant.

Cost schedules

The same cost schedule was used to estimate costs for each country and US State. In effect, this ignores cost differences related to geography, climate and input costs. Consequently, cost relativities (between and within countries) would be different when the many factors additional to population distribution are taken into account.

ACA cost data suggests that the cost relativities between high-and low-density areas in Australia may be more pronounced than the relativities reflected in the US cost schedules. Hence, the use of US cost schedules, may, to some extent, have tended to disadvantage Australia in the comparisons.

Australia may have higher costs associated with the 'remoteness' of some lower density areas. Remoteness loosely describes the distance an area is from developed areas, in particular, major population centres. Providing services away from developed areas usually increases the cost of labour, transport and materials.[8]

Remoteness — potentially an important driver of many Australian infrastructure costs — is not readily captured by measuring (population or) line density. Low density areas in Australia would tend to be more remote than similar low-density

8 Remoteness is likely to increase the resource requirements of telecommunication service provision, because materials need to be moved greater distances to a remote area. Labour may be more expensive as well, because higher wages may be required to compensate for isolation.

areas in the other countries and US States being compared (Alaska excluded). Consequently, Australian line costs in these areas are likely to be higher (or at least would be if all other factors were held equal).

If ‘remoteness’ is not adequately reflected in the original US cost schedules, then the modified schedules designated ‘ACA 1’ in appendix C may be more reflective of Australia’s cost structure. For this schedule a larger number of low-density cost categories of the US schedules were replaced with cost relativities based on Australian conditions.

In the ACA 1 modified schedules, the costs at low densities are 15 to 150 per cent higher than the original HAI and BCPM average line cost estimates.

That said, there could be climatic or other factors increasing line costs in the other countries or US States — for example, the cold climate in Finland and Alaska.

Population distribution adjustments

The average line cost estimates were based on line density distribution estimates, which were based on estimated population density distributions. As identified in chapter 2, estimates of population density distributions are highly dependent on the level of aggregation used.

An attempt was made to adjust the distribution estimates so that the population density distributions from different countries could be compared.

Broadly, the population density distribution adjustment is sensitive, to some known and unknown extent, to the robustness of the adjustment method that was used. However, this problem was identified and addressed in chapter 2 and appendix B — thereby improving on previous studies.

Line density distribution estimation

The line density distributions were not estimated directly but were, instead, inferred from population density distributions based on the Australian relationship between population densities and line densities (with further adjustment to maintain country- or State-wide averages).

This approach may be reasonable for countries that are similarly developed and not otherwise too dissimilar in climate or geography. For these countries, line density distributions probably follow population density distributions in broadly similar ways.[9] However, care would have to be exercised if this is not thought to be the case.

4.3 Robustness of the results

One measure of robustness is that changes to assumptions, in this case, the shape of the cost schedule, do not change the average cost rankings of the countries and US States examined.

Country rankings did not change, significantly, when different cost functions were used (see appendix C). The only changes in rank order were between Oregon and New Zealand. However, the average line cost estimates for the two countries were very close together and their rank order only changed places six times with twenty different sets of cost estimates.[10]

Significant variation in the magnitude of relative cost differences was apparent. The HAI based cost schedule produces significantly larger estimates of cost differences between countries. This is because of the larger proportionate cost differences between low and high-density categories in the HAI based schedule. This tends to increase the relative cost differences.

The failure of this study to produce good estimates for Alaska can be attributed to the inaccurate estimates of its line density distribution.

4.4 Further research

In this paper, a method for estimating the differences in line costs attributable to differences in population and hence line distributions was developed and applied to a small number of countries and US States.

The method is attractive because it is relatively easy to implement with readily available census data and may be modified so it can be applied to wire-centre (line) data.[11]

9 Clearly, Alaska does not fit this category.

10 Ten different cost schedules were used, and two different methods of adjusting population distributions to line distributions were tried (twenty sets of results in all).

11 Applying the method to wire-centre data would simply require the use of cost schedules based on average line estimates provided by wire-centre.

The study examines only the cost differences attributable to differences in line density. Further research might usefully involve the inclusion of more variables and applying the approach to more US States and other developed countries.

The approach might also be modified so it can be applied to provide cost estimates for other infrastructure industries that display significant economies of density — for example, electricity distribution.

A Recent studies

The issue of the impact of cross-country differences in population density on international price comparisons has been addressed in two recent studies — Ovum (1998) and Alger and Leung (1999).

The Ovum study was undertaken to assist the Australian Competition and Consumer Commission (ACCC) in making its recent telecommunications access determinations. The Alger and Leung (1999) study is the only study found that was singularly devoted to the issue. This study was a significant advance on previous work having used more detailed data for inferring line distributions and estimating costs.

Other studies have tended to use less detailed data and, for the most part, have simply addressed the issue in passing as part of studies on wider issues (see, for example, Ergas, Ralph and Sivakumar 1990, Ovum 1998, NECG 1999).[1]

A.1 Ovum 1998 — An assessment of Telstra's access undertakings

The ACCC commissioned the Ovum study to assist it in determining whether to accept or reject three access undertakings lodged by Telstra. The study was to provide a comparative assessment of various elements of Telstra's undertakings against prevailing charges for equivalent elements (and conditions) found overseas.

The impact of differences in line density on access costs was addressed, in passing, as part of Ovum's assessment of the validity and robustness of their comparisons of

1 Ergas, Ralph and Sivakumar (1990) suggested that Australia did not have a cost disadvantage sourced in its population distribution. They claimed that the population density in the inhabited parts of Australia (where there is at least one inhabitant per 8 sq km) was not significantly lower than that in the inhabited parts of Canada and the US. They also suggested that the distribution of subscriber loop lengths in the Australian network is not very different to that in the US.

In contrast, NECG (1999) suggest that Australia has a cost disadvantage. They support their claim with a simple ten-country comparison of country-wide average line densities.

undertakings — that is, to assess whether overseas access charges would require adjustment to be relevant benchmarks for Australian conditions.

Approach

Ovum conducted two separate statistical analyses to assess the impact of different population densities on average costs. The analyses assessed the influence on average line costs of country-wide measures of, first, the degree of urbanisation and, second, average line density.

Ovum concluded that between 40 to 62 per cent of the variation in costs and charges among the US States and European countries examined could be explained by variation in their broad measure of urbanisation (the proportion of the population in towns and cities). Cost data for US States generated by the HAI model and data on access charges in European countries was used.

For the European countries, Ovum found a correlation between access charges and urbanisation of –0.79. However, a weaker correlation (–0.31) was found between access charges and broad measures of average line density.[2]

Results

Relative to the UK and US, Australia was identified as having a very low country-wide line density but also being highly urbanised. Ovum intended to use the results of their analysis to make adjustments, if required, to their comparisons of UK, US and Australian access charges. However, the results proved inconclusive:

> We can not tell which has the greater effect [urbanisation or average line density] because the statistical evidence is not robust enough and, in any case, Australia falls so far outside the European/US range on access line density that there's no way to translate our analysis between the two domains.
>
> We believe it would be unadvisable to try to adapt the main benchmark model on the basis of the Australian condition analysis … because the uncertainties introduced are likely to undermine rather than strengthen the base case (Ovum 1998 p.29).

2 It is worth noting that correlation coefficients of –0.79 and –0.31 are equivalent to R-squareds of 0.62 and 0.10 respectively.

A.2 Alger and Leung 1999 — The relative costs of telephony across five countries

Alger and Leung's main objective was to estimate the relative differences in telephony costs (the basic local service) that could be attributed solely to cross-country differences in the distributions of line densities.[3] The five countries compared were Australia, New Zealand, Sweden, the United Kingdom and the United States.

Approach

Alger and Leung used a similar approach to the current study. Average line costs for each country were estimated based on estimates of line density distributions and average line costs associated with particular average line densities.

Relatively dissagregated census data from each country was used. Countries were divided into between 41 to 437 separate areas and the population density of each area was calculated (its population count divided by its area in square miles).[4] The numbers of areas used and the median population count of each country's areas is provided in table A.1.[5]

Table A.1 **Alger and Leung 1999 — description of data**

Country	*Number of census areas*	*Median population count*
Sweden	288	15 695
Australia	274	42 056
New Zealand	41	45 785
United Kingdom	437	108 000

Source: Data provided by Dan Alger.

Line densities for each area were estimated using the country-wide average lines per person to convert each area's population density to a line density.

3 Alger and Leung focused on line density as a fundamental source of unavoidable cost differences between countries — which they identified as the most important determinant of costs minimally affected by differences in regulatory regimes. Assessment of the size of unavoidable cost differences, between countries, they identified as being helpful when gauging the extent to which differences in telecommunication prices may reflect differences in performance.

4 For some rural areas adjustments were made to eliminate uninhabited areas. The relative sizes of the inhabited and uninhabited areas were estimated using the ratio of inhabited to uninhabited area for areas with similar density in the US (Alger and Leung 1999, p. 40).

5 Dan Alger kindly provided the author with the raw data used in the study.

Average line costs for each area were estimated in three different ways, namely as being equal to the:

- average line cost of the US State with the closest line density;
- average of the line costs of the two US States with closest densities; and
- expected line cost for that density as provided by a regression model.

The average line cost for each country was then estimated as a weighted average cost with the weights being the proportions of lines in each area.

The average line cost estimates for each US State used to estimate the regression model were obtained from the HAI model.[6] State-wide average line densities were calculated by dividing the total number of lines by the total area covered by wire centres in that State.[7]

The regressions used HAI estimates for 20 351 US wire centres. These estimates of average line cost for each wire centre were regressed on the wire centre's line density. In total, three regression models were estimated (see table A.2). The cubic regression model chosen as being 'best fitting' is in the last column of table A.2.[8]

Results

Cost estimates for each country (based on the three approaches to estimating the line costs) are presented in tables A.3 and A.4.[9]

Alger and Leung also assessed the accuracy of their cross-country comparisons by applying their estimation procedures to each US State and comparing these results with State-wide average line costs as estimated by the HAI model.

---

6 The HAI model is an engineering model that has been used in US regulatory hearings to estimate the minimum cost of providing basic local service to customers in a variety of different situations.

7 In all cases, the area covered by wire centres was significantly smaller than the total area of the State. Hence, adjustments were made to account for the uninhabited areas.

8 In the model the logarithm of average cost is a cubic function of the logarithm of a wire centre line density. The chosen equation was estimated by Feasible Generalised Least Squares using White's procedure to adjust for heteroscedasticity.

9 For comparative purposes, Alger and Leung also calculated average costs using the country-wide average line density as well as results based on relatively disaggregated census data. These results are not reproduced here.

Table A.2 **Alger and Leung 1999 — regression results**

Coefficients and (t-statistics)

	Quadratic model	Cubic model(s)	
Variable	*OLS*	*OLS*	*FGLS*
Constant	5.9205 (660.89)	6.2530 (527.04)	6.2526 (20390.55)
Log line density	-0.8288 (-195.58)	-1.1216 (-135.96)	-1.1214 (-4894.10)
(Log line density) squared	0.0431 (100.31)	0.1125 (64.17)	0.1124 (2063.77)
(Log line density) cubed	–	-0.0046 (-40.75)	-0.0046 (-1141.32)
Adjusted R Squared	0.8835	0.8923	0.8792

Note The dependent variable was the natural logarithm of the average line cost for the wire centre (as estimated by the HAI model). Density was measured as lines per square mile (not per square kilometre) for the area of the wire centre. FGLS — feasible generalised least squares.

Source: Alger and Leung 1999, Appendix A2, Table 2.1

Using the average line costs calculated by the first method and overall State line densities, Alger and Leung found that their cost estimates for 22 States were within 10 per cent of the HAI direct estimates, 43 States within 20 per cent and 46 within 30 per cent. Using costs calculated by the second method (and overall State line densities), they again found their estimates for 22 States within 10 per cent of HAI values, 39 within 20 per cent and 47 States within 30 per cent.

Table A.3 **Alger and Leung 1999 — average line cost estimates**

Total monthly cost in US dollars

Country	*Closest density US State's average line cost*	*Average of the two closest US State's average line costs*	*Cubic regression model*
Australia	$16.76	$16.38	$652.63[a]
New Zealand	$17.58	$17.17	$17.58
Sweden	$18.71	$18.42	$25.32
United Kingdom	$11.96	$11.60	$11.49
United States	$14.70	$14.92	$18.19

a This surprisingly high estimate for Australia is because the cubic cost function used implies a negative marginal cost at low densities. Note that this implausibly high estimate is the only one that is larger than the corresponding estimate based on the whole country. It can be shown that if a cost function has everywhere diminishing marginal costs then estimates will tend to increase when more aggregated data is used.

Source: Alger and Leung (1999), Table 5, p.41.

For the first two methods of estimating costs, Alger and Leung used the (HAI estimates of) average line cost for the State with the next closest density (rather than the closest).[10]

Table A.4 **Alger and Leung 1999 — relative cost estimates**

Country	*Closest density US State's average line cost*	*Average of the two closest US State's average line costs*	*Cubic regression model*
Australia	100.00	100.00	100.00
New Zealand	104.89	104.82	2.69
Sweden	111.63	112.45	3.88
United Kingdom	71.36	70.82	1.76
United States	87.71	91.09	2.79

Note Australian costs have been normalised to 100.

Source: Based on Alger and Leung (1999), Table 5, p.41.

The regression based cost function did not perform well at all. Only 8 States were within 10 per cent of HAI values, with 23 within 20 per cent and 40 within 30 per cent. The regression results also appeared to have an upward bias, with 47 overestimates and 3 underestimates of the HAI values.[11]

A.3 Comment

Ovum's study results, as they acknowledge, are not robust. They used highly aggregated data — and for some of the analysis, country-wide average costs. Considerable detail and differences between countries and regions is lost when highly aggregated data is used and this probably explains the poor results.

Alger and Leung used reasonably disaggregated data.[12] However, although it was a significant improvement over previous studies, it did not identify or address the issues related to the level of data aggregation used. This omission is likely to have

10 The closest in density to each State, of course, would be itself, and this would have resulted in a perfect 'fit'.

11 The upward bias would have been the result of the estimated equation, which was based on wire centre data, being used to estimate average costs using average line densities from much higher levels of aggregation (that is, US State-wide averages). It can be shown that, for a cost function with everywhere diminishing marginal cost, this will tend to bias cost estimates upwards.

12 Although, the data used was not as disaggregated as the data used in this study.

compromised the accuracy of their comparisons. As the current study illustrates, these aggregation issues and they way they are addressed can have a substantial influence on the results obtained.

B Methodology

Average line costs were estimated using line density distributions (estimates of the proportions of lines in various line density categories) and a cost function (where line cost is a function of line density). The average cost per line was estimated as a weighted sum of the costs per line for each line density category, using the proportion of lines falling in each density category as weights.

Line densities were estimated from population densities. In the course of the study, methodological issues arose concerning the estimation of population densities, their conversion into line densities and the choice and construction of a suitable cost function. Details of how these issues were addressed are provided below.

B.1 Estimating population densities

Comparable data on line density distributions across countries were unobtainable.[1] Therefore, line density distributions were estimated from population density distributions.

Estimating comparable population density distributions broadly involved two steps. Census data from each country and US State were used to create cumulative distribution functions (CDFs) of population density. These population density CDFs were then adjusted to ensure they were comparable with each other.

Constructing the cumulative distribution functions

The CDFs — functions representing the proportion of population (or lines) at or below a given density — were constructed as follows.[2]

1 Although data, for some countries, was available, it was not possible to adjust this data to take account of cross-country differences in collection and reporting methods.

2 In addition, the data was used to create probability density functions (PDFs). These functions provide an indication of the concentration of population (or lines) at and around a given density. Technically, the integral of a PDF is the associated CDF. Graphical representations of the population and line density PDFs appear in chapter 3. The PDFs were estimated using kernel density estimation. Silverman (1986) and Tapia and Thompson (1978) describe this technique.

For census purposes, and at a particular reporting level, a country is divided into a number of distinct reporting areas (say T areas in total). For a particular reporting area i, the population count p_i and area in square kilometres a_i is provided. With this information, the population density was calculated as the average number of persons per square kilometre ${}_p d_i$ (where the subscript p stands for population). Also calculated was the share of the country or State's total population ${}_p\phi_i$:

$$ {}_p d_i \;=\; p_i / a_i \qquad \text{B.1} $$

$$ {}_p\phi_i \;=\; p_i \Big/ \sum_{j=1}^{T} p_j \qquad \text{B.2} $$

The population density CDF at a particular reporting level — for example, at the Australian collector district (CD) reporting level — is a function which provides the sum of population shares (cumulative population share ${}_p\Phi_{j,CD}$) for all areas at or below a given density x :[3]

$$ CDF_{p,CD}(x) \;=\; \sum_{i\in A_{x,CD}} {}_p\phi_i \;=\; {}_p\Phi_{j,CD} \qquad j\in\{0,1...T\} \qquad \text{B.3} $$

$$ A_{x,CD} \;\equiv\; \left\{ i \;\middle|\; {}_p d_{i,CD} \;\leq\; x \right\} \qquad \text{B.4} $$

Corresponding inverse CDFs were also defined and calculated. The inverse CDF is defined as a function, taking as its argument a cumulative population share $y \in [0,1]$, and returning the lowest density ${}_p d_{j,CD}$ such that the CDF of that density is greater than or equal to that cumulative population share:[4]

$$ CDF^{-1}_{p,CD}(y) \;=\; {}_p d_{j,CD} \;=\; \min\left\{ {}_p d_{i,CD} \;\middle|\; y \;\leq\; CDF_{p,CD}({}_p d_{i,CD}) \right\} \qquad \text{B.5} $$

3 The set $A_{x,CD}$ is the set of index values corresponding to reporting areas with population densities equal to or less than the given density x.

4 Note that the inverse CDF as defined is not an ordinary inverse of the CDF (step functions do not have ordinary inverses). This inverse is instead a convenient function that approximates an inverse in the following way. For any arbitrary $x \in [0,1]$, let $CDF(CDF^{-1}(x)) \;=\; w$, then $|x-w| < \varepsilon$ where ε is the value of the largest population share (population shares are defined in equation B.2). This value is very small when there are a large number of census areas (data corresponding to a low level of aggregation).

Essentially the direct and inverse (empirical) CDFs are step functions.[5] For an empirical CDF, the step (or incremental increase in the cumulative population share) is an increase of ${}_p\phi_i$ at density ${}_p d_i$.[6]

Data issues

Each country's statistical agency, to varying degrees, collects, collates and reports census data in different ways.[7] Consequently, the census data obtained was at various levels of aggregation (or reporting levels) that did not 'match' across the countries (see table B.1).

Table B.1 **Reporting levels — median population counts and areas**

Country/State	*Reporting level*	*Median population count*	*Median area (square kilometres)*	*Number of areas*	
				Inhabited areas	*All areas*
Australia	Statistical local area	5189.0	109.24	1 321	1 336
	Collector district	506.0	0.37	34 259	34 500
Finland	Municipality	4833.5	380.70	452	452
	Postal code	498.5	54.7	2 963	2 996
New Zealand	Area unit	1891.0	3.08	1 706	1 772
	Meshblock	89.0	0.08	34 762	36 808
Alaska	Tract	2886.0	53.13	176	190
	Block group	750.0	5.99	652	691
California	Tract	4670.5	1.60	5 603	5 858
	Block group	1144.0	0.50	21 094	21 412
Oregon	Tract	3732.0	7.37	679	727
	Block group	930.0	1.86	2 618	2 675
Washington	Tract	3953.5	6.33	1 129	1 152
	Block group	906.5	1.19	4 575	4 618

Differences between the reporting levels used in different countries present challenges when estimating and comparing average line costs. Estimates of population densities (and their distribution) are quite sensitive to the 'typical' size

5 Because empirical data is discrete these CDFs are step functions.

6 Due to the large number of observations used in this study graphs of the CDFs appear to be smooth (see, for example, the CDF figures in chapter 3).

7 When conducting a census, a statistics department divides a country into separate geographic regions — referred to in this appendix as (statistical) reporting units. At the most detailed level provided these regions are referred to as base reporting units. More aggregated reporting levels use units, which are obtained by grouping several contiguous base reporting units together.

of the area or number of people or households used for a reporting level.[8] This impacts on estimates of line density distributions and hence, estimates of cost.

For example, using the same cost function, the estimated average line costs per month for Australia can differ by 50 per cent when the base reporting level is used — the collector district — compared with the next reporting level above — the statistical local area (see chapter 2).

Assumptions

It was assumed that the same broad approach is likely to have been taken by the statisticians in different countries when they divided their country into geographic areas for census purposes. That is, for any particular reporting level they would vary the size of collection areas in broadly similar ways, influenced by local factors.

At the base reporting level a significant influence on the relative sizes of each of the areas is likely to be the rate at which the data could be collected. Presumably in localities with lower density or difficult terrain collection is more time consuming. Hence, the areas used would be larger, the number of people to be counted smaller.

Collection practices are likely to differ in each country — for example, the amount of data collected from each household, the size of collection teams, work practices and collection productivity. In particular, the sizes of collection areas and their population counts (at a base reporting level) are likely to differ significantly (even where local factors were identical).

Adjustment approach

The approach taken to adjust for cross-country differences in census reporting levels was to:

1. choose one reporting level to which every country's census data would be adjusted for comparison;

8 At any particular reporting level, the size of individual reporting units varies because statistics departments use smaller geographic regions in densely populated areas and larger regions where the population is sparse. This variation makes it difficult to identify the 'standard' size being used. This increases the difficulty of comparing reporting levels between countries.

To some extent, the standard being used can be identified from the median population count and the median area size — that is, the observation where half the observations are larger and half smaller. For an even number of observations, the median is the average of the middle two.

2. construct a numerical indicator to measure or estimate the ‘relative size’ of the reporting levels used in each country; and
3. use the reporting level estimates to adjust each country’s census data to make all data consistent with the chosen reporting level.

Reporting level chosen as the basis for comparison

The US Census Bureau’s Block Group (CBG) reporting level was chosen as the basis for cross-country comparisons because the cost functions used in the study are based on average line cost data provided at this reporting level (see chapter 2 and section B.3).

Reporting level indicator

There are significant differences across countries in their choice of a standard or ‘typical’ size for each reporting level.[9] For example, the base reporting level in New Zealand — the meshblock — is much smaller than Australia’s base reporting level — the collector district — both in terms of the median area size or median population count used. At the next level up, New Zealand’s ‘area unit’ reporting level is also smaller than Australia’s ‘statistical local area’ (see table B.1).

For a given reporting level, reporting units in sparsely populated parts of a country tend to be larger in area and have a lower population count when compared with units in more densely populated areas. For example, in Australia at the statistical local area level and at the collector district level, the correlation between area sizes and population counts is –0.07.

Given these differences and the need to compare the reporting levels (levels of aggregation) being used across countries, a numerical index — a reporting level indicator (RLI) — was required. A suitably designed RLI (a function of the census data) would provide a numerical value corresponding to the data’s reporting level or level of aggregation.

Median population count and median area size, and a combination of both were investigated as potential arguments of an RLI.[10]

9 The Australian Bureau of Statistics (ABS) indicated that many statistical departments base their unit size around some chosen number of households. Consequently, as population density declines the area of individual reporting units tends to increase.

10 For a given reporting level, the median population count, for example, is the population count of the reporting unit where half of the units have a higher population count than this unit and

Medians rather than means appeared to be good candidates for use in an RLI because medians are generally more robust to data anomalies. For example, some countries, including Australia, have several extremely large (or small) areas or population counts due to their geography or population density. These extremes, which are unrepresentative of more typical collection areas, would significantly influence the estimates of aggregation levels provided by an RLI based on the mean population count or mean area.

Table B.2 **Reporting level indicator models — parameter estimates**

Coefficients (t-statistics)

Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Constant	-0.2474 (-2.13)	0.3696 (1.74)	-0.2899 (-5.28)	-4.5918 (-9.55)	0.2201 (0.97)	-4.2007 (-43.84)
Median population count	0.0003 (7.65)	–	0.0003 (15.24)	–	–	–
Log median population count	–	–	–	0.6763 (10.64)	–	0.6092 (46.49)
Median area	–	0.0134 (1.21)	0.0085 (4.74)	–	–	–
Log median area	–	–	–	–	0.2200 (1.80)	0.0895 (12.78)
R Squared	0.9069	0.1970	0.9831	0.9496	0.3516	0.9985
Adjusted R Squared	0.8914	0.0632	0.9763	0.9412	0.2436	0.9979

Six different RLI models were calibrated using data from four US States — Alaska, California, Oregon and Washington. The RLIs used the median population counts and median areas of US Census tract and block group reporting units for each State. Regression was used to calibrate each model with two known levels of aggregation. The dependent variable in the regressions was assigned a value of 1 when data was at the tract level and 0 for the block group level.[11] Results are presented in table B.2.

The RLI model chosen for the study is based on the estimates obtained using the logarithms of both median population count and median area (see the last column of

half have a lower population count. Again, with the median area, half of the units in the country (or State) are larger in area and half are smaller.

11 Each RLI model is unique up to an affine transformation and, hence, needed to be calibrated to a pair of arbitrary values. Arbitrarily, the two values assigned to CBG and tract data were 0 and 1. Note that the dependent variables, and the RLI models, potentially range over all the real numbers (minus infinity to plus infinity). The data used to estimate the parameters was obtained from only two reporting levels and hence corresponds to only two values within this range.

table B.2). Fitted values for this indicator applied to the US Census data are presented in table B.3.

Table B.3 **Reporting level estimates by US States**

State	*Median Population count*	*Median Area (sq. km.)*	*True value* [a]	*Estimate* [b] *using RLI*	*Error (per cent)* [c]
Tract					
Alaska	2886.0	53.13	1.0	1.009	0.9
California	4670.5	1.60	1.0	0.989	-1.1
Oregon	3732.0	7.37	1.0	0.989	-1.1
Washington	3953.5	6.33	1.0	1.010	1.0
Block group					
Alaska	750.0	5.99	0.0	-0.007	-0.7
California	1144.0	0.50	0.0	0.028	2.8
Oregon	930.0	1.86	0.0	0.019	1.9
Washington	906.5	1.19	0.0	-0.037	-3.7

a The values assigned to the tract and block group reporting levels. **b** The fitted values of the regression in the right hand column of table B.1. **c** Errors expressed as a percentage of the difference between the assigned value for the tract reporting level (1.0) and the assigned value for the block group reporting level (0.0).

Adjustments to obtain one population density CDF for each country

The reporting level indicator derived above was used to estimate numerical values for the reporting levels used in the other countries — Australia, Finland and New Zealand (see table B.4). In all cases, the values for each country pair of reporting levels span the value of zero assigned to the US Census block group reporting level.

Table B.4 **Reporting level estimates by country**

Country	*Reporting level*	*Median Population count*	*Median Area (sq. km.)*	*Estimate using RLI*
	Higher levels			
Australia	Statistical local areas	5189.0	109.24	1.43
Finland	Municipalities	4833.5	380.70	1.50
New Zealand	Area units	1891.0	3.08	0.50
	Lower levels			
Australia	Collector Districts	506.0	0.37	-0.50
Finland	Postal codes	498.5	54.7	-0.06
New Zealand	Meshblocks	89.0	0.08	-1.70

Note A negative value for a reporting level estimate indicates that the reporting level was constructed using a lower level of aggregation than the CBG level. A positive value means the data is more aggregated than the CBG level.

The data for each country pair of reporting levels was adjusted using the RLI estimates to create a new data series (a CDF) more consistent with the US CBG level.

The weights used in the process (θ and (1–θ)) were based on the pair of RLIs for each country, and were chosen so that the pair of weights multiplied by the pairs of RLI summed to zero — the RLI value assigned to the US CBG level.

Let RLI_H be the value of the reporting level indicator for the higher level of aggregation and RLI_L, the lower level. Then the θ for a particular country is:

$$\theta = \mathrm{RLI_H}/(\mathrm{RLI_H} - \mathrm{RLI_L}) \qquad \text{B.6}$$

The RLI estimates and the weights used for each country's census data are presented in table B.5.

Table B.5 Estimates of reporting level and adjustment weights

Country	*Reporting level*	*Estimate using RLI*	*Weights θ (1-θ)*
Australia	Collector Districts	-0.50	0.74
	Statistical local areas	1.43	(0.26)
Finland	Postal codes	-0.06	0.96
	Municipalities	1.50	(0.04)
New Zealand	Meshblocks	-1.70	0.23
	Area units	0.50	(0.77)

The new CDF was estimated using inverse CDFs. The adjusted inverse CDF is a weighted harmonic average of the two inverse CDFs. The inverse CDFs correspond to a pair of reporting levels (for the country) above and below the US CBG level.

For a given cumulative population share value $y \in [0,1]$ these inverse CDFs provide a pair of population densities. These densities are used to form a weighted harmonic average. This 'average' of the two densities becomes the estimated density, at the CBG level, for that cumulative population share.

Using Australia as an example, the inverse CDF adjusted to the CBG level for a particular country is defined as:

$$_p d_{j,\hat{C}BG} = CDF^{-1}_{p,\hat{C}BG}(y) \qquad \text{B.7}$$

Where the inverse CDF is a weighted harmonic mean of the pair of inverse CDFs corresponding to the CD and SLA reporting levels:

$$CDF^{-1}_{p,CBG}(y) \;=\; \left(\theta\left(CDF^{-1}_{p,CD}(y) \right)^{-1} + (1-\theta)\left(CDF^{-1}_{p,SLA}(y) \right)^{-1} \right)^{-1} \qquad \text{B.8}$$

That is, each density in the adjusted inverse CDF is a weighted harmonic mean of the densities from the pair at a particular cumulative population share:

$$_{p}d_{j,CBG} \;=\; \left(\theta\left(_{p}d_{j,CD} \right)^{-1} + (1-\theta)\left(_{p}d_{j,SLA} \right)^{-1} \right)^{-1} \qquad \text{B.9}$$

The corresponding CDF is then:

$$CDF_{p,CD}(x) \;=\; {}_{p}\Phi_{j,CBG} \;=\; \max\left\{ {}_{p}\Phi_{i,CBG} \;\middle|\; x \ldots\; CDF^{-1}_{p,CBG}\left({}_{p}\Phi_{i,CBG}\right) \right\} \qquad \text{B.10}$$

The harmonic mean was chosen because it can be shown that this average (unlike an arithmetic or geometric average) has the desirable property of producing densities consistent with the country-wide average persons per square kilometre.[12]

The population shares corresponding to the densities (rather than the cumulative population share) were used to convert the adjusted population densities to line densities. These population shares can be readily extracted from the CDF adjusted to the CBG level, because, as mentioned earlier, the CDFs are step functions and the share corresponding to a density is simply the size of that step.

12 The ‘averaging’ adjustment approach is motivated by considering the underlying CDFs (for a particular country) as members of a family of distributions continuously indexed by a real number v representing correspondence of a member of that family to a level of aggregation. (The empirical CDFs are estimates of appropriate members of this family. The values provided by the RLI are estimates of the corresponding index value v.) Assuming this family is differentiable with respect to the value of this number v over the range of interest, the averaging process should provide an estimated CDF which is more in the neighbourhood of the underlying but unknown CDF (this latter CDF corresponding to the CBG level of aggregation). Of course the closeness of the averaged (estimated) CDF to the true but unknown CDF is likely to vary with population density. However, where accuracy (for the purpose of estimating average line costs) is most important — at low population densities — the CDFs from different levels of aggregation are observed to be closer to each other (see, for example, box 2.2). This suggests that in this important part of an estimated CDF’s range, the accuracy of the adjustment will be greatest.

B.2 Converting population to line densities

Line density CDFs for each country were inferred from the population density CDFs (which had been adjusted to the block group level).

Adjustment approach

The starting point for deriving the line density distributions was each country's adjusted population density data set — adjusted to the US CBG level. As outlined in section B.1, this data included the population density ${}_pd_i$ and population share ${}_p\phi_i$ associated with each area i. Population densities were adjusted to line densities using a 'concordance' function $\lambda({}_pd_i)$. The population shares ${}_p\phi_i$ were also converted to line shares ${}_l\phi_i$ using a concordance function. The concordance function provides the average number of lines per person as a function of population density.

Line shares were estimated first because they were used in the process of estimating the line densities. Estimating the line shares involved two steps.

Initial line share estimates ${}_l\hat{\phi}_i$ were obtained by multiplying the population shares ${}_p\phi_i$ by their associated number of lines per person $\lambda({}_pd_i)$:

$$ {}_l\hat{\phi}_i = {}_p\phi_i \cdot \lambda({}_pd_i) \qquad \text{B.11} $$

Final line share estimates ${}_l\bar{\phi}_i$ were obtained by multiplying the initial line estimates by a constant — so that the final estimates would sum to one:

$$ {}_l\bar{\phi}_i = {}_l\hat{\phi}_i \cdot \left(\sum_{j=1}^{T} {}_l\hat{\phi}_j \right)^{-1} \qquad \text{B.12} $$

In effect, each population share ${}_p\phi_i$ is associated with an area i containing a number of persons p_i. The lines per person $\lambda({}_pd_i)$ multiplied by p_i would give an estimate of the number of lines in the area l_i.[13] Line share would then be l_i divided by total lines.

[13] Note that this estimate of lines in each area, might contain a systematic bias — the estimates might be proportionately too high or too low in every area. This is because the concordance function was estimated using Australian data. Countries more affluent than Australia could be expected to have more lines per person in areas with the same population density and countries less affluent, fewer.

However, a proportional bias across all areas does not matter when shares are being calculated because any such bias is eliminated when the shares are required to sum to one.

Instead, multiplying the population share ${}_p\phi_i$ by the number of lines per person $\lambda({}_pd_i)$ gives the number of lines in the area l_i divided by the total population. These numbers (that is, the numbers of lines in an area divided by total population) are proportional to the correct line share. The correct line share can be obtained from them by multiplying by the total population divided by the number of lines — that is, by multiplying by the constant provided in equation B.12.

The line density estimates ${}_ld_i$ were also obtained in two steps.

Initial line density estimates ${}_l\hat{d}_i$ were obtained by multiplying population densities ${}_pd_i$ by their associated lines per person $\lambda({}_pd_i)$:

$$ {}_l\hat{d}_i = {}_pd_i \cdot \lambda({}_pd_i) \qquad \text{B.13} $$

A further adjustment was made to ensure that the resulting line density estimates ${}_l\bar{d}_i$ and their associated line shares would be consistent with the country-wide average line density (in inhabited areas).[14] This requirement meant that the sum of each line share ${}_l\phi_i$ for an area i, multiplied by the reciprocal of its associated line density $1/{}_ld_i$ had to equal the total inhabited area of the country divided by the total number of lines — that is, equal the reciprocal of the country-wide average line density:[15]

$$ \frac{Total\ area}{Total\ lines} = \sum_{i=1}^{T} {}_l\phi_i \frac{1}{{}_ld_i} \qquad \text{B.14} $$

This was achieved by multiplying the initial line density estimates by an appropriate constant:

$$ {}_l\bar{d}_i = k \cdot {}_l\hat{d}_i \qquad \text{B.15} $$

Where:

$$ k = \left(\sum_{j=1}^{T} {}_p\phi_j \frac{1}{{}_pd_j} \right)^{-1} \cdot LPP_{Country\ m} \cdot \sum_{j=1}^{T} {}_l\bar{\phi}_j \frac{1}{{}_l\hat{d}_j} \qquad \text{B.16} $$

---

14 As noted in equation B.14, the areas totalled to obtain total area are only those with lines (which also means they are inhabited).

15 Proof of equation B.14:

$$ \frac{Total\ area}{Total\ lines} = \frac{\sum_{i=1}^{T} Area\ of\ area\ i}{Total\ lines} = \sum_{i=1}^{T} \frac{Lines\ in\ area\ i}{Total\ lines} \cdot \frac{Area\ of\ area\ i}{Lines\ in\ area\ i} = \sum_{i=1}^{T} {}_l\phi_i \frac{1}{{}_ld_i} $$

With $LPP_{Country\ m}$ being the country-wide average lines per person in country m.[16] The lines per person numbers used, were country-wide averages from the International Telecommunications Union (ITU 1998) and US State averages based on line numbers from the US Federal Communications Commission (FCC 1999) and population numbers from the US Census Bureau (1999). See tables B.6 and B.7.

Table B.6 Country-wide average lines per person

Country	*Lines per person*	*Country*	*Lines per person*
Australia	0.5188	New Zealand	0.4992
Finland	0.5490	US	0.6399

Note Lines per person from World *Telecommunications Development Report, Universal Access*, International Telecommunications Union, March 1998.

Source: International Telecommunications Union 1998.

Table B.7 US State-wide average lines per person

US State	*Population*[a]	*Total Lines*[b]	*Lines per person*
Alaska	608 846	397 536	0.6529
California	32 217 708	21 482 732	0.6668
Oregon	3 243 254	2 022 395	0.6236
Washington	5 604 105	3 499 719	0.6245

[a] The population estimates are for 1 July 1997 and are from *ST-99-3 State Population Estimates: Annual Time Series, July 1, 1990 to July 1, 1999* produced by the Population Estimates Program, Population Division, U.S. Census Bureau. [b] The line (loop) numbers are as at December 31, 1997 and are from Table 20.2 Telephone Loops by State in *Trends in Telephone Service*, Industry Analysis Division, Common Carrier Bureau, Federal Communications Commission, September 1999.

Sources: US Census Bureau 1999, US Federal Communications Commission 1999.

16 Proof that the adjustment in B.15 and B.16 satisfies equation B.14:

$$\frac{Total\ population}{Total\ area} = \left(\sum_{j=1}^{T} {}_p\phi_j \frac{1}{{}_p d_j} \right)^{-1} \qquad \text{(See equation B.14)} \qquad \text{B.17}$$

$$\left(\frac{Total\ lines}{Total\ population} \right)_{Country\ m} = LPP_{Country\ m} \qquad \text{B.18}$$

Hence:

$$k = \left(\frac{Total\ lines}{Total\ area} \right)_{Country\ m} \cdot \sum_{j=1}^{T} {}_l\bar{\phi}_j \frac{1}{{}_l\hat{d}_j} \qquad \text{B.19}$$

The proof is completed by substituting equation B.19 into B.20.

$$\frac{Total\ area}{Total\ lines} = \sum_{j=1}^{T} {}_l\bar{\phi}_j \frac{1}{{}_l\bar{d}_j} = \sum_{j=1}^{T} {}_l\bar{\phi}_j \frac{1}{(k \cdot {}_l\hat{d}_j)} \qquad \text{B.20}$$

Finally, line density CDFs were constructed from the estimated line densities and line shares using the same approach that was used to obtain population density CDFs from the population density and population share estimates (described in section B.1).

Estimating the concordance function

The concordance function $\lambda({}_p d)$ — the average number of lines per person associated with a given population density ${}_p d$ — was estimated using Australian Exchange Service Area (ESA) data provided by Telstra. The data included the number of lines in each of Telstra's 631 ESAs, as well as concordance information to match the ESA data with ABS Census data (at the CD level).

This data was adjusted to obtain population density estimates ${}_p d_i$ (consistent with the CBG level) and estimates of average lines per person LPP_i associated with each collector district i.

A linear spline function was fitted to this data to estimate the concordance function $\lambda({}_p d)$.

Telstra's Exchange Service Area data

An ESA is, as the name suggests, the area served by a single exchange. All the lines within an ESA eventually terminate at that exchange.

The ESA data provided the area of each ESA, in square kilometres, the number of lines covered by that area and an identifier.

Telstra provided information that allowed the ESA data to be matched with ABS CD data. Each ESA identifier was matched with several CD identifiers, the corresponding CDs approximately covering the same area.

In most cases an ESA's area was significantly different from the total area covered by the associated CDs. Of the 3914 ESAs, only 631 of them had area's within 10 per cent of the total area of their associated CDs. This subset was used; the rest were discarded. These ESAs and 11 297 associated CDs represented 3 510 437 lines and a population of 6 168 731 (or about one third of Australia).

Adjusting the data

With the subset of useable data, the average lines per person LPP_j associated with each ESA j was calculated. This was done by dividing the number of lines in the

ESA l_j by the total population of all the associated CDs p_j. This average lines per person was then assigned to each of the associated CDs.

The population density used, for each CD, was not the CD's population density ${}_pd_{i,CD}$, but an adjusted population density equivalent to that that would have been obtained if the data was reported at the US Census Block Group level — that is, ${}_pd_{i,CBG}$. The CDF associated with the collector district reporting level $CDF_{CD}({}_pd_{i,CD})$ was used to obtain the cumulative population share ${}_p\Phi_{i,CD}$ associated with the CD's population density.

$$ {}_p\Phi_{i,CD} = CDF_{CD}({}_pd_{i,CD}) \quad \text{B.21} $$

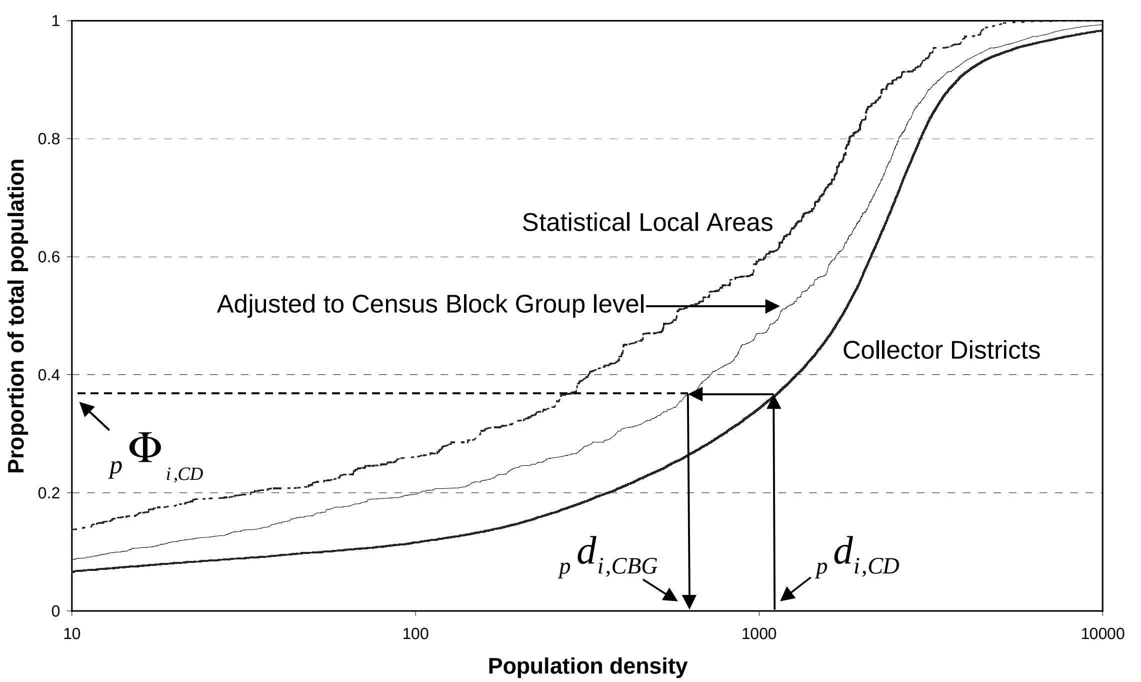
This cumulative population share ${}_p\Phi_{i,CD}$ was used with the inverse CDF corresponding to the CBG reporting level to obtain a CBG adjusted density ${}_pd_{i,CBG}$.

$$ {}_pd_{i,CBG} = CDF_{CBG}^{-1}({}_p\Phi_{i,CD}) \quad \text{B.22} $$

The process has been illustrated graphically in figure B.1. The result of these adjustments was a data set associated with CDs, each CD having associated with it a lines per person estimate LPP_i and a population density estimate ${}_pd_{i,CBG}$.

Figure B.1 Adjusting Collector District population densities

Using population density cumulative distribution functions



Note The figure illustrates the process of converting population densities derived from data at the Collector District level to densities equivalent to the US Census Block Group level.

Regression results

The data was partitioned into various density ranges and the average lines per person were calculated for these ranges (as total lines divided by total population within the range). These averages were used to guide the choices made in relation to 'knots' in the spline function. The estimated concordance equation and details of the spline function used are provided in table B.8.

The purpose of the concordance function was to estimate overall average number of lines per person for any given population density.[17] The t-scores (and standard errors) indicate that the conditional mean is estimated with a reasonable degree of accuracy.[18]

The adjusted data is illustrated in figures B.2 and B.3. A graph of the estimated function is provided in figure B.4.

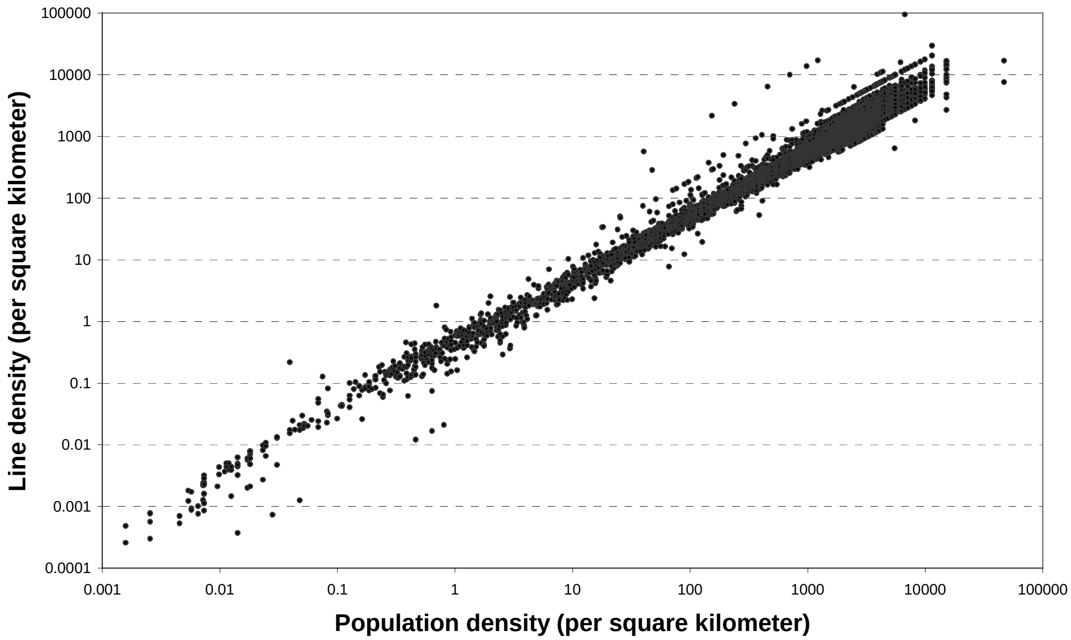
---

17 Essentially, the line CDF is inferred from the population CDF using lines per person times population density for the conversion. This approach is reasonable because (log of) line density and (log of) population density are highly correlated (see figure B.2). If they were not then a more sophisticated approach would be required. Line density distributions conditional on population density could be estimated from the Australian data (in figure B.2). This information could be used to create a joint distribution of line densities and population densities for each country and US State — the line density CDFs could be constructed from these joint distributions.

18 A significantly higher R-squared would have been required if the intention had been to accurately estimate the actual average lines per person for every CBG area (instead of the conditional mean of lines per person — conditional on population density).

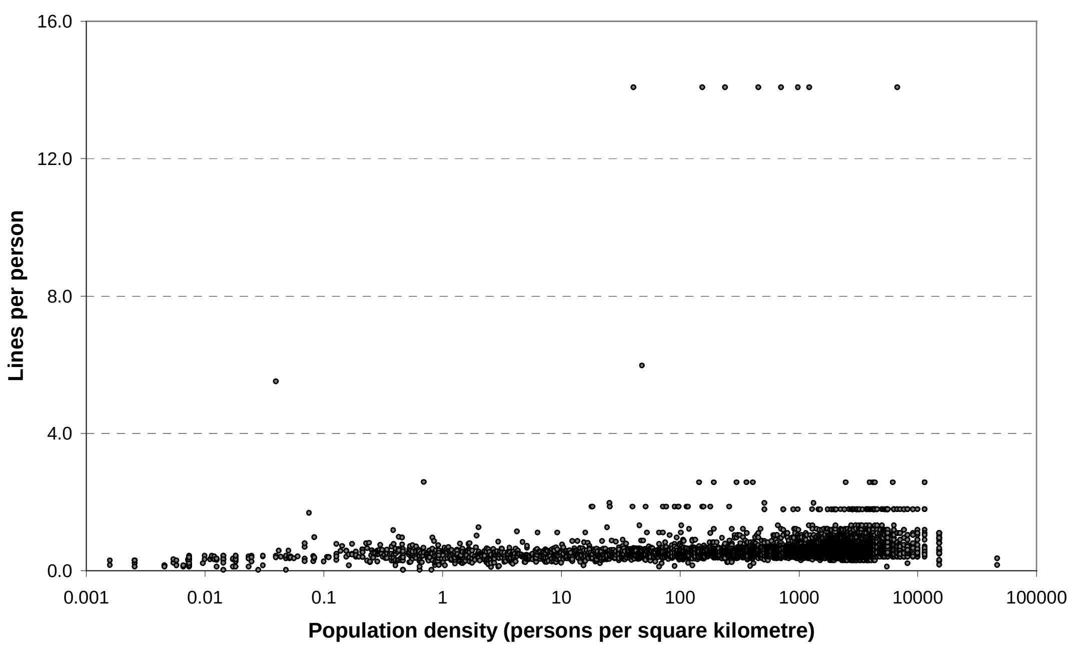
Notice that the correlation between the log of line density and the log of population density is very high (0.9913) and that the R-squared for the regression lines per person (line density divided by population density) regressed on a linear spline function of log of population density is very low (0.0161). Essentially the same data is presented in figures B.3 and B.4. The inconsistency between the high R-squared for one representation and low R-squared for the other is only apparent. In figure B.3 the vertical axis represents the (log of) line density. In figure B.4 the vertical axis is lines per person (calculated as line density divided by population density). Dividing line density by population density flattens the data downwards and reduces the R-squared close to zero. The dependent variable used in the regression, lines per person, assumes the strong relationship between line density and population density demonstrated in figure B.2 and is simply more convenient to estimate than an equivalent equation with line density as the dependent variable. The specification used reduces heteroskedasticity. The equation also provides information directly on how the conditional mean of lines per person varies with population density. It would be less convenient to obtain this information (indirectly) from the alternate specification.

Figure B.2 **Relationship between population density and line density**
(density per square kilometre)



Note The correlation between the logarithm of population densities and the logarithm of line densities is 0.9913. Population (and line) densities were adjusted to the CBG level.

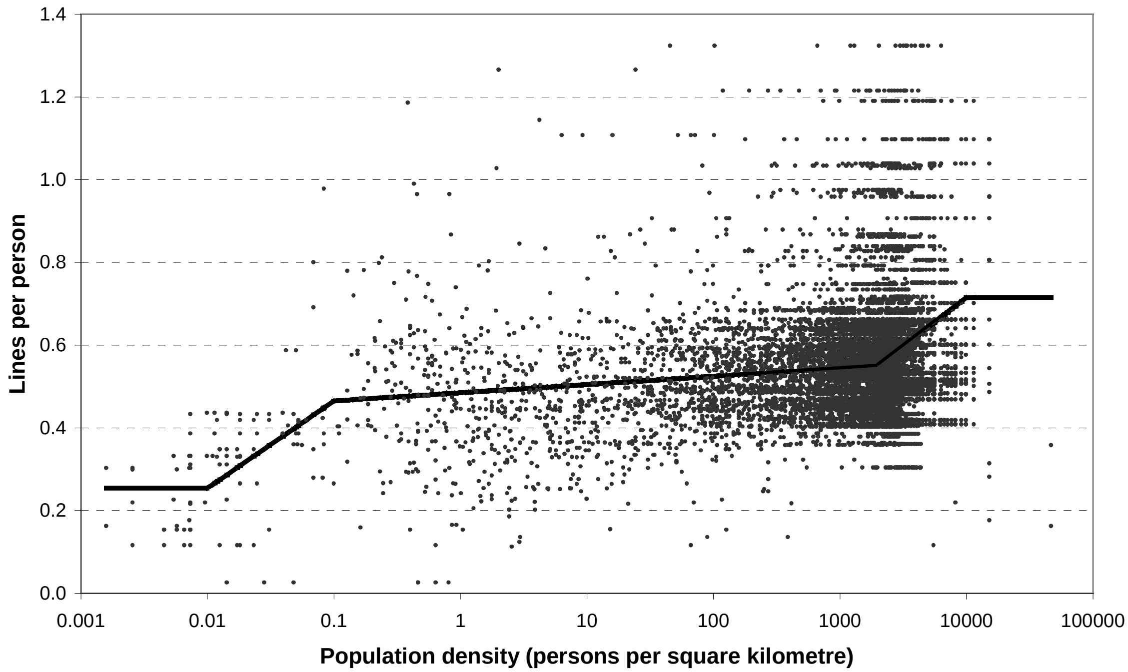
Figure B.3 **Adjusted Exchange Service Area and Collector District Data**
Lines per person by CD (CD population densities adjusted to the CBG level)



Data source: Based on Telstra Exchange Service Area and Australian Bureau of Statistics 1996 Census Collector District data

Figure B.4 **Concordance function based on Telstra ESA data**

Lines per person as a function of population density (CBG level)



Data source: Based on Telstra Exchange Service Area and Australian Bureau of Statistics 1996 Census Collector District data.

Table B.8 **Concordance function — regression results**

Lines per person as a function of population density

Variable	*Coefficient (t-statistic)*		*Variable*	*Coefficient (t-statistic)*	
Constant	0.2498	(57.11)	Variable 2	–0.0939	(–47.64)
Variable 1	0.1008	(51.72)	Variable 3	0.1002	(218.21)
R Squared	0.0161		Adjusted R Squared	0.0161[a]	

Variable definitions

$$\text{Variable 1} = \begin{cases} \text{if the } \textit{population density} \text{ is} \\ \quad \text{less than 0.01 lines per square kilometre} \\ \qquad \text{then Variable 1} = 0 \\ \quad \text{between 0.01 and 10 000 lines per square kilometre} \\ \qquad \text{then Variable 1} = \ln(\textit{population density}) - \ln(0.01) \\ \quad \text{greater than 10 000 lines per square kilometre} \\ \qquad \text{then Variable 1} = \ln(10\ 000) - \ln(0.01) = 13.816 \end{cases}$$

$$\text{Variable 2} = \begin{cases} \text{if the } \textit{population density} \text{ is} \\ \quad \text{less than 0.1 lines per square kilometre} \\ \qquad \text{then Variable 2} = 0 \\ \quad \text{between 0.1 and 10 000 lines per square kilometre} \\ \qquad \text{then Variable 2} = \ln(\textit{population density}) - \ln(0.1) \\ \quad \text{greater than 10 000 lines per square kilometre} \\ \qquad \text{then Variable 2} = \ln(10\ 000) - \ln(0.1) = 11.513 \end{cases}$$

$$\text{Variable 3} = \begin{cases} \text{if the } \textit{population density} \text{ is} \\ \quad \text{less than 2000 lines per square kilometre} \\ \qquad \text{then Variable 3} = 0 \\ \quad \text{between 2000 and 10 000 lines per square kilometre} \\ \qquad \text{then Variable 3} = \ln(\textit{population density}) - \ln(2000) \\ \quad \text{greater than 10 000 lines per square kilometre} \\ \qquad \text{then Variable 3} = \ln(10\ 000) - \ln(2000) = 1.609 \end{cases}$$

Note The dependent variable was lines per person. Variables 1 to 3 were functions of log line density (lines per square kilometre). See variable definitions above. The observations provided the lines per person of the wire centre associated with a collector district (CD). The population density associated with the CD were population densities adjusted to the US Census Block Group reporting level (see section B.1). The CDs used covered a total population of 6 168 731 people (just under one third of Australia's population). The equation was estimated using Generalised Least Squares (GLS) using an adjustment for grouped data. The weights used for each CD related observation were that CD's population count. [a] The adjusted R Squared is equal to the R Squared to several decimal places due to the large number of observations.

Source: Based on Telstra Exchange Service Area and Australian Bureau of Statistics 1996 Census Collector District data

B.3 Choosing and constructing the cost functions

The cost functions employed in the study were chosen and constructed to match the common reporting level used (the Census Block Group) and to provide sufficient detail on costs to enable cost differences at low densities to be distinguished.

The cost functions must match the chosen reporting level, because as noted in chapter 2, failure to do so would result in significantly biased results.[19] A different choice of common reporting level is unlikely to have introduced systematic bias (as long as another cost function to match that level was used).

However, a different choice would affect the accuracy of results. The CBG level appeared to be a good choice because it provided a significant level of detail without being so disaggregated that it would suffer from problems sometimes associated with discrete data.[20]

The cost functions also must be capable of distinguishing cost differences at low densities because costs rise rapidly at these densities, and across the countries and US States compared the distribution of population and lines at these densities also differs, considerably. Thus, failure to distinguish cost differences at these densities would have reduced the accuracy of cross-country comparisons.

Some uncertainty exists about the cost relativities between different density zones. As noted in chapter 2, different cost models, even when calibrated to the same level of aggregation, provide significantly different estimates. The main differences are related to the magnitude of line costs.

Cost relativities, between low- and high-density areas, generated by these models, also vary. Therefore, several cost functions were used to enable sensitivity analysis to be conducted (see appendix C).

19 Cost estimates, based on distribution data from a higher reporting level, obtained using a cost function matched to that level, should be similar, at least in expectation, to estimates based on a lower reporting level, using a cost function matched to that level. As noted in chapter 2, the estimates based on a higher reporting level, could in general, be expected to be less accurate — a lot of detail differentiating one country from another could be lost as one reporting level is aggregated up into another. That said, beyond some point results based on less aggregated data, due to the discrete nature of the fundamental units (lines and persons), would tend to be less accurate.

20 Eventually, with a very low level of aggregation the population counts in each area will be small integers, and many areas will be uninhabited (have zero population counts). These effects are likely to increase the errors associated with a cost function estimated on data at this level and also increase the errors associated with estimating the corresponding CDF.

BCPM and HAI cost schedules

The cost functions used in this study were based on the results of US engineering models — specifically, the Benchmark Cost Proxy Model (BCPM) and the Hatfield Associates Incorporated (HAI) cost model.

These engineering cost models were developed for use by protagonists in US (State and Federal) regulatory hearings held to determine interconnect access charges and universal service subsidy payments.

The models use very detailed data (information on customer locations, forecast usage, topography, soil conditions and climate, as well as labour, material and capital costs) and software incorporating engineering principles to design a network capable of serving existing customers. They provide efficient 'forward-looking' cost estimates, that is, the costings are based on assumptions that the 'best in use' technology is used to provide the services at least cost.

The raw cost estimates of both models are provided in various forms — for example, by individual US Census Block Group, Census Block or wire centre. The raw estimates are also aggregated into average line cost within a density range. These aggregated results — aggregated from CBG level data — were used in the study (see table B.9).

Table B.9 **BCPM and HAI average line cost – line density schedules**
(average cost per line per month US$)

Density categories (ranges)		*BCPM*	*HAI*
Lines per square mile	Lines per square kilometre	(US$ per month)	(US$ per month)
0 to 5	0 to 1.93	162.33	130.69
5 to 100	1.93 to 38.58	63.41	40.61
100 to 200	38.58 to 77.16	39.30	22.37
200 to 650	77.16 to 250.76	33.23	17.44
650 to 850	250.76 to 327.92	31.50	14.44
850 to 2550	327.92 to 983.76	28.56	12.01
2550 to 5000	983.76 to 1928.94	26.91	10.03
5000 to 10 000	1928.94 to 3857.88	23.80	9.15
Greater than 10 000	Greater than 3857.88	20.66	6.37

Telstra provided the cost schedules used (as being typical of the relationship between cost and line density, although not necessarily reflective of Australian conditions). These schedules are aggregated line cost averages (aggregated by CBG) for five US States — Florida, Georgia, Maryland, Missouri and Montana. They are consistent with BCPM and HAI cost schedules obtained from other sources.

Augmenting the schedules with Telstra and ACA data

The lowest density category for the BCPM and HAI cost schedules is for 0 to 5 lines per square mile (0 to 1.93 lines per square kilometre). Costs vary significantly within this range and a failure to distinguish these cost differences would have impacted on the accuracy of comparisons. Accordingly, more detail on costs within this range was sought.

Cost data, supplied by Telstra and the Australian Communications Authority (ACA) was used for this purpose. Both sets of cost data provided had been generated in the process of assessing the magnitude of the universal service obligation (USO).

The data provided by Telstra was obtained from a cost study commissioned to support their cost claims. It provided estimates of average line costs for 40 wire centres located in low-density areas.[21] Wire centre cost data was provided by the ACA. Average line costs had been estimated using their net universal service cost (NUSC) model.[22]

Adjustment approach

The ACA and Telstra average line cost data was regressed on dummy variables that represented a number of density ranges. This regression was an expedient to calculate the (line weighted) average cost per line in the different line density categories.

These provided relativities between the average line costs in the selected ranges. These relativities were then 'spliced' onto the BCPM and HAI schedules using a density range that was common to both.[23] In effect, the ACA or Telstra relativities replacing the BCPM or HAI relativities over their lower density range — splitting this single range 0 to 1.93 lines per square kilometre into two ranges, 0 to 0.2 and 0.2 to 1.93 in most cases, and 0 to 0.1 and 0.1 to 1.93 in the others.

21 The 40 wire centres had a total of 12 591 lines.

22 Each of the wire centres had been disaggregated into up to three sub areas. Thus the wire centres provided 6122 observations (representing a total of 2 464 714 lines).

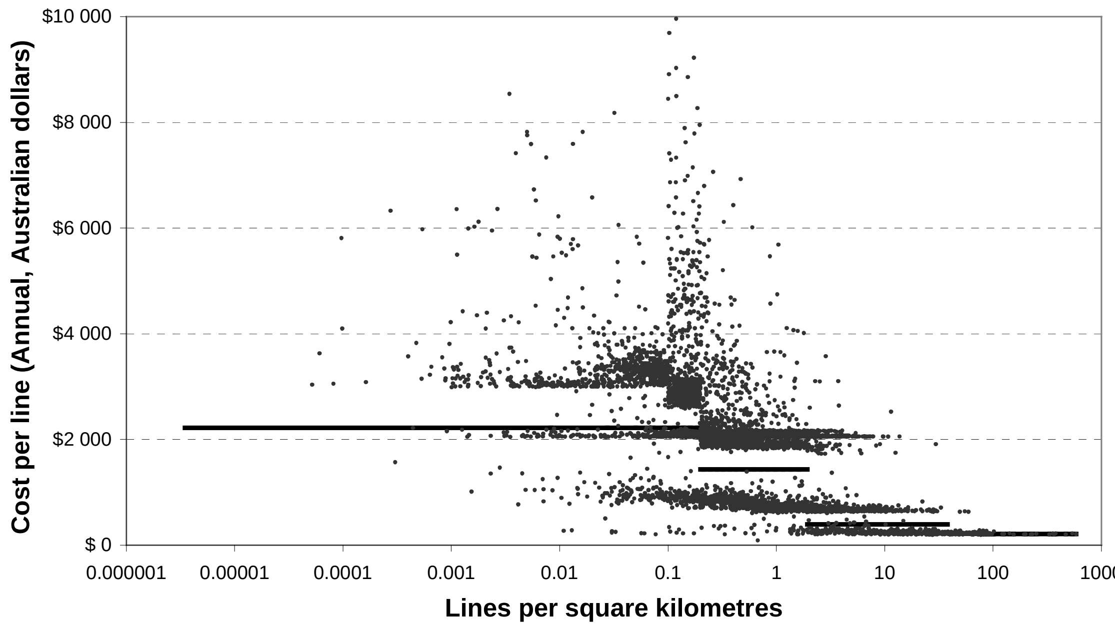
The NUSC model is an 'forward looking' 'cost proxy' engineering model (similar to the BCPM and HAI) developed by Bellcore Research to assist the ACA in determining an Australian universal service provider's net universal service costs (for a financial year). The cost of providing the USO is then shared among all telecommunications carriers operating in the Australian market on the basis of total eligible revenue.

23 This is the way many other series are spliced together. For example, the same approach is used to join overlapping Consumer Price Indexes.

Adjustments based on ACA data

The regression results obtained using ACA data are presented in table B.10. The ACA data and, also, a graphical representation of the regression results are shown in figure B.5.

Figure B.5 **ACA cost data and regression results**



Note Estimates of average cost per line (total cost divided by total number of lines in a density range. Some observations are not shown. Estimates for complete lines range from $17 811 to $87.50 A$ per year per line.

The average cost estimates and relativities obtained from the regression are presented in table B.10. The relativities (obtained from ACA cost data) allowed the lowest BCPM and HAI density range to be split into 0 to 0.2 and 0.2 to 1.93 lines per square kilometer ranges.

Table B.10 **Cost function regression using ACA cost data**

Dependent variable line cost per year A$

Variable	*Coefficient*	*(t-statistic)*	*Variable*	*Coefficient*	*(t-statistic)*
Constant	209.76	(243.4)	Dummy variable 3	184.43	(182.1)
Dummy variable 1	2011.81	(1189.1)	Dummy variable 4	6.00	(5.0)
Dummy variable 2	1222.54	(1054.7)	–		–
R Squared	0.544		Adjusted R Squared	0.544	

Variable definitions

$$\text{Dummy variable 1} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{less than 0.2 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

$$\text{Dummy variable 2} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{between 0.2 and 1.93 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

$$\text{Dummy variable 3} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{between 1.93 and 38.58 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

$$\text{Dummy variable 4} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{between 38.58 and 77.16 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

The adjustments to the BCPM and HAI schedules are presented in table B.11. In the first two adjusted schedules — ACA1 and ACA2 — the adjustment was achieved by joining the two series at a density range — 38.58 to 77.16 or 1.93 to 38.58 lines per square kilometer. This involved estimating the average cost by multiplying the original value (in the BCPM or HAI cost schedules) by the adjustment value (cost relativity). The cost relativities are presented in table B.11.

Thus, the ACA cost relativities replaced the original schedule values for densities below the join. For example, the average line cost in the 0 to 0.2 density range, in BCPM ACA1 schedule, was US$39.30 times 10.30 (the ACA1 cost relativity) or US$404.66.

Table B.11 **Cost relativities obtained from ACA cost data regression**

Density categories (ranges)	*Average line cost*	*Cost relativities*		
(lines per square kilometre)	*(A$ per year)*	*ACA1*	*ACA2*	*ACA3*
0 to 0.2	2221.60	10.30	5.64	1.51
0.2 to 1.93	1432.30	6.64	3.63	0.97
1.93 to 38.58	394.20	1.83	1.00	–
38.58 to 77.16	215.80	1.00	–	–

The third adjustment — producing ACA3 — involved replacing the lowest density category in the BCPM and HAI schedule with the ACA cost relativities for the 0 to 0.2 and 0.2 to 1.93 density ranges in a different manner. The ACA3 values used to replace the BCPM and HAI values were 'normalised' so that when they replaced the original BCPM or HAI value they would still provide the same estimates of average line cost over this density range when applied to Washington State. For this adjustment, the ACA3 relativities in table B.11 were multiplied by the BCPM or HAI cost schedule values from the 0 to 1.93 lines per square kilometre range to obtain new values for the 0 to 0.2 and 0.2 and 1.93 ranges.

It seemed reasonable to assume that, of the four US States included, Washington State was the most similar at low densities to the States from which the BCPM and HAI schedules had been obtained from Telstra (Florida, Georgia, Maryland, Missouri and Montana). The adjustment, using this State, was intended to ensure that adjusted parts of the schedules when applied to these States would still provide cost estimates similar to the original BCPM and HAI estimates.

With this adjustment, the average line cost in the 0 to 0.2 density range, in BCPM ACA1 schedule, for example, was estimated as US$162.33 times 1.51 (the ACA3 cost relativity) or US$246.52 (see table B.12).

Table B.12 **Cost schedules adjusted using regression results based on ACA data**

Density categories (ranges)	*BCPM* ACA 1	*BCPM* ACA 2	*BCPM* ACA 3	*HAI* ACA 1	*HAI* ACA 2	*HAI* ACA 3
Lines per square kilometre	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)
0 to 0.2	404.66	357.36	246.52	230.34	228.87	198.47
0.2 to 1.93	260.90	230.40	158.94	148.50	147.56	127.96
1.93 to 38.58	71.80	63.41	63.41	40.87	40.61	40.61
38.58 to 77.16	39.30	39.30	39.30	22.37	22.37	22.37
77.16 to 250.76	33.23	33.23	33.23	17.44	17.44	17.44
250.76 to 327.92	31.50	31.50	31.50	14.44	14.44	14.44
327.92 to 983.76	28.56	28.56	28.56	12.01	12.01	12.01
983.76 to 1928.94	26.91	26.91	26.91	10.03	10.03	10.03
1928.94 to 3857.88	23.80	23.80	23.80	9.15	9.15	9.15
Greater than 3857.88	20.66	20.66	20.66	6.37	6.37	6.37

Adjustments based on Telstra data

Telstra also provided estimates of line costs. These estimates were based on a commissioned study that estimated line costs for 47 wire centres in low-density areas. The study was conducted to assist in the process of assessing the magnitude of the universal service obligation (USO).

The regression results obtained using Telstra's data are presented in table B.14. The Telstra data and a graphical representation of the regression results for the two models — Telstra 1 and Telstra 2 — are shown in figure B.6.

Several models were estimated using different partitions of the 0 to 1.93 lines per square kilometre range. Amongst these, Telstra 1 was the preferred model — in the sense that it fitted the data best. The Telstra 2 model was included because it uses the same ranges that were used in the ACA models.

Table B.13 **Cost function regressions using Telstra cost data**

Telstra 1 regression			Telstra 2 regression		
Variable	*Coefficient*	*(t-statistic)*	*Variable*	*Coefficient*	*(t-statistic)*
Constant	5 274.5	(75.9)	Constant	5 274.5	(66.37)
Dummy variable 1,1	28 056.4	(98.2)	Dummy variable 2,1	12 540.0	(78.2)
Dummy variable 1,2	8 925.2	(89.9)	Dummy variable 2,2	8 963.7	(72.3)
R Squared	0.546		R Squared	0.406	
Adjusted R Squared	0.546		Adjusted R Squared	0.406	

Variable definitions

$$\text{Dummy variable 1,1} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{less than 0.1 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

$$\text{Dummy variable 1,2} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{between 0.1 and 1.93 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

$$\text{Dummy variable 2,1} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{less than 0.2 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

$$\text{Dummy variable 2,2} = \begin{cases} 1 \text{ if } \textit{line density} \text{ is} \\ \quad \text{between 0.2 and 1.93 lines per square kilometre} \\ 0 \text{ otherwise} \end{cases}$$

Figure B.6 **Telstra cost data and regression results**

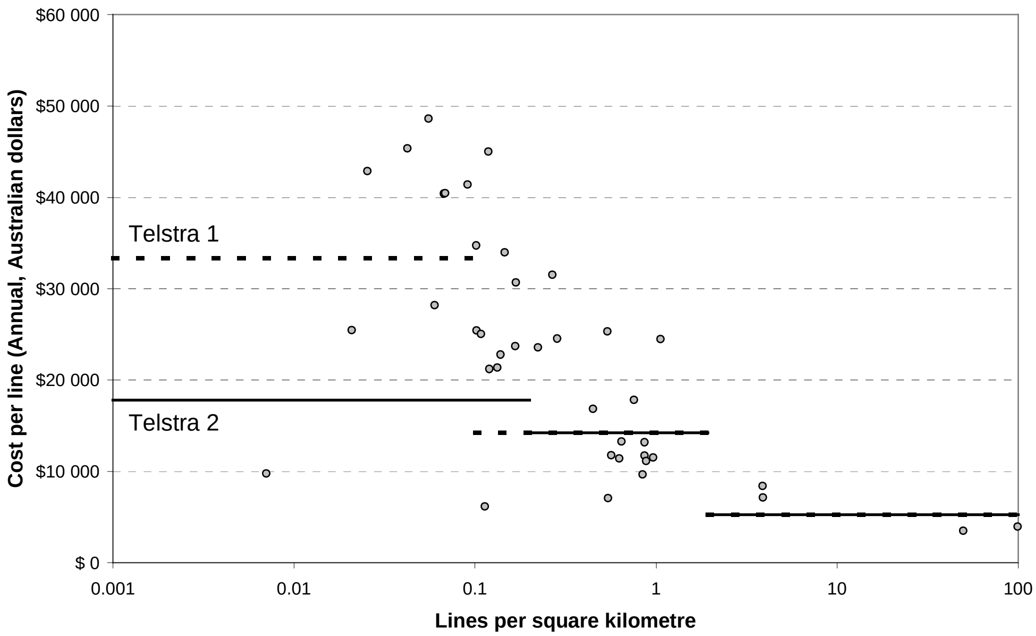


Table B.14 **Cost relativities obtained from Telstra cost data regressions**

Density categories (ranges)	*Telstra 1*		*Telstra 2*	
	Average line cost	*Cost relativities*	*Average line cost*	*Cost relativities*
Lines per square kilometre	(A$ per year)		(A$ per year)	
0 to 0.1	33 330.92	2.30	17 814.56	1.24
0.1 to 0.2	14 199.75	0.98	17 814.56	1.24
0.2 to 1.93	14 199.75	0.98	14 238.30	0.99

The average cost estimates and cost relativities obtained from the regression are presented in table B.13. The relativities provided in table B.13 were used to ‘splice’ the Telstra results into the BCPM and HAI schedules using the same approach used for ACA3.

Table B.15 **Cost schedules adjusted using Telstra data**
(line cost per month US$)

Density categories (ranges)	*BCPM*		*HAI*	
	Telstra 1	*Telstra 2*	*Telstra 1*	*Telstra 2*
Lines per square kilometre	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)
0 to 0.1	372.99	201.15	300.29	161.94
0. to 0.2	158.90	201.15	127.93	161.94
0.2 to 1.93	158.90	160.77	127.93	129.43
1.93 to 38.58	63.41	63.41	40.61	40.61
38.58 to 77.16	39.30	39.30	22.37	22.37
77.16 to 250.76	33.23	33.23	17.44	17.44
250.76 to 327.92	31.50	31.50	14.44	14.44
327.92 to 983.76	28.56	28.56	12.01	12.01
983.76 to 1928.94	26.91	26.91	10.03	10.03
1928.94 to 3857.88	23.80	23.80	9.15	9.15
Greater than 3857.88	20.66	20.66	6.37	6.37

The adjusted cost schedules

The adjustments resulted in ten cost schedules overall. These cost schedules are presented for comparison in tables B.16 and B.17.

The cost schedules are also presented graphically in figure B.7.

Country- or State-wide average line cost estimates based on the Telstra 1 adjusted schedules, for the most part, fall in the middle of the other ACA and Telstra adjusted schedules. For this reason only, the main estimates presented in chapter 4 are based on the Telstra 1 adjusted schedule.

Table B.16 **Adjusted BCPM schedules**

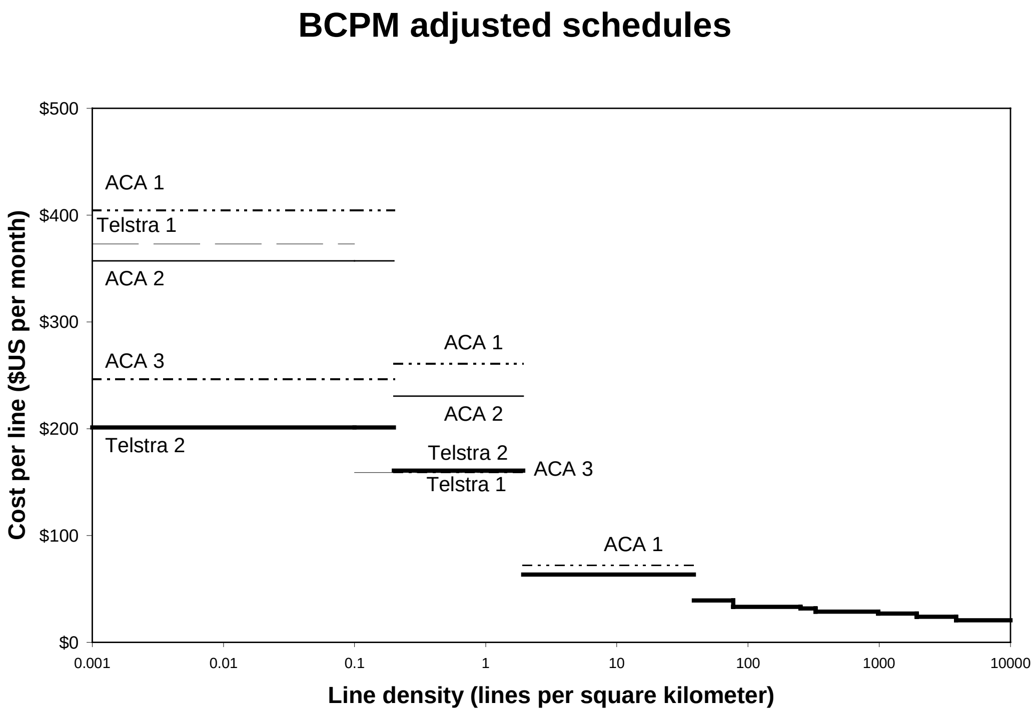
Adjustments based on Telstra and ACA cost data

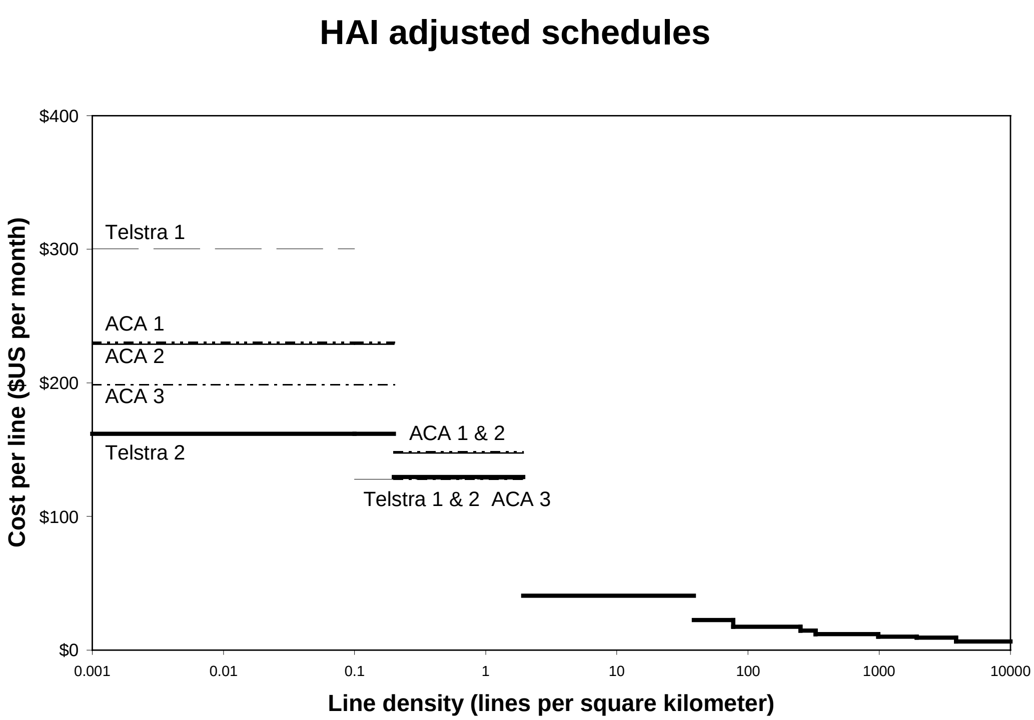
Density categories (ranges)	*BCPM*				
	ACA1	*ACA2*	*Telstra 1*	*ACA3*	*Telstra 2*
Lines per square kilometre	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)
0 to 0.1	404.66	357.36	372.99	246.52	201.15
0.1 to 0.2	404.66	357.36	158.90	246.52	201.15
0.2 to 1.93	260.90	230.40	158.90	158.94	127.93
1.93 to 38.58	71.80	63.41	63.41	63.41	63.41
38.58 to 77.16	39.30	39.30	39.30	39.30	39.30
77.16 to 250.76	33.23	33.23	33.23	33.23	33.23
250.76 to 327.92	31.50	31.50	31.50	31.50	31.50
327.92 to 983.76	28.56	28.56	28.56	28.56	28.56
983.76 to 1928.94	26.91	26.91	26.91	26.91	26.91
1928.94 to 3857.88	23.80	23.80	23.80	23.80	23.80
Greater than 3857.88	20.66	20.66	20.66	20.66	20.66

Table B.17 **Adjusted HAI schedules**

Density categories (ranges)	*HAI*				
	ACA1	*ACA2*	*Telstra 1*	*ACA3*	*Telstra 2*
Lines per square kilometre	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)	(US$ per month)
0 to 0.1	230.34	228.87	300.29	198.47	161.94
0.1 to 0.2	230.34	228.87	127.93	198.47	161.94
0.2 to 1.93	148.50	147.56	127.93	127.96	129.43
1.93 to 38.58	40.87	40.61	40.61	40.61	40.61
38.58 to 77.16	22.37	22.37	22.37	22.37	22.37
77.16 to 250.76	17.44	17.44	17.44	17.44	17.44
250.76 to 327.92	14.44	14.44	14.44	14.44	14.44
327.92 to 983.76	12.01	12.01	12.01	12.01	12.01
983.76 to 1928.94	10.03	10.03	10.03	10.03	10.03
1928.94 to 3857.88	9.15	9.15	9.15	9.15	9.15
Greater than 3857.88	6.37	6.37	6.37	6.37	6.37

Figure B.7 **BCPM and HAI schedules adjusted using ACA and Telstra data**





C Further results

This appendix contains further results — principally average line cost estimates additional to those provided in chapter 4.[1]

C.1 Cost schedules

The ten cost schedules presented in table C.1 and C.2 were used to obtain the estimates of average line costs for each country and US State contained in this appendix. The construction of these cost schedules is outlined in appendix B.

Table C.1 **Adjusted BCPM schedules**
(US$ per month)

Density categories (lines per square kilometre)	*BCPM*				
	ACA1	*ACA2*	*Telstra 1*	*ACA3*	*Telstra 2*
0 to 0.1	404.66	357.36	372.99	246.52	201.15
0.1 to 0.2	404.66	357.36	158.90	246.52	201.15
0.2 to 1.93	260.90	230.40	158.90	158.94	127.93
1.93 to 38.58	71.80	63.41	63.41	63.41	63.41
38.58 to 77.16	39.30	39.30	39.30	39.30	39.30
77.16 to 250.76	33.23	33.23	33.23	33.23	33.23
250.76 to 327.92	31.50	31.50	31.50	31.50	31.50
327.92 to 983.76	28.56	28.56	28.56	28.56	28.56
983.76 to 1928.94	26.91	26.91	26.91	26.91	26.91
1928.94 to 3857.88	23.80	23.80	23.80	23.80	23.80
Greater than 3857.88	20.66	20.66	20.66	20.66	20.66

Note Schedule construction outlined in appendix B.

1 As noted in chapter 3, line distribution estimates for Alaska are inaccurate because its population density – line density relationship is substantially different to the Australian relationship, which was used in the study. Therefore, the Alaskan results are estimates of what Alaska's line distribution would be *if* it followed the Australian pattern.

Table C.2 **Adjusted HAI schedules**

(US$ per month)

Density categories (Lines per square kilometre)	*HAI*				
	ACA1	*ACA2*	*Telstra 1*	*ACA3*	*Telstra 2*
0 to 0.1	230.34	228.87	300.29	198.47	161.94
0.1 to 0.2	230.34	228.87	127.93	198.47	161.94
0.2 to 1.93	148.50	147.56	127.93	127.96	129.43
1.93 to 38.58	40.87	40.61	40.61	40.61	40.61
38.58 to 77.16	22.37	22.37	22.37	22.37	22.37
77.16 to 250.76	17.44	17.44	17.44	17.44	17.44
250.76 to 327.92	14.44	14.44	14.44	14.44	14.44
327.92 to 983.76	12.01	12.01	12.01	12.01	12.01
983.76 to 1928.94	10.03	10.03	10.03	10.03	10.03
1928.94 to 3857.88	9.15	9.15	9.15	9.15	9.15
Greater than 3857.88	6.37	6.37	6.37	6.37	6.37

Note Schedule construction outlined in appendix B.

As outlined in appendix B, population density distributions, adjusted to the US Census Block Group level of aggregation, were used to impute corresponding line density distributions.

C.2 Line distributions based on the concordance function

Table C.3 **Line density distribution estimates 1**

Conversion from population densities based on Australian data (per cent)

Density categories (lines per square kilometre)	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
0 to 0.1	6.239	0.058	0.697	0.225	0.134	0.034	0.013
0.1 to 0.2	1.519	0.141	0.553	0.224	0.221	0.048	0.030
0.2 to 1.93	7.032	4.093	3.920	3.075	5.070	2.040	0.619
1.93 to 38.58	19.198	35.002	12.198	17.488	9.221	10.774	4.084
38.58 to 77.16	4.785	6.511	2.814	4.057	2.400	6.063	1.896
77.16 to 250.76	14.265	11.177	10.395	11.424	8.710	12.201	5.334
250.76 to 327.92	2.621	3.875	4.263	3.144	3.319	3.920	2.252
327.92 to 983.76	16.083	19.638	27.799	26.782	30.259	28.129	14.681
983.76 to 1928.94	19.827	9.615	25.971	23.415	35.782	25.356	22.811
1928.94 to 3857.88	7.422	7.347	7.625	8.729	4.846	9.357	26.314
Greater than 3857.88	1.008	2.542	3.765	1.437	0.038	2.078	21.965

Note These distributions were based on population distributions. The conversion used a concordance function based on Australian data. See appendix B.

The central method for converting population densities to line densities used a concordance function (lines per person as a function of population density) based on

Australian data. The results of these line density distribution estimates — the proportions of lines falling in different line density categories — are presented in table C.3. Cost estimates and indexes are presented in tables C.4 to C.6.

Table C.4 **Average line cost estimates 1**

(US$ per month)

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	82.874	54.578	47.467	45.101	45.601	38.577	29.080
BCPM ACA 2	75.450	50.299	44.656	42.483	43.113	37.011	28.528
BCPM Telstra 1	68.382	47.102	40.865	39.875	39.070	35.462	28.028
BCPM ACA 3	61.825	47.154	40.470	39.788	39.096	35.462	28.038
BCPM Telstra 2	58.434	47.138	39.974	39.641	39.027	35.462	28.030
BCPM	55.532	47.125	39.551	39.514	38.969	35.462	28.024
HAI ACA 1	44.759	28.964	23.624	22.557	22.320	18.583	12.225
HAI ACA 2	44.528	28.831	23.537	22.476	22.243	18.534	12.208
HAI Telstra 1	46.071	27.927	22.707	21.806	21.121	18.109	12.065
HAI ACA 3	40.792	27.969	22.389	21.737	21.141	18.109	12.073
HAI Telstra 2	38.062	27.956	21.990	21.618	21.086	18.109	12.067
HAI	35.726	27.946	21.649	21.516	21.039	18.109	12.061

Note Average line costs estimated using the table C.1 and C.2 schedules and the table C.3 line distribution.

Table C.5 **Average line cost indexes 1**

Australia normalised to 100

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	174.595	114.983	100.000	95.016	96.069	81.271	61.264
BCPM ACA 2	168.956	112.635	100.000	95.133	96.544	82.881	63.884
BCPM Telstra 1	167.336	115.262	100.000	97.577	95.608	86.779	68.587
BCPM ACA 3	152.768	116.516	100.000	98.316	96.605	87.626	69.282
BCPM Telstra 2	146.177	117.921	100.000	99.165	97.631	88.712	70.121
BCPM	140.408	119.152	100.000	99.908	98.529	89.663	70.855
HAI ACA 1	189.461	122.602	100.000	95.481	94.479	78.659	51.747
HAI ACA 2	189.184	122.492	100.000	95.490	94.501	78.745	51.866
HAI Telstra 1	202.892	122.987	100.000	96.032	93.013	79.752	53.133
HAI ACA 3	182.197	124.921	100.000	97.086	94.427	80.885	53.925
HAI Telstra 2	173.084	127.131	100.000	98.306	95.888	82.352	54.874
HAI	165.023	129.086	100.000	99.386	97.182	83.650	55.713

Note Average line costs estimated using the table C.1 and C.2 schedules and the table C.3 line distribution.

The rankings of cost from the ten cost models and the line distributions contained in table C.3 are presented in table C.7. Except in two cases, (Oregon and New Zealand), rankings do not change when different cost schedules are used. The changes in rank order were primarily because the cost estimates for both countries were very close in all cases.

Table C.6 **Average line cost indexes 2**

Australia Telstra 1 models normalised to 100

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	202.801	133.558	116.155	110.365	111.589	94.401	71.161
BCPM ACA 2	184.632	123.086	109.278	103.960	105.501	90.570	69.811
BCPM Telstra 1	167.336	115.262	100.000	97.577	95.608	86.779	68.587
BCPM ACA 3	151.291	115.389	99.033	97.365	95.671	86.779	68.613
BCPM Telstra 2	142.992	115.352	97.821	97.004	95.503	86.779	68.593
BCPM	135.892	115.320	96.784	96.695	95.360	86.779	68.576
HAI ACA 1	197.115	127.555	104.040	99.339	98.296	81.837	53.837
HAI ACA 2	196.099	126.970	103.655	98.981	97.955	81.623	53.762
HAI Telstra 1	202.892	122.987	100.000	96.032	93.013	79.752	53.133
HAI ACA 3	179.644	123.171	98.599	95.726	93.104	79.752	53.170
HAI Telstra 2	167.620	123.117	96.843	95.203	92.861	79.752	53.142
HAI	157.333	123.071	95.340	94.755	92.653	79.752	53.117

Table C.7 **Average line cost ranking 1**

Ranking from 1 (highest average line cost) to 7 (lowest average line cost)

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	1	2	3	5	4	6	7
BCPM ACA 2	1	2	3	5	4	6	7
BCPM Telstra 1	1	2	3	4	5	6	7
BCPM ACA 3	1	2	3	4	5	6	7
BCPM Telstra 2	1	2	3	4	5	6	7
BCPM	1	2	3	4	5	6	7
HAI ACA 1	1	2	3	4	5	6	7
HAI ACA 2	1	2	3	4	5	6	7
HAI Telstra 1	1	2	3	4	5	6	7
HAI ACA 3	1	2	3	4	5	6	7
HAI Telstra 2	1	2	3	4	5	6	7
HAI	1	2	3	4	5	6	7

C.3 Line distributions based on simple proportionality

As part of the sensitivity analysis, line density distributions were also estimated from population densities with the assumption that the ratio of lines per person remained constant as population density varied (see table C.8).

Table C.8 Line density distribution estimates 2

Conversion from population densities based on country- or State-wide average lines per person (per cent)

Density categories (lines per square kilometre)	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
0 to 0.1	7.625	0.057	0.856	0.192	0.106	0.032	0.016
0.1 to 0.2	1.823	0.132	0.517	0.203	0.279	0.028	0.027
0.2 to 1.93	7.501	3.967	4.310	3.130	5.236	2.039	0.653
1.93 to 38.58	19.750	36.632	13.238	18.082	10.212	11.072	4.565
38.58 to 77.16	5.052	6.870	2.847	4.367	2.224	6.359	2.056
77.16 to 250.76	13.781	11.361	10.504	11.733	9.204	12.383	5.824
250.76 to 327.92	3.141	4.032	4.477	3.213	3.304	4.055	2.227
327.92 to 983.76	15.866	19.562	28.057	26.160	30.657	28.062	15.743
983.76 to 1928.94	19.699	10.182	26.847	24.979	35.917	26.953	26.566
1928.94 to 3857.88	5.256	6.079	6.401	7.264	2.832	7.725	27.362
Greater than 3857.88	0.505	1.125	1.945	0.678	0.030	1.291	14.962

Note These distributions were based on population distributions (as outlined in appendix B).

Table C.9 Average line cost estimates 2

(US$ per month)

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	90.728	55.172	49.487	45.436	46.625	38.778	29.846
BCPM ACA 2	82.314	50.798	46.412	42.777	43.989	37.199	29.243
BCPM Telstra 1	74.524	47.708	42.438	40.166	39.708	35.690	28.726
BCPM ACA 3	66.481	47.753	41.811	40.103	39.821	35.675	28.730
BCPM Telstra 2	62.330	47.739	41.267	39.981	39.742	35.684	28.723
BCPM	58.780	47.728	40.802	39.876	39.674	35.693	28.716
HAI ACA 1	49.357	29.399	24.860	22.790	22.961	18.723	12.742
HAI ACA 2	49.096	29.263	24.764	22.707	22.879	18.674	12.723
HAI Telstra 1	51.229	28.392	24.008	22.025	21.646	18.268	12.579
HAI ACA 3	44.753	28.428	23.503	21.974	21.736	18.256	12.583
HAI Telstra 2	41.412	28.417	23.065	21.876	21.673	18.263	12.577
HAI	38.554	28.408	22.690	21.792	21.618	18.270	12.572

Note Average line costs were estimated using the schedules in tables C.1 and C.2 and the line distribution in table C.8.

The simple proportionality assumption (used to convert population densities to line densities) results in relatively more lines estimated as being in the very lowest density categories (see tables C.8 and C.3). This results in consistently higher average line cost estimates (see tables C.9 and C.4).

Table C.10 **Average line cost indexes 3**

Australia normalised to 100

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	183.338	111.488	100.000	91.815	94.216	78.360	60.310
BCPM ACA 2	177.354	109.450	100.000	92.168	94.778	80.148	63.008
BCPM Telstra 1	175.605	112.417	100.000	94.646	93.566	84.099	67.688
BCPM ACA 3	159.002	114.211	100.000	95.915	95.239	85.323	68.714
BCPM Telstra 2	151.042	115.684	100.000	96.884	96.304	86.472	69.602
BCPM	144.063	116.975	100.000	97.733	97.236	87.479	70.381
HAI ACA 1	198.540	118.260	100.000	91.673	92.362	75.312	51.255
HAI ACA 2	198.250	118.167	100.000	91.693	92.388	75.404	51.377
HAI Telstra 1	213.386	118.263	100.000	91.741	90.161	76.094	52.397
HAI ACA 3	190.419	120.958	100.000	93.496	92.484	77.675	53.537
HAI Telstra 2	179.549	123.208	100.000	94.845	93.965	79.184	54.528
HAI	169.916	125.201	100.000	96.041	95.277	80.521	55.406

Table C.11 **Average line cost indexes 4**

Australia Telstra 1 models normalised to 100

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	213.788	130.005	116.609	107.064	109.864	91.375	70.327
BCPM ACA 2	193.962	119.699	109.364	100.799	103.654	87.653	68.908
BCPM Telstra 1	175.605	112.417	100.000	94.646	93.566	84.099	67.688
BCPM ACA 3	156.652	112.523	98.522	94.497	93.831	84.062	67.698
BCPM Telstra 2	146.873	112.491	97.240	94.209	93.645	84.085	67.681
BCPM	138.507	112.464	96.143	93.963	93.486	84.105	67.666
HAI ACA 1	205.588	122.458	103.550	94.928	95.641	77.986	53.075
HAI ACA 2	204.499	121.892	103.152	94.584	95.300	77.781	52.997
HAI Telstra 1	213.386	118.263	100.000	91.741	90.161	76.094	52.397
HAI ACA 3	186.412	118.413	97.896	91.529	90.538	76.040	52.410
HAI Telstra 2	172.495	118.368	96.072	91.119	90.273	76.073	52.386
HAI	160.590	118.329	94.511	90.769	90.047	76.102	52.365

Moreover, the simple proportionality assumption tends to exaggerate the differences between countries and between cost models (see tables C.10 and C.11 and tables C.5 and C.6). Further, two additional changes in rank order result (see table C.12 and C.7).

Table C.12 **Average line cost ranking 2**

Ranking from 1 (highest average line cost) to 7 (lowest average line cost)

Cost model	*Alaska*	*Finland*	*Australia*	*Oregon*	*New Zealand*	*Washington*	*California*
BCPM ACA 1	1	2	3	5	4	6	7
BCPM ACA 2	1	2	3	5	4	6	7
BCPM Telstra 1	1	2	3	4	5	6	7
BCPM ACA 3	1	2	3	4	5	6	7
BCPM Telstra 2	1	2	3	4	5	6	7
BCPM	1	2	3	4	5	6	7
HAI ACA 1	1	2	3	5	4	6	7
HAI ACA 2	1	2	3	5	4	6	7
HAI Telstra 1	1	2	3	4	5	6	7
HAI ACA 3	1	2	3	4	5	6	7
HAI Telstra 2	1	2	3	4	5	6	7
HAI	1	2	3	4	5	6	7

C.4 Results for high and low density areas

Relative average line costs in low-density and remaining areas are provided in tables C.13 to C.16. The average costs are relative to Australia's country-wide average line costs normalised to 100. Cost schedules used are BCPM Telstra 1 and HAI Telstra 1. The line distributions are from table C.3.

Table C.13 **Indexes of line costs using the BCPM Telstra 1 cost schedule**

Low density — 0 to 1.93 lines per square kilometre

Country or State	*Per cent of lines in Low density areas*	*Index of average line cost*		
		Low density areas[a]	*Remaining areas*[b]	*Overall*
Alaska	14.79	610	91	167
Finland	4.29	396	103	115
Australia	5.17	459	80	100
Oregon	3.52	422	86	98
New Zealand	5.43	402	78	96
Washington	2.12	397	80	87
California	0.66	399	66	69

Note The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The BCPM based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. Average cost relativities in the low-density area vary because these costs are weighted averages of two cost categories (the weights vary with different line density distributions).

[a] Low-density areas are those with line densities between 0 and 1.93 lines per square kilometre (0 and 5 lines per square mile). [b] Remaining areas are those with more than 1.93 lines per square kilometre.

Table C.14 **Relative line costs using the HAI Telstra 1 cost schedule**
Low density — 0 to 1.93 lines per square kilometre

Country or State	*Per cent of lines in Low density areas*	*Index of average line cost*		
		Low density areas[a]	*Remaining areas*[b]	*Overall*
Alaska	14.79	884	85	203
Finland	4.29	574	103	123
Australia	5.17	666	69	100
Oregon	3.52	612	77	96
New Zealand	5.43	582	65	93
Washington	2.12	576	69	80
California	0.66	578	50	53

Note The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The HAI based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. Average cost relativities in the low-density area vary because these costs are weighted averages of two cost categories.

a Low-density areas are those with line densities between 0 and 1.93 lines per square kilometre (0 and 5 lines per square mile). **b** Remaining areas are those with more than 1.93 lines per square kilometre.

Table C.15 **Indexes of line costs using the BCPM Telstra 1 cost schedule**
Low density — 0 to 38.58 lines per square kilometres

Country or State	*Per cent of lines in Low density areas*	*Index of average line cost*		
		Low density areas[a]	*Remaining areas*[b]	*Overall*
Alaska	33.98	353	72	167
Finland	39.29	181	72	115
Australia	17.36	246	69	100
Oregon	21.01	200	70	98
New Zealand	14.64	247	70	96
Washington	12.89	195	71	87
California	4.74	189	63	69

Note The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The BCPM based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. Average cost relativities in the low-density area vary because these costs are weighted averages of three cost categories.

a Low-density areas are those with line densities between 0 and 38.58 lines per square kilometre (0 and 100 lines per square miles). **b** Remaining areas are those with more than 38.58 lines per square kilometre.

Average line costs for the low line density areas of the countries and US States are estimated to be considerably higher than in the remaining higher density areas and the proportion of lines in low density areas is estimated as having a large influence on overall average line costs. The correlation between overall costs and share of lines in 0 to 1.93 range in both table C.13 and C.14 is 0.96.

Table C.16 **Relative line costs using the HAI Telstra 1 cost schedule**

Low density — 0 to 38.58 lines per square kilometres

Country or State	*Per cent of lines in Low density areas*	*Index of average line cost*		
		Low density areas[a]	*Remaining areas*[b]	*Overall*
Alaska	33.98	486	57	203
Finland	39.29	222	59	123
Australia	17.36	324	53	100
Oregon	21.01	251	55	96
New Zealand	14.64	328	53	93
Washington	12.89	244	55	80
California	4.74	234	44	53

Note The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The HAI based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. Average cost relativities in the low-density area vary because these costs are weighted averages of three cost categories.

a Low-density areas are those with line densities between 0 and 38.58 lines per square kilometre (0 and 100 lines per square miles). **b** Remaining areas are those with more than 38.58 lines per square kilometre.

Table C.17 **Line and cost shares using the BCPM Telstra 1 cost schedule**

Country or State	*Per cent of total lines in density range*		*Per cent of total line costs*	
	0 to 1.93 lines per square kilometre	*0 to 38.58 lines per square kilometre*	*0 to 1.93 lines per square kilometre*	*0 to 38.58 lines per square kilometre*
Alaska	14.79	33.98	54.02	71.83
Finland	4.29	39.29	14.77	61.84
Australia	5.17	17.36	23.73	42.71
Oregon	3.52	21.01	15.16	42.88
New Zealand	5.43	14.64	22.74	37.67
Washington	2.12	12.89	9.67	28.89
California	0.66	4.74	3.82	12.98

Note The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The BCPM based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. Average cost relativities in the low-density area vary because these costs are weighted averages of two cost categories (the weights vary with different line density distributions).

The proportion of total line costs associated with low-density areas apparent in tables C.17 and C.18, confirm that low-density areas have a significant impact on total line costs.

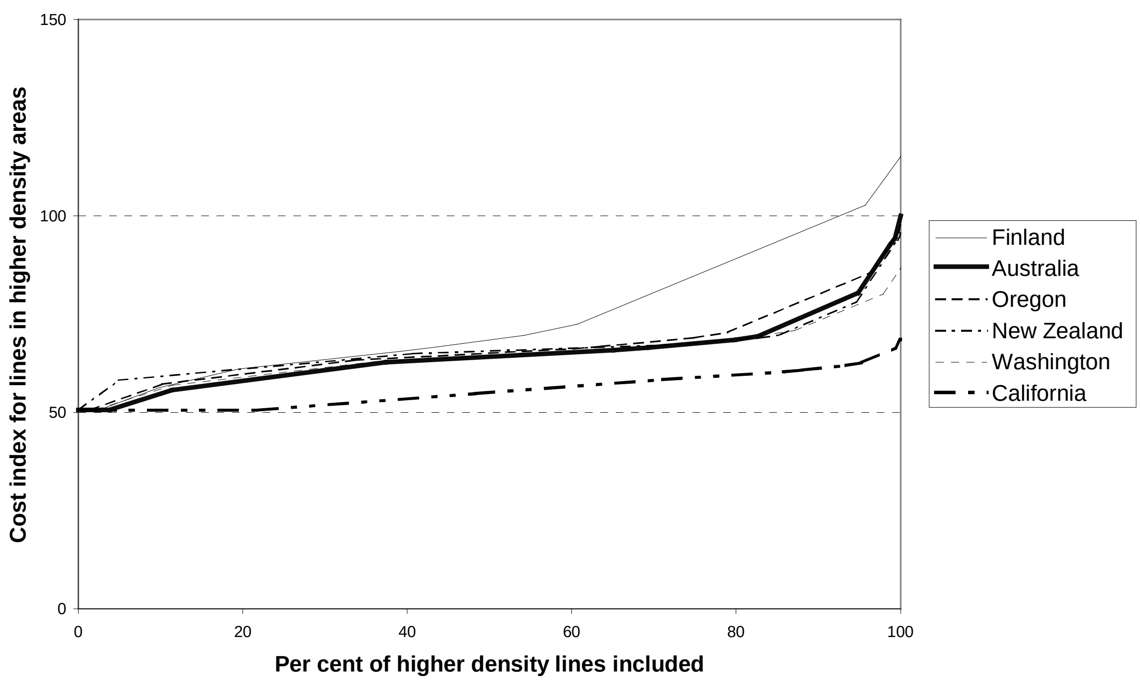
Table C.18 **Line and cost shares using the HAI Telstra 1 cost schedule**

Country or State	*Per cent of total lines in density range*		*Per cent of total line costs*	
	0 to 1.93 lines per square kilometre	*0 to 38.58 lines per square kilometre*	*0 to 1.93 lines per square kilometre*	*0 to 38.58 lines per square kilometre*
Alaska	14.79	33.98	64.41	81.35
Finland	4.29	39.29	20.02	70.91
Australia	5.17	17.36	34.43	56.25
Oregon	3.52	21.01	22.44	54.93
New Zealand	5.43	14.64	33.98	51.63
Washington	2.12	12.89	15.26	39.31
California	0.66	4.74	7.20	20.93

Note The same cost relationship (cost per line as a function of lines per square kilometre) was used for each country in order to isolate the impact of different population distributions. The BCPM based cost schedule was adjusted using Telstra cost data to improve cost estimates over the range 0 to 1.93 lines per square kilometre. Average cost relativities in the low-density area vary because these costs are weighted averages of two cost categories (the weights vary with different line density distributions).

Figure C.1 **Average line costs in higher density areas BCPM Telstra 1 cost schedule**

Australian country-wide average line cost normalised to 100

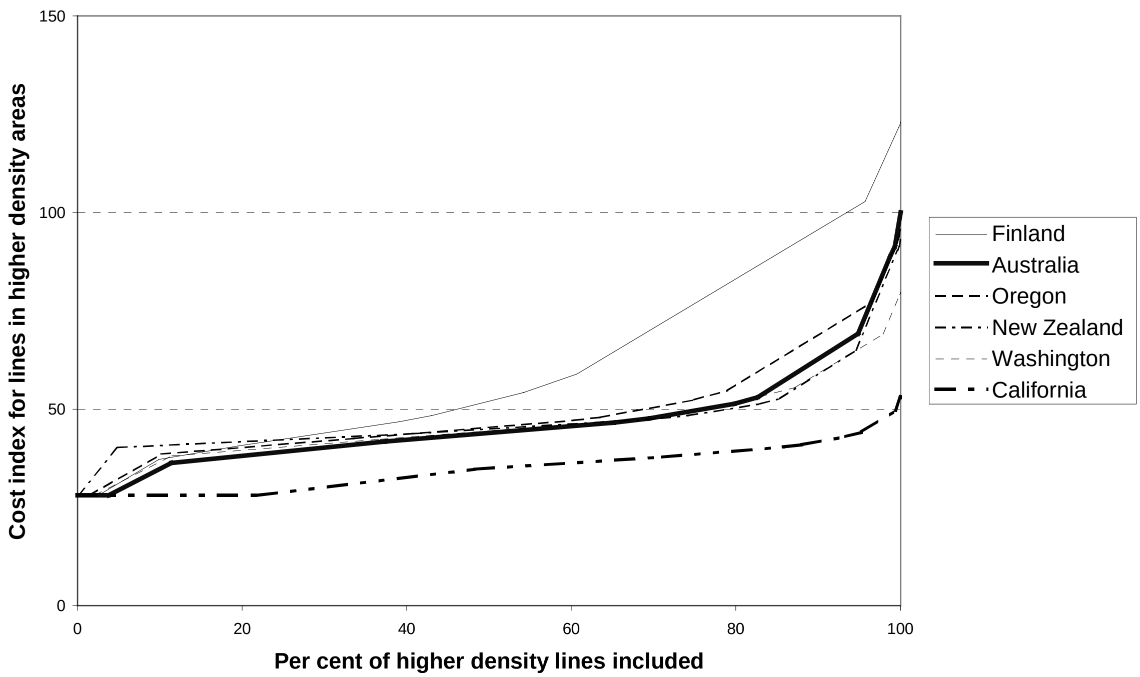


Note From left to right the average costs represented are the average line costs of the per cent of lines in the higher density areas (in the country or US State) compared to Australia's country-wide average which has been normalised to 100.

For Australia, Oregon, New Zealand and Washington, average line costs increase dramatically as more low-density areas are included (see figures C.1 and C.2).

Figure C.2 **Average line costs in higher density areas HAI Telstra 1 cost schedule**

Australian country-wide average line cost normalised to 100



Note From left to right the average costs represented are the average line costs of the per cent of lines in the higher density areas (in the country or US State) compared to Australia's country-wide average which has been normalised to 100.

References

Alger, D. and Leung, J. 1999, *The relative costs of local telephony across five countries*, New Zealand Institute for the Study of Competition and Regulation (NZISCR), Wellington, New Zealand.

BIE (Bureau of Industry Economics) 1995, *International Performance Indicators: Telecommunications 1995*, Research Report 65, BIE, Canberra.

Ergas, H., Ralph, E. and Sivakumar, S. 1990, *Reforming Australian Telecommunications: A review of issues and options*, Monash Information and Communications Technology Centre Working Paper, Monash University, Clayton.

FCC (Federal Communications Commission) 1999, *Trends in Telephone Service*, Industry Analysis Division, Common Carrier Bureau, FCC, September, US.

Gabel, D. and Kennet, M. D. 1994, 'Economies of scope in the local telephone exchange market', *Journal of Regulatory Economics*, vol. 6, p. 381.

Guldmann, J. M. 1991, 'Economies of scale and density in local telephone networks', *Regional Science and Urban Economics*, 20(4), February, pp. 521-35.

ITU (International Telecommunications Union) 1998, *World Telecommunications Development Report, Universal Access*, ITU, March.

NECG 1999, *The USO and the impact of geography on costs,* Paper commissioned by Telstra Corporation Ltd, mimeo.

Ovum 1998, *An assessment of Telstra's access undertakings*, Report for the ACCC, mimeo, June.

PC (Productivity Commission) 1999a, *International Benchmarking of Australian Telecommunications Services*, Research Report, AusInfo, Melbourne, March.

PC 1999b, *International Benchmarking of Telecommunications Prices and Price Changes*, Research Report, AusInfo, Canberra.

Silverman, B. W. 1986, *Density Estimation for Statistics and Data Analysis,* Chapman & Hall, London.

Tapia, R.A. and J.R. Thompson. 1978, *Nonparametric Probability Density Estimation*, Johns Hopkins University Press, Baltimore.

US Census Bureau 1999, *ST-99-3 State Population Estimates: Annual Time Series, July 1, 1990 to July 1, 1999*, Population Estimates Program, Population Division, US Census Bureau.