Frontier Shift for Dutch Gas and Electricity TSOs

Report prepared for

Netherlands Authority for Consumers and Markets

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CONTENTS

EXECUTIVE SUMMARY

The purpose of this report is to estimate the rates of technical change (or frontier shift) and of real input price movements relevant to electricity and gas TSOs in the Netherlands. These two together make up the dynamic efficiency parameter in the Authority for Consumers and Markets' (ACM) regulation of electricity and gas TSO's. The main methodology used in this report is based on a study by Oxera (2016) which had a similar purpose. This involves using index analysis to estimate the long-term average rate of dynamic efficiency in a group of industries that are relevant comparators to the electricity and gas transmission sectors. Other analytical methods are used in this study to shed light on specific questions that need to be addressed in order to be confident that the results are reliable and correctly interpreted. The overall results for the long-term average rate of dynamic efficiency are relevant for forecasts that can be applied in regulatory plans.

Benchmarking involves measuring the performance of businesses over time and against their peers, and particularly against best practice or the best performers. Regulatory agencies in many countries have given increasing attention to the role of productivity benchmarking in the economic regulation of natural monopolies. There are two main aspects to benchmarking regulated firms:

(1) Quantifying the comparative levels of technical or cost efficiency of regulated businesses operating in the same industry sector. This provides information to regulators about adjustments needed to a regulated firm's price or revenue cap to reflect the scope for efficiency improvement relative to the best performing firms in that sector.

(2) Estimating rates of change in productivity and technical change over time in order to predict future productivity gains achievable by a firm that is on the efficiency frontier. Such improvements are often taken into account when setting price or revenue paths over a regulatory period.

This report is focussed on benchmarking analysis of the second kind.

Benchmarking in Regulatory Practice

Applications of benchmarking and productivity trend analysis in the regulatory frameworks of various countries are summarised in chapter 3, with a more detailed review in Appendix A. This survey includes regulatory decisions, consultant reports and academic studies. General observations drawn from this survey indicate:

- Most, but not all regulators have sought to quantify total factor productivity (TFP) trends or frontier shift for use in regulatory plans. Examples of regulators that do not do so include Norway, which uses a yardstick regulation framework which is updated annually, and Belgium, which has waived productivity adjustments in several regulatory decisions.
- Decomposition of TFP change into frontier shift, catch-up efficiency and other effects has only occurred in a minority of the studies surveyed. Examples of jurisdictions that have done so include Peru, Brazil, the UK and the USA.
- Studies of productivity trends display a wide range of estimates. This means that regulators have often needed to make decisions about prospective trends in productivity or technical

change without the benefit of quantitative productivity trend estimates that yield narrow confidence intervals. One recent example is in Austria, where E-Control engaged in a thorough examination of frontier shift estimates produced by several consultants for different parties, with estimates ranging from 0.3 to 2.6 per cent. It needed to use its own judgement to determine a single rate within this wide range.

- More recent decisions tend to forecast rates of technical change lower than those adopted in many of the earlier decisions. Examples are drawn from Australia, New Zealand, Austria, Brazil and Germany. This finding is consistent with the observation of longer-term studies (e.g. in the UK) which have found that the rate of technical changes appears to have declined over time. This might be due to the diminishing efficiency gains following structural reforms, or it may reflect wider economic factors.

Available Data

Several databases that could in principle be used for productivity analysis are surveyed and their availability is investigated (chapter 4). It is concluded that the EU KLEMS database is the most suitable source of data for this study. The data drawn from this database, including the countries and industries and original variables, are fully documented. Also documented are the formulas for calculating the variables used in analysis, including currency adjustments.

EU KLEMS data is used for three analyses which are presented in chapters 5 to 7 of the report. In each case the analysis is of the eight comparator industry sectors that have previously been adopted as the most comparable to activities carried out by the energy TSOs. These analyses are:

- Index-based methods for calculating TFP and real input price indexes (IPI) indexes – and their rates of change – for comparator industries using data for the Netherlands only;
- For a set of European countries, data envelopment analysis (DEA) is used to calculate Malmquist TFP indexes and decompose TFP growth into the effects of technical change and catch-up effects for each comparator industry; and
- For the same set of European countries and comparator industries, econometric analysis is employed to estimate the parameters of a production function which allows for both disembodied technical change, and technical change embodied in capital equipment.

Productivity Indexes

Chapter 5 of this report applies an index-based method of TFP calculation to eight comparator industries in the Netherlands, using data from the EU-KLEMS database. Indexes and growth rates are calculated for total factor productivity (TFP), opex and capital partial factor productivity (PFP), real input price indexes (IPI), and real output price indexes (OPI). Weighted averages of these growth rates and indexes are calculated using weights previously developed for ACM by Ecorys (2019). The rate of change of dynamic efficiency is calculated from the TFP and Real IPI movements.

This analysis finds that over the period 1995 to 2017, the average annual growth rates of the weighted average indexes were:

- Inputs: 1.9 per cent
- Outputs: 2.4 per cent
- TFP: 0.5 per cent
- Real OPI: -0.54 per cent
- Real IPI: -0.04 per cent
- Dynamic efficiency: 0.54 per cent.

These results indicate that over the full sample period, the movement of real input prices have not had a significant effect on dynamic efficiency, which is predominantly associated with TFP growth. Rates of change of the same indexes are carried out over several other periods. An important feature of the TFP series is that in the period up to 2008, TFP growth averaged 1.0 per cent. In the period from 2011 to 2017, TFP growth averaged only 0.1 per cent. Although in the period since the Global Financial Crisis (GFC) the rate of change in TFP has been quite low, there has been a large decline in real input prices at the same time, so that dynamic efficiency is estimated to have increased more strongly.

The index analysis in chapter 5 shows that over the period from 1995 to 2017, the average rates of growth of opex and capital PFP (i.e. the weighted average for the comparator industries) were both similar to the average rate of TFP growth.

Malmquist Productivity Decomposition

Malmquist TFP indexes are calculated for each industry using a sample of 11 European countries (chapter 6). This analysis produces an alternative set of TFP trend estimates that can be compared to the TFP index results, and most importantly, can be used to decompose TFP growth into the constituent effects of:

- technical change (also called ‘frontier shift’, referring to the expansion of the frontier of the set of production possibilities achievable with a given set of inputs – i.e. shifts of the ‘efficiency frontier’)
- changes in technical efficiency (for a firm not on the efficiency frontier, a change in the mix of outputs and inputs which moves it closer to the efficiency frontier – i.e. ‘catch-up’ – or further from the frontier), and
- changes in scale efficiency (if there are economies of scale, then an increase in demand for the firm’s outputs may increase its productivity, or if there are decreasing returns to scale, a change in demand may have the opposite effect).

This analysis uses a well-established method of decomposition due to Färe et al (1994). The key findings from this analysis:

- Over the period 1995 to 2017, the Malmquist TFP index grew at an average annual rate of 0.61 per cent. This estimate is similar to the results of the TFP index analysis using data from the Netherlands, which indicated that over the same period the average TFP growth was 0.50 per cent per year. The consistency of these results tends to support the reliability of inferences drawn from the Malmquist index analysis.

- Over the same period the average rate of technical change is estimated to be 0.82 per cent per year. The effect of changes in scale efficiency are small, contributing 0.11 per cent per year to the average rate of TFP growth. The rate of efficiency change (or catch-up) is found to be -0.31 per cent. These results suggest that TFP change is driven by technical change (frontier shift) and that negative trends in average efficiency relative to the frontier indicate that businesses that are not on the efficiency frontier have, on average, been falling further behind the firms that are on the efficiency frontier in terms of their technical efficiency.
- In the period up to 2007, the Malmquist TFP index grew at an average rate of 1.0 per cent per year (before the effects of the GFC were felt in 2008 and 2009), whereas from 2010 to 2017, the Malmquist TFP index grew at a much slower average rate of 0.3 per cent per year. In the period up to 2007, technical change averaged 1.15 per cent per year, whereas from 2010 to 2017, it averaged 0.45 per cent per year. Hence, technical change had a declining trend over the sample period.
- These findings indicate that the rate of overall TFP change does not overstate the rate of frontier shift. On the contrary, the estimated rate of frontier shift, together with the effects of scale change, have been higher than the rate of TFP growth. This indicates that the rate of TFP growth can reasonably be used as a conservative estimate of the rate of frontier shift in the comparator industries of the Netherlands.

Econometric Analysis of Technical Change

In chapter 7 an econometric analysis is employed which is designed to separately estimate rates of productivity change, one of which is associated with disembodied technical change, and the other is technical change which is embodied in capital equipment. Disembodied technical change influences the use of opex and capital inputs to produce given outputs, whereas capital-embodied technical changes affects capex only.

In this analysis, the data for all eight industries and the same 11 European countries is pooled, and the weights applicable to different industries are incorporated into the regression analysis, so that the results are analogous to those for the weighted average of the eight comparator industries. Unlike the other analyses in this report, the measure of output is real gross value added, rather than real gross output. This means that to put the results on a comparable basis to the other results, the estimated rates of technical change need to be adjusted by the ratio of nominal value added to nominal gross output. The weighted average of this ratio over the comparator industries is 0.42.

The parameter estimates for disembodied and capital-embodied technical change produced by the econometric analysis, after adjustment into a gross output equivalent basis, are:

(a) disembodied technical change: 0.59 per cent per year; and

(b) capital-embodied technical change: -0.14 per cent per year.

The rate of disembodied technical change is quite similar to the TFP growth rate obtained using index methods applied to Netherlands industries in chapter 5, and also to the TFP growth rate calculated using the Malmquist index for the same 11 European countries in chapter 6. The estimated rate of capital-embodied technical change has a problematic negative sign but is in any event quite close to zero.

This analysis suggests that capital-embodied technical change can reasonably be regarded as inconsequential and the great majority of overall technical change can be best characterised as disembodied technical change. This in turn implies that technical change applies to the use of opex inputs and to capital inputs in a similar way.

Evaluation

The calculation of TFP trends using TFP indexes, presented in chapter 5, is the preferred method in this study because it has been previously endorsed by the Netherlands appeal body. The other analytical methods, the Malmquist index and the econometric analysis, provide supporting evidence for the trends in TFP and also help to interpret, and if necessary adjust, the overall TFP trends to ensure they reflect frontier shift. The evaluation in chapter 8 reaches overall conclusions on the estimated historical rates of dynamic efficiency that are likely to best serve as forecasts for the forthcoming regulatory period.

To use the TFP indexes to derive average rates of productivity growth, the periods over which the averages are calculated need to be determined. Several criteria apply to selecting the period of averaging:

- The period should cover complete business cycles. Oxera preferred to use two complete business cycles.
- Since older data are likely to be less informative than newer data, the period should, if possible, include the most recent data available. It may also be desirable to give greater weight to more recent periods.
- Earlier data should be discarded if there is evidence of structural breaks. At least eight years of robust data should be used. Thus, it may be feasible to use only a single whole cycle.
- The period should preferably be a long period, such as two decades, which is another way of smoothing out cyclical effects.

The full sample period of 22 years from 1995 to 2017 is one candidate for the period of averaging given the last criterion. Growth cycle periods were defined based on the weighted average index for gross output for the comparator industries as follows:

- cycle mid-points (downswing) in 2001, 2008 and 2017;
- cycle peaks in 1998, 2007 and 2015; and
- cycle mid-points (upswing) in 1995, 2006 and 2014.

The first of these is consistent with the Oxera study, which used cycle mid-points of 1991, 2001 and 2008, and it best fits the criteria we used for selecting the period of averaging and is therefore the preferred basis for calculating the average rates to serve as recommended forecasts.

We have also considered the post-GFC period, which is from 2009 to 2017 and which is slightly shorter than the second cycle period defined by mid-points (downswing). Table E.1 shows average TFP growth rates and Real IPI declines in each cycle period, which combine to give the dynamic efficiency measure.

The three alternative ways of defining the cycle-based periods yield slightly different rates for average rates of TFP growth, but quite similar results for the average dynamic efficiency rate. The mid-cycle (downswing) definitions of cycle periods is consistent with the approach taken by Oxera, and has the advantage of including some more recent data, and less older data, compared to the other cycle-based periods. However, all three ways of defining the cycle are relevant and tend to corroborate each other. They suggest that the rate of dynamic efficiency is close to 0.50 per cent per year.

In the post-GFC period, the average TFP growth rate is much lower at 0.05 per cent per year. However, Real IPI decreases in this period by 1.20 per cent per year, resulting in a net rate of increase in dynamic efficiency of 1.25 per cent per year. Although this period does just meet the criterion that at least eight periods of change are included in the average, it includes slightly less than one full cycle, and therefore does not meet the criterion of using at least one and preferably two full cycle periods. Furthermore, this period results in a high estimated rate of dynamic efficiency relative to all of the other periods considered.

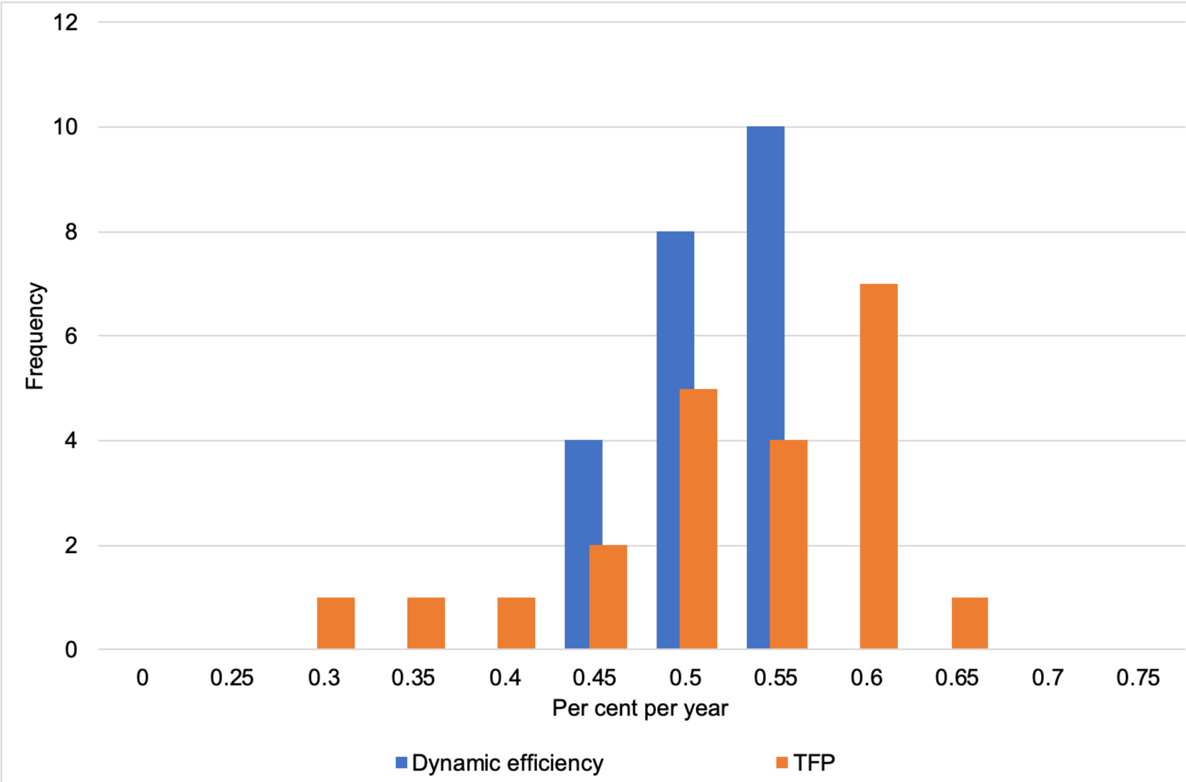
Table E.1: Average Growth of TFP and Dynamic Efficiency Using Alternative Periods

Period	*Definition*	*TFP growth (%)*	*Real IPI decline (%)*	*Dynamic efficiency rate (%)*
1995 - 2017	Full sample period	0.50	0.04	0.54
2001 - 2017	Two cycles based on mid-cycle (downswing) years	0.30	0.20	0.50
1998 - 2015	Two cycles based on peak-cycle years	0.50	-0.03	0.47
1995 - 2014	Two cycles based on mid-cycle (upswing) years	0.56	-0.10	0.47
2009-2017	Post-GFC period	0.05	1.20	1.25

A sensitivity analysis of the calculated TFP growth rates obtained by varying the sample period is shown in Figure E.1. This is based on calculating the average TFP growth rates, Real IPI rates of decline and rates of increase in dynamic efficiency for 22 alternative periods. The different periods used include every continuous period with 17 or more years and that commence no later than 2001 and end no earlier than 2014.

Figure E.1 shows that the average rate of TFP growth is centred on 0.5 per cent per year, and for the bulk of scenarios it is between 0.4 per cent and 0.6 per cent. The average rate of dynamic efficiency is also centred on 0.5 per cent per year, however, the frequency distribution is much narrower than for TFP. This suggests that TFP and Real IPI growth rates move in the same directions over business cycles and when calculating the difference between them, they tend to offset each other.

Figure E.1: TFP & Dynamic Efficiency Growth Rate Sensitivity Analysis



The results of the sensitivity analysis are consistent with the results obtained using the preferred period for averaging of 2001 to 2017. These observations lead us to conclude that an average rate of dynamic efficiency, which includes both the rate of frontier shift and the effect of changes in real input prices, is 0.50 per cent per year based on this preferred averaging period and is consistent with the results obtained using alternative business-cycle definitions and the sensitivity analysis for different periods.

The Malmquist TFP analysis finds that the average annual rate of efficiency change over the period 1995 to 2017 (weighted average for the comparator industries) is -0.31 per cent, and if the period 2001-2017 is used, based on mid-cycle (downswing) periods, then the rate of efficiency change is -0.27 per cent. This suggests that firms that are not on the efficiency frontier have tended to fall behind the most efficient firms, and consequently the rate of TFP change *understates* the rate of frontier shift. The amount to which it is understated is 0.31 percentage points, based on the full sample, or 0.27 percentage points, based on the 2001-2017 sample.

This confirms that the rate of TFP change used in the calculation of dynamic efficiency does not overstate the rate of frontier shift, as it would if the rate of efficiency gain (or catch-up) had been positive and a substantial contributor to TFP growth. As it is, with efficiency gain estimated to be negative, the TFP trend represents a conservative estimate of frontier shift.

It should be noted that the estimated decomposition of TFP trends is based on a sample of European countries, and is not confined to data for the Netherlands. This does raise the question as to how representative these results are for the Netherlands. The consistency of the Malmquist index results with the TFP trends estimated only with data from the Netherlands tends to support a view that the results are likely to provide a good indicative guide for the comparator industries in the Netherlands. Nevertheless, we do not recommend making any specific upward adjustment to the estimated rate of dynamic efficiency to take account of the estimated faster rate of frontier shift. We do consider that the results are certainly sufficiently robust to draw the conclusion that the TFP rate of growth for the Netherlands is a conservative estimate of the rate of frontier shift.

Accordingly, the preferred estimate of dynamic efficiency growth of 0.50 discussed in the previous section, and based on the Fisher index methods of calculating TFP and Real IPI movements applied to Netherlands data for the comparator industries, represents a sound basis for forecasting dynamic efficiency.

We have examined the effect of applying separate weights for TenneT and GTS, when averaging the TFP and real IPI across the eight comparator industries, to obtain estimates for the rates of dynamic efficiency for TenneT and GTS over the period 2001 to 2017. While there are slightly different estimates of dynamic efficiency using separate sets of weights for TenneT and GTS, there is a real question about how material these differences are. It would be entirely reasonable to use the average weights for both TenneT and GTS. In that case, the applicable annual rate of dynamic efficiency growth would be 0.5 per cent. If, on the other hand, it is preferred that the weights specific to each of the two businesses should be used, as has been done in past decisions, then the rates of dynamic efficiency growth would be 0.5 for TenneT and 0.4 for GTS.

We have also been asked to advise on the rate of dynamic efficiency that would be appropriate to apply separately to the opex and capex components of totex. Two parts of the analysis in this report are directly relevant to this question. Firstly, the econometric analysis of the nature of technical change in the comparator industries in chapter 7 finds that technical change can be characterised as disembodied. That is, it applies to inputs in an equal and similar way. Second, the PFP indexes and partial input price indexes calculated for opex and capital inputs in chapter 5 indicate that the partial dynamic efficiency associated with the use of opex inputs is similar to the totex dynamic efficiency. We have also concluded that the partial dynamic efficiency of capital inputs, although estimated to be higher than that for totex over the preferred sample period, should be discounted for the greater degree of uncertainty of this measure.

Based on these findings we would recommend using the same rate of dynamic efficiency for opex and for capex as for totex.

1 INTRODUCTION

The Dutch energy regulator, the Authority for Consumers and Markets (ACM), has engaged Economic Insights Pty Ltd ('Economic Insights') to provide advice on the projected rate of frontier shift for energy transmission businesses over the next regulatory period. The regulated Dutch energy transmission businesses are Gasunie Transport Services (GTS) and TenneT, and the next regulatory period commences in 2022 for a period of five years (CEER, 2019).

1.1 Purpose and Scope

The purpose of this report is to analyse trends in productivity and technical change in a number of industries that are relevant comparators to electricity and gas transmission system operators (TSOs) in the Netherlands. Several complementary methods of analysis are employed:

(a) An index-based approach, similar to that used by Oxera (2016b), which the ACM relied on when determining price controls for the current regulatory period. This approach involves constructing total factor productivity (TFP) indexes for eight industry sectors in the Netherlands which were considered to be most comparable to activities carried out by the energy TSOs. Movements in real input price indexes (IPI) and real output price indexes (OPI) are also to be examined for comparison with TFP trends. The index analysis includes the calculation of partial factor productivity indexes for opex inputs and capital inputs.

(b) Data envelopment analysis (DEA) is used to compute Malmquist TFP indexes, and to use well-established methods to decompose the growth of TFP into the separate effects of: technical change (i.e. frontier shift); changes in efficiency (i.e. catch-up efficiency); and changes in scale efficiency, for each of the eight comparator industries. This analysis relies on a panel of European countries to establish an efficiency frontier in each year. This analysis assists to disentangle the effects of catch-up efficiency, which is often dealt with separately to frontier shift in regulatory plans.

(c) An econometric analysis is employed to decompose TFP trends into separate productivity trends that can be used to establish separate frontier shifts for opex and capex for the purposes of forecasting the main components of costs that make up the revenue requirement over the forthcoming regulatory period. This analysis will assist to inform the ACM in regard to how it applies the productivity trends in its regulatory decision.

1.2 Outline of the Report

This report is structured as follows:

- Chapter 2 provides an overview of economic benchmarking and its application in the economic regulation of firms.
- Chapter 3 summarises the key findings of a literature review covering the regulatory arrangements and use of productivity estimates in setting regulated prices. It also discusses relevant academic studies of productivity trends and various efficiency estimates including technical efficiency (frontier) shift and 'catch-up' efficiency.

- Chapter 4 reviews the candidate databases that were considered for each of the analyses described in items (a) through (c) of section 1.1 above. These are grouped into two categories: those suitable for industry-level productivity analysis using a panel of European countries that can be informative in relation to frontier shifts in the Netherlands; and those suitable for enterprise level productivity analysis within industries of interest. A preferred database is chosen for industry-level analysis and the specific data drawn from it, and the calculations or adjustments made to that data, are also documented.
- Chapter 5 details the methodology to be employed in index-based analysis of TFP, OPI and IPI, and presents a preliminary analysis of TFP, OPI and IPI indexes for the comparative industry sectors in the Netherlands as described in item (a) above.
- Chapter 6 details the methodology for using DEA to calculate Malmquist TFP indexes, and to decompose them into separate frontier shift and catch-up efficiency effects as discussed in item (b) above. It also presents the calculated Malmquist TFP indexes and their decomposition.
- Chapter 7 describes a methodology for econometric estimation of a constant elasticity of substitution (CES) production function which is designed to facilitate the identification of separate sources of technical change that may apply differently to opex and capex (as discussed in item (c) of section 1.1). Disembodied technical change affects the use of both opex and capital inputs. An additional effect that applies to capex is capital-embodied technical change. This chapter also presents an econometric analysis of this model.
- Chapter 8 discusses and evaluates the results of the analyses presented in chapters 5 to 7 based on the appropriate measurement period. It forms recommendations on the main questions to be addressed regarding the average rate of frontier shift and dynamic efficiency relevant to the forthcoming regulatory period.
- Appendix A presents a literature review for 12 countries. The review discusses the methods of regulation used and regulatory decisions on adjustments to price or revenue plans to account for productivity change or technical change in energy transmission or distribution networks. It also discusses the methods used to arrive at the estimates of productivity or technical change, and reviews academic studies relating to productivity in electricity and gas transmission and distribution networks relevant to the countries covered in the review.
- Appendix B is a note on capital partial factor productivity and embodied capital change.

1.3 Economic Insights' experience and consultants' qualifications

Economic Insights has been operating in Australia for 25 years as an infrastructure consulting firm. Economic Insights provides strategic policy advice and rigorous quantitative research to industry and government. Economic Insights' experience and expertise covers a wide range of economic and industry analysis topics including:

- infrastructure regulation;
- productivity measurement;

- benchmarking of firm and industry performance; and
- infrastructure pricing issues.

2 BENCHMARKING OVERVIEW

2.1 Benchmarking concepts

Benchmarking involves measuring the performance of businesses over time and against their peers, and particularly against best practice or the best performers. Its purpose is to assist businesses to improve their performance by better identifying what is achievable and the best practice businesses or processes that can be emulated. Unlike process benchmarking and the use of performance indicators — which are generally directed at measuring the efficiency or effectiveness of specific processes, programs or activities — 'economic benchmarking' treats the firm as a whole production process, with inputs and outputs, and seeks to measure a firm's performance over time and against other businesses using holistic economic measures such as productivity or cost efficiency (see: Coelli et al. 2003; Bogetoft 2012, Economic Insights 2013).

2.2 Productivity and efficiency measures

Productivity is a measure of the physical output produced from the use of a given quantity of inputs.[1] All enterprises use a range of inputs including labour, capital, land, fuel, materials and services, and they may produce a number of different outputs. Productivity is measured by the ratio of a measure of total output to a measure of inputs used to produce those outputs. Two of the main productivity measures are: total factor productivity (TFP) – which measures (an index of) total output relative to an index of all inputs used; and partial factor productivity (PFP) – which measures total output relative to the quantity of a single input. These concepts are shown in equations (2.1) and (2.2):

Given an index of all outputs (*Q*) and an index of all inputs (*X*):

$$TFP = Q/X \qquad (2.1)$$

Given the quantity of one input, X_i, the PFP of factor *i* is defined as:

$$PFP_i = Q/X_i \qquad (2.2)$$

The rate of change of TFP is the difference between the rates of change of the output index (*Q*) and the input index (*X*). The rate of change of the PFP of factor *i* is the difference between the rate of change in the output index and the rate of change in input *i*.

If there is scope to improve productivity, this may be because there is an improvement in technology that the firm can take advantage of, or it may be because there is technical inefficiency in the firm's production process which can be removed. In the latter situation, the business could, by moving more closely to best practice operation, produce more outputs with the same inputs or use fewer inputs to produce the same amount of outputs. If the enterprise is not using its inputs as efficiently as possible then there is scope to lower costs through

[1] Changes in the quality of inputs or outputs can also be important. And outputs are not necessarily only those sold in markets, but may for example, include measured impacts of the production process on the environment.

productivity improvements and, hence, lower the prices charged to consumers. This might come about by using better quality inputs including a better trained workforce, adopting technological advances, removing restrictive work practices and other forms of waste, or implementing a more efficient organisational or institutional structure.

Some of the most commonly used methods of measuring TFP growth assume that firms are all fully efficient. For example, the growth accounting approach, which is also based on other assumptions, especially:

- 'neoclassical economics' assumptions: markets for outputs are competitive and factor inputs are all compensated at the value of their marginal productivity; and
- technical change assumptions: technical change is neutral and not embodied in any inputs. Shifts in the production function are defined as neutral if they leave marginal rates of substitution between the inputs unchanged, and simply increase or decrease the output attainable from a given set of inputs (Solow, 1957, p. 312).

Under these assumptions, given an unknown production function: $Q^* = f(\mathbf{x}, t)$, where $\mathbf{x}$ is a vector of inputs and Q^* is the maximum output that can be produced with those inputs, and t is time, the rate of technical change ($\dot{f}$) can be expressed as:

$$\dot{f} = \dot{Q} - \sum_k s_k \dot{x}_k = \dot{Q} - \dot{X} = T\dot{F}P \quad (2.3)$$

where s_k is the cost share of factor k, and X is an aggregate measure of inputs with cost shares used as weights. This is the *growth accounting* approach to measuring total factor productivity, since under the assumptions made, the rate of change in TFP is equal to the rate of technical progress. The rate of technical change in (2.3) is also called the 'Solow residual' (after Robert Solow) because it is the remainder after taking account of the influence of changes in each of the inputs. When working with data in discrete periods, the cost shares (s_k) can change between periods, and is common practice to use improved index methods to calculate the rate of change of the input index, $\dot{X}$. Extending this to a multi-output setting involves constructing an output index, analogous to the input index, with value-share weights. This study uses the Fisher index method to construct input and output indexes as explained in chapter 5.

Chapter 5 also presents measures of partial factor productivity, which are defined above. PFP measures are widely used, partly because it is not always feasible to measure TFP, if data for one factor such as the capital stock is not readily available. Nevertheless, even where TFP indexes can be measured, PFP indexes can assist to interpret TFP trends. The rate of change in the PFP for factor k is equal to: $P\dot{F}P_k = \dot{Q} - \dot{x}_k$. Equation (2.3) can be rearranged to obtain:

$$T\dot{F}P = \sum_k s_k \left(\dot{Q} - \dot{x}_k\right) = \sum_k s_k \, P\dot{F}P_k \quad (2.4)$$

The overall rate of change in TFP is equal to a weighted average of the rates of change in all of the partial factor productivities for each input, the weights being the input cost shares.

Empirical studies of productivity use either gross output-based (GO) measures or value added-based (VA) measures. The first approach views a production unit as using capital, labour, energy, materials and services to produce goods and/ or services. The total market value of these outputs is gross output, expressed in either current or real monetary terms. The second approach treats intermediate inputs as negative outputs which are effectively netted off the value of gross output (again in either current or real monetary terms). The production unit is conceived as transforming capital and labour into (real) value added. Under standard economic assumptions of profit maximisation, competition, and constant returns to scale, the GO-based productivity index measures technological change (Balk, 2009). For this reason, this study primarily uses the GO approach to productivity measurement. An exception in the analysis in chapter 7 which uses the VA-based approach. However, the VA-based results can be translated into a GO equivalent. GO and VA-based productivity indexes are related via the ratio of VA to GO, both in current prices. Denoting the rates of change in the GO-based and VA-based productivity indexes as $T\dot{F}P$ and $T\dot{F}P_{VA}$ respectively, and the ratio of current price VA to GO as S_{VA}, then the relationship between the two measures is: $T\dot{F}P_{VA} = T\dot{F}P/S_{VA}$ (Schreyer, 2001).

One of the assumptions used in the growth accounting approach is that technical change affects the productivity of all inputs in the same way. That is, it is ‘disembodied’ which means that it affects the use of inputs such as opex and capital inputs in the same way, and with regard to capital inputs “its effects are assumed not to depend on the vintage structure of the inputs. In particular, variations over time in the composition and characteristics of the surviving vintages of capital plant and equipment do not affect the measure of capital input, as would be the case if technical change were embodied” (Berndt, 1990, p. 485). In chapter 7 of this report, the assumption that technical change must be disembodied is relaxed to examine whether technical change may have different effects on the productivity of opex and capex.

The assumption that firms are all fully efficient, which is also used in the growth accounting approach, is relaxed in chapter 6 which examines the effect of changes in the degree of efficiency of firms on the overall measured changes in TFP. The *technical efficiency* of a firm refers to a comparison between its current combinations of inputs and outputs, against a combination of inputs and outputs that would be used and produced by a best practice or fully efficient firm. The measure may be based on the level of outputs achieved by the firm with its given set of inputs, compared to the level of output achieved by a best practice firm with the same set of inputs (‘output-oriented technical efficiency’). Or it may be based on the quantity of inputs used by the firm to produce a given set of outputs, compared to the level of input used by a best practice firm to produce the same set of outputs (‘input-oriented technical efficiency’).[2] Another concept of efficiency refers to the cost incurred by a firm to produce a given level of output compared to the cost that would be incurred by a fully optimal production process to produce the same outputs. This concept of efficiency (‘cost efficiency’) includes the optimality of the mix of inputs given the relative input prices (i.e. ‘input allocative efficiency’) and the input-oriented technical efficiency. The concept of cost efficiency is not used here. The

[2] Efficiency measures are usually, by convention, expressed as the ratio of the optimum to the actual (Fried, Lovell and Schmidt, 2008, p. 22). Thus, for a production function: $Q^* = f(\mathbf{x})$, where **x** is a set of inputs, the measure of output-oriented technical efficiency is given by: $TE_O = f(\mathbf{x})/Q \geq 1$. For an input requirements function: $X^* = g(\mathbf{q})$, where **q** is a set of outputs, the measure of input-oriented technical efficiency is given by: $TE_I = g(\mathbf{q})/X \leq 1$.

analysis in chapter 6 examines the contribution of changes in the degree of technical efficiency to changes in TFP.

One measure of technical efficiency is given by the *distance function*, which measures a firm's technical efficiency given its inputs and outputs and the available technology. The distance function can also be expressed in an output-oriented form, $D_O(\mathbf{x},\mathbf{y})$, or input-oriented form, $D_I(\mathbf{x},\mathbf{y})$. Distance functions are regularly used in the parametric or nonparametric analysis of efficiency frontiers and to calculate the Malmquist TFP index (see chapter 6).[3]

More specifics about productivity index calculation and the use of distance functions to measure the Malmquist index are included in the relevant sections.

Productivity and efficiency measurement are focussed on differences; either differences over time for a given firm or sector, or differences between firms, or between corresponding sectors of different nations. In principle, differences in productivity can be attributed to:

- differences in production technology (also called 'frontier shift')
- differences in the scale of operation (when there are economies or diseconomies of scale)
- differences in operating efficiency (that is, the efficiency of a firm relative to the best practice efficiency frontier), and
- differences in the operating environment in which production occurs (i.e. external factors that affect the ability of a best practice firm to transform inputs into outputs).

It is usually desirable to attempt to disentangle these different elements. For example, some are under management control and others are not. In regulatory plans, the third element which relates to improvement or deterioration in efficiency relative to best practice, is of central importance to the aims of the regulatory framework, whilst the first two sources of productivity differences need to be identified in order to ensure that an appropriate share of cost savings are passed on to consumers in a timely way.

2.3 Applications in regulation

Regulatory agencies in many countries have given increasing attention to the role of productivity benchmarking in the economic regulation of natural monopolies. There are two main aspects to benchmarking regulated firms:

(1) Quantifying the comparative *degrees* of technical or cost efficiency of regulated businesses operating in the same industry sector (e.g. electricity transmission system operators). This provides information to regulators about adjustments needed to price or revenue caps appropriate to the scope that a firm has to improve its efficiency relative to the best performing firms that define an efficiency 'frontier'. These studies may draw a sample from a single country or across a number of countries as needed to establish an adequate data sample. Methods often used in this type of analysis include:

[3] The inverse of the output-oriented distance function is equal to the output-oriented technical efficiency; i.e. $TE_O = 1/D_O(\mathbf{x},\mathbf{y})$; and the inverse of the input-oriented distance function is equal to the input-oriented technical efficiency; i.e. $TE_I = 1/D_I(\mathbf{x},\mathbf{y})$.

Multilateral TFP indexes, data envelopment analysis (DEA), and stochastic frontier analysis (SFA). The general aim is to produce static measures of efficiency at a particular time.

(2) Estimating rates of change in productivity or technical efficiency from period-to-period, or a long-term trend. These are dynamic measures of efficiency improvement (or regress). Although productivity trends can in principle be calculated for individual firms, in regulatory plans the industry-wide productivity changes are the relevant consideration. The aim of analysing past productivity trends is to predict future productivity improvement, but with an emphasis only on what is likely to be achievable by a firm that is on the efficiency frontier (adjustments for inefficiency being dealt with under (1)). This will ideally require the historical productivity trend to be separated into the components representing technical change – i.e. shifts in the efficiency frontier – and productivity changes associated with changes in the degrees of inefficiency of the firms in the industry (i.e. movements relative to the frontier). Methods often used in these types of analysis include total factor productivity (TFP) indexes, partial factor productivity (PFP) indexes, and Malmquist indexes.

The Australian Energy Regulator (AER), when setting a generic productivity adjustment factor applicable to all utilities in a given sector considers that "both economies of scale and technological change are components of productivity change and they indicate the gas distribution businesses should achieve positive productivity growth, to the extent that output grows" (AER, 2017a, p. 26). The rationale for this approach is that, in a utility setting, businesses are often taken as having little influence over their outputs, and minimize costs subject to output levels and input prices (Coelli et al., 2003). This is only an approximation because utilities may influence their outputs particularly if the quality of outputs is taken account of in the measurement of outputs, or if output measures such as provision of capacity (which may influence the security of supply for customers, or the extent of areas served) are used. When outputs are exogenous, technical efficiency is usually measured from an input-oriented perspective; that is, where it is feasible to proportionately reduce inputs and still produce the same outputs, but not necessarily at the optimum scale. Because demand is largely exogenous, scale efficiency is not within the control of the business. When there are economies of scale and growth of demand, even a best-practice firm may achieve productivity gains associated with the increase in its scale of outputs.

Regulatory applications of benchmarking in various jurisdictions are discussed in chapter 3, focussing mainly on the purposes described in (2). In general, the choice of method(s) will depend on the objectives of the benchmarking analysis, and on data availability. More than one method may be desirable because this would enable the results of different quantitative methods and model specifications to be compared, which would assist to determine or improve the robustness and credibility of the results.

2.4 Frontier shift measures in price plans

Price-cap or revenue-cap regulation plans typically specify a minimum real rate of decline in the average price or revenue of the regulated firm; often called an 'X-factor'. This plays a crucial part in creating efficiency incentives for the regulated businesses while at the same time ensuring that some part of the efficiency gains pass on to consumers in a reasonably timely manner, as would be the case in a competitive market.

Bernstein and Sappington (1999) and Bernstein (2000) have emphasised that the 'X-factor' should reflect the *extent* to which the regulated industry:

i) has historically achieved, and is expected in the future to attain, higher productivity growth than competitive industries in the economy;

ii) has faced, and is expected to continue facing, lower input price inflation than competitive industries in the economy.

The reasons why the X factor should have these two components, expressed relative to the economy as a whole, are as follows. In principle, the rate of change in the regulated firm's output price index should be equal to the rate of change in the firm's input price index minus its rate of TFP growth.

$$\dot{P}_I = \dot{W}_I - T\dot{F}P_I \tag{2.3}$$

where a dot above a variable represents a rate of change, and subscript I refers to the regulated industry; P is the index of output prices and W is the index of input prices. When output prices increase at this rate, the economic profits of the regulated firm neither increase nor decrease (in expectation terms). However, price-caps are commonly formulated in terms of the general inflation rate less an X-factor, rather than indexing to a basket of input prices specific to the regulated businesses. Competitive industries also satisfy a formula like (2.3) because they also have no change in economic profits (which are generally close to zero). The competitiveness assumption means that the general economy-wide inflation rate can be expressed as: $\dot{P}_E = \dot{W}_E - T\dot{F}P_E$, where subscript E refers to the economy. And $\dot{P}_E$ is taken to be measured by the rate of change in *CPI*. So if the regulatory price cap formula is: $\dot{P}_I = C\dot{P}I - X$, it follows that:

$$X = C\dot{P}I - \dot{P}_I = T\dot{F}P_I - T\dot{F}P_E - \left(\dot{W}_I - \dot{W}_E\right) \tag{2.4}$$

Oxera (2016b) uses the same principle, although expressed in a slightly different form to Bernstein and Sappington, namely:

$$X = T\dot{F}P_I - \left(\dot{W}_I - C\dot{P}I\right) \tag{2.5}$$

It needs to be emphasised that the notion of TFP being used in equations (2.3) to (2.5) assumes that all firms are fully efficient; i.e. it refers only to technical change. Bernstein stresses that the X-factor should be set by the regulator for the whole regulatory period and not reviewed or revised within the period, which would undermine the incentive for productivity improvement. He indicates two further principles for determining the appropriate productivity adjustment in a regulatory price plan:

(1) "One of the key requirements for proper price cap regulation is to base the offset on an *industry-wide productivity index*, instead of the performance of a particular regulated firm. … If price cap regulation is to emulate competitive markets the regulated firms should be rewarded for superior productivity performance." (Bernstein, 2000, p. 25). Incentives would be diluted if outperformance by a firm gave rise to a more stringent productivity target for that firm.

(2) Proper implementation of price caps requires "the ability to distinguish the *long-term trend in TFP* from short-term fluctuations. Use of the secular productivity trend causes the average price of the regulated firm to adjust to a long-term productivity potential, thereby contributing to the stability of the regulatory plan" (Bernstein, 2000, p. 25). A long-term average is likely to be most representative for prediction and least influenced by cyclical factors.

2.5 Data requirements

The scope and nature of the data requirements will depend on the objectives of the study. Analysis that focuses on the performance over time of a single business, or selected businesses, can be carried out using productivity indexes (partial or total). If the aim is to compare the efficiency of a business against a group of comparable businesses, then a consistent set of data will be needed for all of the businesses included in the study. This data may be cross-sectional if a snapshot of comparative productivity is the object. However, if the aims also include separately identifying the sources of productivity change over time, such as changes in efficiency and technical change, and any factors that may cause those changes, then panel data will be needed. Similarly, if one analytical method is to be used for both efficiency comparisons over time and between businesses (e.g. using frontier analysis), then a panel data sample of sufficient size will be needed.

Oxera (2016b) distinguishes between two main approaches for calculating dynamic measures of efficiency improvement.

- *direct benchmarking*: which uses data for regulated companies in a particular industry over time, whether in a single jurisdiction or across jurisdictions;
- *indirect benchmarking*: based on data from comparator sectors in the economy, based on the assumption that their rate of technological change is a good indicator for that in the regulated sector in question.

This study is focussed on the second of these approaches. For the purpose of calculating the productivity performance over time of the group of comparator industries, data for the Netherlands is sufficient, and is the most closely related to the regulated entities to which the study indirectly relates. When it comes to decomposing productivity into component effects, such as trends in efficiency and technical change, or into embodied and disembodied technical change, then a panel of European countries is used. For a given industry sector, each of those industries in each country is treated as a decision-making entity (or production unit) within a balanced panel set.

The first step is to collect data on the operations of the industry sectors being analysed. The quality of the analysis depends crucially on the quality and completeness of the data on which it is based. It is therefore highly desirable to use data that has been fully audited, is as complete as possible, and has a high degree of consistency in terms of data items and definitions. That said, when less complete data is available, benchmarking can still be informative and provide impetus to improving data collection.

3 LITERATURE REVIEW

3.1 Introduction

This chapter makes some observations based on the detailed literature review provided in Appendix A. The review examines key aspects relevant to setting regulated prices for energy network businesses having regard to regulatory decisions and commissioned consultant reports. It covers 12 countries: Australia, Austria, Belgium, Brazil, Germany, the Netherlands, New Zealand, Norway, Peru, Sweden, the United Kingdom, and the USA.

The literature review focusses in particular on the estimates of rates of productivity growth and technical change (or frontier shift) for energy network businesses, for the most part produced to inform plans for setting X-factors in incentive regulation plans. The emphasis is on reasonably recent decisions and studies, and recognising differences in methods used to derive the estimates. The review also identifies published academic studies of productivity trends of electricity and gas transmission and distribution networks. Studies of this kind tend to have different purposes, and use a wider range of analytical techniques; but some of these studies may shed light on questions of relevance here. Table 3.1 provides a summary of the key results for regulatory decisions and estimated productivity trends.

Although much of the analysis reviewed is limited to estimating TFP and opex PFP trends, some of the studies attempt to decompose the trends into technical change and efficiency change effects. A key question (for those studies that address this question) is the degree to which efficiency catch-up effects were found to contribute to productivity trends in these sectors so that these effects can be separated from estimates of frontier shift. Also of interest is evidence of recent trends in overall efficiency and its components.

3.2 Uses of benchmarking and productivity analysis in regulation

Most of the countries reviewed use some form of incentive regulation such as price-caps or, more commonly, revenue-caps. Some forms of benchmarking and productivity trend analysis are used in almost all of the jurisdictions that use these forms of regulation. The jurisdictions that use different forms of regulation include: Norway, which uses an annual yardstick regulation framework; and the USA, where a cost-of-service regulatory framework is often used. The Norwegian framework is based on static benchmarking that requires no productivity trend analysis. In the USA, parties to rate-case proceedings often submit benchmarking and productivity trend studies as part of the information provided to the regulatory body, but this analysis does not usually have a formal role within the price determination framework.

Historical productivity trend estimates are used for forecasting, and the periods over which productivity trends are forecast depends on the regulatory period used. Most of the jurisdictions examined use regulatory periods of three to five years. Exceptions include: the UK's energy network regulation which between 2013 and 2018 used eight-year periods; and the USA, where decisions have no fixed term – decisions generally remain in force until consumer groups or regulated businesses apply for another rate determination. Often the regulator has discretion to decide the length of the regulatory period at the time it makes its regulatory decisions. For example, Ofgem in the UK has recently decided to revert to five-year periods, and the ACM in the Netherlands can choose a period of three to five years. In some cases, new transmission infrastructure is established under terms that include long-term price escalation formulas. Examples include electricity transmission concessions in Brazil, Norwegian gas transmission pipelines, and the undersea electricity transmission line between Belgium and the UK.

Revenue cap formulas usually include a productivity trend component to reflect ongoing technical change (or frontier shift) in the industry. This is sometimes called ‘X-gen’ (e.g. Germany and Austria). It is most commonly applied only to controllable costs, operating and maintenance costs (‘opex’) or controllable opex. This adjustment will usually include not only technical change but also the differential between the general rate of inflation rate and the movement in input prices of TSOs. The combination of the two elements is referred to in this report as the ‘dynamic efficiency’ factor. This ‘X-gen’ or dynamic efficiency factor may be only one part of the ‘X-factor’ in a regulatory price or revenue cap formula. If an energy network is found to be comparatively inefficient relative to best practice businesses among those it is benchmarked against, regulators may make an adjustment within the X-factor to impose a requirement that regulated businesses ‘catch-up’ to the efficiency frontier. A number of other incentive elements are often included in regulatory plans such as adjusting the revenue cap in subsequent periods to allow firms to keep some of gains from cost saving efficiencies for longer. Service quality incentives are also commonly applied ex post through adjustments to the revenue cap in the subsequent regulatory period. The jurisdictions surveyed take several different approaches to incorporating a ‘catch-up’ efficiency requirement in price plans.

- A firm-specific adjustment may be applied within the X-factor, based on a principle that these inefficiencies should be unwound over a specified time (e.g. two regulatory periods). Examples of this practice include Germany and Austria. The measured inefficiency may be adjusted to obtain a more ‘conservative’ measure. For example, Norway measures inefficiencies against the average firm rather than the firms on the efficiency frontier in addition to only requiring that part of the inefficiency be removed in a specific period.
- Alternatively, any material inefficiencies may be removed from the base-period cost base. Australia and the UK are examples of this practice. This may include only the most significant inefficiencies. For example, Ofgem in the UK has measured opex inefficiency relative to the upper third, or the upper quarter, of the distribution of efficiency scores.
- A third alternative, is that the regulator makes no explicit adjustment for inefficiencies, instead relying on the assumed incentives that regulated businesses have to reduce costs. The U.S. regulatory framework could be interpreted in this way.
- Somewhere between these approaches, regulators may trade-off between up-front adjustments to the efficient cost base, and the element of efficiency catch-up included in the X-factor.

Hence, whereas in the theoretical framework of incentive regulation discussed in section 2.4 the X-factor of an incentive plan is based on the forecast for ‘dynamic efficiency’ gains of best practice firms, in practice the X-factors determined by regulators may take other factors into account, or may only partially reflect dynamic efficiency.

3.3 Observations on productivity analysis in benchmarking

The nature of the measurements of productivity trends and measurements of comparative efficiency depend on scope and design of the benchmarking studies. Most of the benchmarking studies used by regulators use a measure of cost as the only input, and some studies use opex as the measure of costs while others use 'totex'. Totex is defined differently, especially between the UK and the continental European countries. For the former it refers to capital expenditure plus opex, whereas for the latter, 'capex' is usually used to refer to a measure of the cost of capital including depreciation and the opportunity cost of the funds employed. Thus, benchmarking studies can differ quite fundamentally in terms of the basis on which the comparisons between businesses are made. This needs to be borne in mind when comparing the results of such studies.

Not all regulators have needed to, or attempted to, forecast frontier shift. Examples include Norway, which uses a yardstick regulation framework which is updated annually, and Belgium, which has waived productivity adjustments in several regulatory decisions.

Decomposition of TFP change into frontier shift, catch-up efficiency and other effects has only occurred in a minority of the examples surveyed. Examples discussed include Peru, Brazil, the UK and the USA. In some cases, decomposition is difficult to determine, and may not be robust. For those countries where decomposition of TFP has occurred, total factor productivity change has been largely driven by technical change (frontier shift). Examples include:

- Brazil electricity distribution (1998-2005)
- Norway electricity distribution (2004-2012)
- Peru electricity distribution (1996-2006), and
- UK electricity distribution (1991-92 to 2016-17), gas distribution (2009-10 to 2016-17), and electricity transmission (2001-02 to 2016-17) and gas transmission (2007-08 to 2016-17).

The USA gas pipelines were an exception with technical efficiency change tending to be more important than technical change (1996-2004).

Estimates of productivity trends yield a wide range of estimates. This can be seen from the examples shown in Table 3.1. Other surveys tend to find that productivity growth or technical change estimates have a wide range. For example, in Austria, E-Control engaged in a thorough examination of frontier shift estimates for electricity DSOs produced by several consultants for different parties, and after corrections derived a range from 0.3 to 2.6 per cent. Oxera (2016b, pp. 44–46) cited estimates of dynamic efficiency for gas TSOs ranging from -0.5 to 1.20 per cent per year; and dynamic efficiency estimates for electricity TSOs ranging from -1.0 to 3.5 per cent per year. Sometimes a wide range of estimates is obtained from a single study. For example, the Jamasb et al (2008) study of productivity trends for gas TSOs in the USA found estimates of technical change of between -0.5 and 2.5 per cent per year. For the UK, electricity transmission, TFP growth (driven by technical change) was negative in a base model but strongly positive in model variants that took account of quality variables.

Regulators have often needed to make decisions about prospective trends in productivity or technical change without the benefit of analysis that could provide estimates the regulator can rely on with reasonable confidence. As mentioned, in regard to electricity DSOs, E-Control was faced with a wide range of estimates of technical change, and therefore needed to rely on its judgement to determine a single rate within this range. In Germany (according to a source quoted in the literature review), X-gen rates chosen by BNetzA in the two regulatory periods up to 2013 were largely judgmental due to a lack of reliable data and analysis. A recent consultant study in the UK commented that the available data was surprisingly incomplete, and in some instances unreliable.

More recent decisions tend to forecast rates of technical change lower than those adopted in many of the earlier decisions. For example,

- In Australia the AER's forecast opex partial productivity growth rate for electricity DSOs adopted by the AER in 2019 was 0.5 per cent compared with earlier estimates in the range of 0.6 to 1.6 per cent, and in New Zealand in the same year the NZCC adopted a rate of zero per cent.
- In Austria, E-Control's decision set the X-gen rate for controllable costs for electricity DSOs from 2006 to 2013 at 1.95 per cent per year, and adopted the same rate for gas DSOs. In more recent decisions E-Control has used 0.95 per cent for electricity and 0.5 per cent for gas TSOs.
- In Brazil, in a 2010 decision for electricity DSOs, ANEEL based the annual productivity adjustment on an estimated annual average of productivity growth of 1.1 per cent. In 2015, ANEEL estimated average rate of technical change for electricity TSO opex to be 0.2 per cent and adopted an X-factor at zero per cent.
- In Germany, X-gen rates for gas networks in 2009-2013 and 2014-2018 were set at 1.25 and 1.5 per cent respectively, whereas in 2018, BNetzA adopted a rate of 0.49 per cent for gas networks.

The tendency for lower forecast rates of technical change in recent years is consistent with the observation of longer-term studies (e.g. in the UK and the US) which have found that the rates of technical change and total factor productivity growth appear to have declined over time. This might be due to the diminishing efficiency gains following structural reforms or additional investment to meet quality or environmental requirements as well as wider economic factors.

Table 3.4: Summary – Estimates of Productivity Trends by Country

Country	Sector	Measure of productivity (% change per year)	Basis of estimate	Date for application/estimation
Australia	Gas distribution	Frontier shift for opex PFP of 0.6-1.6%	Empirical study and regulatory judgement	2018-2022
	Electricity distribution	Frontier shift for opex PFP of 0.5%	Empirical study and regulatory judgement	2019
Austria	Electricity distribution	Frontier shift for controllable opex of 1.95%.	Sample of 23 empirical studies of infrastructure sectors and negotiations	2006-2009, 2010- 2013
		Frontier shift for controllable opex of 1.25%.	Regulatory judgement.	2014-2018
		Frontier shift for controllable opex of 0.95%.	Range of empirical studies of frontier shift of 0.3 to 2.6%	2019-2023
	Gas distribution	Frontier shift for controllable opex of 1.95%.	Sample of 23 empirical studies of infrastructure sectors and negotiations.	2008-2012,2013-2017
	Gas transmission	Average adjustment for controllable opex of 2.5% but lower for more efficient businesses.	Regulatory judgement.	2012-2016
		Average adjustment for controllable opex of 2.45% over two regulatory periods plus allowance of 1.94% for real increases in input prices, so net effect on controllable opex was -0.5%, with no additional allowance for frontier shift.	International benchmarking.	From 2017
Belgium	Gas/electricity distribution transmission	Efficiency factor applied to controllable costs (not details).	Benchmarking (no details).	2008-2011
	Gas/electricity distribution transmission	Estimates of individual cost inefficiency and frontier shift.	DEA for 25 electricity DSOs and 17 gas DSOs (no details).	2012-2015

Country	Sector	Measure of productivity (% change per year)	Basis of estimate	Date for application/estimation
	Gas/electricity, transmission	50% of difference between actual and forecast controllable costs added to revenue requirement for next regulatory period, no other incentives.	Forecast controllable costs in principle subject to benchmarking but no benchmarking for this period.	2016-2019
Brazil	Electricity transmission	No evidence of significant technical change according to study by regulator, but results challenged in academic study.	Malmquist index, with opex as input, and data from 2009 to 2014 for 38 TSOs.	2015
	Electricity distribution	X factor for manageable costs of 1.26% for 2007 to 2010.	Engineering based model to calculate efficient cost of supply.	2003-2006, 2007-2010
	Electricity distribution	X factor for opex has an ex ante productivity term of 1.08% and an ex post quality term.	DEA benchmarking of opex.	2011-2014
	Electricity distribution	X factor for opex and an ex ante productivity term of 1.5% and an ex post quality term.	Törnqvist TFP index for 2005-2012.	2015-2019
	Electricity distribution	Average TFP change of 0.9% comprising frontier shift of 4.9%, catch-up of -3.7% and scale efficiency of -0.3% indicating a move on average away from the frontier with effects varying depending on firm size and TFP declining in the last two years of the period.	Academic study using SFA of a distance function for a panel of 18 Brazilian electricity DSOs.	1998-2005
	Gas distribution	Results were not statistically significant.	Academic study using SFA of a translog distance function for a panel of 15 gas DSOs.	2001-2009
Germany	Gas/electricity distribution, transmission	General productivity factor (frontier shift) for controllable costs of 1.25%.	Regulatory judgement.	2009-2013

Country	Sector	Measure of productivity (% change per year)	Basis of estimate	Date for application/estimation
	Gas/electricity distribution, transmission	General productivity factor (frontier shift) for controllable costs of 1.5%.	Regulatory judgement.	2014-2018
	Gas/electricity distribution, transmission	General productivity factor (frontier shift) for controllable costs of 0.49% for gas and 0.9% for electricity.	Törnqvist and Malmquist index analysis.	2019-2023
Netherlands	Electricity transmission	TFP growth in excess of economy wide growth of 0.5% is 0.75-1.75% for TenneT electricity transmission.	Consultant review of TFP trends in electricity, gas and water sectors in the UK, Australia, New Zealand, UK and USA.	2006
	Gas/electricity distribution, transmission	TFP growth of 0.4% and input price growth of -0.1% meaning cost efficiency of 0.5%. With supporting evidence that scale and catch-up effects were insignificant, the TFP estimate measures the frontier shift.	Consultant study of TFP and input prices for a comparator set of eight industries over the period 1992-2008. Also reviewed regulatory precedents and academic studies with ranges that encompassed the comparator estimates but that were considered less reliable.	2017-2021
New Zealand	Electricity distribution	The regulatory arrangements determine forecast efficient capex and separately an allowance was made for opex with a partial productivity adjustment, currently of 0.0%.	Regulatory judgment based on productivity trends in electricity distribution (in the UK, Norway and Canada), comparable sectors in New Zealand, a changing policy environment and the application of incentive sharing schemes.	2020-2025

Country	Sector	Measure of productivity (% change per year)	Basis of estimate	Date for application/estimation
Norway	Gas/electricity distribution, transmission	The regulatory arrangements do not entail producing any productivity forecasts but there is some use of benchmarking for electricity DSOs.		
	Electricity distribution	Average rate of technical change of 1%. TFP 1.5% comprising technical change of 1.3% and efficiency improvement of 0.2%.	Academic study consistent with earlier studies. Academic study using SFA and Malmquist indexes.	1998-2001 2004-2012
Peru	Electricity distribution	TFP 3.6-4.3%. Technical change 2.9-4.0%. Technical efficiency change 0.3-0.7%.	Academic study of 14 companies estimating a Malmquist TFP index with models of physical capital and real monetary capital.	1996-2006
Sweden	Gas/electricity distribution, transmission	Common efficiency gain 1.0% DSO-specific efficiency gain of 0.00-0.82% depending on relative efficiency. Applied to controllable operating costs.	Regulatory calculations and judgement.	From 2016
	Electricity distribution	Technical change found to be negative.	Academic study using SFA input distance function.	2000-2006
United Kingdom	Electricity distribution	Trend TFP growth of 3.1% for DSOs for period estimated but preferred forecast of 2.4 per cent which after subtracting economy wide TFP led to a recommended X factor of 1.1%	Consultant study of TFP using Törnqvist index of 14 DSOs. Also estimated TFP of National Grid Company and for US and German DSOs	1992-2002

Country	Sector	Measure of productivity (% change per year)	Basis of estimate	Date for application/estimation
	Electricity distribution/transmission and gas transmission	Trend PFP growth of 0.5 to 2.8% (with preference for 1%) and TFP of 0.7%. Taking account of inflation differentials real price changes for opex, capex and totex ranged from 0.2-0.8% for different networks.	Regulator study of opex PFP and TFP based on trends in EU KLEMS data	1970-2007
	Electricity/gas/water distribution, transmission	Literature review supports 1% TFP on average for periods and sectors covered. For electricity, gas and water sectors across several countries TFP was -2.3% (UK), 0.2% (Netherlands), 0.8% (Germany) and slightly negative (USA). With firm level data for electricity distribution in the UK average Malmquist TFP from 1992 to 2017 was 1.1%, all explained by technical change. With firm level data for gas distribution in the UK, the base model Malmquist TFP was 1.6% mostly explained by technical change. With firm level data for electricity transmission in the UK, average TFP was negative at -2.2%, all explained by technical change, but with model variants that recognise quality variables TFP was 6.5-6.6%. With firm level data for gas transmission in the UK average TFP was 5.6%, all explained by technical change. The literature, in general, shows significant increases in productivity growth and quality of service following privatisation and the introduction of incentive regulation, but usually only for a short run of years after the policy change.	Consultant study comprising literature review and index-based analyses for electricity, gas, water sectors for Germany, Netherlands, UK, USA and separate analysis of firm level data for electricity and gas for the UK.	Various periods spanning 1992-2017

Country	Sector	Measure of productivity (% change per year)	Basis of estimate	Date for application/estimation
		Estimates tended to showing slowing growth over the periods studied with the decline being most evident since the 2008 financial crisis.		
USA	Electricity/gas distribution	Limited use of statistical benchmarking for regulatory purposes Electricity DSOs TFP 1.08% Gas DSOs TFP 0.63% Gas TFP 1.18 for 1999-2008, 0.99% 2004-2008 Electricity TFP 0.5% for 1996-2007, 0.22% for 2008-2014	Consultant study of 77 electricity and 34 gas utilities using Törnqvist TRP index Consultant study of gas DSOs using TFP index Consultant study of electricity DSOs using Törnqvist TFP index	1994-2004 1998-2008 1980-2014
	Gas transmission	TFP 2.9 to 6.9% depending on input and output measures Technical change -0.5 to 2.5% Technical efficiency change 1.75 to 5.0 %	Academic study of 39 pipelines using DEA and Malmquist indexes	1996-2004

Source: See Appendix A

4 REVIEW OF DATABASES

This chapter discusses the availability of data for industry level analysis of productivity trends, and also discusses databases that have data for individual firms within those industries or parameterize the distributions or moments of the distributions of data across individual firms. It then discusses the choice of database for this study and documents fully the data used. And the definitions of the variables used in the analysis.

4.1 Candidate Industry-level Databases

Two databases which have industry-level data for a wide range of European countries, and some non-European countries, are the EU KLEMS and OECD STAN databases. This section provides a brief summary of the data relevant to the present study available from each source.

4.1.1 EU-KLEMS & OECD-STAN databases

The EU KLEMS database was developed as a collaboration of 15 European academic institutions and national economic policy research institutes, with the support of statistical offices and the OECD. It includes measures of economic growth, productivity, employment creation, capital formation and technological change at the industry level for all European Union member states from 1970 onwards. The input measures include various categories of *capital, labour, energy, material and service inputs*.[4] It also includes newly developed measures of intellectual property assets. The 2019 release of EU KLEMS provides data for 28 European countries, Japan and the USA. For many countries, including the Netherlands, the data required for this study (including capital stock data) is available from 1995 to 2017. The 'statistical' database is consistent with National Accounts data and is the focus of interest here.[5]

The OECD STAN ('structural analysis') database is designed for analysing industrial performance by providing a wide range of data for OECD countries within standard industry classifications. It includes annual measures of output, value added and its components, labour input, investment and capital stock, from 1970 onwards. It has been developed by the OECD primarily based on member countries' annual national accounts by activity tables and uses data from other sources, such as results from national business surveys/censuses. The OECD cautions that "many of the data points in STAN are estimated and therefore do not represent official member country submissions".[6] The OECD-STAN database includes data for 37 OECD countries (24 European and 13 non-European). It covers a period from 1970 to 2017 (although coverage is more limited before 1995, and there is only a small amount of data for

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[4] These categories are the source of the acronym 'KLEMS'.

[5] There is also an 'analytical' database which incorporates a wider range of intangible assets than are capitalised in the National Accounts. It is more experimental, and the 'statistical' database has the further advantage of providing a greater breakdown of capital stock into certain asset types.

[6] <http://www.oecd.org/sti/ind/stanstructuralanalysisdatabase.htm>.

2017). For the Netherlands, data is available from 1970 to 2016, however, it is incomplete before 1995, and there are even some gaps after 1995, as discussed below.

4.1.2 Comparison against requirements

The *minimal* data requirements for TFP and OPI analysis are, for each of the comparator industries considered by Oxera (2016b), the following:

- Gross output (current prices) and gross output volume measure and gross output price index;
- Compensation of labour (current prices) and quantity of labour inputs;
- Intermediate inputs (current prices) and intermediate input volume measure (or intermediate inputs price index);
- Capital services volume measure (i.e. net capital stock at constant prices).

The availability of data meeting the minimum requirements listed above, for each comparator industry of the Netherlands, is shown in Table 4.1 for each of the two databases. EU KLEMS 2019 has all of the required information for the period 1995 to 2017. OECD-STAN has the required information for most, but not all of the comparator industries, for the period 1995-2016. Net capital stock data is missing for earlier years and is missing for one of the comparator industries post-1995. Therefore EU-KLEMS 2019 appears to meet the requirements for TFP and OPI analysis, and would not need to be supplemented by data from OECD-STAN (as Oxera did in the previous study). The EU-KLEMS data also provides additional capital stock breakdown not used in this study.

Table 4.1: Database Coverage of Comparator Industries

Industry	*EU KLEMS code*	*OECD STAN code(s)*
IT and other information services	1995-2017	1995-2016
Professional, scientific, technical, administrative and support service activities	1995-2017	1995-2016
Telecommunications	1995-2017	1995-2016
Construction	1995-2017	1995-2016
Electricity, gas and water supply[(a)]	1995-2017	1995-2016
Transport and storage	1995-2017	1995-2016
Other manufacturing; repair and installation of machinery and equipment	1995-2017	NA[(b)]
Financial and insurance activities	1995-2017	1995-2016

Notes: (a) Also includes sewerage and waste management. (b) No data for net capital stock.

4.1.3 Discussion

The EU KLEMS database is used for each of the three main analyses or this study which are presented in chapters 5 to 7 of this report. These are:

- Using index-based methods, calculate TFP and OPI indexes and rates of change for comparator industries, using data for the Netherlands only (chapter 5);
- For a set of European countries, and for each of the same eight comparator industries, use data envelopment analysis (DEA) to calculate Malmquist TFP indexes and decompose TFP growth into the effects of technical change and catch-up effects (chapter 6); and
- For the same set of European countries and comparator industries, using econometric analysis to estimate the parameters of a production function which allows for both disembodied technical change, and technical change embodied in capital equipment (chapter 7).

4.2 Candidate Firm-Specific Databases

Three databases which have been developed at a firm-level basis are the Orbis, OECD MultiProd and CompNet databases. These databases either allow analysis to be carried out at a firm level or, more commonly, provide aggregate data at an industry sector level together with detailed information on the numbers of firms in various percentiles for most of the indicators reported. This section briefly describes the Orbis, OECD MultiProd and CompNet databases, and discusses their availability and suitability for this project.

4.2.1 CompNet

The Competitiveness Research Network (CompNet) at the Halle Institute for Economic Research (IWH) produces a leading micro-level dataset with productivity indicators for 18 European countries. Some discussions of this database have been published (CompNet, 2018a; Lopez-Garcia, di Mauro and CompNet, 2015). It includes company financial and other company information, including employment, productivity, mark-ups, financial constraints etc. The data is aggregated to the sector level before being made available to researchers. In addition to the aggregates, there are moments of distributions across firms. It was last updated in 2018 (CompNet, 2018b).

The data is available to researchers but is not made available for commercial purposes, so it could not be obtained for the purposes of this study.

4.2.2 Orbis

ORBIS is a commercial database compiled by the Bureau van Dijk Electronic Publishing (BvD), which contains accounting and ownership data on a large number of firms worldwide. A subset of the database covering Europe is marketed as AMADEUS. The data is gathered from public sources, such as the statutory disclosure obligations of companies, and this data is collected by BvD from a variety of sources (Gal, 2013). It includes firm-level data for approximately 24 countries, at least for the period 1997 to 2014 (Kalemli-Ozcan et al., 2015). For European countries ORBIS-AMADEUS generally has the latest 10 years of data.

The main part of the ORBIS-AMADEUS database is the financial and ownership information for individual firms. There is a range of other information, including details of board members and auditors, among other things. BvD organizes the data into a standard format, including harmonized balance sheets and income statements, to facilitate company comparisons. Most European countries require companies of all sizes to file most of the balance sheet data included in the database, and therefore its coverage is relatively good for those countries. Nevertheless, missing values can be a problem for users of the database – for example missing fields in the financial statements. Kalemli-Ozcan et al. (2015) note also that BvD may drop firms from the database if they did not report anything during the last 5 years. "[I]f we want to calculate total factor productivity, then we need to have the variables output, employment, capital stock and materials reported and hence, we need to go down to a subset of firms that report all these variables" (Kalemli-Ozcan et al., 2015, p. 17). Missing data and this culling process may make the resulting data less representative.

This database was used by Andrews et al (2016) to analyse changes in the dispersion of productivity performance of frontier firms and less efficient firms during the productivity slowdown. They report that "since the information is primarily collected for use in the private sector typically with the aim of financial benchmarking, a number of steps need to be undertaken before the data can be used for economic analysis" (Andrews, Criscuolo and Gal, 2016, p. 12). The data only includes nominal magnitudes and to obtain estimates of quantities of most inputs and the output of firms, deflators are applied. These are from the country and 2-digit industry group to which the firm is classified. Measurement of real capital may be estimated by deflating the company book value of fixed assets. Output for each firm is the deflated estimated value added. Labour inputs are measured by employee numbers. From these data, labour productivity and MFP measures were calculated for each firm. The database mostly covered larger firms and smaller firms were underrepresented. Andrews *et al* made adjustments to MFP for variations in gross mark-ups to control for variations in market power and compensate for the "limitations from not observing firm-level prices" (Andrews, Criscuolo and Gal, 2016, p. 13). The methods used to make these adjustments are quite complex. The study then identified a set of frontier firms in each 2-digit industry, while pooling data across countries. The frontier firms are defined as the *N* highest productivity firms in the industry in a given year, where *N* is 5% of the average number of firms in the industry over the whole sample period.

This database was available upon subscription. The cost of subscription varies with the amount of data to be accessed. The possibility of obtaining data for the eight comparator industries for the Netherlands was explored. However, given the cost and the amount of data management and data cleaning likely to be required, it was decided not to utilize this data for this study.

4.2.3 OECD MultiProd

The MultiProd database, developed by the OECD, involves accessing jurisdictional microdata, generally at enterprise level, to produce a database with consistent definitions across countries. The data collection and analysis routines produce "a set of statistics based on micro-level longitudinal information on output, inputs (labour and capital), labour costs, sector of activity, and possibly age and ownership of the firm. The information is used to calculate firm-level labour and multifactor productivity (MFP), which are then aggregated to the 2-digit sector level, separately for each year. … some statistics are further refined by age and size classes, ownership characteristics, quantiles of the productivity distribution, and quantiles of the size distribution (defined in terms of sales or employment)" (Berlingieri et al., 2017). Business Register data (such as Orbis, which has a wider representation for firms) is combined to calculate weights and provide more detailed information on entry and exit.

The database includes gross output, value added, capital stock and other variables necessary for productivity analysis. The input measures are relatively simple – e.g. employee numbers and a single measure of capital without any disaggregation by asset type. The data is presented at a sectoral level. Within each sector, in addition to aggregated data, there are data on the distributions of various measures across firms: such as: (i) moments of the distribution of firms (e.g. standard deviation); and (ii) quantiles of firms by measures such as gross output, employment etc. There is also information on the age distributions of firms, entry, exit etc. There are also other variables such as calculated measures of productivity, the number of firms at the frontier, decomposition of productivity components, and measures of allocative efficiency.

A strength of the OECD MultiProd database for the present purpose is that it includes calculated productivity measures for labour productivity and index-based MFP measures by industry (and country) and includes information on the distributions of productivity levels and trends across firms within each industry (and country). The index-based MFP measures are calculated on both gross output and value-added bases (using the Solow residual and current-period weights derived from cross-country industry-specific labour and intermediate shares). There is also reportedly a value-added MFP measure based on the residuals of regressions using the method developed by Wooldridge (2009).

It was our hope that this database might be available at sectoral level, with data on moments and quantiles of the distributions of productivity across the enterprises in each sector. We would then extract such data for the eight comparator industries. We have communicated with the OECD, and they advised us that the database is not publicly available (even at an aggregate level) because, for confidentiality reasons, the participating countries have not agreed to release it. The OECD has released some data on the dispersion of labour productivity (the ratio of the 90^{th} percentile to the 10^{th} percentile) by high-level industry classifications, for the following countries: Belgium, Denmark, Finland, France and Portugal. However, this is not suitable for the present study.

4.2.4 Summary

Both the Orbis and CompNet databases are primarily based on data from companies including financial statements and other reporting. The Orbis has a worldwide coverage and may be the more comprehensive. The CompNet data is not available for commercial purposes. Studies carried out using the Orbis database suggest that information on quantities and deflators at firm-level may be lacking. Real values were obtained using deflators for industry sectors. Some economic magnitudes (e.g. capital) may be estimated from company book values. These approximations can affect the reliability of analysis. These are some of the issues that make it less than ideal for the purposes of this study.

The OECD MultiProd database draws primarily from micro-level data provided by national statistical agencies, although it also utilises company-based information (e.g. from the Orbis database) to improve the estimates of distributions across firms. The reliance on statistical agency information suggests that the measurement of economic magnitudes such as gross output, value added, capital and productivity may be more reliable. However, the OECD does not have authority from the data providers to release the data to others.

These observations suggest that none of the more disaggregated databases were either available or suitable for this study.

4.3 Data Used from EU-KLEMS

This section describes the data fields used from the EU-KLEMS database and the calculations made from that data.

4.3.1 Comparator industries

Table 4.2 shows the industry classifications, and the industry code in EU KLEMS, for the eight comparator industries.

Table 4.2: Comparator Industries

code	*Industry*
19	Other manufacturing; repair and installation of machinery and equipment
22	Construction
27	Transport and storage
36	Telecommunications
37	IT and other information services
38	Financial and insurance activities
40	Professional, scientific, technical, administrative and support service activities
993	Electricity, gas and water supply

4.3.2 Countries

Table 4.3 shows the 11 countries included in the sample, and the country codes used in EU-KLEMS. It also shows:

- the sample period for each country. Note that the USA and Japan have been excluded in order to focus the sample of European comparators. There are more than 20 observations per country, on average. In total there is 237 observations per *industry*.

- The currency used in EU-KLEMS (and the OECD national accounts) is the national currency.

Table 4.3: Countries and Periods

code	*Mnemonic*	*Name*	*Period*	*Obs*	*Currency (NAC)*
1	AT	Austria	1995 - 2017	23	Euro
2	BE	Belgium	1999 - 2017	19	Euro
5	CZ	Czech Republic	1995 - 2017	23	Czech Koruna
6	DE	Germany	1995 - 2016	22	Euro
7	DK	Denmark	1995 - 2017	23	Danish Krone
11	FI	Finland	1995 - 2017	23	Euro
12	FR	France	1995 - 2016	22	Euro
16	IT	Italy	1995 - 2015	21	Euro
21	NL	Netherlands	1995 - 2017	23	Euro
25	SE	Sweden	1995 - 2016	22	Swedish Krona
27	SK	Slovakia	2000 - 2015	16	Euro
Total				237	

4.3.3 Variables

The main variables extracted from the EU-KLEMS dataset are shown in Table 4.4. There are two alternative output measures: *GO* and VA. There are three inputs: labour (*LAB*), intermediate inputs (*II*), and capital services (*CAP* or *K*). Generally, we will refer to the net capital stock as *K*, and the remuneration of capital as: $CAP = VA - LAB$. If *VA* is used as the output measure, only *LAB* and *CAP* are used as inputs. For each of the outputs and inputs there is a measure of value, quantity and price.

The quantity indexes, *LAB_QI* and *CAP_QI*, are both quality-adjusted indexes which, for each country, are equal to 100.0 in 2010. The quality-adjustments of these variables are of limited use for the purposes of this study. The approach taken here is to:

- to define labour inputs by the physical measure $LAB\_Q = H\_EMP$, the total hours worked by all employed persons (whether employees or self-employed);
- to define the quantity of capital inputs based on the deflated value of the net capital stock in 2010 prices using the variable: *Kq_GFCF* (but also with currency adjustment).

Table 4.4: Variables sourced from EU-KLEMS

Variable	*Descriptor**
GO	Gross output, current prices (NAC mn)
GO_Q	Gross output, volume 2010 prices (NAC mn)
GO_PI	Gross output, price indices, 2010 = 100
VA	GVA, current prices (NAC mn)
VA_Q	GVA, volume 2010 ref.prices (NAC mn)
VA_PI	GVA, price indices, 2010 = 100
LAB	Labour compensation (NAC mn)
H_EMP (aka *LAB_Q*)	Total hours worked by persons engaged (th)
LAB_QI	Labour inputs, volume indices, 2010=100
II	Intermediate inputs, current prices (NAC mn)
II_Q	Intermediate inputs, volume 2010 prices (NAC mn)
II_PI	Intermediate inputs, price indices, 2010 = 100
CAP	Capital compensation (NAC mn)
CAP_QI	Capital services, volume indices, 2010=100
K_GFCF	All assets: Capital stock net, current replacement costs (NAC mn)
Kq_GFCF	All assets: Capital stock net, volume 2010 prices (NAC mn)

* 'NAC mn' means millions of units of national currency.

To ensure that each measure of value (e.g. *GO*, *VA*, *II*) is equal to the product of the corresponding price and quantity, the following price indexes are defined, for which the base year (2010) is equal 1.0 rather than 100.

- $GO\_P \ = \ GO\_PI \ / \ 100$;
- $VA\_P \ = \ VA\_PI \ / \ 100$;
- $II\_P \ = \ II\_PI \ / \ 100$;
- $K\_P = K\_GFCF / Kq\_GFCF$.

4.3.4 Currency conversion

Many of the variables listed in Table 4.4 are expressed in units of national currency ('NAC'). The currencies for each country are shown in Table 4.3. Three of them have national currencies and the remainder use Euro. For the quantities derived from values and price indexes to be comparable, values need to be adjusted into a common currency. Even in the Euro area, currency conversion may be relevant if Purchasing Power Parities (PPP) are taken into account. The exchange rates and PPPs used in this study are taken from *OECD.Stat*. The exchange rates are year averages. The PPPs are for GDP. The exchange rates and PPPs in *OECD.Stat* are both expressed as units of national currency per US dollar (USD). Dividing a value expressed in national currency by the exchange rate (or by PPP), yields the value expressed in USD. Multiplying a value expressed in USD by the exchange rate (or the PPP) yields the value expressed in national currency.

Here we use a currency conversion factor that is an average of the exchange rate and the PPP. Let CF_i be the conversion factor for country *i* in any given year; XR_i is the price of 1 USD in country i's national currency; and PPP_i is the corresponding PPP for country *i*.

$$CF_i = (XR_i + PPP_i)/2 \tag{4.1}$$

One of the countries is the Netherlands (NL) and therefore, to transform a value from the currency of country *i* into NL currency involves dividing by CF_i (to express the value in USD) and multiplying by CF_{NL} (to convert from USD to NL Euros). For example, to convert GO into NL currency:

$$GOa_t = GO_t \left(\frac{CF_{NL}}{CF_i}\right)_t \tag{4.2}$$

An analogous formula is used to transform *VA*, *II*, *CAP*, and *LAB*, into *VAa*, *IIa*, *CAPa*, and *LABa*. Similarly, the net capital stock at current prices is transformed into NL currency by:

$$Ka_t = K\_GFCF_t \left(\frac{CF_{NL}}{CF_i}\right)_t \tag{4.3}$$

Equations (4.2) and (4.3) are used to transform value variables. For quantity variables measured in deflated value terms, only the currency conversion factor in the base year is used, since variations in relative currency values are price effects. Hence:

$$GO\_Qa_t = GO\_Q_t \left(\frac{CF_{NL}}{CF_i}\right)_{2010} \tag{4.4}$$

A similar formula is used to transform *VA_Q* and *II_Q* into: *VA_Qa*, and *II_Qa*. Also:

$$K\_Qa_t = Kq\_GFCF_t \left(\frac{CF_{NL}}{CF_i}\right)_{2010} \tag{4.5}$$

Note that LAB_Q is measured in physical units and therefore not adjusted in this way. These currency-adjusted values and quantities give rise to the following adjusted variables:

- $GO\_Pa = GOa \,/\, GO\_Qa$
- $VA\_Pa = VAa \,/\, VA\_Qa$
- $II\_Pa = IIa \,/\, II\_Qa$
- $LAB\_Pa = LABa \,/\, LAB\_Q$
- $CAP\_Pa = CAPa/K\_Qa.$

The adjusted variables that are used in the analysis.

5 PRODUCTIVITY TRENDS IN COMPARATOR INDUSTRIES

This chapter presents a similar analysis to that used by Oxera (2016b). That study involved constructing total factor productivity (TFP) indexes for eight Dutch industry sectors which were considered to be most comparable to activities carried out by the energy TSOs. Movements in output prices (OPI) were also examined for comparison with TFP trends. A similar analysis is carried out here. In addition to TFP indexes, partial factor productivity indexes are calculated for opex and capex inputs. Input price indexes (IPI) are also calculated to derive dynamic efficiency estimates, after adjustment for the consumer price index (CPI).

5.1 Method

In the Oxera study, both TFP and OPI were measured using gross output (GO) in preference to gross value added (GVA) as the single measure of output. The three inputs were labour, capital and intermediate products. Eight comparator industries were used as listed in Table 5.1. Oxera selected these industries by first identifying the main TSO activities, and then selecting comparator industries for each of those functions. This was not a one-to-one matching. For some activities more than one industry was relevant, and some industries were relevant to several TSO functions. Unweighted averages of the TFP and OPI growth rates for these industries were used to derive a representative TFP and OPI growth rate for energy TSOs.

ACM's decision on energy TSO revenue caps in 2016 partly relied on the Oxera study. That decision was subject to judicial review which, among other things, concluded that the use of the eight comparator industries was a valid basis for estimating productivity trends for energy TSOs. However, the review concluded that weights should be used when calculating an average across the comparator sectors. An unweighted average of comparator sectors tended to overweight IT and Telecommunications sectors, which have relatively high productivity, and thereby overestimate frontier shift. The review panel required that the weights should reflect the types of costs incurred by TSOs, aligning them to the comparator sectors. Ecorys (2019) estimated appropriate weights to be applied for deriving average TFP growth rates across the eight sectors, including separate weights for Tennet and for GTS and overall average weights.

Table 5.1: Weights for comparator Industries

code	*Industry*	*Tennet*	*GTS*	*Average**
19	Other manufacturing; repair and installation of machinery and equipment	22%	26%	24%
22	Construction	22%	26%	24%
27	Transport and storage	10%	16%	13%
36	Telecommunications	5%	4%	5%
37	IT and other information services	7%	4%	6%
38	Financial and insurance activities	2%	2%	2%
40	Professional, scientific, technical, administrative and support service activities	7%	7%	7%
993	Electricity, gas and water supply	25%	14%	20%

* Average for Tennet & GTS.

This study uses the set of average weights shown in the last column of Table 5.1, unless otherwise indicated. These weights have been applied to the year-on-year growth rates for each of the eight industries to obtain weighted average growth rates. Reported indexes for the average of eight industries are calculated using the weighted average growth rates.

5.1.1 Measuring TFP

With real gross output (Y) as the output measure, and the three inputs, labour (X_L), capital (X_K) and intermediate inputs (X_I), TFP growth can be defined as:

$$T\dot{F}P = \dot{Y} - \dot{X} \tag{5.1}$$

where: $$\dot{X} = w_L \dot{X}_L + w_K \dot{X}_K + w_I \dot{X}_I \tag{5.2}$$

and where a dot above a variable signifies the rate of change;[7] X is the total input index, and the w's are input weights. Oxera appears to have used, for each period, the nominal factor cost of shares for that period as the weights, which is an approach commonly used in the growth accounting literature.[8] We have used the Fisher Ideal Index, in which the weights depend on both the current period (t) and previous period (t–1) factor costs.[9] The Fisher Index formula for the input index is:

$$\frac{X_t}{X_{t-1}} = \left[\left(\frac{\sum_{i=L,K,I} w_{i,t} X_{i,t}}{\sum_{i=L,K,I} w_{i,t} X_{i,t-1}}\right)\left(\frac{\sum_{i=L,K,I} w_{i,t-1} X_{i,t}}{\sum_{i=L,K,I} w_{i,t-1} X_{i,t-1}}\right)\right]^{1/2} \tag{5.3}$$

5.1.2 Measuring Partial Factor Productivities

The partial productivity growth rates reported in this study are for opex inputs and capital inputs. These are defined respectively as:

$$P\dot{F}P_O = \dot{Y} - \dot{X}_O \tag{5.4}$$

where: $$\dot{X}_O = \left(\frac{w_L}{w_L + w_I}\right)\dot{X}_L + \left(\frac{w_I}{w_L + w_I}\right)\dot{X}_I$$

$$P\dot{F}P_K = \dot{Y} - \dot{X}_K \tag{5.5}$$

For the combined opex inputs, the opex input index is again measured using the Fisher index:

$$\frac{X_{O,t}}{X_{O,t-1}} = \left[\left(\frac{\sum_{i=L,I} w_{i,t} X_{i,t}}{\sum_{i=L,I} w_{i,t} X_{i,t-1}}\right)\left(\frac{\sum_{i=L,I} w_{i,t-1} X_{i,t}}{\sum_{i=L,I} w_{i,t-1} X_{i,t-1}}\right)\right]^{1/2} \tag{5.6}$$

[7] The rate of change of a variable between period t–1 and period t is defined here as the log of the ratio of the period t value of that variable to its period t–1 value.

[8] That is, if Y', L', and I' are nominal gross output, labour cost and intermediate input cost respectively, then $w_L = L'/Y'$; and $w_I = I'/Y'$; and $w_K = 1 - w_L - w_I$.

[9] For reasons for favouring the Fisher Ideal Index, see: (Economic Insights, 2009, pp. 16–18)

5.1.3 Measuring OPI

In the Oxera study, the growth rate of OPI, which is a directly measured variable, was shown to be related to the growth rate of TFP via the formula:

$$\dot{OPI} - \dot{CPI} = \left(\dot{IPI} - \dot{CPI}\right) - \dot{TFP} \qquad (5.7)$$

where *CPI* is the consumer price index which the regulator uses to specify the regulated price path and *IPI* is an index of input prices. The right-hand side of (5.4) is therefore analogous to a (negative) 'X-factor'. It is referred to as a 'dynamic efficiency parameter' by Oxera, including both the change in productivity and the real change in the input price index. Equation (5.7) is not correct if there is any change in economic profits between the two periods being compared,[10] and Oxera states that it is assuming the comparator industries are effectively competitive (or in the case of certain energy, water and telecommunications markets, that they are effectively regulated). This, of course, is an empirical question and, without more information, it might be challenged as a possible source of bias in the findings. Nevertheless, we make the same assumption.

In the special case where: $\dot{IPI} = \dot{CPI}$ (and the comparator markets are competitive as mentioned) the rate of change in the real *OPI* index, on the left-hand side of (5.7), is equal to the negative of the change in TFP, and is therefore another way of approaching its measurement. Oxera examined average input price inflation in each of the comparator industries for the period 1998 to 2008 (estimated at 2.2 per cent per year), and compared it to the average CPI movement (2.3 per cent) – hence finding an average rate of real IPI growth of –0.1 per cent per year. It was therefore only a small item in their calculations.

In principle, real IPI can be derived in the same way as the input quantity index. That is:

$$\dot{IPI} = w_L.\dot{P}_L + w_K.\dot{P}_K + w_I.\dot{P}_I \qquad (5.8)$$

where the *w*'s are related to the weights used for calculating the input quantity index in (5.2), and the *P*'s are the individual input price indexes. The benefit of calculating (5.8) is that it enables $\dot{TFP}$ to be explicitly estimated for each industry using (5.7) (again assuming competitive conditions in the comparator industries). The approach taken here is to compute the Fisher Index formula for the input price index:

$$\frac{IPI_t}{IPI_{t-1}} = \left[\left(\frac{\sum_{i=L,K,I} w_{i,t}X_{i,t}}{\sum_{i=L,K,I} w_{i,t-1}X_{i,t}}\right)\left(\frac{\sum_{i=L,K,I} w_{i,t}X_{i,t-1}}{\sum_{i=L,K,I} w_{i,t-1}X_{i,t-1}}\right)\right]^{1/2} \qquad (5.9)$$

Where partial factor productivities are reported, we also report the input price index movements relevant to them. The separate price index for capital inputs poses a problem in that, since capital remuneration can be negative, and hence the price index for capital inputs can take negative values. We have treated all such cases as missing values in calculating the price index

[10] Defining economic profit as the ratio of revenue to economic cost, then: $\pi = OPI.Y/(IPI.X)$, where *Y* is the output index and *X* is the input index. The rate of change (which is the log of the ratio of period *t* values to period *t*–1 values) is then: $\dot{\pi} = \dot{OPI} - \dot{IPI} + \dot{TFP}$ (using equation 5.1). Rearranging (including subtracting $\dot{CPI}$ from both sides) gives: $\dot{OPI} - \dot{CPI} = \dot{\pi} + \left(\dot{IPI} - \dot{CPI}\right) - \dot{TFP}$. This is the same as equation (5.4) only if $\dot{\pi} = 0$.

for capital inputs and its weighted average change across industry sectors. The input price indexes for opex inputs are calculated in an analogous way to the quantity index for these inputs:

$$\frac{IPI_{O,t}}{IPI_{O,t-1}} = \left[\left(\frac{\sum_{i=L,I} w_{i,t} X_{i,t}}{\sum_{i=L,I} w_{i,t-1} X_{i,t}}\right)\left(\frac{\sum_{i=L,I} w_{i,t} X_{i,t-1}}{\sum_{i=L,I} w_{i,t-1} X_{i,t-1}}\right)\right]^{1/2} \qquad (5.9)$$

5.2 TFP and PFP Indexes

Output and input indexes are presented in the supporting tables at the end of this chapter. Table 5.2 shows the TFP indexes for each comparator industry, and Table 5.3 shows the year-on-year TFP growth rates for each industry. Opex partial factor productivity (PFP) indexes and growth rates are shown in Tables 5.4 and 5.5 respectively. Capital PFP indexes and growth rates are shown in Tables 5.6 and 5.7 respectively.

There is considerable variation between the industries in terms of TFP growth rates (and the supporting tables at the end of the section show there is a great deal of variation between industries in regard to the rates of input growth and of output growth):

- the highest average TFP growth rates over the whole sample period (1995 to 2017) are in Telecommunications (2.2 per cent per year) and in Financial and insurance activities (1.6 per cent) and IT and other information services (1.2 per cent);
- the lowest average TFP growth rates over the same period are in Professional, scientific, technical, administrative and support service activities (-0.1 per cent), Other manufacturing; repair and installation of machinery and equipment (0.2 per cent), and Construction (0.3 per cent);
- industries with intermediate TFP growth rates include Transportation and Storage (0.7 per cent) and Electricity, gas, water supply, and waste management (0.5 per cent).

Table 5.3, in the last column, shows the weighted average TFP growth rates for the eight industries using the Ecorys weights, and Table 5.2 shows the associated average TFP indexes. Over the period 1995 to 2017, the average growth rates of the weighted average TFP index was 0.5 per cent per year. The supporting tables at the end of this chapter show the input and output indexes, and using the weighted average growth rates for the eight sectors:

- The average input growth rate from 1995-2017 was 1.9 per cent per year.
- The average output growth rate over the same period was 2.4 per cent per year.

Table 5.2: TFP indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.003	0.981	1.003	0.961	0.985	1.031	1.004	1.024	0.999
1997	1.013	0.974	1.018	1.014	1.030	1.055	1.015	1.016	1.007
1998	1.049	0.984	1.040	1.075	1.061	1.075	1.020	1.030	1.029
1999	1.056	1.000	1.035	1.135	1.062	1.099	1.034	1.029	1.038
2000	1.074	1.006	1.052	1.195	1.083	1.105	1.048	1.048	1.054
2001	1.099	1.007	1.050	1.239	1.108	1.096	1.067	1.050	1.065
2002	1.105	1.006	1.045	1.354	1.104	1.115	1.050	1.064	1.072
2003	1.096	1.007	1.061	1.454	1.138	1.131	1.040	1.070	1.079
2004	1.093	1.006	1.084	1.460	1.155	1.165	1.027	1.072	1.082
2005	1.110	1.022	1.104	1.507	1.161	1.185	1.037	1.125	1.106
2006	1.110	1.031	1.124	1.556	1.184	1.217	1.038	1.138	1.117
2007	1.124	1.040	1.144	1.605	1.214	1.266	1.009	1.134	1.127
2008	1.132	1.049	1.147	1.638	1.201	1.309	1.020	1.138	1.134
2009	1.090	1.036	1.120	1.606	1.179	1.319	1.014	1.126	1.113
2010	1.086	1.010	1.146	1.634	1.188	1.358	1.010	1.121	1.109
2011	1.094	1.010	1.152	1.616	1.217	1.362	1.011	1.114	1.111
2012	1.102	0.995	1.159	1.601	1.239	1.355	1.012	1.113	1.111
2013	1.082	0.992	1.162	1.594	1.280	1.357	1.001	1.119	1.108
2014	1.075	1.005	1.175	1.611	1.285	1.370	1.008	1.122	1.113
2015	1.067	1.026	1.169	1.631	1.299	1.401	0.980	1.140	1.119
2016	1.062	1.052	1.151	1.615	1.307	1.414	0.977	1.133	1.121
2017	1.045	1.063	1.158	1.620	1.291	1.412	0.982	1.119	1.117
Avg.%	0.20	0.28	0.67	2.19	1.16	1.57	-0.08	0.51	0.50

Source: Economic Insights calculations.

Table 5.3: TFP growth rates: Netherlands comparator sectors, 1995–2017 (%)

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	0.27	-1.90	0.25	-4.01	-1.50	3.09	0.35	2.37	-0.09
1997	1.07	-0.76	1.52	5.41	4.49	2.24	1.16	-0.76	0.78
1998	3.42	1.04	2.16	5.79	2.93	1.91	0.43	1.34	2.13
1999	0.71	1.65	-0.49	5.46	0.06	2.22	1.35	-0.12	0.89
2000	1.63	0.61	1.62	5.13	2.02	0.54	1.41	1.86	1.59
2001	2.35	0.03	-0.14	3.65	2.26	-0.82	1.76	0.14	1.00
2002	0.55	-0.05	-0.50	8.90	-0.34	1.70	-1.63	1.39	0.67
2003	-0.84	0.08	1.55	7.08	2.99	1.41	-0.87	0.49	0.61
2004	-0.24	-0.09	2.06	0.47	1.48	3.02	-1.31	0.26	0.32
2005	1.52	1.53	1.89	3.14	0.50	1.65	0.94	4.76	2.20
2006	-0.01	0.88	1.79	3.18	1.98	2.72	0.15	1.20	1.02
2007	1.28	0.90	1.72	3.11	2.56	3.90	-2.84	-0.35	0.85
2008	0.66	0.86	0.29	2.06	-1.12	3.40	1.12	0.34	0.65
2009	-3.75	-1.23	-2.38	-1.99	-1.84	0.73	-0.66	-1.10	-1.95
2010	-0.33	-2.52	2.25	1.71	0.75	2.90	-0.37	-0.42	-0.31
2011	0.67	-0.01	0.58	-1.07	2.39	0.32	0.11	-0.60	0.21
2012	0.78	-1.54	0.57	-0.92	1.81	-0.53	0.09	-0.09	-0.07
2013	-1.89	-0.28	0.25	-0.47	3.31	0.13	-1.08	0.48	-0.29
2014	-0.65	1.32	1.10	1.07	0.36	0.97	0.67	0.34	0.51
2015	-0.70	2.00	-0.49	1.21	1.05	2.24	-2.80	1.54	0.52
2016	-0.46	2.52	-1.60	-0.93	0.63	0.92	-0.33	-0.57	0.16
2017	-1.62	1.07	0.61	0.26	-1.20	-0.11	0.50	-1.23	-0.32
Avg.	0.20	0.28	0.67	2.19	1.16	1.57	-0.08	0.51	0.50

Source: Economic Insights calculations.

Table 5.4: Opex PFP indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.000	0.982	1.000	0.920	0.981	1.024	1.000	1.017	0.994
1997	1.006	0.974	1.012	0.937	1.019	1.025	1.009	1.006	0.997
1998	1.037	0.984	1.034	0.933	1.047	1.032	1.015	1.009	1.012
1999	1.043	0.999	1.029	0.945	1.050	1.038	1.030	0.998	1.016
2000	1.058	1.005	1.046	0.973	1.074	1.050	1.045	1.008	1.029
2001	1.084	1.005	1.045	0.989	1.102	1.048	1.067	0.995	1.036
2002	1.090	1.005	1.041	1.076	1.107	1.069	1.055	1.003	1.043
2003	1.081	1.006	1.062	1.155	1.148	1.081	1.050	1.005	1.050
2004	1.076	1.005	1.080	1.165	1.167	1.106	1.036	1.008	1.052
2005	1.089	1.020	1.100	1.205	1.169	1.102	1.047	1.043	1.072
2006	1.087	1.028	1.118	1.250	1.190	1.108	1.048	1.059	1.082
2007	1.097	1.036	1.131	1.284	1.221	1.134	1.042	1.055	1.091
2008	1.105	1.045	1.135	1.334	1.209	1.173	1.051	1.058	1.098
2009	1.069	1.034	1.113	1.350	1.192	1.187	1.050	1.050	1.082
2010	1.066	1.012	1.141	1.377	1.206	1.215	1.040	1.041	1.079
2011	1.073	1.011	1.146	1.368	1.231	1.209	1.037	1.044	1.083
2012	1.082	0.997	1.155	1.347	1.257	1.211	1.035	1.064	1.087
2013	1.064	0.995	1.158	1.328	1.302	1.211	1.027	1.073	1.085
2014	1.056	1.008	1.168	1.335	1.298	1.197	1.027	1.079	1.089
2015	1.045	1.028	1.161	1.354	1.307	1.200	1.023	1.111	1.098
2016	1.040	1.054	1.143	1.323	1.345	1.217	1.017	1.119	1.103
2017	1.023	1.065	1.149	1.316	1.359	1.218	1.020	1.112	1.101
Avg. %	0.10	0.29	0.63	1.25	1.39	0.89	0.09	0.48	0.44

Source: Economic Insights calculations.

Table 5.5: Opex PFP growth rates: Netherlands comparator sectors, 1995–2017 (%)

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	-0.04	-1.85	-0.02	-8.38	-1.95	2.41	-0.05	1.64	-0.61
1997	0.66	-0.77	1.23	1.89	3.85	0.01	0.99	-1.06	0.31
1998	3.02	0.97	2.12	-0.40	2.66	0.76	0.51	0.27	1.46
1999	0.60	1.54	-0.52	1.24	0.32	0.59	1.48	-1.10	0.42
2000	1.43	0.62	1.64	2.93	2.23	1.15	1.50	1.02	1.30
2001	2.36	0.01	-0.08	1.61	2.56	-0.22	2.07	-1.25	0.68
2002	0.63	-0.04	-0.32	8.44	0.53	2.00	-1.11	0.81	0.67
2003	-0.83	0.09	1.96	7.13	3.58	1.07	-0.52	0.20	0.66
2004	-0.50	-0.09	1.66	0.79	1.65	2.28	-1.31	0.22	0.21
2005	1.24	1.50	1.82	3.41	0.14	-0.36	1.00	3.43	1.80
2006	-0.25	0.81	1.69	3.65	1.85	0.53	0.15	1.52	0.96
2007	0.99	0.78	1.15	2.68	2.51	2.39	-0.62	-0.33	0.79
2008	0.64	0.84	0.29	3.87	-0.94	3.37	0.86	0.30	0.71
2009	-3.28	-1.04	-1.96	1.20	-1.46	1.14	-0.12	-0.83	-1.46
2010	-0.31	-2.20	2.48	1.93	1.15	2.40	-0.88	-0.78	-0.28
2011	0.70	-0.04	0.52	-0.64	2.06	-0.57	-0.31	0.20	0.32
2012	0.84	-1.45	0.71	-1.56	2.11	0.19	-0.20	1.96	0.37
2013	-1.70	-0.22	0.33	-1.39	3.56	0.04	-0.79	0.81	-0.17
2014	-0.79	1.31	0.86	0.51	-0.33	-1.16	0.00	0.56	0.32
2015	-1.00	1.97	-0.68	1.46	0.69	0.26	-0.36	2.98	0.83
2016	-0.52	2.48	-1.50	-2.38	2.85	1.40	-0.62	0.68	0.45
2017	-1.58	1.05	0.47	-0.52	1.05	0.02	0.33	-0.63	-0.13
Avg.	0.10	0.29	0.63	1.25	1.39	0.89	0.09	0.48	0.44

Source: Economic Insights calculations.

Table 5.6: Capital PFP indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.035	0.997	1.023	1.033	1.126	1.047	1.061	1.041	1.033
1997	1.089	0.987	1.061	1.161	1.324	1.128	1.097	1.041	1.068
1998	1.169	0.980	1.087	1.383	1.414	1.184	1.091	1.082	1.110
1999	1.189	0.957	1.083	1.599	1.372	1.265	1.089	1.106	1.120
2000	1.230	0.967	1.100	1.782	1.364	1.251	1.092	1.152	1.149
2001	1.258	0.944	1.093	1.961	1.356	1.221	1.074	1.204	1.161
2002	1.256	0.915	1.072	2.169	1.257	1.232	1.004	1.244	1.152
2003	1.245	0.905	1.053	2.326	1.226	1.260	0.958	1.262	1.146
2004	1.276	0.908	1.109	2.325	1.227	1.323	0.946	1.267	1.163
2005	1.336	0.940	1.136	2.389	1.267	1.415	0.948	1.388	1.216
2006	1.368	0.975	1.164	2.448	1.304	1.545	0.949	1.391	1.244
2007	1.428	1.017	1.225	2.542	1.341	1.689	0.766	1.385	1.265
2008	1.441	1.030	1.228	2.523	1.313	1.749	0.790	1.392	1.274
2009	1.310	0.976	1.164	2.352	1.253	1.741	0.751	1.367	1.205
2010	1.302	0.870	1.170	2.384	1.217	1.810	0.784	1.373	1.176
2011	1.304	0.889	1.182	2.344	1.284	1.843	0.820	1.336	1.184
2012	1.304	0.821	1.175	2.345	1.267	1.812	0.850	1.265	1.151
2013	1.246	0.775	1.170	2.369	1.276	1.817	0.809	1.260	1.118
2014	1.265	0.796	1.205	2.418	1.363	1.896	0.892	1.257	1.148
2015	1.312	0.843	1.213	2.436	1.419	2.000	0.647	1.229	1.148
2016	1.319	0.910	1.187	2.486	1.208	2.002	0.665	1.187	1.152
2017	1.284	0.942	1.205	2.539	1.021	1.996	0.680	1.154	1.141
Avg.%	1.14	-0.27	0.85	4.23	0.09	3.14	-1.75	0.65	0.60

Source: Economic Insights calculations.

Table 5.7: Capital PFP growth rates: Netherlands comparator sectors, 1995–2017 (%)

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	3.47	-0.28	2.28	3.22	11.84	4.59	5.90	4.06	3.22
1997	5.09	-0.98	3.68	11.68	16.23	7.48	3.38	-0.08	3.36
1998	7.06	-0.75	2.40	17.51	6.56	4.85	-0.57	3.86	3.89
1999	1.65	-2.36	-0.33	14.53	-3.02	6.60	-0.20	2.24	0.89
2000	3.46	1.06	1.50	10.84	-0.57	-1.17	0.28	4.09	2.57
2001	2.24	-2.47	-0.60	9.58	-0.54	-2.43	-1.71	4.43	1.02
2002	-0.19	-3.12	-1.93	10.06	-7.63	0.91	-6.68	3.26	-0.79
2003	-0.89	-1.12	-1.80	7.00	-2.46	2.29	-4.69	1.41	-0.51
2004	2.51	0.35	5.16	-0.06	0.02	4.85	-1.32	0.39	1.42
2005	4.53	3.52	2.42	2.71	3.25	6.72	0.23	9.12	4.51
2006	2.43	3.60	2.43	2.46	2.85	8.80	0.16	0.23	2.27
2007	4.27	4.23	5.07	3.77	2.83	8.89	-21.53	-0.41	1.63
2008	0.91	1.23	0.29	-0.77	-2.14	3.50	3.21	0.49	0.77
2009	-9.54	-5.37	-5.37	-7.03	-4.66	-0.42	-5.18	-1.85	-5.59
2010	-0.62	-11.43	0.51	1.36	-2.90	3.84	4.42	0.48	-2.42
2011	0.13	2.09	1.04	-1.71	5.39	1.81	4.49	-2.76	0.70
2012	0.05	-7.93	-0.63	0.04	-1.39	-1.70	3.56	-5.48	-2.91
2013	-4.61	-5.81	-0.37	1.03	0.72	0.28	-5.00	-0.36	-2.84
2014	1.52	2.73	2.91	2.04	6.56	4.28	9.80	-0.25	2.59
2015	3.68	5.76	0.71	0.75	4.05	5.32	-32.12	-2.23	0.05
2016	0.53	7.64	-2.18	2.05	-16.06	0.14	2.77	-3.55	0.30
2017	-2.65	3.44	1.51	2.08	-16.87	-0.33	2.23	-2.75	-0.91
Avg.	1.14	-0.27	0.85	4.23	0.09	3.14	-1.75	0.65	0.60

Source: Economic Insights calculations.

Figure 5.1 depicts the annual growth rates for inputs, outputs and TFP for the weighted average of the industries. There is significant volatility in the growth rates of output and inputs, and there may be an underlying decline in their growth rates over the whole period. Alternatively, it may be a longer form of cycle. Because these two series move mostly in parallel, the effect of cyclical factors on TFP growth is less pronounced, being mostly in the years 2009 and 2010 when the effects of the global financial crisis (GFC) are most apparent. A significant feature of the TFP series is that in the period up to 2008, TFP growth averaged 1.0 per cent. In the period from 2011 to 2017, TFP growth averaged only 0.1 per cent.

Figure 5.2 presents the growth rates of opex inputs alongside the output growth rates for the weighted average of the comparator industries and shows the Opex PFP growth rates. Opex inputs growth rates tend to follow a similar pattern to output growth rates and Opex PFP is relatively stable and follows a similar pattern to the TFP growth rates shown in Figure 5.2. Figure 5.3 plots the capital inputs growth rates against the output growth rates and shows the Capital PFP growth rates. Although there is some correlation between the growth of capital inputs and the growth of outputs, it is much weaker than for opex inputs, and consequently, Capital PFP tends to be volatile compared to Opex PFP, and strongly pro-cyclical.

Figure 5.1: Output, input & TFP growth rates: Netherlands comparator sectors, 1995–2017 (%)

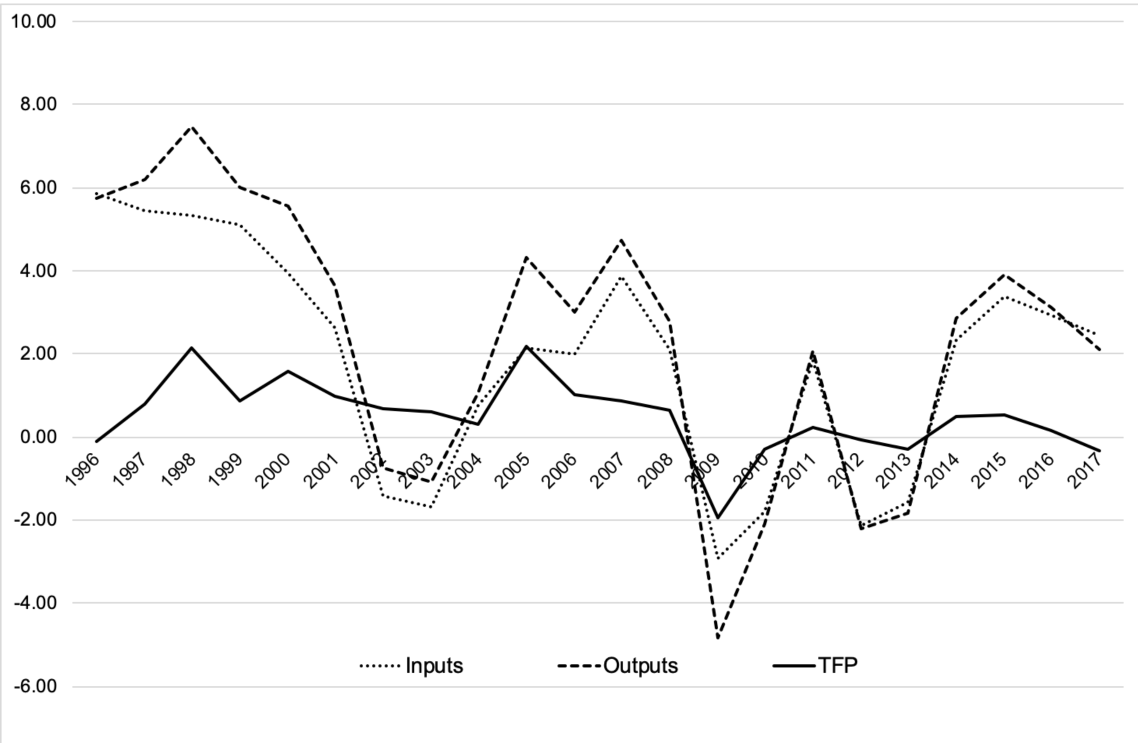


Figure 5.2: Output, opex input & Opex PFP growth rates: Netherlands comparator sectors, 1995–2017 (%)

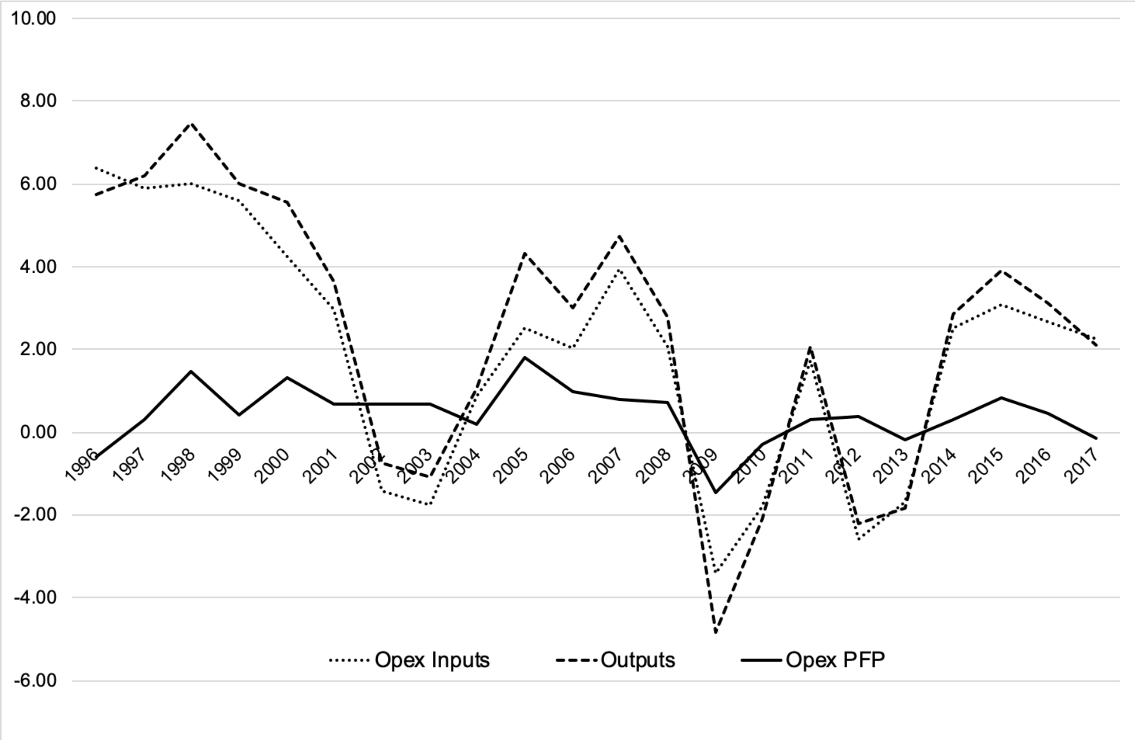
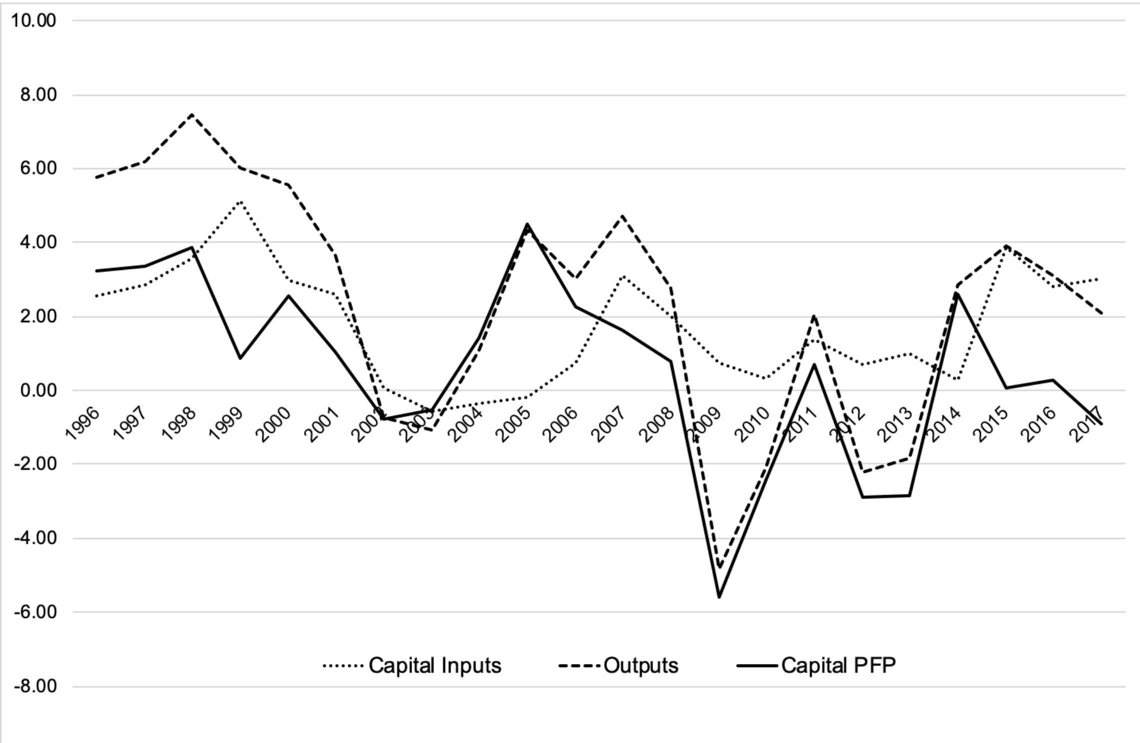


Figure 5.3: Output, capital input & Capital PFP growth rates: Netherlands comparator sectors, 1995–2017 (%)



5.3 OPI and dynamic efficiency rate

Table 5.8 shows the real output price indexes (OPI) for each comparator industry. These are the equal to the nominal OPI indexes divided by the Netherlands consumer price index (CPI). Table 5.10 shows the real input price indexes (IPI) for each comparator industry. They are also based on nominal input prices deflated by the CPI. The nominal IPI indexes are calculated using the Fisher index method. These tables also show the weighted average indexes.

Tables 5.9 and 5.11 show the annual growth rates for the real OPI and real IPI indexes respectively. As previously explained, the growth rate of the real OPI minus the growth rate of the real IPI also measures the (negative of) the rate of TFP growth.

Tables 5.8 to 5.11 indicate that on average over the period 1995 to 2017:

- real OPI growth was -0.54 per cent per year.
- Real IPI growth was -0.04 per cent per year.
- The negative of the difference between these two growth rates is an estimate of the TFP growth rate: 0.50 per cent per year, which is identical to that calculated using the more direct method.

From these results we obtain a *rate of dynamic efficiency* (which is relevant to the X-factor) of 0.54 per cent per year, which comprises the average TFP growth rate of 0.50 per cent per year and the average annual rate of *decline* in Real IPI of 0.04 per cent. It is also equal to the rate of change in real OPI.

Table 5.8: Real OPI indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	0.986	1.004	0.982	0.956	1.001	0.960	1.002	0.994	0.991
1997	0.976	1.002	0.994	0.896	0.996	0.936	1.003	0.998	0.987
1998	0.975	1.006	0.989	0.807	1.001	0.907	1.011	0.996	0.982
1999	0.964	1.015	0.969	0.707	1.009	0.892	1.013	0.985	0.970
2000	0.958	1.038	0.979	0.647	1.013	0.897	1.028	0.992	0.974
2001	0.929	1.044	0.962	0.597	1.014	0.906	1.034	0.990	0.962
2002	0.913	1.059	0.955	0.567	0.998	0.907	1.040	0.971	0.954
2003	0.909	1.068	0.943	0.555	0.989	0.913	1.047	0.984	0.955
2004	0.909	1.076	0.948	0.544	0.992	0.901	1.062	0.963	0.953
2005	0.912	1.077	0.963	0.520	0.996	0.897	1.068	0.977	0.957
2006	0.918	1.099	0.972	0.501	1.004	0.848	1.081	1.024	0.972
2007	0.915	1.108	0.964	0.482	1.027	0.808	1.100	1.044	0.975
2008	0.918	1.119	0.980	0.453	1.020	0.760	1.100	1.065	0.980
2009	0.926	1.133	0.944	0.439	0.993	0.872	1.100	1.081	0.982
2010	0.931	1.141	0.950	0.440	0.990	0.946	1.091	1.031	0.978
2011	0.927	1.121	0.947	0.437	0.937	0.932	1.075	1.057	0.972
2012	0.918	1.101	0.945	0.425	0.898	0.958	1.051	1.044	0.959
2013	0.903	1.074	0.935	0.406	0.869	0.936	1.033	0.993	0.933
2014	0.903	1.056	0.931	0.390	0.859	0.948	1.025	0.936	0.915
2015	0.914	1.032	0.935	0.375	0.861	0.926	1.026	0.913	0.907
2016	0.919	1.021	0.928	0.367	0.857	0.884	1.029	0.879	0.896
2017	0.913	1.012	0.923	0.348	0.851	0.865	1.029	0.873	0.888
Avg. (%)	-0.41	0.06	-0.36	-4.79	-0.73	-0.66	0.13	-0.62	-0.54

Source: Economic Insights calculations.

Table 5.9: Real OPI growth rates: Netherlands comparator sectors, 1995–2017 (%)

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	-1.38	0.40	-1.83	-4.53	0.07	-4.04	0.19	-0.59	-0.87
1997	-1.05	-0.21	1.23	-6.50	-0.48	-2.56	0.07	0.35	-0.47
1998	-0.10	0.43	-0.47	-10.39	0.55	-3.18	0.85	-0.11	-0.49
1999	-1.13	0.86	-2.07	-13.20	0.76	-1.70	0.17	-1.13	-1.18
2000	-0.62	2.25	1.03	-8.88	0.42	0.58	1.48	0.72	0.36
2001	-3.05	0.52	-1.74	-8.05	0.03	1.07	0.57	-0.25	-1.21
2002	-1.74	1.51	-0.73	-5.19	-1.57	0.04	0.57	-1.89	-0.83
2003	-0.48	0.85	-1.29	-2.14	-0.93	0.67	0.71	1.26	0.07
2004	-0.03	0.74	0.48	-2.08	0.30	-1.34	1.43	-2.11	-0.20
2005	0.39	0.08	1.57	-4.35	0.45	-0.42	0.59	1.46	0.45
2006	0.66	2.02	1.01	-3.71	0.75	-5.59	1.18	4.71	1.53
2007	-0.37	0.80	-0.88	-3.96	2.26	-4.91	1.70	1.89	0.32
2008	0.37	0.96	1.63	-6.28	-0.69	-6.00	0.07	2.02	0.46
2009	0.78	1.23	-3.66	-3.02	-2.64	13.71	0.00	1.47	0.26
2010	0.58	0.77	0.65	0.12	-0.27	8.11	-0.90	-4.70	-0.44
2011	-0.44	-1.83	-0.33	-0.50	-5.52	-1.46	-1.40	2.48	-0.57
2012	-0.94	-1.73	-0.22	-2.96	-4.21	2.76	-2.30	-1.21	-1.41
2013	-1.62	-2.56	-1.08	-4.46	-3.39	-2.31	-1.75	-5.07	-2.73
2014	-0.03	-1.68	-0.42	-4.07	-1.15	1.29	-0.72	-5.88	-1.92
2015	1.21	-2.29	0.36	-4.04	0.32	-2.35	0.06	-2.53	-0.94
2016	0.56	-1.01	-0.70	-2.07	-0.50	-4.68	0.34	-3.76	-1.14
2017	-0.66	-0.89	-0.49	-5.16	-0.71	-2.20	0.00	-0.71	-0.91
Avg.	-0.41	0.06	-0.36	-4.79	-0.73	-0.66	0.13	-0.62	-0.54

Source: Economic Insights calculations.

Table 5.10: Real IPI indexes: Netherlands comparator sectors, 1995–2017 (%)

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	0.989	0.985	0.984	0.918	0.986	0.991	1.005	1.018	0.990
1997	0.989	0.976	1.012	0.908	1.026	0.987	1.018	1.014	0.993
1998	1.023	0.990	1.029	0.867	1.062	0.975	1.031	1.026	1.010
1999	1.018	1.015	1.003	0.803	1.071	0.980	1.047	1.014	1.007
2000	1.029	1.045	1.030	0.773	1.098	0.991	1.077	1.040	1.027
2001	1.021	1.050	1.011	0.740	1.123	0.993	1.103	1.039	1.025
2002	1.009	1.066	0.998	0.768	1.102	1.011	1.091	1.034	1.023
2003	0.996	1.076	1.001	0.807	1.125	1.032	1.090	1.052	1.030
2004	0.994	1.083	1.027	0.794	1.145	1.050	1.091	1.033	1.031
2005	1.013	1.101	1.063	0.784	1.156	1.063	1.108	1.099	1.059
2006	1.019	1.133	1.093	0.780	1.188	1.032	1.122	1.166	1.086
2007	1.029	1.152	1.102	0.773	1.247	1.022	1.110	1.184	1.099
2008	1.039	1.174	1.124	0.741	1.224	0.996	1.123	1.212	1.111
2009	1.009	1.174	1.058	0.705	1.171	1.150	1.116	1.217	1.093
2010	1.011	1.153	1.089	0.718	1.176	1.284	1.102	1.156	1.085
2011	1.014	1.132	1.092	0.707	1.140	1.270	1.087	1.178	1.081
2012	1.012	1.096	1.096	0.680	1.113	1.298	1.064	1.162	1.065
2013	0.977	1.065	1.086	0.647	1.112	1.270	1.034	1.110	1.033
2014	0.970	1.061	1.094	0.628	1.103	1.299	1.033	1.050	1.019
2015	0.975	1.058	1.093	0.611	1.118	1.298	1.005	1.040	1.015
2016	0.976	1.074	1.068	0.593	1.120	1.250	1.005	0.996	1.005
2017	0.954	1.076	1.069	0.564	1.099	1.221	1.010	0.977	0.992
Avg. (%)	-0.21	0.33	0.30	-2.60	0.43	0.91	0.05	-0.11	-0.04

Source: Economic Insights calculations.

Table 5.11: Real IPI growth rates: Netherlands comparator sectors, 1995–2017 (%)

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	-1.11	-1.51	-1.58	-8.54	-1.44	-0.95	0.54	1.78	-0.96
1997	0.02	-0.97	2.75	-1.09	4.01	-0.32	1.23	-0.41	0.31
1998	3.32	1.46	1.69	-4.60	3.48	-1.28	1.28	1.23	1.64
1999	-0.42	2.52	-2.57	-7.74	0.83	0.52	1.52	-1.25	-0.30
2000	1.01	2.87	2.65	-3.76	2.44	1.12	2.89	2.58	1.95
2001	-0.70	0.56	-1.87	-4.40	2.30	0.25	2.33	-0.11	-0.21
2002	-1.19	1.47	-1.23	3.71	-1.91	1.74	-1.06	-0.50	-0.16
2003	-1.31	0.93	0.26	4.94	2.06	2.08	-0.15	1.76	0.69
2004	-0.27	0.65	2.54	-1.61	1.78	1.68	0.12	-1.85	0.12
2005	1.91	1.61	3.47	-1.21	0.95	1.23	1.52	6.22	2.64
2006	0.65	2.90	2.80	-0.52	2.73	-2.88	1.34	5.91	2.55
2007	0.90	1.70	0.84	-0.85	4.81	-1.01	-1.15	1.54	1.18
2008	1.03	1.81	1.92	-4.23	-1.81	-2.61	1.19	2.36	1.10
2009	-2.97	0.00	-6.04	-5.01	-4.47	14.44	-0.66	0.36	-1.68
2010	0.25	-1.75	2.90	1.82	0.48	11.00	-1.26	-5.12	-0.75
2011	0.23	-1.83	0.26	-1.58	-3.13	-1.15	-1.30	1.87	-0.35
2012	-0.16	-3.27	0.35	-3.88	-2.40	2.23	-2.22	-1.31	-1.47
2013	-3.52	-2.84	-0.83	-4.93	-0.08	-2.18	-2.83	-4.59	-3.01
2014	-0.68	-0.36	0.68	-3.01	-0.79	2.25	-0.05	-5.54	-1.41
2015	0.50	-0.29	-0.12	-2.82	1.37	-0.11	-2.74	-0.99	-0.41
2016	0.10	1.51	-2.29	-3.00	0.13	-3.76	0.00	-4.32	-0.98
2017	-2.28	0.18	0.12	-4.90	-1.92	-2.31	0.50	-1.94	-1.24
Avg.	-0.21	0.33	0.30	-2.60	0.43	0.91	0.05	-0.11	-0.04

Source: Economic Insights calculations.

5.4 Periods for calculating averages

Oxera summarised the following principles for choosing a period for calculating trend rates of productivity growth using TFP indexes. The period should:

(1) cover complete business cycles, since the inclusion of partial business cycles at either the beginning or end of the period may bias the trend estimates obtained;

(2) older data is likely to be less informative than more recent data for forecasting future productivity growth;

(3) "In some instances, earlier data should be discarded if there is evidence of structural breaks or atypical fluctuations that introduce bias in productivity estimates."[11]

(4) At least eight years of robust and consistent data should be used.

To these principles we would add one of the principles stated by Bernstein and quoted in chapter 2; that the period over which the average TFP growth is measured should preferably be a long period (such as two decades), to reduce the influence of cycles and other economic episodes on the results.

Oxera's use of full business cycle periods is quite common because measuring from peak to trough will downwardly bias productivity trend measures, whereas measuring from trough to peak will upwardly bias TFP measures.[12] Europe Economics uses a related approach. However, rather than choosing one period claimed to include only whole cycles, Europe Economics calculated productivity trends over a number of different time periods as a sensitivity analysis.[13] These periods included whole business cycles, combinations of more than one cycle period, and also the whole of the EU KLEMS period (and others). Economic Insights has recently carried out a similar sensitivity analysis of TFP trend estimates for different chosen periods in work for the Australian Energy Regulator (AER).[14]

Business cycles can be measured from peak-to-peak; from trough-to-trough; or from some mid-cycle point to a corresponding mid-cycle point. Oxera chose the last of these options, choosing mid-cycle points as those at which the annual GO growth rate for the comparator industries (or Dutch GDP growth) was close to the average for 1989 to 2009. For comparison, the Center for Economic Policy Research's (CEPR) timing of the European business cycle is shown in Table 5.12. An alternative to identifying full cycles and calculating averages over those cycles is to use the approaches of Europe Economics and Economic Insights, previously referred to, by carrying out sensitivity analysis of TFP trend growth rates by varying the period over which they are calculated. Through sensitivity analysis of this kind, the central tendency and most reliable estimates of TFP trend growth rates can be ascertained.

[11] (Oxera, 2016b, p. 29)

[12] TFP is usually pro-cyclical because of fixed inputs and lagged adjustment of partially-fixed inputs.

[13] (Europe Economics, 2019)

[14] Economic Insights, *Forecast Opex Productivity Growth*, Memorandum prepared by Denis Lawrence and Tim Coelli for the Australian Energy Regulator (4 February 2019),

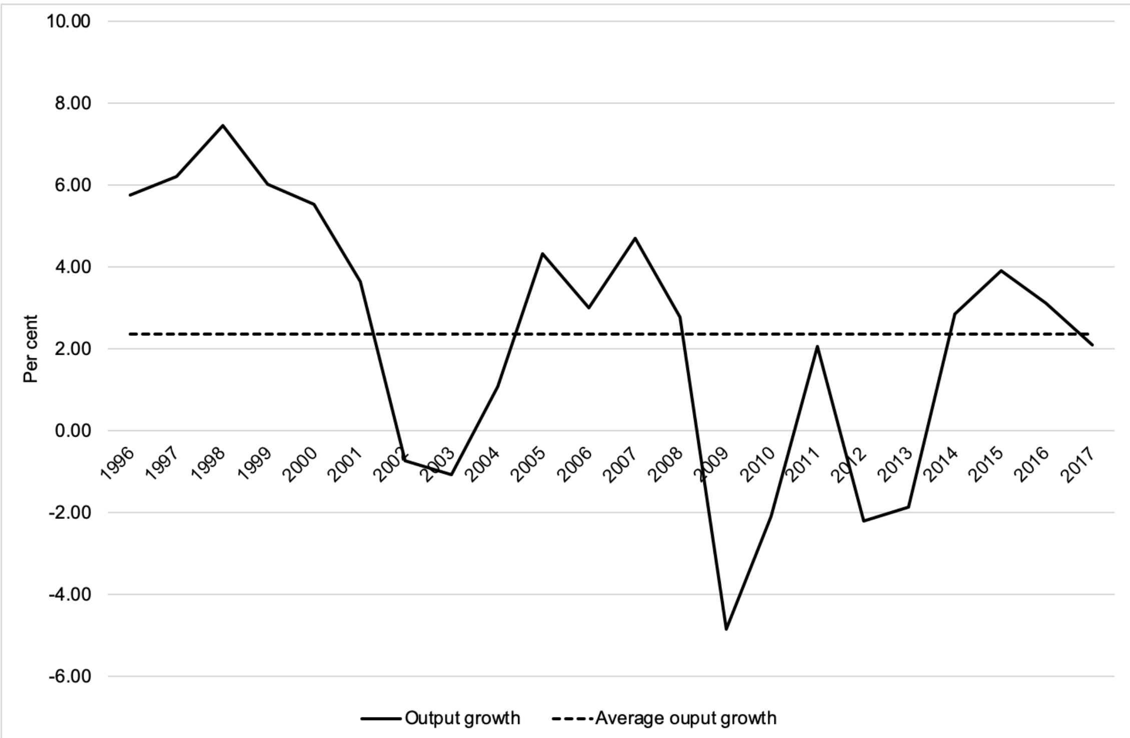
Table 5.12: European Business Cycle Timing (CEPR opinion)

Date	*Peak/Trough*	*upswing (yrs)*	*downswing (yrs)*	*peak-to-peak (yrs)*
2019Q1	Peak?	6		7.5
2013Q1	Trough		1.5	
2011Q3	Peak	2.25		3.5
2009Q2	Trough		1.25	
2008Q1	Peak	14.5		16
1993Q3	Trough		1.5	
1992Q1	Peak	9.5		11
1982Q3	Trough		1.5	
1980Q1	Peak	5		5.5
1975Q1	Trough		0.5	
1974Q3	Peak			
Avg (Std dev)		7.45 (4.7)	1.25 (0.4)	8.7 (4.9)

Source: Center for Economic Policy Research: Euro Area Business Cycle Dating Committee
https://cepr.org/content/euro-area-business-cycle-dating-committee

Figure 5.4 shows the pattern of annual output growth rates over the full sample period, being the weighted average output index for the eight comparator industries in the Netherlands. The average annual rate of change in the output index over the whole period from 1995 to 2017 is 2.35 per cent. The timing of cycle peaks and troughs is based on the peaks and troughs of this output growth series.

Figure 5.4: Output growth rates, weighted average of comparator industries



Oxera determined the timing of the mid-points of cycle as the periods in which the growth rate of output is closest to its long-term average. These may be periods mid-way through a downswing, or midway through an upswing, and these are alternative approaches to defining the cycles. Oxera used downswing mid-cycle periods, which here are 2001, 2008 and 2017. Combining two cycles implies using the 16 annual growth rates from 2001 to 2017 for calculating averages. Alternatively, using the mid-cycle upswings, the best estimates appear to be 1995, 2006, and 2014, although this timing is not quite as clear. This implies an overall 19-year period of growth rates from 1995 to 2014 for averaging. The cycle peaks are in 1998, 2007 and 2015. Troughs are in 2003 and 2009. If the periods are defined from cycle peak to cycle peak, the 19-year period of growth rates from 1998 to 2015 can be used for averaging.

This approach produces different periods to the CEPR view based on European business cycle timing reported in Table 5.12. In this report we follow the more targeted Oxera approach to defining business cycles based on the output index for the eight comparator sectors as our preferred method.

5.5 Discussion

The foregoing sections present the results using the index-based methods of TFP calculation applied to the EU-KLEMS data to produce results for TFP, partial factor productivity, real IPI and real OPI growth rates. Although details have been provided for individual sectors, the key results are based on the weighted average of the eight comparator sectors. The average trends depend on the periods chosen. Table 5.13 summarises, for various alternative periods, the average growth rates for inputs, outputs, TFP, real OPI and real IPI. It also shows partial productivities and associated input price movements: opex PFP, capital PFP, real opex IPI and real capital IPI. The real price indexes for capital IPI should be seen as approximations for the reasons previously given.

Table 5.13: Productivity and Real Price Growth (%)

Period definition:	*Full sample* *1995-2017*	*Mid-cycle (downswing)* *2001-2017*	*Peak cycle* *1998-2015*	*Mid-cycle (upswing)* *1995-2014*	*Post-GFC** *2010-2017*
Input quantity	1.85	0.77	1.10	1.68	0.93
Output quantity	2.35	1.07	1.59	2.24	0.99
TFP	0.50	0.30	0.50	0.56	0.05
Real IPI	-0.04	-0.20	0.03	0.10	-1.20
Real OPI	-0.54	-0.50	-0.47	-0.47	-1.26
Opex PFP	0.44	0.38	0.48	0.45	0.21
Capital PFP	0.60	-0.11	0.20	0.72	-0.68
Real Opex IPI	-0.07	-0.12	0.00	-0.04	-0.70
Real Capital IPI	-0.38	-1.60	-0.55	0.88	-9.61

* The post-GFC period is slightly less than a full-cycle period from 2009-2017.

The estimated long-term average rate of dynamic efficiency is 0.54 per cent per year. This comprises:

- an average TFP growth rate per year of 0.50 per cent; and
- an average decline in real input prices of 0.04 per cent per year.

The average rate of TFP growth has also been decomposed into partial factor productivity growth rates for capital and opex inputs. The estimated PFP growth rates are:

- for Opex PFP the long-term average growth rate per year is 0.44 per cent; and
- for Capital PFP the long-term average growth rate per year is 0.60 per cent.

Table 5.14 presents similar information to Table 5.13, except rather than using the average weights (shown in the last column of Table 5.1) it uses separate weights for TenneT and for GTS (also shown in Table 5.1).

Table 5.14: Productivity and Real Price Growth: Alternative Weights (%)*

Period definition:	*Full sample*	*Mid-cycle (downswing)*	*Peak cycle*	*Mid-cycle (upswing*	*Post-GFC*
	1995-2017	*2001-2017*	*1998-2015*	*1995-2014*	*2010-2017*
Using Tennet Weights					
Input quantity	1.93	0.84	1.18	1.78	1.01
Output quantity	2.44	1.15	1.69	2.36	1.06
TFP	0.52	0.31	0.51	0.58	0.05
Real IPI	-0.05	-0.23	0.02	0.10	-1.33
Real OPI	-0.56	-0.54	-0.49	-0.48	-1.38
Opex PFP	0.45	0.41	0.50	0.45	0.26
Capital PFP	0.60	-0.16	0.22	0.78	-0.82
Real Opex IPI	-0.07	-0.15	0.00	-0.04	-0.76
Real Capital IPI	-0.29	-1.57	-0.51	0.94	-9.40
Using GTS Weights					
Input quantity	1.69	0.68	0.96	1.49	0.82
Output quantity	2.15	0.94	1.41	2.01	0.86
TFP	0.47	0.26	0.45	0.52	0.04
Real IPI	0.00	-0.16	0.05	0.12	-1.05
Real OPI	-0.47	-0.42	-0.40	-0.40	-1.09
Opex PFP	0.40	0.32	0.43	0.42	0.15
Capital PFP	0.57	-0.05	0.14	0.62	-0.53
Real Opex IPI	-0.04	-0.08	0.02	-0.02	-0.62
Real Capital IPI	-0.51	-1.64	-0.61	-0.75	-9.99

* The alternative weights are presented in Table 5.1.

5.6 Supporting Tables

Tables 5.15 and 5.17 show the output and input indexes for each comparator industry in the Netherlands. The input indexes are calculated using the Fisher formula. There is only one output, so the output indexes are merely the original output measure expressed relative to the base period. Tables 5.16 and 5.18 show the growth rates of outputs and inputs respectively. Table 5.19 presents index for opex inputs, which is an aggregation of labour and intermediate inputs (again using the Fisher formula). The growth rates for opex inputs are presented in Table 5.20. The remaining input is capital inputs, and the indexes and growth rates for capital inputs are shown in Tables 5.21 and 5.22 respectively.

Table 5.15: Output indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.024	1.036	1.042	1.091	1.257	1.063	1.091	1.068	1.059
1997	1.069	1.071	1.103	1.359	1.645	1.159	1.177	1.085	1.127
1998	1.145	1.119	1.166	1.800	2.045	1.269	1.251	1.128	1.215
1999	1.170	1.199	1.204	2.497	2.343	1.367	1.343	1.149	1.290
2000	1.207	1.258	1.260	3.258	2.612	1.401	1.429	1.188	1.363
2001	1.233	1.294	1.275	3.896	2.826	1.400	1.487	1.230	1.414
2002	1.214	1.259	1.269	4.298	2.662	1.399	1.430	1.261	1.403
2003	1.184	1.226	1.279	4.479	2.615	1.394	1.384	1.270	1.388
2004	1.192	1.220	1.354	4.391	2.723	1.423	1.391	1.274	1.403
2005	1.215	1.265	1.398	4.481	2.962	1.479	1.432	1.391	1.465
2006	1.233	1.320	1.444	4.577	3.237	1.576	1.503	1.401	1.510
2007	1.280	1.411	1.528	4.768	3.684	1.656	1.568	1.412	1.583
2008	1.302	1.472	1.560	4.709	3.891	1.695	1.654	1.442	1.628
2009	1.188	1.400	1.470	4.521	3.789	1.665	1.582	1.441	1.550
2010	1.181	1.246	1.503	4.460	3.816	1.670	1.558	1.489	1.518
2011	1.179	1.293	1.559	4.297	4.125	1.676	1.619	1.505	1.550
2012	1.175	1.186	1.567	4.208	4.258	1.615	1.685	1.473	1.516
2013	1.119	1.118	1.574	4.207	4.404	1.583	1.684	1.512	1.489
2014	1.132	1.144	1.624	4.294	4.811	1.579	1.750	1.568	1.532
2015	1.159	1.220	1.673	4.330	5.656	1.605	1.827	1.575	1.592
2016	1.165	1.338	1.680	4.391	6.294	1.599	1.892	1.561	1.643
2017	1.139	1.419	1.741	4.442	6.722	1.631	1.975	1.560	1.678
Avg.%	0.59	1.59	2.52	6.78	8.66	2.22	3.09	2.02	2.35

Source: Economic Insights calculations.

Table 5.16: Output growth rates: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	2.42	3.52	4.16	8.73	22.91	6.10	8.73	6.54	5.76
1997	4.22	3.30	5.63	21.95	26.87	8.64	7.60	1.59	6.21
1998	6.94	4.39	5.60	28.09	21.78	9.10	6.08	3.88	7.47
1999	2.16	6.93	3.19	32.75	13.60	7.45	7.09	1.90	6.01
2000	3.06	4.83	4.56	26.57	10.86	2.45	6.19	3.28	5.55
2001	2.13	2.81	1.13	17.90	7.87	-0.07	3.94	3.49	3.64
2002	-1.56	-2.77	-0.50	9.82	-5.99	-0.11	-3.85	2.48	-0.74
2003	-2.45	-2.62	0.85	4.12	-1.75	-0.32	-3.27	0.71	-1.09
2004	0.67	-0.47	5.68	-1.97	4.02	2.02	0.50	0.37	1.07
2005	1.92	3.62	3.16	2.02	8.41	3.85	2.91	8.73	4.33
2006	1.45	4.25	3.27	2.12	8.88	6.38	4.79	0.73	3.01
2007	3.76	6.62	5.63	4.09	12.93	4.99	4.28	0.82	4.72
2008	1.64	4.29	2.10	-1.25	5.47	2.30	5.31	2.10	2.77
2009	-9.10	-5.07	-5.94	-4.07	-2.65	-1.79	-4.46	-0.06	-4.85
2010	-0.59	-11.60	2.22	-1.36	0.70	0.31	-1.51	3.28	-2.09
2011	-0.24	3.69	3.66	-3.72	7.79	0.36	3.86	1.05	2.05
2012	-0.26	-8.66	0.51	-2.11	3.17	-3.69	3.96	-2.16	-2.20
2013	-4.91	-5.89	0.43	-0.02	3.38	-2.04	-0.08	2.59	-1.84
2014	1.18	2.33	3.11	2.05	8.83	-0.21	3.87	3.66	2.85
2015	2.35	6.44	2.96	0.83	16.18	1.64	4.34	0.45	3.89
2016	0.47	9.18	0.43	1.40	10.69	-0.40	3.48	-0.91	3.11
2017	-2.22	5.92	3.56	1.16	6.58	2.01	4.27	-0.07	2.11
Avg.%	0.59	1.59	2.52	6.78	8.66	2.22	3.09	2.02	2.35

Source: Economic Insights calculations.

Table 5.17: Input indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.022	1.056	1.040	1.136	1.276	1.031	1.087	1.043	1.060
1997	1.054	1.099	1.084	1.340	1.597	1.099	1.160	1.067	1.119
1998	1.092	1.137	1.121	1.675	1.928	1.181	1.227	1.095	1.181
1999	1.108	1.199	1.164	2.201	2.207	1.244	1.300	1.117	1.243
2000	1.124	1.250	1.198	2.727	2.411	1.268	1.363	1.133	1.293
2001	1.122	1.285	1.214	3.145	2.550	1.278	1.394	1.172	1.328
2002	1.098	1.251	1.214	3.174	2.410	1.255	1.363	1.184	1.309
2003	1.081	1.218	1.205	3.081	2.299	1.233	1.331	1.187	1.287
2004	1.091	1.213	1.250	3.007	2.358	1.221	1.355	1.188	1.297
2005	1.095	1.238	1.266	2.974	2.552	1.248	1.382	1.236	1.325
2006	1.111	1.281	1.284	2.942	2.735	1.295	1.448	1.231	1.351
2007	1.139	1.356	1.336	2.971	3.033	1.309	1.554	1.245	1.405
2008	1.150	1.404	1.360	2.874	3.240	1.294	1.621	1.267	1.435
2009	1.090	1.351	1.312	2.815	3.214	1.262	1.560	1.280	1.394
2010	1.087	1.233	1.312	2.730	3.212	1.230	1.543	1.329	1.369
2011	1.078	1.280	1.353	2.659	3.391	1.230	1.602	1.351	1.395
2012	1.066	1.192	1.352	2.628	3.437	1.192	1.665	1.323	1.365
2013	1.035	1.127	1.355	2.640	3.440	1.166	1.682	1.351	1.344
2014	1.054	1.138	1.382	2.666	3.744	1.153	1.736	1.397	1.376
2015	1.086	1.190	1.431	2.655	4.355	1.146	1.865	1.382	1.423
2016	1.097	1.272	1.460	2.718	4.816	1.131	1.937	1.377	1.466
2017	1.090	1.335	1.504	2.743	5.206	1.155	2.012	1.393	1.502
Avg. %	0.39	1.31	1.85	4.59	7.50	0.66	3.18	1.51	1.85

Source: Economic Insights calculations.

Table 5.18: Input growth rates: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	2.15	5.42	3.90	12.74	24.41	3.01	8.38	4.17	5.85
1997	3.15	4.06	4.12	16.55	22.38	6.40	6.44	2.35	5.43
1998	3.52	3.36	3.44	22.29	18.84	7.20	5.65	2.54	5.34
1999	1.45	5.27	3.69	27.29	13.53	5.23	5.74	2.02	5.13
2000	1.43	4.21	2.94	21.45	8.84	1.91	4.78	1.42	3.96
2001	-0.22	2.78	1.27	14.25	5.61	0.75	2.19	3.35	2.64
2002	-2.10	-2.72	0.00	0.92	-5.65	-1.81	-2.22	1.08	-1.41
2003	-1.61	-2.70	-0.70	-2.96	-4.74	-1.73	-2.40	0.22	-1.70
2004	0.91	-0.39	3.61	-2.44	2.55	-1.00	1.82	0.11	0.75
2005	0.40	2.09	1.27	-1.12	7.91	2.20	1.97	3.97	2.14
2006	1.45	3.36	1.48	-1.06	6.91	3.66	4.64	-0.47	1.99
2007	2.49	5.72	3.91	0.98	10.37	1.08	7.12	1.17	3.86
2008	0.98	3.43	1.81	-3.31	6.59	-1.10	4.19	1.76	2.13
2009	-5.35	-3.84	-3.56	-2.08	-0.82	-2.52	-3.81	1.04	-2.90
2010	-0.26	-9.08	-0.03	-3.06	-0.05	-2.59	-1.15	3.70	-1.78
2011	-0.91	3.69	3.08	-2.65	5.40	0.04	3.75	1.66	1.84
2012	-1.04	-7.12	-0.06	-1.19	1.36	-3.16	3.88	-2.07	-2.13
2013	-3.02	-5.60	0.18	0.45	0.07	-2.18	1.00	2.11	-1.55
2014	1.83	1.01	2.00	0.98	8.47	-1.18	3.20	3.32	2.34
2015	3.05	4.44	3.45	-0.38	15.13	-0.60	7.14	-1.09	3.37
2016	0.93	6.66	2.03	2.34	10.06	-1.32	3.82	-0.34	2.95
2017	-0.59	4.86	2.95	0.89	7.79	2.11	3.77	1.16	2.43
Avg.	0.39	1.31	1.85	4.59	7.50	0.66	3.18	1.51	1.85

Source: Economic Insights calculations.

Table 5.19: Opex input indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.025	1.055	1.043	1.187	1.282	1.038	1.092	1.050	1.066
1997	1.062	1.099	1.090	1.450	1.614	1.131	1.166	1.078	1.130
1998	1.105	1.137	1.128	1.928	1.954	1.230	1.233	1.118	1.200
1999	1.122	1.200	1.171	2.643	2.232	1.317	1.305	1.152	1.270
2000	1.140	1.252	1.206	3.347	2.433	1.334	1.367	1.178	1.325
2001	1.138	1.287	1.220	3.940	2.565	1.336	1.393	1.236	1.364
2002	1.113	1.253	1.218	3.995	2.403	1.308	1.355	1.256	1.345
2003	1.095	1.219	1.205	3.876	2.279	1.290	1.319	1.263	1.322
2004	1.108	1.214	1.254	3.771	2.333	1.287	1.343	1.265	1.333
2005	1.116	1.240	1.271	3.719	2.534	1.342	1.369	1.334	1.367
2006	1.135	1.284	1.291	3.663	2.719	1.423	1.434	1.323	1.396
2007	1.167	1.361	1.350	3.715	3.018	1.460	1.506	1.338	1.452
2008	1.178	1.409	1.375	3.529	3.217	1.445	1.574	1.363	1.482
2009	1.112	1.353	1.321	3.348	3.179	1.403	1.507	1.373	1.432
2010	1.109	1.232	1.318	3.240	3.165	1.374	1.498	1.430	1.407
2011	1.098	1.278	1.360	3.141	3.352	1.387	1.561	1.442	1.431
2012	1.086	1.190	1.357	3.124	3.388	1.334	1.628	1.384	1.395
2013	1.052	1.124	1.359	3.168	3.382	1.307	1.639	1.409	1.372
2014	1.073	1.136	1.390	3.217	3.706	1.319	1.704	1.453	1.407
2015	1.109	1.187	1.441	3.197	4.327	1.337	1.786	1.417	1.451
2016	1.120	1.270	1.469	3.320	4.680	1.313	1.861	1.395	1.490
2017	1.113	1.333	1.516	3.376	4.947	1.340	1.936	1.403	1.524
Avg.%	0.49	1.31	1.89	5.53	7.27	1.33	3.00	1.54	1.91

Source: Economic Insights calculations.

Table 5.20: Opex input growth rates: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	2.45	5.36	4.17	17.11	24.86	3.69	8.78	4.90	6.37
1997	3.56	4.07	4.41	20.06	23.02	8.63	6.62	2.65	5.89
1998	3.93	3.42	3.48	28.49	19.12	8.35	5.58	3.61	6.01
1999	1.56	5.38	3.71	31.51	13.27	6.85	5.61	3.01	5.60
2000	1.63	4.21	2.93	23.64	8.63	1.30	4.69	2.26	4.24
2001	-0.23	2.80	1.21	16.29	5.31	0.15	1.87	4.74	2.96
2002	-2.19	-2.73	-0.18	1.38	-6.52	-2.11	-2.74	1.67	-1.41
2003	-1.62	-2.70	-1.11	-3.01	-5.33	-1.39	-2.75	0.51	-1.75
2004	1.17	-0.38	4.02	-2.76	2.37	-0.27	1.82	0.15	0.86
2005	0.68	2.12	1.35	-1.39	8.27	4.21	1.91	5.30	2.53
2006	1.70	3.44	1.58	-1.52	7.03	5.85	4.64	-0.80	2.04
2007	2.77	5.84	4.47	1.41	10.42	2.60	4.90	1.15	3.93
2008	1.00	3.45	1.80	-5.12	6.41	-1.07	4.45	1.81	2.06
2009	-5.82	-4.03	-3.98	-5.27	-1.19	-2.93	-4.34	0.77	-3.39
2010	-0.28	-9.40	-0.25	-3.28	-0.45	-2.09	-0.64	4.06	-1.80
2011	-0.94	3.73	3.14	-3.08	5.73	0.93	4.17	0.85	1.73
2012	-1.10	-7.20	-0.20	-0.55	1.07	-3.88	4.17	-4.12	-2.57
2013	-3.22	-5.67	0.11	1.37	-0.18	-2.08	0.71	1.78	-1.68
2014	1.98	1.02	2.25	1.54	9.16	0.95	3.87	3.11	2.52
2015	3.35	4.47	3.64	-0.63	15.49	1.38	4.70	-2.53	3.07
2016	0.99	6.69	1.93	3.79	7.84	-1.80	4.11	-1.59	2.66
2017	-0.63	4.87	3.09	1.68	5.54	1.99	3.94	0.55	2.24
Avg.%	0.49	1.31	1.89	5.53	7.27	1.33	3.00	1.54	1.91

Source: Economic Insights calculations.

Table 5.21: Capital input indexes: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	0.989	1.039	1.019	1.057	1.117	1.015	1.029	1.025	1.026
1997	0.981	1.084	1.039	1.171	1.242	1.027	1.073	1.042	1.055
1998	0.980	1.141	1.073	1.302	1.447	1.072	1.147	1.043	1.094
1999	0.985	1.252	1.111	1.562	1.708	1.081	1.234	1.039	1.151
2000	0.981	1.300	1.146	1.828	1.915	1.121	1.309	1.031	1.186
2001	0.980	1.371	1.166	1.986	2.083	1.147	1.385	1.021	1.218
2002	0.966	1.376	1.183	1.982	2.118	1.136	1.424	1.013	1.218
2003	0.951	1.355	1.215	1.925	2.133	1.106	1.445	1.006	1.211
2004	0.934	1.344	1.221	1.889	2.220	1.076	1.471	1.006	1.207
2005	0.910	1.346	1.230	1.876	2.337	1.045	1.511	1.002	1.205
2006	0.901	1.354	1.241	1.870	2.483	1.020	1.583	1.007	1.214
2007	0.896	1.387	1.247	1.875	2.747	0.981	2.049	1.019	1.252
2008	0.903	1.430	1.270	1.866	2.964	0.969	2.093	1.036	1.277
2009	0.907	1.434	1.263	1.922	3.024	0.956	2.108	1.054	1.287
2010	0.907	1.432	1.285	1.871	3.135	0.923	1.986	1.084	1.291
2011	0.904	1.455	1.319	1.834	3.211	0.910	1.974	1.127	1.309
2012	0.901	1.444	1.334	1.795	3.361	0.892	1.982	1.165	1.318
2013	0.898	1.443	1.345	1.776	3.452	0.871	2.082	1.200	1.331
2014	0.895	1.437	1.348	1.776	3.531	0.833	1.962	1.247	1.335
2015	0.884	1.447	1.378	1.777	3.986	0.803	2.825	1.281	1.387
2016	0.883	1.470	1.415	1.766	5.209	0.798	2.845	1.315	1.426
2017	0.887	1.507	1.444	1.750	6.585	0.817	2.904	1.351	1.470
Avg. %	-0.54	1.86	1.67	2.54	8.57	-0.92	4.85	1.37	1.75

Source: Economic Insights calculations.

Table 5.22: Capital input growth rates: Netherlands comparator sectors, 1995–2017

Year	*Repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical and admin. serv.*	*Electricity, gas, water and waste management*	*Weighted average*
1996	-1.06	3.80	1.88	5.51	11.07	1.50	2.83	2.48	2.54
1997	-0.87	4.28	1.96	10.27	10.65	1.16	4.22	1.66	2.85
1998	-0.11	5.14	3.20	10.57	15.22	4.25	6.65	0.02	3.58
1999	0.51	9.28	3.53	18.22	16.62	0.84	7.29	-0.34	5.13
2000	-0.40	3.77	3.06	15.73	11.43	3.62	5.91	-0.81	2.97
2001	-0.11	5.27	1.74	8.32	8.41	2.36	5.65	-0.94	2.61
2002	-1.37	0.36	1.43	-0.24	1.64	-1.02	2.83	-0.79	0.05
2003	-1.56	-1.50	2.65	-2.88	0.71	-2.61	1.42	-0.70	-0.58
2004	-1.85	-0.82	0.52	-1.91	4.00	-2.83	1.82	-0.03	-0.36
2005	-2.61	0.10	0.74	-0.69	5.16	-2.88	2.68	-0.38	-0.18
2006	-0.98	0.64	0.84	-0.34	6.03	-2.42	4.63	0.49	0.74
2007	-0.51	2.39	0.55	0.32	10.10	-3.91	25.81	1.23	3.09
2008	0.74	3.06	1.81	-0.48	7.61	-1.20	2.11	1.61	2.00
2009	0.44	0.30	-0.56	2.96	2.01	-1.37	0.72	1.79	0.75
2010	0.03	-0.17	1.71	-2.72	3.61	-3.53	-5.93	2.80	0.34
2011	-0.37	1.60	2.62	-2.01	2.40	-1.45	-0.63	3.81	1.35
2012	-0.31	-0.73	1.14	-2.15	4.56	-2.00	0.41	3.32	0.71
2013	-0.31	-0.08	0.80	-1.05	2.65	-2.33	4.91	2.95	1.00
2014	-0.34	-0.40	0.20	0.00	2.26	-4.49	-5.93	3.91	0.26
2015	-1.33	0.68	2.26	0.08	12.13	-3.68	36.45	2.67	3.85
2016	-0.05	1.54	2.62	-0.65	26.75	-0.54	0.72	2.64	2.81
2017	0.44	2.48	2.05	-0.92	23.45	2.33	2.04	2.68	3.02
Avg.	-0.54	1.86	1.67	2.54	8.57	-0.92	4.85	1.37	1.75

Source: Economic Insights calculations.

6 IDENTIFYING FRONTIER SHIFT

In principle, TFP change is the combined effect of:

- *technical change*: shifts in the efficiency frontier which represents the maximum feasible outputs that can be produced with different mixes of inputs, or the minimum feasible inputs that can be used to produce different mixes of outputs;
- *changes in efficiency*: movements in the position of a firm's input-output mix relative to the efficiency frontier, such as when a firm moves closer to the frontier (i.e, 'catch-up');
- *changes in scale efficiency*: which arise when there are variable returns to scale due to changes in the average levels of outputs (or inputs) per firm, which shifts that firm closer to, or away from, the optimum scale of production.

This chapter presents a method for identifying and removing catch-up productivity effects from the measured rate of productivity change. In its 2016 study Oxera said that the evidence is limited in this area, however, they concluded that catch-up and scale effects were not sufficiently material to require an adjustment (Oxera, 2016b). Europe Economics used a broadly similar method and came to a similar conclusion.

It is important to separate the catch-up effects from the other sources of productivity change because the regulator will often apply a separate form of correction to the cost base of a firm to account for the assessed scope for catch-up productivity gains. For example, a major study of the cost efficiency levels of European electricity and gas TSO's has recently been carried out by Sumicsid and the Council of European Energy Regulators (CEER) (2019a, 2019b); and studies of this kind may be used by regulators to include a firm-specific catch-up requirement in the regulatory plans of inefficient networks. The aim of the present study in seeking to identify historical rates of 'catch-up' productivity change, is to enable the regulator to separate this effect from the rate of technical change (or frontier shift), and other sources of productivity growth, to ensure there is no 'double counting' of the catch-up efficiency effects.

Given the potential importance of this question, we have analysed the components of productivity change in the comparator industries. This analysis:

- uses the EU KLEMS database and includes eleven European countries in a longitudinal analysis of each of the comparator industries (separately);
- uses data envelopment analysis (DEA) to calculate the Malmquist TFP index (on a GO basis) and its decomposition in accordance with the method developed by Färe et al (1994),[15] which uses countries as the entities being compared in the analysis.

Since reliable data for the individual firms within the comparator industries is not available, the analysis undertaken in this chapter is only feasible when there are a number of countries in the data sample. The decomposition of productivity trends into its constituent parts requires

[15] (Fare et al., 1994) It is noted that under certain conditions the rate of TFP growth measured by the Malmquist TFP index is equal to that obtained using the Fisher Ideal Index; 73.

data that has both cross-sectional (i.e. across production units) and time-series dimensions. In this analysis, for each comparator industry sector, the set of countries represent a set of production units, using a well-established method discussed in section 6.1. The econometric analysis in the following chapter uses the same group of European countries because in that analysis it is imperative to use a data sample of sufficient size to yield reliable results, given the small trends being estimated.

The main benchmarking method used in this report, as set out in chapter 5, follows previous approaches used by ACM in using productivity trends in eight Dutch industry sectors as a guide to the productivity trends of Dutch electricity and gas TSOs. The weighting scheme produced by Ecorys is designed to reflect the varying degrees of similarity of the comparator sectors to the activities of the energy TSOs. This approach is based on the assumption that the "rate of technological progress in these sectors is a good indicator of the rate of technological progress in the regulated sector in question" (Oxera, 2016b, p. 8). The weighted average of the eight comparator industries is essentially taken to be a proxy for the energy TSOs.

The analysis in this and the next chapter uses data for the same eight comparator industries in a set of comparable European jurisdictions. While these may not be as closely related to the Dutch energy TSOs as the data for the comparator industries in the Netherlands, but they are nevertheless useful comparators because the European jurisdictions used in this analysis have many similarities. To put this another way, to implement the methods required to get more detailed information on the composition of productivity growth, we need access to more observations than are available from the Netherlands alone.

One way to view this method is as an indirect way of comparing energy TSOs in a number of European jurisdictions. This follows the logic that just as the weighted average of the eight comparator industries in the Netherlands is used to serve as a proxy for the energy TSOs in that country, so the same eight comparator industries in other jurisdictions, similarly averaged, could be viewed as proxies for the energy TSOs in those jurisdictions. Hence, by comparing the same eight comparator industries of each jurisdiction, and applying the same weights to derive averages, this analysis can be viewed as indirectly comparing the energy TSOs between the jurisdictions.

Thus, the analysis in this and the following chapter can assist to better understand the productivity estimates derived from Netherlands data.

This analysis in this chapter produces the following estimates, for each comparator industry:

- the Malmquist TFP index and its rate of change;
- the rate of technical change;
- the rate of efficiency change, or catch-up, for each country; and
- that contribution of the effect of changes in scale efficiency.

6.1 Method

The Malmquist productivity index measures TFP changes based on distance functions. Distance functions are functional representations of multiple-output, multiple-input technology in which the 'distance' referred to is a measure of distance from an efficiency frontier. Because distance functions only require data on input and output quantities, the Malmquist TFP index, unlike most other TFP index methods, does not require information on prices or values to aggregate inputs and outputs. Distance functions can be estimated parametrically using econometric analysis, or nonparametrically using data envelopment analysis (DEA); a technique that uses linear programming to construct convex efficiency frontiers. The distance measures are the reciprocals of the efficiency scores measured by DEA.

We denote the distance function, defined in terms of period *t* technology, as: $D^t(x_t, y_t)$, here shown as a function of period *t* inputs, x_t, and period *t* outputs, y_t. A Malmquist index representing the productivity change (or relativity) between periods *t* and *t*+1 may be defined in terms of period *t* technology as:

$$M^t = \frac{D^t(x_{t+1}, y_{t+1})}{D^t(x_t, y_t)}$$

Alternatively, it may be defined in terms of period *t*+1 technology as:

$$M^{t+1} = \frac{D^{t+1}(x_{t+1}, y_{t+1})}{D^{t+1}(x_t, y_t)}$$

It is conventional to use the geometric mean of these two measures as the Malmquist index:

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \left[\frac{D^t(x_{t+1}, y_{t+1})}{D^t(x_t, y_t)} . \frac{D^{t+1}(x_{t+1}, y_{t+1})}{D^{t+1}(x_t, y_t)}\right]^{1/2} \qquad (6.1)$$

In DEA the date of the technology is defined by the period of data used for the peer firms when calculating the efficiency score for a given firm. Since the Malmquist index uses four distance measures, four DEA programs need to be run to calculate the Malmquist index for each year.

Färe et al (1994) proposed a decomposition of the right-hand-side of equation 6.1 as follows:

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \text{TechCh} \times \text{EffCh} \qquad (6.2)$$

Where TechCh refers to technical change and EffCh refers to efficiency change, defined as:

$$\text{TechCh} = \left[\frac{D^t(x_t, y_t)}{D^{t+1}(x_t, y_t)} . \frac{D^t(x_{t+1}, y_{t+1})}{D^{t+1}(x_{t+1}, y_{t+1})}\right]^{1/2} \qquad (6.3)$$

$$\text{EffCh} = \frac{D^{t+1}(x_{t+1}, y_{t+1})}{D^t(x_t, y_t)} \qquad (6.4)$$

Efficiency change can be further decomposed into pure efficiency change ('PEC') and scale efficiency change ('SEC'): EffCh = PEC × SEC. The latter is defined as:

$$\text{SEC} = \frac{D^{t+1}_{vrs}(x_{t+1}, y_{t+1})}{D^t_{crs}(x_t, y_t)} \qquad (6.5)$$

where the subscripts VRS and CRS refer to the distance measures obtained using DEA programs which impose variable and constant returns-to-scale respectively. PEC is obtained as the balance. In the Färe *et al* method, unless otherwise indicated, the DEA programs assume the reference technology is CRS. Only if the technology is CRS, will the Malmquist index satisfy the basic properties of TFP indexes.[16] Deviations from CRS are nevertheless identified by the SEC term (Färe, Grosskopf and Roos, 1998).

For this study, Malmquist indexes have been calculated in Stata using the community-contributed routine *malmq2*.[17] This routine provides the decomposition by Färe et al discussed above as one of its options.

6.2 Results

The results of the DEA Malmquist index analysis are shown in Tables 6.1 to 6.5. Table 6.1 shows the estimated Malmquist index for each comparator industry, and the weighted average of the eight industries using the same weights produced by Ecorys. Table 6.2 presents the annual growth rates of the Malmquist TFP indexes. The decomposition of the TFP growth rates are then shown in Tables 6.3 to 6.5, namely:

(i) the rates of technical change in Table 6.3;

(ii) the rates of efficiency change in Table 6.4;

(iii) the rates of scale efficiency change in Table 6.5.

Referring to the results for the weighted average of the eight comparator industries, over the whole period from 1995 to 2017 the average rate of growth of the Malmquist TFP index for the selected European countries in aggregate was 0.61 per cent per year. This is similar to the estimated TFP growth rate for the comparator industries in the Netherlands for the same period obtained using the Fisher index of 0.50 per cent.

The decomposition of the Malmquist index into its component effects shows, again for the weighted average of the comparators industries and over the same period:

- The average rate of technical change is estimated to be 0.82 per cent per year.
- The average rate of efficiency change is -0.31 per cent per year.
- The effect of scale efficiency changes is overall negligible, contributing 0.11 per cent per year to the average to the rate of TFP growth.

These findings indicate that the rate of overall TFP change does not overstate the rate of frontier shift. On the contrary, the estimated rate of frontier shift, together with the effects of scale change, together are higher than the rate of TFP change because there has been a small overall average negative trend in average efficiency relative to the best practice efficiency frontier.

For comparison purposes, it is also convenient present the average trends in Malmquist TFP and its components over another of the periods used in Table 5.13 and 5.14, namely the period

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[16] If all inputs are multiplied by a positive scalar δ and all outputs are increased by a non-negative scalar α, then the resulting TFP change index will only equal α/δ, using the Malmquist method, if there are constant returns to scale (Coelli et al., 2005, p. 294).

[17] Available at: < kerrydu.github.io >.

from 2001 to 2017, representing two full cycles defined from mid-cycle (downswing) years – the same method as used by Oxera.

Over this more limited period the weighted average rates of growth of the Malmquist index results for the eight comparator industries, in aggregate for the selected European countries, are as follows:

- The Malmquist TFP growth is 0.45 per cent per year;
- The rate of technical change is estimated to be 0.57 per cent per year.
- The average rate of efficiency change is -0.27 per cent per year.
- The effect of scale efficiency changes is 0.15 per cent per year.

This indicates that the finding that the rate of overall TFP change is less than the rate of frontier shift is robust to the alternative period definition.

Table 6.1: **Malmquist TFP indexes: Comparator sectors for selected European countries, 1995–2017**

Year	*Other manufacturing; repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical, administrative and support service activities*	*Electricity, gas, steam; water supply, sewerage, waste management*	*Weighted average*
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.015	1.010	1.002	1.060	1.011	1.017	0.993	1.034	1.016
1997	1.020	1.001	1.015	1.138	1.057	1.039	0.993	1.036	1.024
1998	1.029	1.009	1.019	1.220	1.086	1.072	0.983	1.036	1.034
1999	1.038	1.006	1.025	1.295	1.080	1.088	0.979	1.046	1.041
2000	1.060	1.013	1.035	1.377	1.063	1.108	0.968	1.066	1.055
2001	1.064	1.002	1.034	1.470	1.069	1.111	0.971	1.078	1.059
2002	1.064	1.011	1.036	1.590	1.055	1.134	0.978	1.100	1.070
2003	1.059	1.012	1.033	1.672	1.062	1.153	0.968	1.128	1.077
2004	1.072	1.025	1.036	1.726	1.086	1.194	0.968	1.148	1.091
2005	1.090	1.028	1.037	1.761	1.100	1.232	0.979	1.150	1.100
2006	1.102	1.038	1.040	1.838	1.127	1.265	0.986	1.163	1.114
2007	1.115	1.040	1.054	1.919	1.174	1.298	0.988	1.172	1.127
2008	1.107	1.033	1.054	2.026	1.161	1.311	0.985	1.179	1.127
2009	1.112	1.015	1.030	2.071	1.160	1.333	0.966	1.159	1.116
2010	1.133	1.012	1.045	2.138	1.168	1.356	0.960	1.168	1.126
2011	1.139	1.008	1.066	2.165	1.204	1.378	0.963	1.147	1.129
2012	1.133	1.006	1.076	2.242	1.211	1.384	0.961	1.164	1.134
2013	1.136	1.002	1.077	2.280	1.210	1.408	0.961	1.150	1.132
2014	1.125	1.000	1.089	2.311	1.211	1.418	0.956	1.142	1.130
2015	1.132	1.005	1.089	2.312	1.237	1.439	0.973	1.150	1.137
2016	1.134	1.013	1.088	2.342	1.245	1.463	0.973	1.144	1.140
2017	1.128	1.015	1.099	2.376	1.236	1.492	0.987	1.148	1.143
Avg.	0.55%	0.07%	0.43%	3.93%	0.96%	1.82%	-0.06%	0.63%	0.61%

Source: Economic Insights calculations.

Table 6.2: **Malmquist TFP growth rates: Comparator sectors for selected European countries, 1995–2017**

Year	*Other manufacturing; repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical, administrative and support service activities*	*Electricity, gas, steam; water supply, sewerage, waste management*	*Weighted average*
1996	1.45	0.97	0.22	5.81	1.11	1.72	-0.69	3.32	1.60
1997	0.54	-0.86	1.25	7.12	4.40	2.15	0.00	0.18	0.78
1998	0.90	0.78	0.42	6.92	2.75	3.07	-1.06	0.01	0.95
1999	0.84	-0.30	0.56	5.97	-0.59	1.53	-0.36	1.02	0.67
2000	2.14	0.73	0.99	6.20	-1.56	1.81	-1.17	1.85	1.34
2001	0.36	-1.11	-0.14	6.52	0.56	0.22	0.34	1.12	0.41
2002	0.02	0.83	0.26	7.82	-1.36	2.08	0.67	2.04	1.03
2003	-0.52	0.12	-0.33	5.06	0.68	1.66	-0.97	2.46	0.61
2004	1.24	1.30	0.30	3.16	2.27	3.48	-0.06	1.76	1.35
2005	1.65	0.30	0.07	2.02	1.24	3.11	1.22	0.17	0.83
2006	1.13	0.92	0.30	4.24	2.41	2.68	0.70	1.16	1.21
2007	1.18	0.23	1.35	4.34	4.15	2.58	0.14	0.76	1.18
2008	-0.74	-0.70	-0.01	5.42	-1.12	1.01	-0.26	0.59	-0.02
2009	0.47	-1.71	-2.25	2.19	-0.10	1.61	-1.98	-1.66	-0.92
2010	1.80	-0.34	1.38	3.18	0.65	1.75	-0.57	0.76	0.87
2011	0.60	-0.41	2.07	1.27	3.07	1.58	0.31	-1.87	0.24
2012	-0.59	-0.19	0.93	3.50	0.56	0.46	-0.20	1.48	0.43
2013	0.27	-0.36	0.03	1.66	-0.10	1.69	-0.05	-1.14	-0.14
2014	-0.93	-0.24	1.14	1.37	0.10	0.73	-0.51	-0.75	-0.23
2015	0.62	0.52	-0.04	0.05	2.12	1.44	1.77	0.74	0.69
2016	0.13	0.80	-0.09	1.29	0.64	1.70	0.03	-0.57	0.23
2017	-0.52	0.20	1.07	1.41	-0.69	1.94	1.37	0.37	0.30
Avg.	0.55	0.07	0.43	3.93	0.96	1.82	-0.06	0.63	0.61

Source: Economic Insights calculations.

Table 6.3: **Technical change growth rates: Comparator sectors for selected European countries, 1995–2017 (%)**

Year	*Other manufacturing; repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical, administrative and support service activities*	*Electricity, gas, steam; water supply, sewerage, waste management*	*Weighted average*
1996	0.64	1.25	0.75	7.09	1.48	1.91	0.47	2.42	1.53
1997	1.74	0.52	1.33	4.37	3.57	1.60	1.08	0.00	1.24
1998	0.79	0.60	1.39	5.71	4.52	1.90	0.03	0.33	1.16
1999	0.79	1.12	1.06	12.26	5.51	3.78	0.10	2.93	2.18
2000	2.63	1.79	1.11	5.40	0.08	0.99	0.13	1.61	1.81
2001	0.36	0.53	0.44	4.42	0.56	0.24	0.28	1.33	0.81
2002	0.11	0.30	0.03	11.55	0.25	0.57	0.00	1.25	0.94
2003	0.09	0.41	0.23	1.15	0.00	2.33	0.00	2.31	0.71
2004	0.45	0.56	0.01	3.79	0.27	2.09	0.00	0.73	0.63
2005	1.15	0.27	0.66	3.16	0.31	3.10	0.00	0.54	0.77
2006	1.72	0.98	0.53	4.74	0.54	2.87	0.00	1.08	1.25
2007	1.15	0.16	0.57	1.73	0.98	2.66	0.34	0.62	0.72
2008	0.58	0.26	0.03	3.12	0.05	3.19	0.37	0.33	0.52
2009	0.31	0.15	0.01	1.41	0.00	0.06	0.00	0.00	0.18
2010	1.64	0.00	0.88	2.96	0.52	1.06	0.00	0.00	0.70
2011	0.31	0.00	0.72	2.36	1.06	0.78	0.00	0.00	0.36
2012	0.84	0.00	0.46	1.37	0.48	0.22	0.00	0.31	0.42
2013	0.72	0.00	0.15	1.28	0.97	2.11	0.00	0.20	0.39
2014	0.00	0.00	0.24	2.40	0.86	1.07	0.00	0.00	0.22
2015	0.85	0.20	0.11	0.40	3.18	1.98	0.00	0.00	0.51
2016	0.18	0.25	0.02	2.08	0.25	3.19	0.05	0.00	0.29
2017	0.70	0.56	0.46	3.08	0.00	1.58	0.00	0.70	0.68
Avg.	0.81	0.45	0.51	3.90	1.16	1.78	0.13	0.76	0.82

Source: Economic Insights calculations.

Table 6.4: **Efficiency change growth rates: Comparator sectors for selected European countries, 1995–2017 (%)**

Year	*Other manufacturing; repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecomm- -unications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical, administrative and support service activities*	*Electricity, gas, steam; water supply, sewerage, waste management*	*Weighted average*
1996	0.24	-0.67	-0.81	-1.35	-1.00	-1.10	-0.73	0.21	-0.36
1997	-0.51	-1.18	-0.19	0.73	-1.39	-0.20	-1.21	0.58	-0.44
1998	-0.28	-0.01	-0.41	-1.26	-0.74	0.98	-0.82	0.15	-0.23
1999	-0.07	-0.52	-0.59	-2.99	-2.77	-2.55	-0.10	-1.45	-0.87
2000	-0.47	-0.81	-0.07	-2.23	-0.72	1.48	-1.25	-0.21	-0.57
2001	-0.99	-0.61	-0.44	2.55	0.66	-0.43	-0.10	0.10	-0.27
2002	-0.06	0.06	0.41	-1.61	-1.28	-0.61	0.08	0.41	-0.03
2003	-1.27	0.28	0.07	0.19	0.26	0.02	-0.96	0.65	-0.14
2004	0.30	0.40	0.02	-0.56	0.90	1.19	0.36	0.74	0.39
2005	0.39	-0.43	-0.31	1.01	-0.61	0.48	1.05	-1.02	-0.16
2006	-0.02	-0.89	0.22	0.20	0.56	-0.13	-0.44	1.42	0.10
2007	-0.24	0.25	-0.19	0.55	1.12	-0.01	-0.58	-1.22	-0.21
2008	-1.40	-1.54	-0.72	0.61	-1.30	-1.58	-1.11	-0.36	-1.02
2009	0.81	-1.97	-1.10	0.95	-0.10	0.94	-2.16	-2.41	-0.98
2010	0.44	-0.17	-0.07	-0.30	0.12	0.57	-0.64	1.15	0.24
2011	0.20	-0.33	0.33	-0.92	0.78	0.64	0.94	-2.02	-0.31
2012	-1.33	-0.41	0.16	0.61	-0.61	0.02	-0.52	0.96	-0.24
2013	-0.15	-0.12	-0.18	-1.06	-1.29	-0.06	-0.01	-1.09	-0.43
2014	-1.14	-0.33	0.56	-0.91	-0.51	0.03	-0.64	-0.65	-0.52
2015	-1.17	-0.17	-0.07	-1.26	-0.37	-0.41	2.04	0.08	-0.26
2016	-0.50	0.30	-0.37	-1.59	0.81	-0.76	0.19	-0.56	-0.24
2017	-0.85	-0.34	0.59	-0.40	-0.86	-0.09	1.38	0.15	-0.16
Avg.	-0.37	-0.42	-0.14	-0.41	-0.38	-0.07	-0.24	-0.20	-0.31

Source: Economic Insights calculations.

Table 6.5: **Scale efficiency contributions to growth rates: Comparator sectors for selected European countries, 1995–2017 (%)**

Year	*Other manufacturing; repair and installation of machinery and equipment*	*Construction*	*Transportation and Storage*	*Telecommun -ications*	*IT and other information services*	*Financial and insurance activities*	*Professional, scientific, technical, administrative and support service activities*	*Electricity, gas, steam; water supply, sewerage, waste management*	*Weighted average*
1996	0.58	0.39	0.28	0.05	0.62	0.92	-0.43	0.69	0.43
1997	-0.70	-0.20	0.11	2.06	2.13	0.75	0.17	-0.42	-0.03
1998	0.39	0.19	-0.55	2.52	-1.05	0.19	-0.28	-0.48	0.02
1999	0.13	-0.89	0.11	-2.90	-2.87	0.33	-0.35	-0.33	-0.57
2000	-0.02	-0.23	-0.04	3.28	-0.79	-0.66	-0.05	0.49	0.13
2001	1.01	-1.03	-0.14	-0.25	-0.49	0.42	0.17	-0.26	-0.10
2002	-0.03	0.48	-0.18	-2.01	-0.32	2.11	0.59	0.38	0.12
2003	0.71	-0.56	-0.63	3.77	0.44	-0.71	-0.01	-0.48	0.06
2004	0.48	0.35	0.27	-0.09	1.09	0.21	-0.42	0.30	0.33
2005	0.12	0.49	-0.29	-2.09	1.66	-0.45	0.18	0.68	0.24
2006	-0.56	0.84	-0.47	-0.72	1.30	-0.05	1.23	-1.28	-0.12
2007	0.29	-0.18	0.97	2.06	2.05	-0.05	0.40	1.46	0.69
2008	0.10	0.59	0.72	1.58	0.17	-0.63	0.50	0.62	0.49
2009	-0.60	0.17	-1.16	-0.14	-0.01	0.62	0.19	0.77	-0.08
2010	-0.27	-0.18	0.57	0.60	0.01	0.12	0.09	-0.39	-0.07
2011	0.09	-0.08	1.02	-0.14	1.23	0.16	-0.62	0.17	0.20
2012	-0.10	0.21	0.31	1.52	0.69	0.22	0.32	0.23	0.26
2013	-0.30	-0.25	0.06	1.42	0.21	-0.34	-0.02	-0.24	-0.10
2014	0.23	0.09	0.31	-0.06	-0.26	-0.36	0.17	-0.08	0.08
2015	0.90	0.50	-0.08	0.88	-0.60	-0.12	-0.25	0.67	0.44
2016	0.44	0.23	0.26	0.86	-0.43	-0.74	-0.21	-0.01	0.18
2017	-0.38	-0.02	0.02	-1.23	0.17	0.47	-0.01	-0.47	-0.23
Avg.	0.11	0.04	0.07	0.50	0.23	0.11	0.06	0.09	0.11

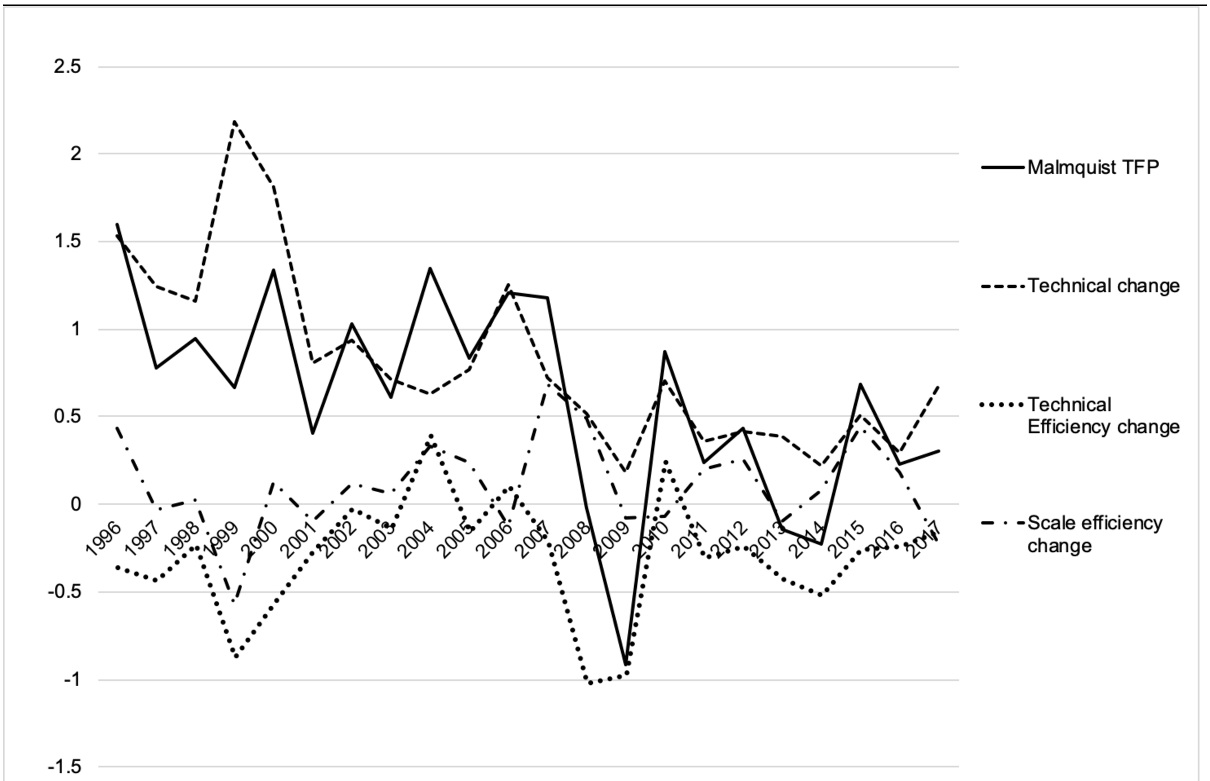
Source: Economic Insights calculations.

6.3 Discussion of trends

The estimated growth rates for the weighted average of the eight industries are depicted in Figure 6.1. In the period up to 2007, the Malmquist TFP index grew at an average rate of 1.0 per cent per year, whilst the influence of the global financial crisis (GFC) is shown in the results for 2008 and 2009. In the period from 2010 to 2017, the Malmquist TFP index grew at a much slower average rate of 0.3 per cent per year. This overall pattern is again similar to the TFP Fisher index results for the Netherlands.

Technical change has been the largest effect on TFP change, and the rate of technical change had a declining trend over the sample period. Over the whole period from 1995 to 2017, In the period up to 2007, technical change averaged 1.15 per cent per year, whereas from 2010 to 2017, it averaged 0.45 per cent per year. While the effect of technical efficiency change was slightly negative on average for the whole period, most of this effect was concentrated in the periods 1999-2000 and 2008-2009. The findings of productivity slowdown combined with negative efficiency change is not unusual. For example, it is consistent with a recent broad-based study of productivity trends in OECD countries in the post-2000 period by Andrews *et al* (2016).

Figure 6.1: Trends in technical change, Efficiency change and Scale efficiency change



7 EMBODIED AND DISEMBODIED TECHNICAL CHANGE

In principle, changes in TFP measures can be readily decomposed into component partial productivity measures for opex and for capital inputs (see chapter 5). However, the PFP for capital inputs only measures the partial productivity of the capital *stock*, which may be different from the rate of technical change relevant to capex (although Appendix B explores a special case in which they are equal). The rate of technical change applying to capex is the more relevant to regulatory decisions on the amount of new investment in capital that should be included when calculating a business's forward-looking revenue requirement. The extent to which the partial productivity of the capital stock can reliably reflect the rate of technical change applying to capex will depend on a number of factors, including depreciation profiles, and the nature of technical progress.

To clarify the distinction between productivity gains on capital stock and productivity gains relating to new capital investment, it is useful to introduce the concepts of disembodied and embodied technical change. Disembodied technical change refers to general improvements in the methods of production that are not specific to the inputs used, but rather represents a broad-based improvement in the productivity of all inputs at the same rate – including opex inputs and capital inputs of all ages. Embodied technical change refers to improvements that make specific inputs more productive. Productivity improvements relating to existing capital stock can include, for example, improvements in the way equipment is used. In this case, efficiency improvements may be made to the operation of a wide range of equipment of different ages. This is an example of disembodied technical change, because it relates to the use of all capital (and the non-capital inputs used with it) and is not specific to capital 'vintages' (i.e. the new equipment installed in a particular year). On the other hand, technical change may relate to the way that new capital equipment is designed or constructed, such that new equipment has a higher efficiency than older vintages. This is referred to as capital-embodied technical change, because it applies differently depending on the capital vintage. Disembodied technical change (i.e. which applies to all factors, and all vintages of capital, equally) is often assumed in empirical work due to its greater tractability. Embodied technical change in capital is a rate of efficiency improvement in new capital and therefore can affect capex requirements, depending on the gains in efficiency and the associated cost.

This chapter uses econometric analysis to decompose frontier shift into two different sources of technical change, one of which is disembodied, and the other is embodied in new capital equipment. The former is relevant to both opex and all capital inputs (including capex) whereas the latter specifically affects the productivity of new capital investment relative to older capital equipment.

This analysis uses gross value added (VA) as the measure of output, hence the rates of productivity change will inevitably differ from those presented in other sections, which were estimated using gross output (GO) as the measure of output. The measures of TFP obtained using VA and GO are different, but are related via the share at current prices of value-added in gross output (Balk, 2009).

The dataset used in this analysis is the same as that used in the previous chapter and comprises the same eight comparator industries for 11 European countries over the period 1995 to 2017, sourced from the EU-KLEMS database and described in detail in section 4.3. The use of a consistent dataset aids in the interpretation of the findings and making inferences from them.

7.1 Method of Estimating Embodied and Disembodied Technical Change

The approach taken in this analysis follows McCarthy (1965); and involves econometrically estimating a production function which is specified to include both disembodied technical change and technical change which is embodied in capital inputs. MacCarthy assumed that the production function has a constant elasticity of substitution (CES) form. With a CES functional form, the elasticity of substitution between capital and labour (σ) is constant, and is a parameter to be estimated. The CES function is considered to be suitable for the present purpose, and was used in the McCarthy study.[18]

In McCarthy's approach, capital inputs are disaggregated into vintages (i.e. the year in which the capital was installed) and labour inputs are disaggregated into the labour employed on capital of each vintage. Total output is an aggregation of the outputs produced using each vintage of capital. This approach is similar to Solow (1957), except a CES specification is used and technical change may be both embodied and disembodied (whereas Solow used a Cobb-Douglas specification and assumed that technical change was embodied). The production function associated with the use of capital of vintage v is:

$$q_v(t) = B.\mathrm{e}^{\gamma t}\left\{(1-\alpha)\left[\mathrm{e}^{\lambda v}D(t-v)I(v)\right]^{-\rho} + \alpha L_v(t)^{-\rho}\right\}^{-1/\rho} \qquad (7.1)$$

where $q_v(t)$ is the output produced with capital of vintage v; γ is the rate of disembodied technical change; λ is the rate of technical change embodied in capital equipment; $D(.)$ is the depreciation function; $I(v)$ is investment in period v; and $L_v(t)$ is the labour employed in period t and used in conjunction with capital of vintage v. Note that: $0 \leq D(a) \leq 1$, where $a = t - v$ is the age of capital of vintage v; and also $D(0) \equiv 1$.

Defining the following aggregates: (a) output: $Q(t) = \int_{-\infty}^{t} q_v(t)dv$; (b) labour inputs: $L(t) = \int_{-\infty}^{t} L_v(t)dv$; and (c) the measured net capital stock: $K(t) = \int_{-\infty}^{t} D(t-v)I(v)dv$; then the aggregate CES production function with the two forms of technical change mentioned is:

[18] CES is a more flexible functional form than the Cobb-Douglas (linear-in-logs) function, where $\sigma = 1$, or the Leontief (fixed factor proportions) form, where $\sigma = 0$. Both can be viewed as special cases of the CES form. The CES form is less flexible than the popular translog functional form, but is *not* a special case of the translog. In the translog form, the elasticity of substitution between capital and labour is defined as: $\sigma_t = 1 + a_{KL}/(s_{K,t}.s_{L,t})$, where a_{KL} is an estimated parameter and s_K and s_L are the compensation of capital and of labour as shares of nominal gross value added. These shares vary from period to period, and hence σ_t varies over the sample period. When there are more than two inputs, the standard CES specification has the limitation that it restricts the elasticities of substitution between each pair of inputs to be the same. But this is not a limitation with only two inputs. The translog form can be difficult to estimate with small data samples because it has a greater number of parameters associated with higher-order and interaction terms; which decreases degrees of freedom and increases the degree of multicollinearity between regressors, causing parameter estimates to be imprecise in small data samples.

$$Q(t) = B.\mathrm{e}^{\gamma t}\left[(1-\alpha)\mathrm{e}^{-\rho\lambda t}K(t)^{-\rho} + \alpha L(t)^{-\rho}\right]^{-1/\rho} \quad (7.2)$$

where $Q(t)$ is the output, $K(t)$ is the measured net capital stock and $L(t)$ is the measured labour input, all at time t; γ is the rate of disembodied technical change; λ is the rate of technical change embodied in capital equipment. Disembodied technical change "implies that there are some increases in efficiency which tend to increase the productivity of labour, regardless of the capital on which it is employed" (McCarthy, 1965, p. 72). Embodied technical change of capital equipment means there is quality improvement which reduces the quantity of new capital needed to produce the same output as the capital it replaces.

McCarthy shows that, assuming allocative efficiency,[19] both these different forms of technical change can be identified by estimating the following two equations econometrically:

$$\ln\left(\frac{Q}{L}\right) = a_1 + a_2 t + a_3 \ln\left(\frac{W}{OPI}\right) + \epsilon_1 \quad (7.3)$$

$$\ln\left(\frac{s_K}{s_L}\right) = b_1 + b_2 t + b_3 \ln\left(\frac{L}{K}\right) + \epsilon_2 \quad (7.4)$$

where W is the nominal wage rate; OPI is the output price index; s_K and s_L are the compensation of capital and of labour as shares of nominal output; and:

- $a_1 = -\sigma \ln \alpha + (1-\sigma)\ln B$
- $a_2 = (1-\sigma)\gamma$
- $a_3 = \sigma$
- $b_1 = (1-\alpha)/\alpha$
- $b_2 = -\rho\lambda$
- $b_3 = \rho$

It is clear that estimates of both γ and λ can be identified, and the parameter α. They are recoverable from parameter estimates using:

- $\gamma = a_2/(1-a_3)$
- $\lambda = -\,b_2/b_3$
- $\alpha = 1/(1+b_1)$

In this specification: $\sigma = 1/(1+\rho)$ is the elasticity of substitution between capital and labour. This implies a nonlinear constraint between the two equations: $a_3 = 1/(1+b_3)$. McCarthy recommends the two equations be estimated jointly with this constraint imposed. Here we test this approach, but also test the model without imposing the cross-equation constraint.

Note that it is also possible to estimate equations (7.3) and (7.4) jointly with the production function itself, which is more conveniently formulated in log form:

$$\ln Q = \ln B + \gamma t - \frac{1}{\rho}\ln\left[(1-\alpha)\mathrm{e}^{-\rho\lambda t}K^{-\rho} + \alpha L^{-\rho}\right] \quad (7.5)$$

[19] That is, the marginal product of labour equals the real wage, and $-(\partial L/\partial K)(K/L) = s_K/s_L$.

Unlike equations (7.3) and (7.4), equation (7.5) is nonlinear. However, if constraint between the values of σ and ρ is to be imposed, nonlinear estimation is needed in any case. Although we have satisfied ourselves that this approach is feasible, it was not an advance on, and produced similar results to the estimation of the two equations (7.3) and (7.4).

In order to relate the two sources of technical change to the overall rate of technical change, we differentiate (7.5) with respect to t, to obtain:

$$\frac{\partial \ln Q(t)}{\partial t} = \gamma + \lambda \left[\frac{(1-\alpha)\mathrm{e}^{-\rho\lambda t}K^{-\rho}}{(1-\alpha)\mathrm{e}^{-\rho\lambda t}K^{-\rho} + \alpha L^{-\rho}} \right] \tag{7.6}$$

The overall rate of technical change is equal to the rate of disembodied technical change (γ) plus a fraction of the rate of technical change embodied in capital equipment (λ), where the fraction is the quantity in square brackets in equation (7.6).

7.2 Results

The preferred approach taken here to estimating the foregoing model involves the following estimation methods:

- Pooling all of the industries together, and imposing the sector weights developed by Ecorys within the regression estimation procedure as frequency weights.[20]
- Including fixed effects for the different countries to take account of systematic differences between them.
- Jointly estimating equations (7.3) and (7.4) using Seemingly Unrelated Regression (SUR) and Nonlinear SUR (NLSUR) methods. The SUR method is used when the nonlinear cross-equation constraint: $\sigma = 1/(1+\rho)$ is *not* imposed, and the NLSUR method is used when this constraint *is* imposed. The estimation algorithms used are feasible generalised least squares (FGLS) and feasible generalised nonlinear least squares (FGNLS) respectively.

The estimation results based on the full sample are shown in Table 7.1 (the estimated fixed effects are not shown). The calculated parameters of interest and their t-statistics are also shown. Alternatively, the model can be estimated over a different sample period, and Table 7.1 also shows the results when using the period described in Tables 5.13 and 5.14 as the mid-cycle (downswing) period, 2001-2017. This represents two full business cycles, and is defined by a method similar to that used by Oxera.

[20] This refers to the *fweights* form of weighting available in Stata, where the weights stand for frequencies of population observations associated with each sample observation. These must be integers, so the Ecory's weights (as proportions) are multiplied by 1000 (and sum to 1000).

Table 7.1: SUR and NLSUR Models with Fixed Effects

	Full sample		*Sample 2001-2017*	
	Unconstrained SUR Model	*Constrained NLSUR model*	*Unconstrained SUR Model*	*Constrained NLSUR model*
Equation 1#				
Intercept	2.747	3.524	3.144	3.896
	(240.42)	(394.31)	(222.86)	(360.92)
trend	-.008087	-.0112	-0.008628	-0.01103
	(-56.53)	(-73.97)	(-41.37)	(-50.34)
ln(W/OPI)	1.601	.	1.714	.
	(540.01)	.	(464.85)	.
Equation 2#				
Intercept	0.6192	.355	0.6872	0.4647
	(134.28)	(76.27)	(122.94)	(81.74)
trend	-.002932	-.001489	-0.004922	-0.003902
	(-16.30)	(-7.86)	(-19.82)	(-15.02)
ln(L/K)	-0.556	.	-0.571	.
	(-659.46)	.	(-645.58)	.
Equations 1 & 2				
rho	.	-.4477	.	-0.4792
	.	(-658.05)	.	(-657.37)
N	180593	180593	137340	137340
BIC	333094	331085	225422	223578
R^2 – eq1	0.688	0.683	0.694	0.682
– eq2	0.762	0.707	0.794	0.751
Calculated parameters				
Gamma	0.0135	0.0138	0.0121	0.0120
	(59.38)	(75.80)	(42.27)	(50.86)
Lambda	-0.0053	-0.0033	-0.0086	-0.0081
	(-16.32)	(-7.86)	(-19.83)	(-15.02)
Sigma	2.2521	1.8107	2.3312	1.9202
	(526.68)	(811.75)	(484.97)	(714.34)
Alpha	0.6176	0.7380	0.5927	0.6827
	(351.14)	(291.10)	(301.82)	(257.62)
Rho	-0.5560	-0.4477	-0.5710	-0.4792
	(-659.46)	(-658.05)	(-645.58)	(-657.37)

Notes: t statistics in parentheses (weighted average is based on absolute values); # fixed effects not shown.

Although the economic theory suggests that the constraint $\sigma = 1/(1+\rho)$ should be imposed, this assumes that aggregation over firms within each sector (and over sectors) does not affect properties of the aggregate production functions. This is a hypothesis that can be tested. The Wald test statistic (and associated p-value) for the hypothesis that this constraint is valid, is as follows:

- Full sample model:
    - Chi-squared statistic (1 degree of freedom) = 18662.7
    - P-value = 0.0000

- Sample 2001-2017 model:
    - Chi-squared statistic (1 degree of freedom) = 12416.2
    - P-value = 0.0000

The constraint is valid because the p-value is less than 0.05. Therefore, the constrained models are preferred. The following discussion of the results focusses on the constrained (NLSUR) models.

The weighted regression method means that estimates for the rates of technical change are equivalent to a weighted average across all comparator industries. The NLSUR model that uses the full sample period produces the following estimates of technical change:

(a) disembodied technical change: 1.38 per cent per year; and

(b) capital-embodied technical change: -0.33 per cent per year.

The NLSUR model that uses the shorter sample from 2001 to 2017, produces estimates for the rates of technical change of:

(a) disembodied technical change: 1.20 per cent per year; and

(b) capital-embodied technical change: -0.18 per cent per year.

All of these estimates of the rates of technical change are statistically significant at the 0.05 level of significance. Equation (7.6) shows that the overall rate of technical change in this model is equal to gamma (the rate of disembodied technical change) plus a fraction of lambda (the rate of embodied technical change), where the fraction is defined as shown in square brackets in equation (7.6). Table 7.2 shows the calculation of the overall rate of technical change.

Table 7.2: Calculations of technical change on GO basis

	VA basis (as estimated)		*Adjusted to GO basis*	
	Full sample	*Sample 2001-2017*	*Full sample*	*Sample 2001-2017*
Ratio VA/GO			41.7	41.1
Disembodied technical change	1.38	1.20	0.58	0.49
Capital embodied technical change	-0.33	-0.18	-0.14	-0.07
Multiplier from (7.6) (%)	10.6	12.4		
Estimated overall technical change	1.34	1.18	0.56	0.49

Table 7.2 shows that the estimated overall rate of technical change is:

(a) 1.34 per cent per year over the full sample period; and

(b) 1.18 per cent per year over the period from 2001-2017.

The econometric analysis uses real value added as the output and relies only on two inputs, labour and capital. The productivity growth rates stated above are thus on a value-added basis of productivity measurement (rather than gross output). The ratio of nominal value added to gross output, averaged across countries and years, varies from 0.38 for Construction to 0.55 for IT and other information services, with a weighted average of 0.42. Hence to translate the trend estimates for disembodied and capital-embodied technical change produced by the econometric analysis, into an equivalent rate based on gross output, we can multiply them by 0.42 to obtain:

- For the full sample model:
  - (a) disembodied technical change: 0.58 per cent per year
  - (b) capital-embodied technical change: -0.14 per cent per year, and
  - (c) the estimated overall rate of technical change is 0.56 per cent per year.
- For the 2001 - 2017 sample model:
  - (a) disembodied technical change: 0.49 per cent per year;
  - (b) capital-embodied technical change: -0.07 per cent per year, and
  - (c) the estimated overall rate of technical change is 0.49 per cent per year.

In both cases the estimate of capital-embodied technical change has a negligible effect on overall technical change and can safely be ignored. The rate of disembodied technical change is quite similar to the TFP growth rate obtained using index methods applied to Netherlands industries in chapter 5, and also to the TFP growth rate calculated using the Malmquist index for the same 11 European countries in chapter 6.

This analysis suggests that capital-embodied technical change can reasonably be regarded as inconsequential and the great majority of overall technical change can be best characterised as disembodied technical change. This in turn implies that technical change applies to the use of opex inputs and to capital inputs in a similar way.

8 EVALUATION

The calculation of TFP trends using TFP indexes, presented in chapter 5, is the preferred method in this study because it has been previously endorsed by the Netherlands appeal body. The other methods, the Malmquist index presented in chapter 6 and the econometric analysis in chapter 7, provide supporting evidence for the trends in TFP and also help to interpret or adjust the overall TFP trends, for example to exclude the effects movements of average efficiency relative to the frontier, allowing for a better focus on frontier shift. This chapter evaluates the results derived in chapters 5 to 7, and reaches overall conclusions on the estimated historical rates of dynamic efficiency that are likely to best serve as forecasts for the forthcoming regulatory period.

8.1 Period of averaging

To use the TFP indexes to derive average rates of productivity growth, the periods over which the averages are calculated need to be determined. In section 5.1.3 we stated several criteria for consideration when selecting the period of averaging (most of them from: Oxera 2016b).

- The period should cover complete business cycles. Oxera preferred to use two complete business cycles.
- Since older data are likely to be less informative than newer data, the period should, if possible, include the most recent data available. It may also be desirable to give greater weight to more recent periods.
- Earlier data should be discarded if there is evidence of structural breaks. At least eight years of robust data should be used. Thus, it may be feasible to use only a single whole cycle.
- The period should preferably be a long period, such as two decades, which is another way of smoothing out cyclical effects.

The last of these criteria suggests that the whole sample period from 1995 to 2017, which includes 22 years for which there are growth rates, remains a valid basis for calculating growth rates because it extends over more than two cycles and can thereby smooth over cyclical effects due to the length of the period used.

Oxera calculated growth cycles based on both GDP and the aggregate GO of the comparator industries and found these two methods to produce consistent results. Their analysis suggested:

- cycle mid-points (downswing) in 1991, 2001 and 2008;
- cycle troughs in 1993, 2003 and 2009;
- cycle mid-points (upswing) in 1995 and 2006 (although these are less clearly identifiable); and
- cycle peaks in 1989, 1998 and 2007.

Our analysis suggests the following cycle timing in the subsequent period to 2017:

- cycle mid-point (downswing) in 2017;
- no other cycle trough after 2009;

- cycle mid-point (upswing) in 2014; and
- cycle peak in 2015.

The cycle defined trough-to-trough is not very useful because there is only one from 2003 to 2009 in the period for which we have data. The other three ways of timing cycles can be considered. The following tables show average TFP growth rates and Real IPI declines in each cycle period, which combine to give the dynamic efficiency measure. Table 8.1 uses cycle periods defined from mid-cycle (downswing) years. Table 8.2 shows cycle periods based on mid-cycle (upswing) years, which are not as clearly identifiable. Table 8.3 shows the results for cycle periods defined from peak to peak.

Table 8.1: Growth rates calculated between mid-cycle (downswing) years

	TFP index (weighted avg.)	*Real IPI index (weighted avg.)*	*TFP growth (%)*	*Real IPI decline (%)*	*Dynamic efficiency rate (%)*
2001	1.065	1.025			
2008	1.134	1.111	0.90	-1.15	-0.25
2017	1.117	0.992	-0.17	1.26	1.09
Average over two cycles			0.30	0.20	0.50

Table 8.2: Growth rates calculated between mid-cycle (upswing) years

	TFP index (weighted avg.)	*Real IPI index (weighted avg.)*	*TFP growth (%)*	*Real IPI decline (%)*	*Dynamic efficiency rate (%)*
1995	1.000	1.000			
2006	1.117	1.086	1.01	-0.75	0.26
2014	1.113	1.019	-0.04	0.80	0.75
Average over two cycles			0.56	-0.10	0.47

Table 8.3: Growth rates calculated between peak-cycle years

	TFP index (weighted avg.)	*Real IPI index (weighted avg.)*	*TFP growth (%)*	*Real IPI decline (%)*	*Dynamic efficiency rate (%)*
1998	1.029	1.010			
2007	1.127	1.099	1.01	-0.94	0.07
2015	1.119	1.015	-0.09	0.99	0.90
Average over two cycles			0.50	-0.03	0.47

These tables show that the three alternative ways of defining the cycle yield slightly different rates for average rates of TFP growth, but quite similar results for the average dynamic efficiency rate.

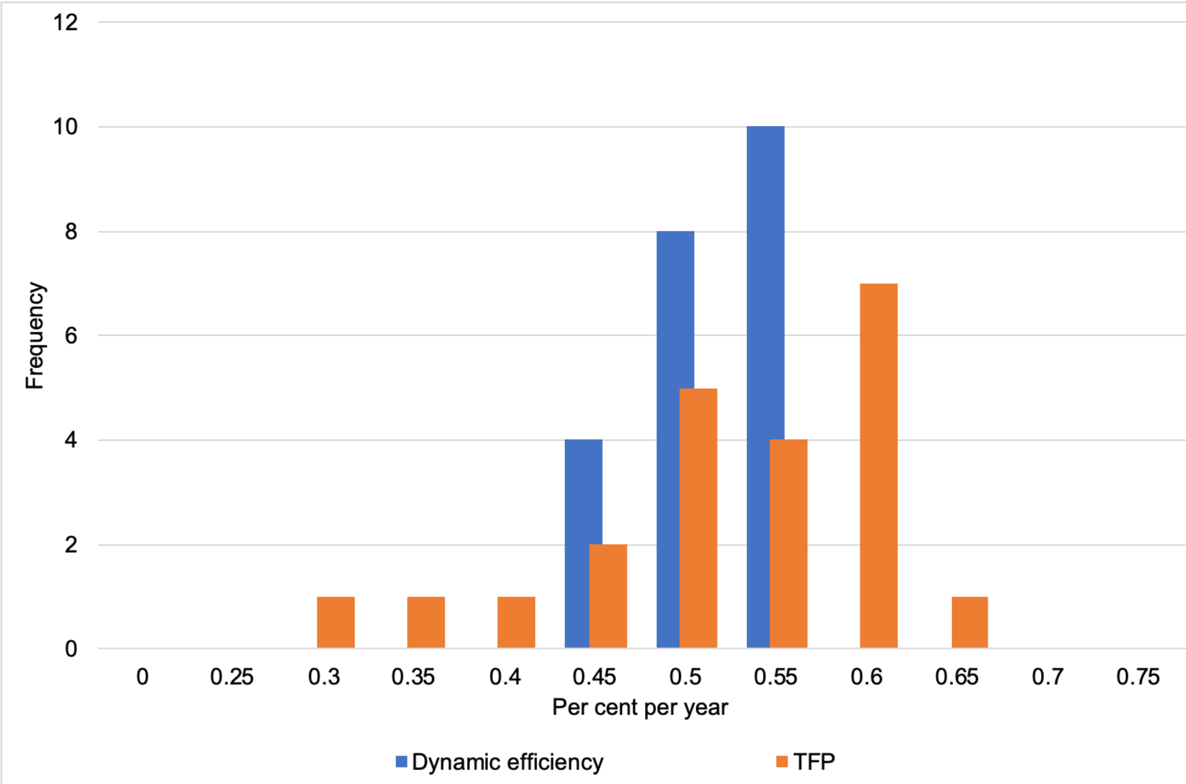
- In the periods covered in Table 8.1 the first six years of the full sample are omitted. The average TFP growth rate is 0.30 per cent per year. Real IPI decreases in this period by 0.20 per cent per year, resulting in a net rate of dynamic efficiency of 0.50 per cent per year.
- This is only slightly lower than the estimated average rate of dynamic efficiency over the full sample period. In Table 8.2, only the last three years of the full sample are omitted. The average TFP growth rate is 0.56 per cent per year, while Real IPI *increases* in this period by 0.10 per cent per year, partially offsetting the productivity gains, and resulting in a net rate of dynamic efficiency of 0.47 per cent per year.
- In Table 8.3 the first three years and last two years of the full sample period are omitted. The average TFP growth rate of 0.50 per cent and the average Real IPI *increase* is 0.03 per cent; with the overall rate of dynamic efficiency being 0.47 per cent. These rates of change are broadly similar to the results for the full sample period.

This comparison shows that all three of these ways of defining the cycle tend to corroborate each other. The mid-cycle (downswing) definitions of cycle periods have some advantages over the other definitions. They are consistent with the approach taken by Oxera, and include an additional full cycle. Compared to the periods used in Tables 8.2 and 8.3, the 2001-2017 period has the advantage of including some more recent data, and less older data. For these reasons, the mid-cycle (downswing) definitions of cycle periods are preferred.

We have also considered the post-GFC period, which is from 2009 to 2017; which is slightly shorter than the second cycle period in Table 8.1. In the post-GFC period, the average TFP growth rate is much lower at 0.05 per cent per year. However, Real IPI decreases in this period by 1.20 per cent per year, resulting in a net rate of increase in dynamic efficiency of 1.26 per cent per year. Although this period does just meet the criterion that at least eight periods of change are included in the average, it includes slightly less than one full cycle, and therefore does not meet the criterion of using at least one and preferably two full cycle periods. Furthermore, this period results in a high estimated rate of dynamic efficiency relative to all of the other periods considered.

A sensitivity analysis of the calculated TFP growth rates obtained by varying the sample period is shown in Figure 8.1. This is based on calculating the average TFP growth rates, Real IPI rates of decline and rates of increase in dynamic efficiency for 22 alternative periods. The different periods used include every continuous period with 17 or more years and that commence no later than 2001 and end no earlier than 2014. The histogram shows that the average rate of TFP growth is centred on 0.5 per cent per year, and for the bulk of scenarios it is between 0.4 per cent and 0.6 per cent. The average rate of dynamic efficiency is also centred on 0.5 per cent per year, however, the frequency distribution is much narrower than for TFP. This suggests that TFP and Real IPI growth rates move in the same directions over business cycles and when calculating the difference between them, they tend to offset each other. The sensitivity analysis confirms that the results obtained by averaging over the 2001 to 2017 period are consistent of the central tendency of estimates over alternative periods.

Figure 8.1: TFP & Dynamic Efficiency Sensitivity Analysis



This discussion leads to the conclusion that:

- over the period 2001-2017, the average annual rate of TFP growth of 0.30 per cent, and the average decrease in real IPI of 0.20 per cent, together imply an average annual rate of increase in dynamic efficiency of 0.50 per cent, and
- this rate of dynamic efficiency is representative of the average rates of increase in dynamic efficiency over alternative periods, including those based on two full business cycles, and those used in the sensitivity analysis for period definitions.

8.2 Differentiating Frontier Shift from TFP growth

The measure of dynamic efficiency used in the previous section combines the rate of change in TFP with the rate of decline in real input prices. However, as shown in chapter 6, the rate of TFP change comprises several different effects including:

- Technical change growth rates
- Efficiency change growth rates, and
- Scale efficiency contributions to growth rates.

Only the first and the third of these components are relevant to a best-practice firm that is operating on the efficiency frontier, and are relevant to the generic productivity adjustment included in price or revenue caps (as distinct from business-specific adjustments to the allowed efficient cost base). As discussion in section 2.3, in a utility setting, businesses are usually taken as having little influence over their outputs, which are determined by demand in their supply areas. They are considered to be operating on the efficiency frontier if it is not feasible to radially contract inputs and still produce the same outputs, even if they are not operating at the optimum scale. Thus, if there are economies of scale at the prevailing output levels, then even a best-practice firm may achieve productivity gains associated with the exogenous increase in its scale of outputs, due to rising demand. For this reason, both technological change and gains from economies of scale are included as components of the ongoing productivity change that is achievable by a best practice utility. Thus, the aim is to derive a productivity change measure that includes technical change and scale efficiency effects but excludes the effect of efficiency changes.

Chapter 6 presents an analysis of this kind including average growth rates of the Malmquist TFP index (based in the sample of European counties, including the Netherlands). Technical change, scale efficiency effects and efficiency changes, calculated over the full sample period are:

- Malmquist TFP index: 0.61 per cent;
- Technical change index: 0.82 per cent;
- Scale efficiency index: 0.11 per cent;
- Efficiency change index: –0.31 per cent.

The negative rate of efficiency change means that the combined effect of technical efficiency and scale change (0.82 + 0.11 = 0.93 per cent) is 31 basis points above the estimated rate of change of TFP.

When the rates of change of these indexes are averaged over the period from 2001 to 2017 (as used in Table 8.1) the following annual average growth rates are obtained:

- Malmquist TFP index: 0.45 per cent;
- Technical change index: 0.57 per cent;
- Scale efficiency index: 0.15 per cent;
- Efficiency change index: –0.27 per cent.

The combined effect of technical efficiency and scale change are (0.57 + 0.15 = 0.72 per cent) is 27 basis points higher than the estimated rate of change of TFP. This suggests that firms that are not on the efficiency frontier have tended to fall behind the most efficient firms, and consequently the rate of TFP change *understates* the rate of frontier shift.

This confirms that the rate of TFP change used in the calculation of dynamic efficiency does not overstate the rate of frontier shift, as it would if the rate of efficiency again (or catch-up) had been positive and a substantial contributor to TFP growth. As it is, with efficiency gain estimated to be negative, the TFP trend represents a conservative estimate of frontier shift.

It should be noted that the estimated decomposition of TFP trends is based on a sample of European countries, and is not confined to data for the Netherlands. This does raise the question as to how representative these results are for the Netherlands. The consistency of the Malmquist index results with the TFP trends estimated only with data from the Netherlands tends to support a view that the results are likely to provide a good indicative guide for the comparator industries in the Netherlands. Nevertheless, we do not recommend making any specific upward adjustment to the estimated rate of dynamic efficiency to take account of the estimated faster rate of frontier shift. We do consider that the results are certainly sufficiently robust to draw the conclusion that the TFP rate of growth for the Netherlands is a conservative estimate of the rate of frontier shift.

8.3 Dynamic efficiency: GTS and TenneT

Separate estimates of frontier shift and dynamic efficiency using weights specific to Tennet and to GTS have also been presented in Table 5.14 in section 5.5. The comparative results are summarised in Table 8.4.

Table 8.4: Growth rates 2001-2017: Alternative weights (%)

	Tennet weights	*GTS weights*	*Average weights*
TFP growth	0.31	0.26	0.30
Real IPI decline	0.23	0.16	0.20
Dynamic efficiency	0.54	0.42	0.50

The comparison shows there are slightly different estimates of dynamic efficiency using separate sets of weights for TenneT and GTS, rather than using average weights. However, there is a real question about how material these differences are. In light of the small size of these differences, and having regard to the overall precision of the estimates as a basis for forecasting, it would be entirely reasonable to use the average weights for both TenneT and GTS. In that case, the estimate of annual dynamic efficiency growth, based on the index analysis of TFP and Real IPI movements using Netherlands data for the comparator industries, would be 0.5 per cent. If, on the other hand, it is preferred that the weights specific to each of the two businesses should be used, as has been done in past decisions, then the rates of dynamic efficiency growth would be 0.5 per cent for TenneT and 0.4 per cent for GTS.

8.4 Opex and Capital Partial Productivities

The analysis of partial factor productivity rates in chapter 5 found that the average growth rates of opex partial factor productivity (PFP) and capital PFP over the full sample period are both similar to the overall TFP growth rate when averaged over the full sample period. Chapter 7 examines partial productivity from a different perspective. It involved econometric analysis designed to separately estimate rates of disembodied technical change and capital-embodied technical change using data for a sample of European countries.

Over the period 2001 to 2017 the average rate of change in opex PFP is 0.38 per cent per year and the average rate of decline in the opex input price index was 0.11 per cent per year. Hence, the rate of partial dynamic efficiency for opex of 0.49 per cent per year is almost the same is that for totex. Over the same period, the average rate of change in capital PFP was -0.11 per cent per year, and the average rate of decline in real capital input prices was 1.60 per cent per year. Hence, the range of change in partial dynamic efficiency associated with capital inputs was 1.49 per cent per year. However, there is much more volatility in the estimated dynamic efficiency of capital inputs depending on the period over which the average is calculated. In these industries, capital inputs generally have a much smaller weight (in terms of compensation of inputs) than labour and intermediate inputs taken together, and the movements in real capital input prices are volatile. This tends to suggest that the estimated movements in the partial dynamic efficiency of capital inputs are less reliable than the overall measure of dynamic efficiency or the measure of partial dynamic efficiency for opex inputs.

In the econometric model estimated over the period 1995 to 2017, the overall rate of technical change on a value-added basis is 1.34 per cent per year. When multiplied by the average share of value added in the value of gross output, which is 42 per cent, the result is a set of estimates of the rate of technical change on a gross output basis, which are more directly comparable to the results from chapters 5 and 6. On a gross-output basis, the econometric estimates are:

(a) disembodied technical change: 0.58 per cent per year

(b) capital-embodied technical change: -0.14 per cent per year, and

(c) the estimated overall rate of technical change is 0.56 per cent per year.

The overall rate of technical change is equal to the rate of disembodied technical change plus a *proportion* of the rate of capital-embodied technical change, as explained in section 7.1. The proportion or multiplier applied to the capital-embodied technical change is calculated from the parameters of the model, and as shown in Table 7.2, is 10.9 per cent.

Chapter 7 also shows that when the preferred period of analysis, 2001 to 2017, is used as the sample in the econometric model, the overall rate of technical change on a value-added basis is 1.18 per cent per year. When multiplied by the average share of value added in the value of gross output, so that the estimates are on a gross output basis, the results are:

(a) disembodied technical change: 0.49 per cent per year;

(b) capital-embodied technical change: -0.07 per cent per year, and

(c) the estimated overall rate of technical change is 0.49 per cent per year.

In this case the multiplier applied to the capital-embodied technical change, when calculating the overall rate of technical change, is 12.4 per cent.

Two key findings of this analysis are that, firstly, the estimated rate of technical change over the period 1995 to 2017 was broadly similar to the productivity growth estimate for the Netherlands, and to the rate of TFP growth for the same European countries estimated using Malmquist analysis. This similarity also applies in both the full sample (1995 to 2017) and the preferred sample period 2001 to 2017. This finding supports the reliability of the analysis for making inferences.

Second, in both models the combined effect of the small estimated value of capital-embodied technical change, and the small weight applied to it, means that capital-embodied technical change has a negligible effect on overall technical change and can safely be ignored. This tends to suggest that technical change in the comparator industries can best be viewed as disembodied technical change, which affects the use of opex and capital inputs in a similar way.

8.5 Conclusion

The analysis of the Malmquist TFP index for a sample of European countries in this report has found that changes in TFP in the comparator industries have been largely associated with technical change, and a small contribution has been made by improvements in scale efficiency. Efficiency change is estimated to have had a small negative trend, perhaps due to the effects of deterioration of capital utilisation (e.g. associated with the GFC and its aftermath). The implication of this finding is that the rate of TFP change can be viewed as a conservative estimate of the rate of frontier shift.

The estimated rate of frontier shift combined with the rate of decline in real input prices gives the rate of dynamic efficiency. In this report the rates of frontier shift and of changes in real input prices is calculated using an index method applied to the eight comparator industries in the Netherlands. Although the rate of frontier shift varies to some extent depending on the period over which the average is calculated, the average rate of decline in input prices tends to vary in the opposite direction, so that the average rate of dynamic efficiency changes very little when different averaging periods are used.

The preferred basis for averaging is the period 2001 to 2017 which covers two business cycles defined using a method similar to that previously used by Oxera. Over this period the rate of dynamic efficiency improvement averaged 0.50 per cent per year. We recommend this as an appropriate forecast of dynamic efficiency applicable to totex for the forthcoming regulatory period.

We have examined the effect of applying separate weights for TenneT and GTS, when averaging the TFP and real IPI across the eight comparator industries, to obtain estimates for the rates of dynamic efficiency for TenneT and GTS over the period 2001 to 2017. While there are slightly different estimates of dynamic efficiency using separate sets of weights for TenneT and GTS, there is a real question about how material these differences are. It would be entirely reasonable to use the average weights for both TenneT and GTS. In that case, the applicable annual rate of dynamic efficiency growth would be 0.5 per cent. If, on the other hand, it is preferred that the weights specific to each of the two businesses should be used, as has been done in past decisions, then the rates of dynamic efficiency growth would be 0.5 per cent for TenneT and 0.4 per cent for GTS.

We have also been asked to advise on the rate of dynamic efficiency that would be appropriate to apply separately to the opex and capex components of totex. Two parts of the analysis in this report are directly relevant to this question. Firstly, the econometric analysis of the nature of technical change in the comparator industries in chapter 7 finds that technical change can be characterised as disembodied. That is, it applies to inputs in an equal and similar way. Second, the PFP indexes and partial input price indexes calculated for opex and capital inputs, in chapter 5 concludes that the partial dynamic efficiency associated with the use of opex inputs is similar to the totex dynamic efficiency. We have also concluded that the partial dynamic efficiency of capital inputs, although estimated to be higher than that for totex over the preferred sample period, should be discounted for the greater degree of uncertainty of this measure.

Based on these findings we recommend using the same rate of dynamic efficiency for opex and for capex as that for totex.

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APPENDIX A: SURVEY OF FRONTIER SHIFT IN REGULATORY REGIMES

This appendix reviews the regulatory frameworks for energy transmission or distribution networks in a number of relevant countries in terms of the methods of regulation and, where applicable, regulatory decisions on any adjustments to be made to price or revenue plans to account for productivity change or technical change and the methods used to arrive at the estimates of productivity or technical change. This review also considers academic studies relating to productivity in electricity and gas transmission and distribution networks relevant to the countries covered in the review.

The source material for this review is published regulatory decisions, consultant reports, and studies published in academic journals. The focus of the review is on estimated rates of technical efficiency improvement or frontier shift, while also taking account of differences in methods used to derive the estimates. A key question is to ascertain (for those studies that address this question) the degree to which efficiency catch-up effects were found to contribute to productivity trends in these sectors so that these effects can be separated from estimates of frontier shift.

A.1 Australia

Energy networks in most of Australia (excluding Western Australia) are regulated by the Australian Energy Regulator (AER). The AER is closely affiliated with (and effectively part of) the Australian Competition and Consumer Commission (ACCC). The five states within the jurisdiction of the AER form the national electricity market (NEM). There are five electricity TSOs in the NEM – one in each of the five states included in the NEM. Three are privately owned and two are state-owned. There are 13 electricity distribution networks, each with a monopoly over its designated area. There are seven regulated gas distribution networks and a number of smaller unregulated networks.

When determining energy network tariffs, the AER uses a ‘building block’ approach which involves forecasting the cost of supply (including a commercial rate of return on assets) and deriving revenue caps consistent with recovering those costs. As part of this exercise the AER must assess whether the expenditure projections submitted by a network provider are consistent with criteria such as efficiency. This depends on the efficiency of past expenditure and on the reasonableness of the projection from past to future expenditure, including the forecasts for outputs. The AER uses economic benchmarking and category analysis (i.e. unit cost benchmarking by cost category), not only to assess the efficiency of past expenditure, but also as one of the methods for assessing the reasonableness of projections. The benchmarking methods it uses include multilateral TFP and econometric modelling (AER, 2013). A base-step-trend method is used to forecast opex. The ‘base’ element involves establishing the base-year efficient level of opex, for example by deducting from actual opex in that year any estimated material inefficiencies. The ‘step’ component accounts for any special circumstances that may impact on costs. The ‘trend’ component consists of: (a) forecast real input price changes; (b) forecast output quantity growth; and (c) forecast rate of shift in the efficient frontier for the industry, as it affects opex. The AER most often determines capex benchmarks using a more detailed scrutiny of asset management plans. However, it does sometimes apply a productivity factor to capex, such as when estimating the unit costs of capital activities, or applied to capitalised overheads (since the latter can be readily shifted from capex to opex or vice versa). Econometric analysis of the opex cost function (or short-run variable cost function) may be used to establish rates of frontier shift relevant to the 'trend' element of the AER's determinations (e.g. Economic Insights, 2019c).

The AER regularly carries out benchmarking analysis of electricity TSOs and DSOs. Having developed its approach to benchmarking in 2013 and 2014, it has published annual benchmarking results for the past five years for the five TSOs and 13 DSOs in the NEM (AER, 2019a, 2019b). Economic Insights provides the productivity analysis underlying these reports (Economic Insights, 2019a, 2019b). For electricity TSOs, multilateral total factor productivity and multilateral partial factor productivity indexes are used to measure relative productivity and productivity changes over time. The AER currently uses economic benchmarking in its price decisions to derive its forecast of future productivity changes used in assessing TSO opex forecasts.

Gas transmission pipelines in Australia (excluding those in Western Australia) are potentially subject to regulation by the AER. The access regulation framework only applies if a pipeline meets certain declaration criteria (including that their use is essential to supply a significant downstream market) or do not benefit from a 15-year 'no coverage' period. Out of 14 major gas pipelines in Eastern Australia, seven are subject to access regulation and seven are uncovered. These pipelines are all privately owned. The APA Group is the largest owner of gas pipelines. It owns all of the seven declared pipelines, and has ownership interests in two of the uncovered major pipelines. The next largest pipeline owner is a consortium of Jemena and Singapore Power, which owns three major uncovered pipelines. There are two different forms of regulation, namely 'full' and 'light' access regulation.[21] Both require the gas TSO to publish standard terms and conditions for access. However, with 'full' regulation, the terms and conditions, including the tariffs, are subject to approval by the AER, which is not the case with 'light' regulation. Instead, the AER monitors tariffs and can arbitrate disputes between the TSO and customers. Light regulation is used where the costs of full regulation are considered to be disproportionate to the benefits. When determining pipeline tariffs under 'full' regulation the AER assesses the cost of supply (including a commercial rate of return) using a 'building block' method and derives reference tariffs consistent with recovering that cost. The AER has not yet used benchmarking in its regulatory decisions for gas transmission pipelines. Nor has it used productivity analysis for the purpose of setting the 'X-factors'. In a recent draft decision the AER said that, while it usually forecasts productivity growth "based on historic industry productivity performance as measured by econometric modelling", it does not yet have an adequate dataset for gas transmission to enable modelling of that kind (AER, 2017b, pp. 7–14).

When the AER assessed the access arrangements of the Victorian gas DSOs in 2017, it said that its "forecast of productivity growth represents our best estimate of the shift in the industry 'efficiency frontier' " (AER, 2017a, p. 13). And, "both economies of scale and technological change are components of productivity change and they indicate the gas distribution businesses should achieve positive productivity growth, to the extent that output grows" (AER, 2017a, p.

[21] Four of the seven regulated pipelines are under 'full' regulation and three are under 'light' regulation.

26). Catch-up to the frontier is not included in the productivity factor used in the annual rate of change calculation. Nevertheless, the AER did not make any explicit allowance for productivity gain because it evaluated the opex forecasts on a "net of productivity gains basis" (i.e. against expectations if adjustments for productivity growth and input cost were explicitly made), and either considered them to be within reason or rejected them. In regard to its specific expectations about productivity gains, the AER said: "Based on the results from Economic Insights and ACIL Allen, AusNet should be able to achieve opex partial factor productivity growth between 0.6 per cent and 1.6 per cent per year over the 2018–22 period. These forecasts of productivity growth are reflected in the models we used to establish the acceptable range of output growth net of productivity" (AER, 2017a: 26).

In its recent guideline relating to productivity in electricity DSO regulation, the AER indicated that the "productivity growth factor captures the improvements in good industry practice that should be implemented by efficient distributors as part of business-as-usual operations. Another way of putting this is that it reflects the improvement in the efficient production frontier within the electricity distribution industry. … the productivity growth factor that we use in trending forward base opex should only capture the productivity growth that would be achieved by a distributor on the efficiency frontier" (AER, 2019c, pp. 7–8). The AER also decided that "a forecast of 0.5 per cent per year represents an appropriate opex productivity growth factor for electricity distributors. This reflects the best estimate of the opex productivity growth that an electricity distributor on the efficiency frontier should be able to achieve going forward, rather than any efficiency catch-up by individual distributors" (AER, 2019c, p. 9). The AER has elsewhere noted important similarities between electricity and gas distribution in cost drivers (AER, 2017c, p. 23).

The AER's use of a common forecast opex productivity growth rate of 0.5 per cent for electricity DSOs appears to have been driven, in part, by the difficulty of separating the effects of technical change from other factors in electricity opex cost function models; which has been less of an issue in gas distribution opex cost function models (Economic Insights, 2019d, pp. 15–20). It is also notable that this productivity trend estimate is based in part on estimates of the shift in the cost frontier over time (ie, technical change) for gas distribution businesses from studies by ACIL Allen and Economic Insights (AER, 2019c, p. 66).

The AER's use of benchmarking operates in tandem with various incentive schemes to improve operating and capital efficiency and service standards (AER 2019d, pp. 80-86). The key schemes are an Efficiency Benefit Sharing Scheme ("EBSS") that applies to opex and a Capital Expenditure Sharing Scheme ("CESS") that applies to capital. There is also a service target performance incentive scheme (STPIS) and schemes relating to demand management and planning and investment framework obligations. The AER is currently investigating a customer service incentive scheme (CSIS) for electricity distribution network service businesses.

The EBSS and CESS have been applied to gas and electricity distribution and transmission utilities and are designed to provide continuous and balanced incentives to pursue efficiency improvements in both capex and opex allowances over the regulatory period and to provide a fair sharing of the efficiency improvements between network service providers and their customers. Both schemes need to apply to avoid bias in the mix of expenditure and need to be complemented by benchmarking or other mechanisms to ensure that operating expenditure in the base year is reasonably efficient and that capital expenditure forecasts are not biased.

A.2 Austria

The Austria energy network regulator is E-Control. There are approximately 120 electricity DSOs, although only about 40 are large enough to be regulated (E-Control, 2018). Austria's electricity TSOs are Austrian Power Gris (APG) and Voralberger Übertragungnetz (VÜN). There are approximately 20 regulated gas DSOs; and there are three main natural gas TSOs: Gas Connect Austria GmbH, TAG GmbH and BOG GmbH.

In the Austrian incentive regulation scheme, an efficiency adjustment (or X-factor) is applied to controllable operating costs which comprise two parts: (a) a general efficiency factor ('X-gen'), which reflects frontier shift (or more specifically the differential of productivity and input prices between the energy network sector and economy); and (b) a firm-specific efficiency adjustment determined via benchmarking.

In the first two periods of incentive regulation of electricity DSOs, from 2006-2009 and 2010-2013, the X-gen rate was set by E-Control at 1.95 per cent. According to Gugler and Liebensteiner (2019), this X-gen rate was based on: (i) a sample of 23 international empirical TFP studies, covering a number of infrastructure sectors including, in addition to electricity and gas networks, telecommunications, sea ports, airports and water supply; and (ii) negotiations with utilities and stakeholders. For electricity DSOs, in the third period (2014-2018) the X-gen rate was reduced to 1.25 per cent. For the third regulatory period, E-Control engaged WIK-Consult to analyse the available cost data for Austrian electricity DSOs from 2010-2016, and also evaluated consultant studies submitted by stakeholders (by Gugler and Liebenstiener and by Frontier Economics). After correcting for some perceived deficiencies in the Gugler and Liebenstiener study, the results of the three studies suggested a range of feasible frontier shift estimates of 0.3 to 2.6 per cent. From this range, and "taking a cautious approach that balances the interests of all affected parties", E-Control decided on a preferred X-gen rate of 0.95 per cent per year for electricity DSOs (E-Control, 2018, p. 16).

The first two regulatory periods for gas DSOs were from 2008-2012 and 2013-2017, and the same X-gen rate of 1.95 per cent, as applied for electricity DSO was used. For gas TSOs in the period 2012-2016, the average productivity adjustment factor was 2.5 per cent per year, but may have been set at a lower rate for the most efficient businesses. For the regulatory period commencing in 2017, the productivity rate was based on the results of an international gas TSO benchmarking exercise, which estimated the average efficiency of Austrian gas TSOs, and a productivity factor of 2.45 per cent was derived by allowing two regulatory periods for those inefficiencies to be removed from controllable costs. This implies no additional allowance for frontier shift. On the other hand, an allowance 1.94 per cent was introduced for real increases in input prices, so that the net effect of the productivity and input price adjustments was –0.5 per cent per year applied to controllable operating costs. Productivity measurement specifically of Austrian gas networks using firm-level data was introduced in 2017 for the third regulatory period beginning in 2018.

In summary, the general efficiency factor reflecting frontier shift was, in early periods, set at around 1.95 per cent per year for DSOs, while in more recent regulatory decisions E-Control has adopted lower rates of 1.25 per cent and most recently 0.95 per cent. For most gas TSOs, the X-factor has been 0.5 per cent.

A.3 Belgium

The federal energy regulator in Belgium is the Commission de Régulation de l'Électricité et du Gaz (CREG), which regulates TSOs, while regional regulators in Wallonia, Flanders and Brussels regulate energy DSOs. The only electricity TSO is Elia System Operator (although CREG and OFGEM jointly oversight the NEMO undersea cable between Belgium and the UK), and the only natural gas TSO is Fluxys Belgium. Both these TSOs are partly owned by the Belgian municipalities and partly privately owned. There are about 24 electricity DSOs and about 17 gas DSOs.

When CREG commenced its regulatory role in 2003, it initially used a 'cost plus' pricing method with one-year regulatory periods. Incentive regulation was introduced in the regulatory period 2008-2011, and included an efficiency 'X factor' applied to controllable costs. This was supported by benchmarking. For the 2012-2015 regulatory period, CREG commissioned a methodological study by Agrell and Bogatoft (2011). The methodology developed in this study used DEA applied to a sample of 25 Belgian electricity DSOs, and to a sample of 17 gas DSOs, for the period 2008-2010 in both cases. The analysis would produce estimates of: (a) individual cost inefficiency levels for a chosen reference year; and (b) productivity improvement rates for the efficient operators (frontier shift). The report does not present any analysis results.

In December 2014, CREG adopted a tariff methodology for electricity and gas TSOs for application during the regulatory period 2016-2019. Costs are grouped into three kinds: (i) controllable costs which are subject to a revenue cap; (ii) uncontrollable costs, which are fully passed-through to customers; and (iii) partially controllable costs subject to partial pass-though. In the revenue cap, the application of an efficiency 'X factor' was waived for the 2016-2019 regulatory period. Instead, 50 per cent of the difference between actual and forecast controllable costs (positive or negative) over the regulatory period is added to the revenue requirement for the next regulatory period. Thus, if there is an efficiency gain that causes controllable costs to be lower than budget, half of that gain flows through to consumers in the next regulatory period via a reduction in the revenue cap. For partially controllable costs there is a more limited pass-on of efficiency gains to consumers. For non-controllable costs, differences between actual and budget are fully allocated to the revenue cap for the following regulatory period. There are also incentives to: promote market integration, security of supply, and market balance; conduct research and development; and improve the quality of services.

Forecast controllable costs are in principle subject to international benchmarking to assess their reasonableness, in terms of comparability with the controllable costs of companies with similar activities in analogous conditions. This generally means that a factor is applied to account for improving productivity and efficiency (i.e. a 'catch-up' factor). That said, CREG suggests that, aside from some specific cost items,[22] controllable costs were not subject to

[22] Managerial salaries are benchmarked against relevant standards.

benchmarking for the 2016-2019 regulatory period (CREG, 2014). In June 2018, CREG made a decision on the tariff methodology for the regulatory period 2020-2023, which appears to be similar to the approach used in the previous regulatory period.

A.4 Brazil

The Brazilian electricity network regulator is Agência Nacional de Energia Elétrica (ANEEL). It determines revenue caps for electricity network businesses. Concessions for new transmission lines have been auctioned by ANEEL, with the winning business being the one that offers the lowest annual revenue cap over the concession period (e.g. 30 years). The natural gas sector is regulated by the National Agency of Petroleum, National Gas and Biofuels (ANP). It has responsibility for approving transmission tariffs and access agreements for gas pipelines.

In December 2007 there were over 20 electricity TSOs in Brazil, mostly government-owned either at federal or state level (Serrato, 2008). However, since then the number of TSOs has at least doubled with the granting of concessions to many new transmission system projects, and with other substantial changes to the industry structure through privatisations, mergers and acquisitions. There are over 60 electricity DSOs according to data published by ANEEL in 2013 (Banker and Zhang, 2016). There is a mix of public and private ownership, since around 20 electricity DSOs were privatised in the 1990s.

In the natural gas industry, state-owned Petrobrás is a major vertically integrated gas producer and owner of transmission and distribution networks. It controls more than half the combined capacity of gas transmission pipelines and has a controlling interest in many of the gas distribution networks. In 2015, Brazil had 24 distribution companies (Tovar, Ramos-Real and Fagundes de Almeida, 2015). Most are partly owned by state government, partly by Petrobrás, and partly by private investors. Gas DSOs that have been partly or wholly privatized are subject to price-cap regulation, with a regulatory period of five years. DSOs that remain wholly state-owned use cost-plus pricing (Tovar, Ramos-Real and Fagundes de Almeida, 2015).

Electricity TSOs have been benchmarked by ANEEL since 2007 using DEA. Benchmarking has focussed on manageable (or controllable) costs and hence the benchmarking models use operating expenses as the only input. Typical outputs are the numbers of power transformers and switch nodes, transformer capacity and network length, and returns to scale are assumed to be non-decreasing. In 2013, ANEEL used panel data for nine TSOs (da Silva, Costa and Lopes, 2017) for comparative efficiency analysis.

For the purpose of calculating the X-factor for TSOs, ANEEL carried out an analysis in 2015 which used a modified version of the Malmquist TFP index and adopted a bootstrapping method to generate confidence intervals (Afsharian et al., 2019). The analysis was based on data from 2009 to 2014 for 38 TSOs. The input was operating expenses. The outputs were network length (km), modules (number) and installed capacity (megavolt-ampere, MVA). ANEEL estimated the average rate of technical change to be 0.2 per cent per year. Having regard to the estimated confidence interval, ANEEL concluded that there was no evidence of significant technical change, and set the X-factor at zero per cent. On the other hand, Afsharian et al (2019) critique ANEEL’s analysis and find greater technical efficiency improvements over the same period.

In electricity distribution, for the regulatory periods from 2003–2006 and 2007–2010, ANEEL used an engineering-based model for a reference network, which calculated the efficient cost of supply, given the activity levels of the DSO (Banker, Førsund and Zhang, 2017, p. 34). For the second of these periods, the X-factor applied to manageable costs was 1.26 per cent.

For the 2011–2014 regulatory period, ANEEL used DEA benchmarking of operating costs. The DEA benchmarking analysis employed by ANEEL had two stages. In the first stage DEA estimation, operating cost was the only input, and there were three outputs (electric power delivered, network length, number of customers). In the second stage, the estimated efficiency scores were regressed against operating environment variables to obtain adjusted efficiency estimates after controlling for those factors. Banker (2011) was critical of the assumption of a non-decreasing returns to scale (NDRS) used by ANEEL; arguing instead that the variable returns to scale (VRS) is less restrictive, and to be preferred. Although there are usually economies of scale when more energy is delivered through the same network assets, the expansion of DSOs can be of a different kind, such as an increase in customer density on parts of the network, or geographical expansion of the network, neither of which necessarily generate economies of expansion. An expansion can sometimes give rise to increased costs if different types of customers are served, or there is greater congestion, or the expansion is into areas that are more difficult to supply.

The X-factor for adjusting tariff revenues, in relation to non-pass through allowed costs, had three components: (i) a productivity term, (ii) a quality of service term and (iii) a transitional operational costs trajectory term (ANEEL, 2012). The productivity term and the transitional term were set on an *ex ante* basis and the quality term was set on an *ex post* basis. The transitional term was set at 0 per cent. The quality term was based on an average of the relative performance outcomes of distribution utilities as measured by indexes for interruption duration and interruption frequency. The productivity term was based on an estimated annual average of productivity growth in the electricity distribution sector of 1.11 per cent and, after various adjustments for variation among distributors and differences relative to the previous regulatory period, this resulted in an annual productivity growth assumption of 1.08 per cent (ANEEL, 2012, p. 56).

The same three-part X-factor was used in the subsequent regulatory period. The productivity component was based on the estimated average rate of TFP growth over the period 2005-2012 of 1.53% per annum, which was calculated using a Törnqvist index (ANEEL, 2015).

Academic studies of energy network productivity in Brazil, in addition to those mentioned, include:

- Tovar et al (2011) employed stochastic frontier analysis (SFA) of a distance function on a panel of 18 Brazilian electricity distribution firms from 1998-2005. The estimation decomposed TFP change into technical change (frontier shift) and technical efficiency (catch-up), with a further decomposition of the latter into pure technical efficiency and scale efficiency, and examined the effects of the reform process in the period. Inputs were employees (number), network length (km), and losses (GWh). Outputs were energy delivered (GWh) and the number of customers served. The study found the average rate of TFP change over the period was 0.9 per cent per year. The estimated decomposition was: technical change (frontier shift) 4.9 per cent and efficiency change

-4.0 per cent; with the latter comprising pure efficiency change (catch-up) -3.7 percent; and scale efficiency change -0.3 per cent. The TFP growth estimate is consistent with an earlier study by Ramos-Real et al (2009) using non-parametric techniques on the same data, however, there appears to be less reliability in relation to the decomposition.

- Tovar et al (2015) empirically examines the technical efficiency of 15 gas DSOs in Brazil during the period 2001–2009. They use stochastic frontier analysis of a translog multi-input, multi-output distance function. The outputs are gas deliveries and network length. The inputs are capital costs, operating costs and cost of sales (i.e. gas purchases). A time trend is included in the (partially stochastic) inefficiency term of the model to identify efficiency 'catch-up' effects. The deterministic part of the model does not include any provision for frontier shift. The coefficient on the time trend was not statistically significant, but the point estimate suggested there may be some underlying efficiency gain over time.

In summary, ANEEL has tended to base the X-factor for electricity networks, at least in part, on the estimated TFP growth over the preceding six or seven years. It has typically used either a Malmquist or Törnqvist TFP index method to calculate TFP growth. The estimates of average TFP growth in electricity distribution have varied from 1.3 per cent (made in 2008), to 1.1 per cent (in 2012), and 1.5 per cent (in 2015). For electricity transmission, ANEEL in 2015 estimated the rate of TFP growth to be close to zero per cent. The academic studies reviewed used econometric analysis, and suggest a TFP growth rate of around 0.9 per cent per year in electricity distribution, but the results were not statistically significant in relation to TFP growth in gas distribution.

A.5 Germany

Germany's energy networks (electricity and gas TSOs and DSOs) are regulated by the Bundesnetzagentur (BNetzA). There are four electricity TSOs and 16 gas TSOs. Although there is unbundling, the electricity TSOs also own major generators and many electricity DSOs. There may be as many as 1,600 electricity and gas DSOs in Germany (Groebel, 2018). However, DSOs with less than 30,000 customers are not subject to economic regulation. Hirschhausen et al (2006) suggest there are about 600 regulated electricity DSOs, and a 2007 benchmarking study of DSOs commissioned by BNetzA included approximately 500 gas DSOs (Agrell and Bogetoft, 2007).

Energy TSOs and DSOs are subject to similar forms of revenue cap regulation. The revenue caps established by BNetzA incorporate both an individual efficiency target and a general sectoral efficiency factor. The individual efficiency target is developed by BNetzA using frontier efficiency benchmarking (SF and DEA analysis). It applies to that part of total costs that are classified as controllable, and is based on removing inefficiencies over a chosen period, such as two regulatory periods (Agrell and Bogetoft, 2013). The general sectoral efficiency factor ('Xgen') reflects technical change and sector-specific input price changes and applies equally to all businesses. There are further adjustments within the revenue cap formula to allow for expansions in demand, and to incentivise investment and quality of service.

The general productivity factor is broadly equivalent to a forecast annual rate of frontier shift. In the first incentive regulation period (2009-2013), the X-gen rate (for gas networks) was set at 1.25 per cent, and in the second regulatory period (2014-2018) it was set at 1.5 per cent. According to Gugler and Liebensteiner they "appeared to be the result of a political decision, rather than being based on empirical evidence—most likely due to a lack of reliable data for a sophisticated scientific analysis (2019, p. 4). In 2018, BNetzA adopted general productivity factors of 0.49 per cent for gas networks; and 0.9 per cent per year for electricity networks for the 3rd regulatory period, commencing in 2018 for gas and 2019 for electricity networks (Bundesnetzagentur, 2018; Groebel, 2018). These estimates were developed by BNetzA using Törnqvist and Malmquist index analysis.

Most of the academic productivity studies of German energy networks we have reviewed only examine comparative efficiency and don't estimate rates of productivity change. For example: Hirschhausen et al (2006) benchmark the efficiency of 307 German electricity DSOs using DEA as the main method, and SF distance function analysis for comparison. It is a cross-sectional study, using a data sample for only one year, 2001. Cullmann (2012) examines the efficiency of 200 German regional and local electricity DSOs in the period 2001 to 2005. The study uses a latent class SF method, and compares this to the True Random Effects SF method. It is found that the two methods produce very different results; the correlation between the efficiencies estimated by both model specifications being low. Although the study uses panel data, it assumes there is no technical change and no changes in efficiency within the period studied. Cullman and Nieswand (2016) study 109 electricity DSOs for the period 2006 to 2012 to test whether the implementation of the incentive regulation had an impact on the investment behaviour of DSOs. They implicitly assumed no technical change.

A.6 Netherlands

The regulator is Autoriteit Consument & Markt (ACM), which is responsible for both competition law enforcement and utility regulation. The Dutch gas network consists of separate networks to transport low calorific gas (used by small users) and high calorific gas (used by industry and power generators). There is one national TSO for gas in the Netherlands, Gasunie Transport Services (GTS), which is fully state-owned, and there is one electricity transmission system operator, TenneT, which is also state-owned. There are eight DSOs that distribute both gas and electricity and two DSOs that distribute gas only. These are owned by municipalities.

The electricity and gas DSOs are subject to price regulation with a system of national yardstick competition. The TSOs are subject to revenue caps with a yardstick comparative efficiency adjustment based on international benchmarks. The annual price adjustment formula has a frontier shift component based on productivity growth in: (i) transmission businesses in other countries and (ii) eight comparator industries in the Netherlands which reflect aspects of the cost structure of electricity and gas transmission.

An early energy benchmarking study of Dutch electricity network businesses was undertaken by Frontier Economics (Burns et al., 2000). The study included DSO and TSO benchmarking components. For distribution benchmarking, DEA was applied to 1996 data for 20 Dutch electricity DSOs, using opex as the input. For transmission benchmarking, the sample comprised TenneT and TZH (a Dutch electricity network provider classified as a TSO for the purposes of the study), and selected TSOs from Europe and the USA using 1998 data. Of particular interest here, the study also examined the average rate of productivity growth of two comparator electricity TSOs in the UK, Scottish Power and NGC, using data for 1993 to 1998.

The input was total cost at 1993 prices, and the outputs were: energy units transported, maximum demand and circuit length (km). Sequential DEA was used to find an average annual productivity growth of 6.8 per cent for NGC and 3.6 per cent for Scottish Power.

On behalf of the then Dutch Office of Energy Regulation (DTe), Europe Economics (2006) surveyed a number of studies, carried out in late 1990s and early 2000s, into TFP trends in the electricity, gas and water sectors in the United Kingdom, Italy, Australia, New Zealand and the United States. Most of the studies surveyed used index-based methods to measure TFP growth, and hence did not attempt to disentangle the effects of efficiency catch-up and frontier shift. Some used econometric and DEA methods and attempted to make such a decomposition. Based on its evaluation of these studies, Europe Economics concluded that the expected TFP growth for TenneT (in excess of the economy-wide productivity growth rate of 0.5 per cent) should be in the range 0.75 – 1.75 per cent per year. This estimate excluded any potential for 'catch up' productivity improvements.

In 2016, ACM commissioned Oxera to conduct a study on the dynamic efficiency of Dutch TSOs (Oxera, 2016b). The objective of the study was to advise on the scope of productivity improvement that an efficient operator could achieve due to the combined impact of technological improvement (i.e. frontier shift) and cheaper inputs for TenneT and GTS, to be applied over the regulatory period from 2017 to 2021.

The report focussed on estimating TFP and changes in an output price index that reflected the combined impact of input price changes and TFP changes. It made clear that TFP only measures technological change if there is no catch-up efficiency or scale effect efficiency to be realised. The main empirical focus for the study was on a comparator set of eight industries in the Netherlands using EU KLEMS and OECD-STAN data covering the period 1988-2009. The data covered most of the period of two complete business cycles. The eight industries in the comparator set were based on a detailed review of their activities and were: telecommunications; IT and other information services; professional, scientific, technical, administrative and support service activities; construction, financial and insurance activities; transportation and storage; other manufacturing, repair and installation of machinery and equipment; and electricity, gas and water supply.

Using the comparator data set and a gross output measure, TFP growth was estimated to be 0.4 per cent and with a small relative decline in input prices (-0.1 per cent) included, the overall gain in cost efficiency per year was estimated to be 0.5 per cent. The robustness of these estimates was checked using alternative data sets, comparator sets and timeframes. The report also presented evidence indicating technological change has been the main driver of productivity change in the Dutch economy with scale and catch-up effects being insignificant and concluded the empirical measures based on the comparator set did not require adjustment for scale or catch-up efficiency changes. The report also reviewed a number of regulatory precedents and academic studies. The key findings from the review of other studies with respect to dynamic efficiency effects were as follows:

- The regulatory precedents point to a range for TFP growth of 0–1.5% per annum for the electricity TSOs and 0.3–1.5% per annum for the gas TSOs, although the upper end estimate (of 1.5%) may encompass catch-up effects.

- The academic studies for electricity TSOs point to a range for TFP growth of -1% to 2.4% per annum, with the higher estimates based on time frames of less than four years. The range for the gas TSOs is between 0.5% and 0.8% per annum.

Oxera was less confident about the regulatory results given lack of clarity about the methodology and data used and for the academic results given the wide ranges found for electricity, some with short time frames, and noting that the gas results were based on only two studies. In a subsequent note Oxera responded to comments by GTS and TenneT on the representativeness of the data set and concluded that their arguments did not change the conclusions (Oxera, 2016a).

A.7 New Zealand

The New Zealand Commerce Commission (NZCC) regulates energy networks in New Zealand. The only electricity TSO in New Zealand is state-owned Transpower; regulated by the NZCC since 2011. There are 17 electricity distributors. The NZCC sets an individual price-quality path for four and five yearly periods, which specifies the maximum allowable revenue, expenditure allowances, and required quality standards. The revenue cap was derived using a 'building block' methodology. Natural gas is only available on the North Island. Since 2016 there is a single gas TSO, First Gas, and there are four gas DSOs, including Powerco, Vector, GasNet, and First Gas, with varied forms of ownership including private, municipal and community trusts. Natural gas businesses have been subject to price regulation by the NZCC since 2012. The form of price control is a revenue cap, with price paths initially based on pre-existing prices and escalation (in real terms) based on long-run average productivity changes for gas networks relative to the economy as a whole. These were estimated using a TFP index methodology (Economic Insights, 2011; ACCC and AER, 2012).

The current building block-based model used in New Zealand uses forecasts of allowed efficient capex, and since these expenses are already deemed to be efficient, no additional productivity factor adjustment is required. Capex forecasts are based on taking distributors asset management plans as the starting point and applying a series of tests of the reliability of the forecasts. The tests include internal consistency (with activity and relative to history) and close examination of large step changes and whether they should be covered under a customised price path. Allowances and incentives for improving quality of supply have also been specified.

However, there is a need to make an allowance for productivity improvement when preparing opex forecasts. A base-step-trend approach is used to forecast opex. The 'base' component is an estimate of efficient costs in the base year. The 'step' component makes adjustments for non-recurrent costs that may be passed through or recovered elsewhere. The 'trend' component relates to the rate of change allowed for operating costs.

Once forecasts of efficient costs (operating and capital) are made, an allowed revenue path is estimated with the path change specified by an appropriate indexation factor and starting point prices such that the expected present value of allowed revenue equals the present value of allowed costs; and the indexation factor need not be directly related to the estimated rate of productivity growth provided the present value condition is satisfied. Typically the indexation factor is simply the CPI. Prior to 2016, a maximum weighted average price cap was set rather than a revenue cap.

On 27 November 2019 the Commerce Commission of New Zealand set the third default price-quality path (DPP) for electricity DSOs subject to price-quality regulation. These price-quality paths will apply for the period 1 April 2020 to 31 March 2025. Two of these distributors are currently on a Customised Price-quality Path (CPP) and will transition back to the DPP when their CPPs expire. These regulatory arrangements set a revenue cap path with various efficiency and quality standard incentives and a wash-up mechanism to ensure recovery of allowed costs over the regulatory period. Starting revenues, a rate of change of revenues and minimum quality standards and incentives to improve quality are specified for the regulatory period. As noted, distribution businesses are allowed to retain a proportion of cost efficiencies realised for opex. In addition to defining maximum allowable revenues (MARs) through this process, allowances for certain pass through costs are defined.

A 0.0 per cent partial productivity factor trend adjustment was determined for operating expenditure. The NZCC was unconvinced that declining productivity in the past was predictive of future declines and based its assessment on overseas productivity trends in electricity distribution (in the UK, Norway and Canada), comparable sectors in New Zealand and a changing policy environment compared with the prior regulatory period.

The default X factor in the CPI-X revenue escalation formula was also set at 0.0 per cent. This reflects the conclusion on the partial productivity change factor relevant to opex, and that the allowed capex was already determined to represent efficient expenditure with base year revenue specified so that the present value of forecast revenues is equal to the present value of forecast efficient costs. There was not sufficient information to identify an aggregate partial productivity factor for capital given the way that the capex allowances were determined.

The NZCC considered that the scope for a capex reopener and increase in incentives under the incremental rolling incentive scheme that applies and allowance for recoverable costs in relation to certain innovation will assist in ensuring there are still incentives to invest efficiently. The incremental rolling incentive scheme allows retention of opex and cost savings by the distribution business of 23.5 per cent of the total saving in present value terms. Separate targeted innovation allowances and incentives for improving quality of supply have also been specified.

A.8 Norway

Electricity distribution service operators (DSOs) are regulated by the Norwegian Water Resources and Energy Directorate (NVE), which sets revenue caps for almost all of the approximately 120 electricity DSOs (Flataker and Nielsen, 2019). State-owned Statnett is the only electricity TSO, and sets its own tariffs. Natural gas transmission is regulated by the Ministry of Petroleum and Energy. Norway has an extensive offshore gas gathering and transportation system (in the North and Baltic Seas) owned by the Gassled consortium and operated by the state-owned company Gassco.[23]

Before 2007, NVE used an *RPI-X* formula for setting revenue caps for DSOs. It then moved to a yardstick model more reliant on benchmarking Norwegian DSOs against each other using a DEA analysis. Revenue caps are set annually for the forthcoming year as a weighted average of: (i) the DSO's estimated actual cost two years previously, and (ii) its efficient cost estimated using the benchmarking model (Banker, Førsund and Zhang, 2017).[24] The usual weight is 0.6 to the benchmark-based cost norm, and 0.4 to the actual cost. There may also be an adjustment to take account of new investments (Agrell and Bogetoft, 2013). At the end of the year, the cost of any energy not supplied is deducted from the revenue allowance. Hence, NVE does not need to forecast productivity.

Natural gas TSO tariffs are specified in regulations. In 2013, the Ministry reduced tariffs for new transport agreements entered into after 2016;[25] so as to yield a forecast real pre-tax rate of return of 7 per cent to Gassled on its historical assets. In making this calculation, the Ministry appears to have relied on Gassco's operating cost forecast rather than making an explicit productivity forecast.

Hence, Norway's energy network regulators do not produce any productivity growth estimates or forecasts. However, there have been several academic studies of comparative efficiency and productivity trends among the Norwegian DSOs. Three of the comparatively recent studies are as follows.

- Kumbhakar et al (2015) used SF analysis to examine technical efficiency, scale economies and technical change in Norwegian DSOs from 1998 to 2010. The study estimated an average rate of technical change "of about 1% per year", and noted that this was consistent with the findings of earlier studies (p.302). Firm-specific inefficiency was restricted to be unchanging.
- Orea and Jamasb (2017) used various SF methods to study the relative efficiency of Norwegian DSOs using data from 2004 to 2011. They assumed no underlying technical change; all changes in efficiency were attributed to efficiency gains. They found that generally there were efficiency gains "albeit not always significant" (p.117).
- Senyong and Bergland (2018) used stochastic frontier analysis, and data from 2004 to 2012, to examine the sources of DSO productivity growth "by parametrically decomposing the Malmquist productivity index into efficiency change, technical change and scale change." (p.231) This study estimated average TFP growth to be 1.5 per cent per year, comprising a rate of technical change of 1.3 per cent, and a rate of efficiency improvement of 0.2 per cent (p. 249 Table 9).

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[23] Another Norwegian state-owned enterprise (Petoro) has a major stake in Gassled and the other owners are private firms. In 2028, the Gassled assets revert to the state.

[24] The efficient cost is calibrated so that a firm of average efficiency will earn a normal rate of return.

[25] This led to a major legal dispute between private participants in the Gassled consortium and the state.

A.9 Peru

Major reforms were implemented for the electricity sector in Peru from 1992 including vertical and horizontal separation of generation, transmission and distribution, some privatisation and tariff restructuring. For some twenty years prior to the reforms two vertically integrated companies, Electroperu and Electronlima dominated the power sector. At the same time a number of independent power producers existed mainly generating power for their own use. There are currently 57 generation companies, 20 private transmission companies and 18 mostly private distribution companies (OECD, 2019).

The regulatory authority is Osinergmin (Energy and Mining Investment Supervisory Body). Osinergmin sets wholesale tariffs for electricity generation, transmission and distribution activities, as well as natural gas pipeline network distribution. Transmission and sub-transmission tariffs are regulated under a cost-based model for existing assets or a bidding process for new assets. Large customers negotiate their rates while regulated rates are set for other customers using yardstick competition and the efficient company benchmark. There is a four-year regulatory period. There is a significant gap in the operational efficiency of private and public distribution companies which, according to Osinergmin, is largely attributable to an investment gap reflecting financing constraints for public companies in rural areas.

Pérez-Reves and Tovar (2009) measure the efficiency for Peruvian electricity distribution companies after the reforms. They estimate a Malmquist TFP index with decompositions of efficiency components and in a second stage explore the relationship between efficiency scores and relevant variables. The data cover various years from 1996 to 2006. The output measures were sales (MWh) and number of customers. Two models were estimated with one using physical input measures for capital and one using real monetary capital values and both using worker numbers. Quality is measured in both models by power losses.

The main results were:

- There were improvements in efficiency in the period analysed.
- 13 of 14 companies experienced increases in TFP for the period studied.
- Generally the reformed firms showed improvements in relative efficiency, which was confirmed with second stage regression tests.
- The same companies are located on the efficiency frontier in both models.
- The main source of productivity change has been technological change.

Table A.1 shows the annual average growth in various efficiency measures for the two models. Model 2 is the preferred model in the study.

Table A.1: Productivity Trends of Peru Electricity DSOs, 1996 to 2006; Pérez-Reves & Tovar (2009) (% p.a.)

	Model 1: Physical capital	*Model 2: Real monetary capital*
Technical change	2.9	4.0
Technical efficiency change	0.7	0.3
- Pure technical efficiency change	0.2	0.4
- Scale efficiency change	0.4	-0.1
TFP	3.6	4.3

A.10 Sweden

The Swedish energy networks regulator is the Energy Markets Inspectorate (Ei). The National Electricity Grid is operated by a single state-owned TSO, Svenska Kraftnät. There are five larger regional electricity DSOs, and approximately 170 smaller electricity DSOs. In the natural gas sector there is a single TSO, Swedegas, and five gas DSOs.

Before 2009, the Inspectorate carried out annual *ex post* reviews of energy network tariffs using a reference network performance assessment model (NPAM), which estimated a monetary value of the services provided by the utility to its customers (taking into account outages etc), which could then be compared to the amounts it had charged, and Ei could intervene if it considered the rates unreasonable (Andréasson, Gynnerstedt and Håkansson, 2014; Jamasb and Pollitt, 2008). Subsequently, *ex ante* revenue cap regulation was introduced, with four-year regulatory periods; the first starting in 2012. In 2013 the same form of regulation was adopted for the gas industry, with the first regulatory period starting in 2015.[26]

There were substantial litigations surrounding the revenue cap decisions made by Ei in the first regulatory period for both electricity and gas networks. For the second regulatory period (commencing 2016), Ei introduced some benchmarking of efficiency which was combined with DSO historical cost data (Grahn et al., 2016). An efficiency requirement was imposed on each DSO in relation to controllable operating costs (which make up about one-quarter of the overall revenue requirement). It consisted of two parts: (i) a common rate of efficiency gain of 1.0 per cent per year for all DSOs; and (ii) a DSO-specific efficiency gain (0.00-0.82 %/year in addition) that is new from 2016. To determine the DSO-specific efficiency gain, the controllable operating cost of each DSO was compared to that of other DSOs with similar customer density. An efficiency requirement was then imposed on those DSOs with above-average controllable operating cost for a given customer density, such that those costs are expected to decline over time. The common efficiency improvement factor of 1 per cent per year was similarly imposed in TSOs.

[26] In this framework, revenue amounts in excess of the cap are deducted from the revenue cap in the subsequent regulatory period, whereas amounts below the income cap are added to the revenue cap in the next period.

A study by Agrell and Brea-Solís (2017) carries out SF analysis of the input distance function for Swedish DSOs using data from 2000–2006. Although the study has the primary purpose of assessing the reliability of latent class SF models for assessing comparative efficiency, compared to other SF techniques, the models included a quadratic time-trend effect which provided an estimate of frontier shift. The study found, incidentally, that "the trend coefficient that captures technical change is negative in almost all the models across classes except for … [one], where it is positive but not significant" (p.368). However, the time period covered by the data was relatively short.

A.11 United Kingdom

The United Kingdom (UK) has three electricity TSOs, National Grid Electricity Transmission (NGET), Scottish Hydroelectric Transmission Limited, and Scottish Power Transmission Ltd, and one gas TSO, National Grid Gas Transmission (NGGT). There are 14 regional electricity distribution networks (owned by seven firms) and four gas distribution networks. The UK energy regulator is the Office of Gas and Electricity Markets (Ofgem). It applies an RPI – X price cap regime to both gas and electricity TSOs and DSOs.

Prior to 2013, Ofgem used five-year regulatory periods, and used a 'building block' method for forecasting total cost (including opex plus the allowed return on and depreciation of the regulatory asset base). The regulated price path was chosen to yield revenues with the same net present value as the cost forecast over the regulatory period. Ofgem has used benchmarking as one tool to assist it to determine the efficient opex. Since 2013 Ofgem has used a framework known as the 'Revenue using Incentives to deliver Innovation and Outputs' (RIIO), initially with regulatory periods of eight years. Within this approach, Ofgem estimates the expected efficient total expenditure ('totex' = opex + capex) using a number of different methods.

Here we discuss some examples of Ofgem's use of productivity analysis. In 2003, on behalf of Ofgem, Cambridge Economic Policy Associates (CEPA 2003a) studied the TFP of 14 electricity DSOs in the UK over the period 1992 to 2002. The analysis used two inputs, operating costs and the value of tangible assets, and three outputs, customer numbers, units distributed and network length. A Törnqvist index method was used, with adjustments made for scale efficiencies and quality improvements. The study derived a preferred estimate of the historical trend TFP growth of 3.1 per cent, which was considerably higher than for the UK economy as a whole (estimated at 1.3 per cent). An estimated TFP growth rate for electricity TSOs was also derived, based on the National Grid Company (NGC), and using the same input definitions and a single output: electricity requirements (TWh). The estimated TFP trend growth was 2.4 per cent per year. Estimates were also produced for TFP growth of US and German DSOs based on 10 years of data, which were 2.2 and 1.2 per cent respectively. CEPA considered that the high TFP growth for UK DSOs was not likely to continue, and having regard also to the TSO and international estimates, its forecast TFP growth for UK electricity DSOs was 2.4 per cent, from which it subtracted the expected TFP growth for the UK economy of 1.3 per cent, and on this basis the X factor in the RPI-X indexation was set at 1.1 per cent.

CEPA noted that trend TFP growth ought to distinguish between movements towards the frontier (catch up) and movements of the frontier (frontier shift) and that it would be unfair to expect frontier firms to achieve an average TFP growth target that included catch-up growth. No information was provided to guide the formulation of differential targets. However, the

CEPA report noted an earlier study had suggested that future TFP would be determined by frontier shift while operating efficiency is likely to be the result of a combination of catch up and frontier shift (2003a, p. 59, 2003b).

Another example is Ofgem's 2009 decision on allowable costs for electricity DSOs for the regulatory period from 2009-10 to 2014-15. A benchmarking study was used as one source of evidence on the efficient opex in the base year. It was based on historical cost data for all UK DSOs over four years, and employed regression analysis with various different degrees of disaggregation of opex, and assigning specific cost drivers to each specific cost component (ACCC and AER, 2012). The estimated efficiency scores were derived from fixed effects in the regression models. Since other factors may influence the fixed effects, Ofgem set the benchmark for opex at the upper third of the distribution for network operator costs efficiency scores and at the upper quartile for other opex efficiency scores. Ofgem also used judgement in determining the efficient opex. The estimated efficient costs were then applied from the beginning of the regulatory period, without any time allowance for 'catch-up' to take place (ACCC and AER, 2012). Ofgem also applied a one per cent annual efficiency saving in making its opex forecast for each year of the regulatory period. This was based on an index number analysis of productivity and unit cost trends in comparator industries of the UK economy based on EU-KLEMS data for the period 1970 to 2005.

In a 2012 decision setting prices for gas distribution networks (GDNs), and for the electricity and gas transmission networks (NGET and the NGGT) for the forthcoming regulatory period (2011-12 to 2020-21), Ofgem (2012) explained that its efficiency assumptions were based on the average historical improvement in productivity for comparator sectors, from 1970 to 2007, as measured by EU KLEMS data. The key assumptions were:

- A one per cent improvement in opex efficiency based on partial factor productivity measures (i.e. labour, and labour and intermediate inputs) for the industry averages (which range from 2.8 to 0.5 per cent p.a.). The assumption of one per cent is also in line with network company assumptions.
- A 0.7 per cent improvement in capex and repex (replacement capex) efficiency which is at the top-end of the estimates for total factor productivity (TFP) for construction, the principal comparator, but below the average TFP for other industries.
- Capital substitution is considered separately when specifying allowances for capital.

Under the regulatory arrangements allowed revenues are indexed by the retail price index but input prices do not necessarily change with inflation. As a result, average annual real price changes for opex, capex and totex ranged from 0.2 to 0.8 per cent for the different network businesses for the period 2011/12 to 2020/21.

In 2018 Ofgem commissioned the Energy Policy Research Group (EPRG) to examine productivity growth in the UK electricity and gas networks over the approximately three decades since privatisation, to inform the current RIIO-2 reviews (Ajayi, Anaya and Pollitt, 2018). The current price controls for gas and electricity TSOs and gas DSOs end in March 2021, the price control for electricity DSOs ends in March 2023, and the new regulatory periods will be five years (Ofgem, 2018). The EPRG study considers both the relative efficiency of the

UK energy network businesses — and, associated with this, the scope for catch-up productivity gains — and the rate of technical change or frontier shift.

EPRG concludes from an overview of the literature that "in most cases, overwhelming evidence of positive but low TFP growth, of the order of 1% p.a. Interestingly, the studies show some short periods of significantly more rapid growth following privatisation, the introduction of incentive regulation or rapid demand growth. However, this is not sustained over long periods, indeed most studies are for short runs of years. There is no evidence that recent growth (since 2005) is likely to be higher than the longer run trend" (Ajayi, Anaya and Pollitt, 2018, p. 21).

Several analyses were carried out:

- An index-based analysis of TFP growth for the whole electricity, gas and water (EGW) sector in Germany, Netherlands, UK and the USA, using the EU KLEMS database for the period 1995-2015. This analysis uses value-added (in 2010 prices) as the output and labour and capital measures as inputs, and employs a Törnqvist index method. In brief the findings are as follows. For the UK in the period 1998-2015 the average TFP growth was -2.3 per cent per year. For the USA there was a slight negative trend over the sample period. In the Netherlands for the period 2001-2015, TFP growth was 0.2 per cent per year. For Germany for 1998-2015, it averaged 0.8 per cent per year.
- An index-based analysis of TFP growth for the three main component industries within the electricity, gas and water sector, for the UK only. Note that these sectors are wider than the infrastructure network components (e.g. electricity includes production). This analysis uses data from the UK Office for National Statistics (ONS) for the period 1995-2016. Capital expenditure is used as the capital input rather than being based on a measure of capital stock. Deflators were drawn from the EU-KLEMS data. The results of this analysis are mixed, with volatile year-on-year estimates of TFP growth, especially for the gas sector, which appear to be due to data quality issues and limitations of the deflators used.
- A DEA Malmquist index for evaluating productivity growth in two regulated sectors, namely electricity and gas distribution.[27] This analysis uses utility-level data provided by Ofgem.
    - For electricity distribution, in the base model the inputs are opex and capex and the outputs are customer numbers, energy delivered and network length. In other model variants, peak demand or customer satisfaction are additional outputs; and quality variables are included as inputs, namely customer minutes lost, the number of interruptions and/or energy losses. For the base model, the average Malmquist TFP growth from 1992 to 2017 is 1.1 per cent per year. This is all driven by technical change. Other variants of the model, or different chosen sample periods, produce average rates of TFP change varying from -0.2 to +2.0 per cent per year indicating the importance of quality variables.

[27] As mentioned, there are 14 electricity DSOs, the 8 gas DSOs.

- For gas distribution, in the base model the inputs are opex and capex and the outputs are customer numbers, units of gas delivered and network length. In other model variants, customer satisfaction is an additional output; and other inputs are customer minutes lost and the number of interruptions. For the base model, the average Malmquist TFP growth from 1999 to 2017 is 1.6 per cent per year. Most is driven by technical change (averaging 1.3 per cent), with small contributions from scale efficiency change (0.2 per cent) and pure efficiency change (0.1 per cent). The variants of the model produce lower TFP growth rates between 0.7 and 1.1 per cent per year.
- Table A.2 shows the annual average growth in various efficiency measures for the electricity and gas distribution sectors in the base model which does not adjust for additional factors such as quality and peak demand.

Table A.2: Productivity Trends of UK Electricity (1991-92 to 2016-17) and Gas (2009-10 to 2016-17) DSOs from base model – % p.a.

	Electricity distribution	*Gas distribution*
Technical change	1.1	1.3
Technical efficiency change	0.0	0.3
- Pure technical efficiency change	0.0	0.2
- Scale efficiency change	0.1	0.1
TFP	1.1	1.6

- An index-based analysis of TFP growth for two regulated sectors, namely electricity and gas transmission. This analysis uses Ofgem data for the individual regulated firms, and EPRG-constructed aggregates for the electricity transmission sector from this data.[28]
  - For electricity transmission, in the base model the inputs are opex and capex and the outputs are energy transmitted and network length. In other model variants, peak demand is an additional output; and quality variables included as inputs are energy not supplied and system unavailability. For the base model, the average TFP growth from 2001 to 2017 is -2.2 per cent per year. Model variants yielded average rates of TFP change of 6.5 and 6.6 per cent per year, indicating the importance of quality variables.
  - For gas transmission, in the base model the inputs are opex and capex and the outputs are gas transmitted (including exports to Ireland), gas delivered in the UK, and network length. A model variant includes gas shrinkage and an additional input. For the base model, the average TFP growth from 2007 to 2017

[28] As mentioned, there are 3 electricity TSOs and one gas TSO.

is 5.6 per cent per year. The variant of the model with gas shrinkage produces a TFP growth rate of 7.6 per cent per year.

- Table A.3 shows the annual average growth in various efficiency measures for the electricity and gas transmission sectors in the base model (which does not adjust for additional factors such as quality and peak demand).

Table A.3: Productivity Trends of UK Electricity (2001-02 to 2016-17) and Gas (2007-08 to 2016-17) TSOs from base model – % p.a.

	Electricity transmission	*Gas transmission*
Technical change	-2.2	5.6
Technical efficiency change	0.0	0.0
- Pure technical efficiency change	0.0	0.0
- Scale efficiency change	0.0	0.0
TFP	-2.2	5.6

These analyses also suggest that TFP growth rates in energy network sectors have generally tended to decline over the periods studied, with the decline being most evident in the period after the 2008 financial crisis.

A.12 USA

In the USA, the Federal Energy Regulatory Commission (FERC) regulates interstate gas and electricity transmission.

- The 30 largest pipeline companies operate the vast majority of interstate gas transmission pipelines. Most gas TSOs are vertically separated from other functions. Although the gas transmission market is reasonably competitive in North America, FERC must approve any increases in tariffs for individual pipelines to ensure they are 'just and reasonable'. The FERC sets rates on a pipeline-by-pipeline basis, and approves a maximum allowable access price for each pipeline.
- Interstate electricity transmission represents an extensive part of the USA's highly interconnected grid. Electricity TSOs are mostly privately owned, although many are owned by (non-profit) cooperatives. They are often vertically integrated, but are required to be functionally unbundled. Each electricity TSO is required to have standard open access terms and conditions and can submit tariffs to FERC for approval.

The FERC uses a cost-of-service method for determining energy transmission access charges. Under this approach there is Annual Transmission Revenue Requirement (ATRR) based on the reasonable operating and maintenance expenses and the allowed return on capital invested and used to serve customers. There is cost allocation to different access services (e.g. point-to-point services, firm/non-firm etc); and translated into unit rates. There are also FERC-approved rate incentives. Rates may be expressed in formulas that are updated annually with the latest historical data and capex forecasts, and there are ‘true ups’ to reconcile forecast costs and loads to actual outcomes.

Intrastate energy networks (e.g. DSOs) are regulated at either the state or municipal level, or not regulated. Electricity DSOs may be investor-owned, publicly-owned, or (not for profit) co-operatives. They are often vertically integrated with electricity generation and retailing. The natural gas industry is largely privately-owned and vertically-separated. Regulated utility rates are determined via rate cases, and usually using a cost-of-service approach to determine a revenue requirement. In most cases this is based on costs in a ‘test year’ (e.g. the most recent year for which data is available, or the forecast costs for the year in which the new rates take effect). The approved tariffs usually remain in place until there is an application for another rate case, which may be three to four years.

Statistical benchmarking studies are rarely commissioned by regulators in North America, but they are occasionally filed by utilities in support of rate applications. The studies mostly use US data and employ econometric and indexing methods (Lowry and Getachew, 2009). This can be seen for example in California. The California Public Utilities Commission (CPUC) is the regulator of privately-owned energy utilities in that state. The regulated electricity utilities are: Pacific Gas and Electric (PG&E); Southern California Edison (SCE); San Diego Gas and Electric (SDG&E); and some smaller electricity utilities. The regulated natural gas utilities are: PG&E; Southern California Gas (SoCalGas); SDG&E; Southwest Gas, and several smaller gas utilities. CPUC regulates the revenues of these utilities through general rate cases (GRCs), and regulates the allocation of costs between customer groups. GRCs are held every three years for each utility. CPUC reviews detailed cost data and approves a revenue requirement for the first year of a regulatory period (the ‘test year’). For the remaining two years of the period (‘attrition years’), the revenue requirements are based on the test year adjusted for “inflation and other factors that may affect costs, such as additional capital projects between test years”.[29]

Productivity analysis may be submitted by a utility as general information in support of its proposed rate plan. For example, SDG&E’s 2006 rate-change application included a study by Pacific Economics Group (PEG), which: (a) examined industry and company-specific TFP trends using a Törnqvist index-number method; and (b) examined SDG&E’s comparative productivity within a sample of gas and electricity utilities, by estimating econometric cost functions. The study used samples of 77 electricity utilities and 34 gas utilities for the period 1994 to 2004. For both electricity and for gas utilities: outputs were energy delivered and customers; and inputs were labour, capital, fuel and non-labour O&M inputs. The output index used revenue weights and the input index used cost weights (ACCC and AER, 2012). The industry TFP growth rates found by this study were:

- For electricity DSOs, the average TFP growth was 1.08 per cent annually;
- For gas DSOs the average TFP growth rate was 0.63 per cent annually.

A similar study by PEG in 2007 for SoCalGas reports the same average TFP growth rate for the U.S. national gas industry (0.63 per cent), but an average of 0.79 per cent is found for the slightly narrower sample of DSOs used in the econometric analysis undertaken. The gas DSOs

[29] https://www.cpuc.ca.gov/General.aspx?id=10431

of above average efficiency (the 1st and 2nd quartiles) had a slightly lower average annual TFP growth rate of 0.5 per cent (PEG, 2007). A subsequent study by PEG for SoCalGas in 2010 only uses Törnqvist index analysis. It found the average growth in TFP for all sampled gas distributors to be 1.18 per cent per year over the 1999-2008 period and 0.99 per cent per year over the last five years of the period. California's gas DSOs had higher productivity growth rates. The productivity trend of the gas industry was estimated to be similar to that of the U.S. private business sector (Lowry and Hovde, 2010).

In summary, whilst productivity analysis does not form an essential part of energy network regulation in most parts of the USA, it has been shown that some studies are carried out to inform regulatory decision-making. However, the examples shown do not attempt to decompose TFP growth into frontier shifts and catch-up gains or into rates partial productivity growth. Two academic studies which have carried out such analysis for energy networks are now discussed.

Jamasb et al (2008) study the productivity development of a panel of U.S. interstate gas transmission companies using data envelopment analysis and Malmquist productivity indexes. The study measures efficiency levels, TFP growth, and its decomposition into efficiency change and technical change. Two key questions are asked are: has average industry productivity increased? And has firm-level technical efficiency converged? The data spans the period 1996-2004 for 39 pipelines, starting several years after a push by the FERC for more competition.

DEA was used for the static efficiency scores (constant returns to scale (CRS) and variable returns to scale (VRS)) and a Malmquist productivity index was used to estimate productivity change (TFPC) and its components: technical change (TC) and technical efficiency change (TEC); with the latter further decomposed into pure TEC (PTEC) and scale efficiency change (SEC). The single input variable is total cost (total expenditure or totex) or revenue. Output variables are total length of pipe and total horsepower rating and, for some models, also total delivery volume. A nonparametric frontier was chosen because it is not necessarily the case that, with cost-of-service regulation, firms are cost minimizing. The Malmquist indexes also allow for different returns to scale across periods. With a single monetary input measure, it is not possible to estimate allocative efficiency and technical efficiency separately.

The key findings in relation to productivity growth and its decomposition are shown in Table A.4. Average TFP growth was strong for the 1996-2004 period. The largest contribution to this growth was made by TEC, which is due partly due to scale efficiency improvements and partly to firms catching up with best practice, which is confirmed by various tests. These effects tend to be weaker after 2000 in some models. The rate of technical change is estimated at between -0.5 and 2.5 per cent per annum for the whole period. The other key finding is that technical efficiency levels vary greatly across utilities and their convergence is weak at best, and may not be occurring for the worst performers.

Table A.4: Productivity Trends of U.S. Gas Pipelines 1996-2004; Jamasb et al (2008)

	Model 1: Totex, incl. delivery	*Model 2: Totex, excl. delivery*	*Model 3: Revenue, incl. delivery*	*Model 4: Revenue, excl. delivery*
TFPC	2.9	5.9	4.5	6.9
TC	-0.5	0.8	2.5	2.0
TEC	3.5	5.0	1.75	4.3
PTEC	1.1	2.4	0.75	1.5
SEC	2.3	3.2	1.0	3.9

Lowry et al (2017) analyse the productivity trends of 86 U.S. electricity DSOs over the period 1980 to 2014 using a Törnqvist index method similar to the PEG reports discussed above. The average results for the whole sample are shown in Table A.5. The results suggest that on average, the TFP of U.S. electricity distributors averaged 0.5 per cent per year over the 12-year period from 1996-2007. However, the TFP growth rate was lower in the period from 2008-2014, averaging 0.2 per cent per year.

Table A.5: Productivity Trends of U.S. Electricity DSOs, 1980 to 2014; Lowry et al (2017) (%)

	1980-1995	1996-2007	2008-2014	1980-2014
TFP	0.53	0.50	0.22	0.45
Opex PFP	0.23	1.05	0.31	0.53
Capital PFP	0.65	0.31	0.16	0.43

APPENDIX B: CAPITAL PFP AND CAPEX

The purpose of this appendix is to show that in some circumstances, the rate of capital partial factor productivity (PFP) is equal to the rate of embodied technical change. Therefore, the Capital PFP could be used as an estimate of the rate of productivity relevant to capital expenditure.

For simplicity, assume 'one-hoss-shay' technology (i.e. each piece of equipment retains the same production level without deterioration until the date at which it is scrapped) and homogeneous capital inputs (all pieces of equipment are the same). All values are in constant dollar terms or physical units. The capital stock in period *t* is:

$$K_t = \sum_{i=0}^{T-1} I_{t-i} \qquad \text{(B.1)}$$

where *T* is the effective asset life. The change in capital stock from *t* – 1 to *t* is;

$$K_t - K_{t-1} = \sum_{i=0}^{T-1} I_{t-i} - \sum_{i=0}^{T-1} I_{t-1-i} = I_t - I_{t-T} \qquad \text{(B.2)}$$

Here: I_{t-T} is the depreciation allowance in period *t*, equal to the retirement of all assets that are *T* periods old, and I_t is the capital expenditure in period *t*. Equation (B.2) is the simplified perpetual inventory formula in this scenario.

Assume output is constant (*Q*) and there is a constant rate of embodied technical change which reduces the amount of capital needed to produce the same output. Denote the rate of embodied technical change as λ. Then the amount of investment needed in period *t* to replace the output of the retiring capital from period t – *T* is:

$$I_t = I_{t-T}(1+\lambda)^{-T} \qquad \text{(B.3)}$$

This can be substituted back into (B.1) to obtain:

$$K_t = (1+\lambda)^{-T} \sum_{i=0}^{T-1} I_{t-T-i} = (1+\lambda)^{-T} K_{t-T} \qquad \text{(B.4)}$$

Thus, the steady-state annual rate of change in capex, which from (B.3) is $(1+\lambda)^{-1}$, is equal to the annual rate of change in the capital stock which can be obtained from (B.4).