Review of Economic Benchmarking of Transmission Network Service Providers – Position Paper

Report prepared for
Australian Energy Regulator

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TNSP NAME ABBREVIATIONS

The following table lists the TNSP name abbreviations used in this report and the State in which the TNSP operates.

Abbreviation	*TNSP name*	*State*
ANT	AusNet Transmission	Victoria
ENT	ElectraNet	South Australia
PLK	Powerlink	Queensland
TNT	TasNetworks Transmission	Tasmania
TRG	TransGrid	New South Wales

EXECUTIVE SUMMARY

Submissions from TNSPs on AER (2016a) raised a number of issues and potential refinements to TNSP economic benchmarking, mainly regarding the specification of outputs. The AER decided to undertake a review of TNSP economic benchmarking based on these and related submissions and asked Economic Insights to prepare an issues paper to focus input to the review (Economic Insights 2017a). Submissions on the issues paper were received from a range of stakeholders and a forum was then held on 31 May 2017 to allow interested parties to provide further input to the review. This position paper draws on this stakeholder input and presents our considered position on the issues raised.

The current TNSP productivity measures have five outputs: energy throughput, ratcheted maximum demand, voltage–weighted entry and exit connections, circuit length and (minus) energy not supplied.

The main issues considered in this position paper are:

- the merits of replacing voltage–weighted connections by the number of end–users
- the merits of placing a cap on the weight given to the reliability variable
- whether the weights applied to the other four outputs should be updated, and
- 'additive' versus multiplicative incorporation of capacity–related outputs.

Voltage–weighted connections versus end–user numbers

The current voltage–weighted connections measure has the advantage of attempting to adjust the number of entry and exit points for the relative 'size' of each connection point using accessible information and in a simple way. However, we accept the criticisms of the measure made by AusNet (2017) that the voltage of the connection point is not necessarily closely related to the capacity of the connection point and that the number of connection points does not necessarily reflect the complexity of the task the TNSP has to perform. Furthermore, Economic Insights (2013) noted that the measure does not score well against the second selection criterion for outputs, namely that the output should directly reflect a service provided to customers.

Substituting jurisdictional end–user numbers for voltage–weighted connections has the advantage of focusing on the service provided to electricity customers. It also uses robust data that is currently readily available. It provides a direct measure of the scale of the transmission task and a good proxy for the complexity of the task facing the TNSP and has the advantage of being similar to the current treatment of DNSP outputs. It also leads to the two smaller TNSPs, TNT and ENT, having similar productivity levels to the larger TNSPs whereas they have considerably higher productivity levels using the voltage–weighted connections output.

It needs to be recognised that the output specification cannot take account of all operating environment factors (OEFs) and unusual circumstances facing a TNSP such as the need to connect a larger number of smaller renewable energy generators than other TNSPs. This may be best dealt with through the application of separate OEF analysis. Future refinement of a connections–based output using a transformer capacity weighting instead of a voltage weighting may assist with this. We thus support expansion of the TNSP EBRIN data collection to include the MVA rating of each TNSP entry and exit point. This will allow eventual development of a more TNSP–specific specification or OEF.

Capping the weight on reliability

While it is important to retain the reliability output in the model in recognition of the vital tole of transmission in the electricity supply chain, the current treatment which leads to a one–off outage at one terminal station leading to reduction in ANT's output for the entire year of 50 per cent and of the industry's output by 13 per cent is not realistic. There is thus a solid case for capping the share given to the reliability output in the TNSP productivity model. We favour placing a cap on the value of energy not served (ENS) as a share of gross revenue of 5.5 per cent, the value consistent with a 95 per cent probability of the cap not being binding, and the cap taking effect by reducing the price of ENS in those years where the cap is binding. This has the advantage of recording somewhat more of a downturn in productivity in those years where the cap binds compared to imposing the cap via changes in the ENS itself.

Updating other output weights

Given that changes are being made to the output specification, output cost shares need to be updated. Leontief cost function–based shares using the latest data set appear to present the most plausible and stable results and have the advantage of being consistent with the approach adopted in the index number method component of the parallel economic benchmarking of DNSPs. We recommend using these shares for a reasonable length of time to permit changes observed over time to be attributed more clearly to productivity changes.

Incorporation of capacity–related outputs

TNSPs have argued that the separate inclusion of the key system capacity variables of ratcheted maximum demand and line length on the output side does not mirror the 'multiplicative' inclusion of line capacity on the input side. It is claimed that this will potentially disadvantage large TNSPs relative to small TNSPs. We do not believe a case has been made that our current treatment of the output and input specifications is inappropriate for an index number method productivity model or that a preferable or more tractable option has been identified. Consequently, we recommend retention of the 'additive' inclusion of ratcheted maximum demand and line length on the output side and the use of MVAkms to measure the quantity of line capacity on the input side.

Position

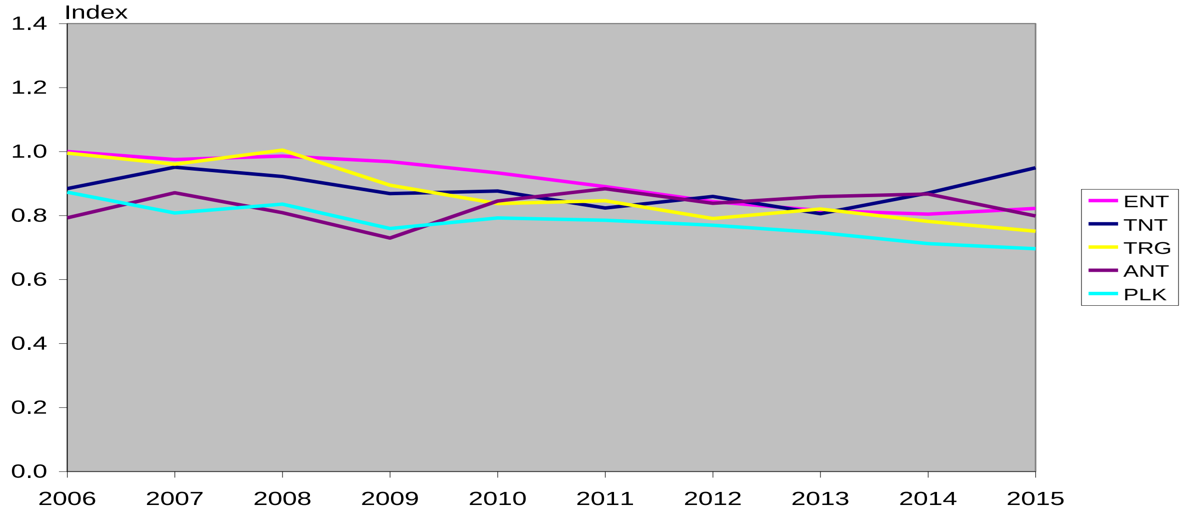
Following assessment of the issues, we recommend making the following three changes to the TNSP economic benchmarking model:

1) substitution of jurisdictional end–user numbers for the current voltage–weighted connections output
2) adoption of revised output cost share weights derived from a Leontief cost function model applied to data for the 2006 to 2015 period, and
3) application of a cap of 5.5 per cent of gross revenue on the output share of energy not served with the cap being achieved by changes in the price of energy not served rather than its quantity.

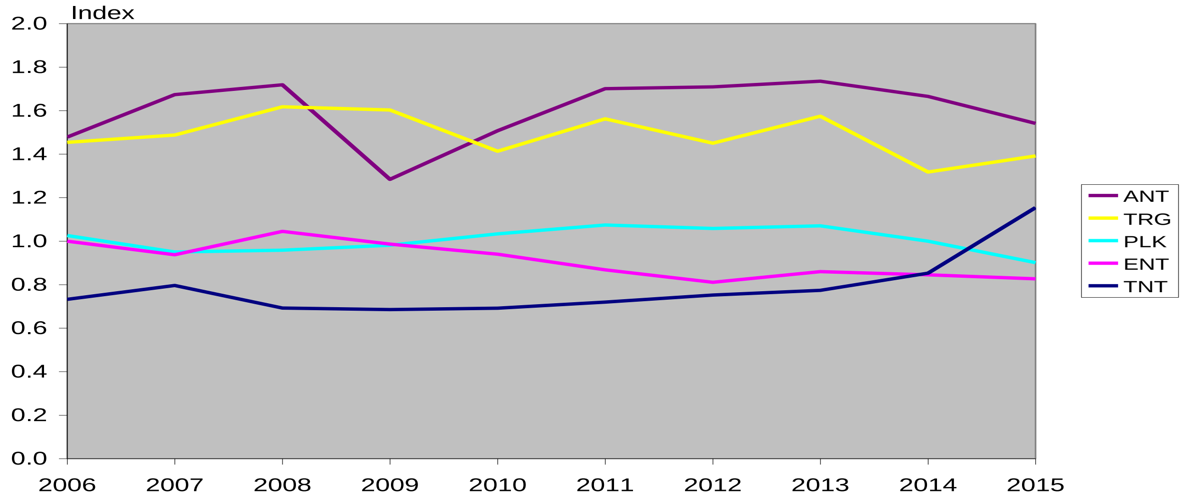
The TNSP economic benchmarking results for the period 2006 to 2015 using the specification recommended are presented in figure A.

Figure A Multilateral productivity indexes by TNSP, 2006 to 2015

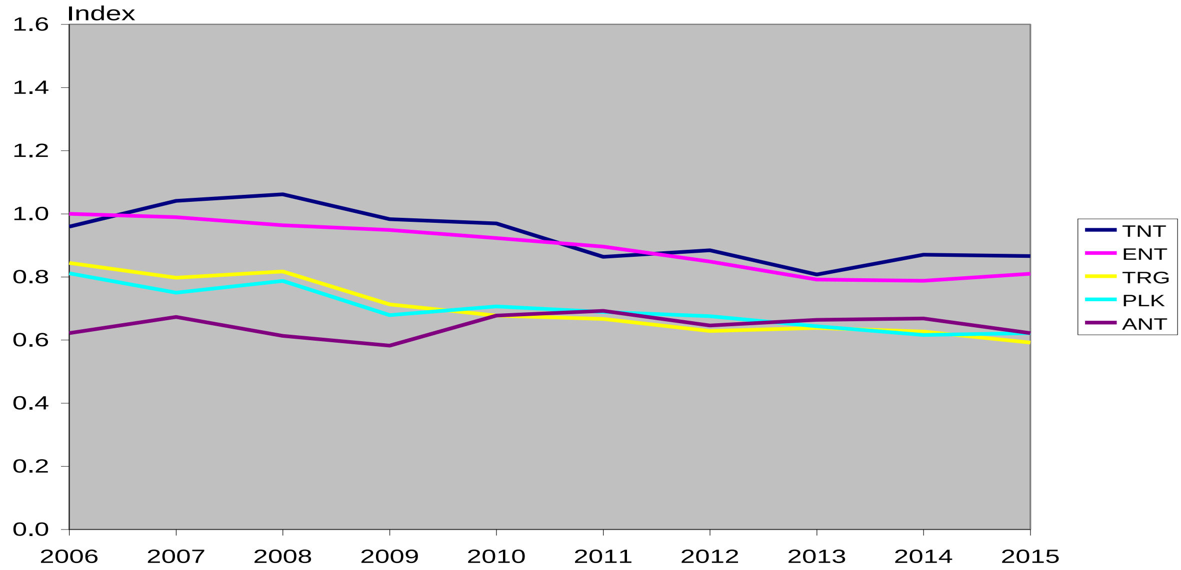
a) Multilateral total factor productivity



b) Multilateral opex partial factor productivity



c) Multilateral capital partial factor productivity



1 BACKGROUND

The Australian Energy Regulator (AER 2014) produced initial benchmarking results for Australia's five transmission network service providers (TNSPs) operating in the National Electricity Market (NEM). As well as presenting a range of partial performance indicators, AER (2014) also presented economic benchmarking results for multilateral total factor productivity (MTFP) and multilateral partial factor productivity (MPFP) measures developed in Economic Insights (2014b). These measure the relative productivity of transmission networks and track productivity changes over time. Productivity is measured as the ratio of the quantity of total outputs produced to the quantity of inputs used. These results were then refined and updated in Economic Insights (2015b, 2016) and AER (2015, 2016a).

The main area where there is not yet a consensus position on the economic benchmarking of electricity networks is the appropriate measurement of outputs for transmission networks. The whole of business benchmarking of transmission networks is relatively new (although transmission networks have benchmarked their own costs at a more specific level for some time). Economic Insights (2014b, p.2) noted:

> 'While economic benchmarking of distribution network service providers (DNSPs) is relatively mature and has a long history, there have been very few economic benchmarking studies undertaken of TNSPs. Economic benchmarking of transmission activities is in its relative infancy compared to distribution. As a result, in this report we do not apply the above techniques to assess the base year efficiency of TNSPs. We present an illustrative set of MTFP results using an output specification analogous to our preferred specification for DNSPs but caution against drawing strong inferences about TNSP efficiency levels from these results. However, output growth rates and opex input quantity growth rates can be calculated with a higher degree of confidence and used to forecast opex partial productivity growth for the next regulatory period which is a key component of the rate of change formula.'

Submissions from TNSPs on AER (2016a) raised a number of issues and potential refinements to TNSP economic benchmarking, mainly regarding the specification of outputs. The AER decided to undertake a review of TNSP economic benchmarking based on these and related submissions and asked Economic Insights to prepare an issues paper to focus input to the review (Economic Insights 2017a). Submissions on the issues paper were received from the five TNSPs, the AER's Consumer Challenge Panel (CCP), Energy Networks Australia (ENA) and two distribution network services providers (DNSPs). A stakeholders' forum was then held on 31 May 2017 to allow interested parties to provide further input to the review. This position paper draws on this stakeholder input and presents our considered position on the issues raised.

1.1 The current TNSP economic benchmarking model specification

The current TNSP MTFP measure has five outputs included as follows:

- Energy throughput (with 21.4 per cent share of gross revenue)

- Ratcheted maximum demand (with 22.1 per cent share of gross revenue)
- Voltage–weighted entry and exit connections (with 27.8 per cent share of gross revenue)
- Circuit length (with 28.7 per cent share of gross revenue), and
- (minus) Energy not supplied (with the weight based on current AEMO VCRs).

The current TNSP MTFP measure includes four inputs:

- Opex (total opex deflated by a composite labour, materials and services price index)
- Overhead lines (quantity proxied by overhead MVAkms)
- Underground cables (quantity proxied by underground MVAkms), and
- Transformers and other capital (quantity proxied by transformer MVA).

In all cases, the annual user cost of capital is taken to be the return on capital, the return of capital and the tax component, all calculated in a broadly similar way to that used in forming the building blocks revenue requirement.

During the AER's economic benchmarking development process, Economic Insights (2014a) considered four different options for the output specification. Each option included measures of reliability, voltage–weighted connection points and energy throughput, with differences being the addition of system capacity, ratcheted maximum demand and/or circuit length. We conducted analysis of each option and recommended the currently adopted option because it did not appear to favour any particular type of TNSP, represented a useful way of capturing the key elements of a TNSP output and was also broadly comparable with the output specification used for DNSPs which has been the subject of extensive development work over many years.

The AER currently uses economic benchmarking in its TNSP regulatory determinations to derive its forecast of future productivity changes used in assessing TNSP opex forecasts, but it does not currently use benchmarking to make efficiency adjustments. AER (2016b, pp.15–16) noted it does not use benchmarking to make efficiency adjustments because:

- there is only a very small sample of transmission businesses which limits the range of benchmarking techniques that can be applied (specifically, only index number methods can be used because more sophisticated econometric models are not tractable)
- economic benchmarking output measures require further refinement, and
- a better understanding of the impact of operating environment factors (OEFs) affecting TNSPs is needed.

This review focuses on the second of these limitations, namely the specification of TNSP outputs for economic benchmarking which has been the main focus of submissions to the review. While some TNSPs have also submitted that more focus on material OEFs and the impact of differences in capitalisation policies is required[1], the AER will consider these issues separately to this process.

1 For example, TransGrid (2016, p.1) and Powerlink (2016, pp.1–2)

1.2 Issues raised by stakeholders

Since the inception of the AER’s transmission benchmarking analysis, the TNSPs have each raised a number of issues with the output specification used. The key issues raised have been:

- the appropriateness of the voltage–weighted entry and exit connections output variable
- the way entry and exit connection points and voltages are measured
- the appropriateness of the VCR–based weight applied to the reliability variable
- the econometrically–derived weights applied to the other four outputs, and
- ‘additive’ versus multiplicative incorporation of capacity–related outputs.

These issues were discussed in Economic Insights (2017a) and both stakeholder submissions and discussion at the forum focussed on these topics. In the following sections of this report we further explore these issues – providing quantification of alternative options where possible – before explaining our preferred way forward.

2 VOLTAGE–WEIGHTED CONNECTIONS OUTPUT

The voltage–weighted connections output was the least developed of the five outputs included in the initial TNSP productivity analysis in 2014. It was included as an equivalent for the customer numbers variable in the DNSP economic benchmarking. In the case of TNSPs, however, connections were weighted by their voltage level 'in recognition of their relative importance' (Economic Insights 2014a, p.1). As noted above, while DNSP economic benchmarking is relatively mature and there are many precedents that can be drawn on, TNSP economic benchmarking is in its relative infancy and there are very few precedents to draw on.

Most of the debate surrounding the TNSP economic benchmarking specification to date has focussed on the voltage–weighted connections variable. There were initially differences in the way TNSPs measured their number of connections which were then standardised. Subsequently, there has been lengthy debate about the technical aspects of measurement, including whether voltage is a reasonable basis for weighting, whether voltage should be taken at the upstream or downstream side of the connection point and whether multiple DNSP connections at the one terminal station should be counted as one connection or as several connections.

Submissions to this review and discussion at the forum on 31 May 2017 have also tended to focus on this output variable. Suggestions for improvement have ranged from replacing the variable with a completely new measure to changing the basis for weighting to excluding the variable altogether.

In this section we will revisit the criteria used for selecting outputs for TNSP economic benchmarking before reviewing the suggestions made in submissions and at the forum and then quantify the effects of a range of options considered.

2.1 TNSP output selection criteria

TNSP output specification issues were discussed at length in Economic Insights (2013) and during the AER's preceding consultation process. It was noted that under building blocks regulation there is typically not a direct link between the revenue requirement that the TNSP is allowed by the regulator and how the TNSP structures its prices. Rather, the regulator typically sets the revenue requirement based on the TNSP being expected to meet a range of performance standards (including reliability performance) and other deliverables (or functional outputs). TNSPs then set prices on the outputs they charge for that have to be consistent with broad regulatory pricing principles but this is a separate process from setting the revenue requirement.

Given that the outputs to be included in economic benchmarking for building blocks expenditure assessments will need to be chosen on a functional basis, Economic Insights (2013) specified criteria to guide the selection of outputs to be included in economic benchmarking based on those proposed by the AER (2012, p.74):

a) the output aligns with the National Electricity Law and National Electricity Rules objectives

b) the output reflects services provided to customers, and

c) the output is significant.

The first selection criterion states that economic benchmarking outputs should reflect the deliverables the AER expects in setting the revenue requirement which are, in turn, those the AER believes are necessary to achieve the expenditure objectives specified in the NER. The NER expenditure objectives for both opex and capex are to:

- meet or manage the expected demand for prescribed transmission services over that period;
- comply with all applicable regulatory obligations or requirements associated with the provision of prescribed transmission services;
- to the extent that there is no applicable regulatory obligation or requirement in relation to:
  1) the quality, reliability or security of supply of prescribed transmission services; or
  2) the reliability or security of the distribution system through the supply of prescribed transmission services,

  and to the relevant extent:

  3) maintain the quality, reliability and security of supply of prescribed transmission services; and
  4) maintain the reliability and security of the transmission system through the supply of prescribed transmission services; and
  5) maintain the safety of the distribution system through the supply of prescribed transmission services.

If the outputs included in economic benchmarking are similar to those the TNSPs are financially supported to deliver then economic benchmarking can help ensure the expenditure objectives are met at an efficient cost.

The second selection criterion is intended to ensure the outputs included reflect services provided directly to customers rather than activities undertaken by the TNSP which do not directly affect what the customer receives. If activities undertaken by the TNSP but which do not directly affect what customers receive are included as outputs in economic benchmarking then there is a risk the TNSP would have an incentive to oversupply those activities and not concentrate sufficiently on meeting customers' needs at an efficient cost.

The third selection criterion requires that only significant outputs be included. TNSP costs are dominated by a few key outputs and only those key services should be included to keep the analysis manageable and to be consistent with the high level nature of economic benchmarking.

Economic Insights (2013, p.36) noted the following:

> 'Considering entry and exit point numbers against the output selection criteria, entry and exit point numbers are one indicator of the requirement for transmission

> services and provide a proxy for the services the TNSP has to provide at connection points. This is a necessary part of maintaining the quality, reliability and security of supply of both transmission services and the transmission system itself. They do reflect services directly provided to users of the transmission network but may not be a good measure of services provided to end–customers. They could reflect services that can be a significant part of TNSP costs. The entry and exit point numbers output, therefore, scores well against the first and third selection criteria but less so against the second criterion.'

The developmental nature of the connections output was recognised in the following passage in Economic Insights (2013, p.36):

> 'We believe this output should be considered for inclusion in economic benchmarking studies, possibly adjusted for voltage, as it is a billed item for some TNSPs and may be an important secondary deliverable. Data on entry and exit point numbers should be assembled and sensitivity analysis undertaken to determine the effect of using different output specifications on economic benchmarking results. Initial data collection is focused on collecting entry and exit point numbers by broad capacity class of the connection.'

The voltage–weighted connections output has been included in TNSP economic benchmarking to date as an equivalent to the number of end–users included in DNSP economic benchmarking. However, it reflects a 'secondary deliverable' rather than a service provided directly to end–users as described in Economic Insights (2013, p.36):

> 'Going back to the road analogy, the TNSP will need to provide and maintain entry and exit ramps to the freeway, regardless of the amount of traffic on the freeway. In economic benchmarking studies, the quantity of these functions could be proxied by the number of TNSP entry and exit points.'

2.2 Connection points output variable versus end–user numbers

As noted above, there has proven to be a number of limitations with the voltage–weighted connections measure including identifying the number of connection points on a consistent basis and the adequacy of the simple multiplication of connection point numbers by their respective voltage levels in approximating a more complex engineering relationship. AER (2014, pp.12–13) stated:

> 'The transmission node identifiers (TNIs) will not perfectly capture the transmission assets at each entry and exit point. This was raised with us in submissions. However the number of TNIs is the most consistent data that is currently available to us. Further we consider that the summation of TNI voltages is a workable reflection of the number and significance of transmission network connections.'

A number of TNSPs have questioned the adequacy and, in some cases, the appropriateness of the current connection point output measure in reflecting the service provided by each transmission network. For example, AusNet (2017, p.3) submitted that using voltage to weight connection points 'is arbitrary because it does not reflect the productive capacity and input costs required at each connection point and, therefore, does not result in a meaningful productive output quantity'. It furthermore argued that exit points are not a meaningful TNSP output as the relevant output should be meeting customer demand at the connection point whilst ensuring the security and reliability of electricity supply to customers. AusNet (2017, p.3) gave the following example to illustrate its point:

> 'if AusNet Services supplied Melbourne's population with power from 20 connections points, we are not 20 times more productive that if we supplied them from one. The current specification produces a nonsensical outcome.'

AusNet (2017, p.3) also noted that the current variable reflects the arbitrary historic network design of each transmission network and does not reflect the true productive output of the TNSP at the connection point. As an example, AusNet (2016, p.7) stated:

> 'Powerlink's large number of 132kV exit connection points reflects the relatively high exit voltage of its network relative to AusNet Services, which primarily has distribution connecting at 66kV. These differences drive the substantive difference between the voltage weighted connection point outputs of each TNSP – approximately 9,000 (AusNet Services) compared with 17,000 (Powerlink) in 2015 – and hence to the productivity scores of each network.
>
> 'The relativity of this output result is in contrast to other measures of output, such as energy throughput and maximum demand, which do not differ to nearly the same extent between AusNet Services and Powerlink. Further, the numbers of electricity customers served in Victoria and Queensland, which are ultimately the reason both transmission networks exist, are in stark contrast to the voltage weighted connection outputs presented above. In 2015 AusNet Services served 32% more end use customers through its network than were served in Queensland, with Queensland having 2.1million customers compared to Victoria's 2.8million.'

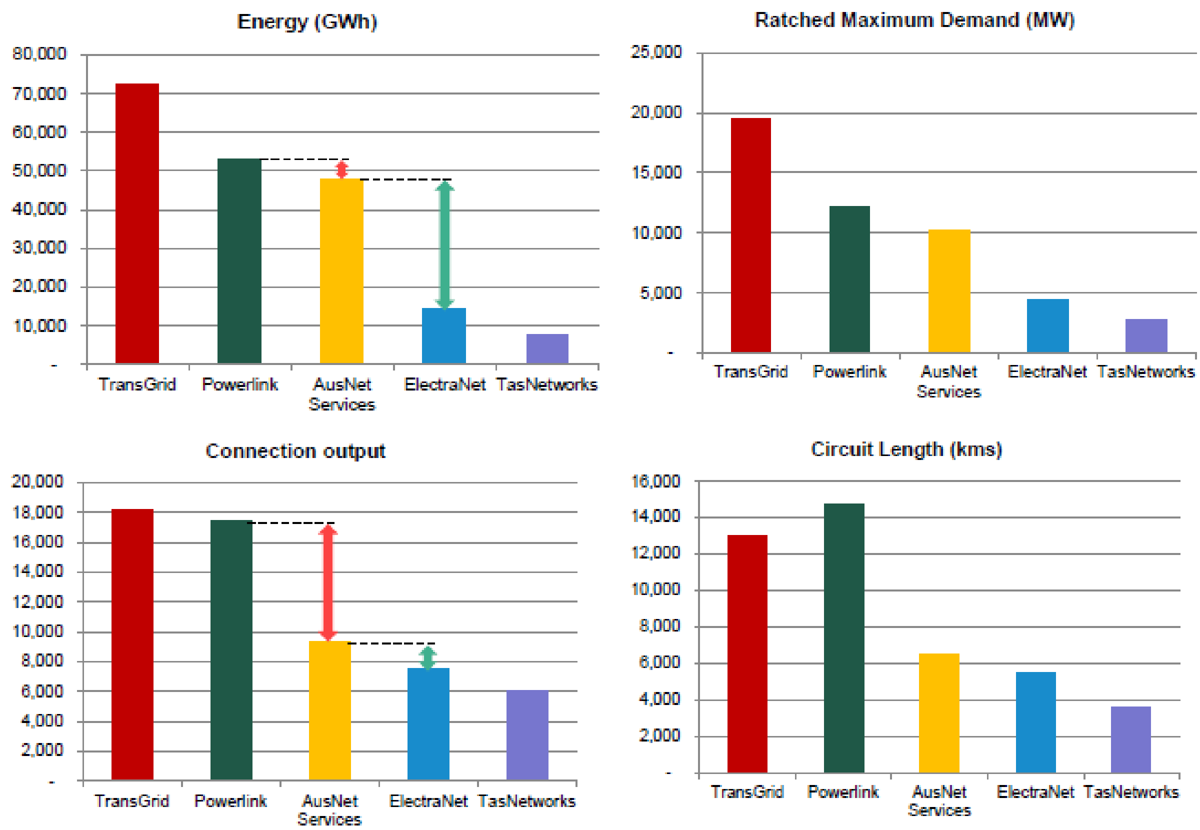
AusNet (2017, p.3) again noted that the current voltage–weighted connections output quantity appears to be out of step with the relative magnitudes of other TNSP outputs. AusNet noted that Powerlink's energy throughput is 11 per cent higher than AusNet's, yet its voltage weighted connections output is 87 per cent higher. Similarly, AusNet noted that its energy throughput is 235 per cent higher than ElectraNet's, yet its voltage weighted connections output is just 25 per cent higher than ElectraNet's. AusNet illustrated the different relativities using figure 1.

AusNet (2017, p.4) went on to argue:

> 'For transmission networks that serve entire jurisdictions containing both metropolitan and rural regions with comparable customer bases, one would expect broadly similar relativities across the output quantities (with the exception of circuit length which logically reflects the physical infrastructure of each network and hence is a valid and reasonable driver of cost). However, the relative output quantities shown above suggest the connection output is not reflective of the scale of connection services provided by each network and, therefore, is distorting the productivity scores produced by the model. This is particularly an

> issue given the relatively high weighting (27.8%) assigned to the connection output.'

Figure 1: TNSP outputs, 2016



Source: AusNet (2017, p.4)

AusNet (2016, p.7) argued that the voltage weighted connection points output did not perform well against the three selection criteria for outputs set out in Economic Insights (2013):

> 'In particular, transmission networks ultimately exist to provide electricity services to end–users, which is reflected in the NER expenditure objective of "meet or manage the expected demand for prescribed transmission services." While end–users do not directly receive prescribed transmission services, they are the ultimate beneficiary and driver of these services.

AusNet (2016, p.7) proposed an alternative to the voltage weight connection point variable as follows:

> 'Accordingly, AusNet Services considers that the AER should give due consideration to the removal of connection from the transmission MTFP model. Connection could be replaced by the number of end–user customers in each TNSP's service area, which, despite not being a direct output of transmission networks, is a more appropriate measure of a product provided by transmission networks.'

AusNet (2017, pp.4–6) provided further arguments in support of its proposition. It argued that end–users can be measured using reliable data reported to the AER in the DNSPs' RINs.

Furthermore, it argued that end–user numbers are unaffected by historic decisions regarding transmission and distribution system boundaries which should not impact productivity scores. It also noted that end–user numbers directly reflect the ‘size’ of the transmission task and so do not require any weighting. It argued that the current practice of weighting TNSP connection point numbers by voltage introduces biases since urban and rural connection points can have the same voltage yet the urban connection point can be several times the capacity of the rural connection point and serve several times the number of customers – but under the current specification the two connection points are treated as being equal in terms of output.

AusNet also argued that the composition of end–users is relatively comparable across the included TNSPs with residential customers as a proportion of total end–users in TNSP service areas ranging from a low of 84 per cent to a high of 89 per cent. Hence, it argued that no material biases would be introduced by differences in end–user composition and, even if differences in composition were greater, no adjustment would be necessary since differences in end–user size are already accounted for by the energy and ratcheted demand outputs.

Finally, AusNet argued that end–users are ultimately the users of the transmission network and their usage drives TNSP investment and costs. It argued that it was therefore appropriate to include end–user numbers as a TNSP output. It also noted that recent AER TNSP determinations have described the impact on residential electricity bills which highlights the impact of TNSP decisions on end–users as an important consideration for building blocks regulation. And it noted that relative TNSP end–user numbers are more in line with relativities in energy throughput and maximum demand.

TransGrid (2017, p.3) agreed that the current voltage–weighted connections variable has limitations and does not provide an accurate measure of transmission services provided. It was receptive to the proposal to use end–user numbers instead and observed:

> ‘TransGrid is open to exploring customer numbers as an output measure. It provides a better reflection of how many end–use customers rely upon the transmission service. Inclusion of customer numbers (along with the separate ratcheted maximum demand and throughput outputs) allows the benchmarking to reflect the average maximum demand per customer and energy per customer.
>
> ‘While an end–use customer number is a proxy for the complexity and level of service provided at the transmission and distribution interface it could be more representative than the current measure.’

TasNetworks (2015, p.1) has previously questioned the assumption in the current specification that higher voltage connections require more or higher capacity assets as follows:

> ‘TasNetworks does not agree that there is a link between voltages and the quantity of assets required to serve a particular connection point. Higher voltage connections do not necessarily require the use of more assets – just higher voltage assets. TasNetworks operates a comparatively low voltage transmission network that delivers a relatively small amount of energy, but has a high number of connection points (and therefore connection assets) because it connects around 30

> generation sites, as well as a significant number of directly connected load customers.
>
> 'Focussing on the sum of connection point voltages as a network output also ignores the complexity of those connections, which is a significant driver of cost for TNSPs.'

TasNetworks (2017, pp.3–4) noted that while downstream customers are the ultimate beneficiaries of transmission services, downstream customer numbers are not always a key driver of the amount of inputs a TNSP needs to use. TasNetworks also expressed a concern that using downstream customer numbers may advantage networks serving large, high density populations. However, we note that while TNSPs serving larger, high density populations will have fewer exit points compared to TNSPs serving lower density and more geographically diffuse populations, each exit point for the former will be need to be of considerably higher capacity, even if it is of the same voltage as the exit points of the lower density TNSP. As will be demonstrated in the following section, this dimension is not captured by the current voltage–weighted connections output but would be better captured by an MVA–weighted connections output. Thus, we would expect there to be less difference between results based on using a more appropriate MVA–weighted connections output and using a downstream customers–based output than there would be between the current voltage–weighted connections output and using a downstream customers–based output.

We also note that the choice of outputs will involve trade–offs across a number of considerations including capturing the scale and complexity of the transmission task and having robust and unambiguous measures based on the soundest and most consistent data. It may be that some operating environment differences (such as some density considerations) will have to be allowed for through operating environment factor analysis rather than being able to be allowed for entirely by the selection of outputs.

TasNetworks was also concerned that changing the output specification at this time would create a step change in the productivity results and render historic information irrelevant. However, we note the intention would be to recalculate any new specification back to 2006 so no information would be lost.

Powerlink (2017, p.2) also expressed concerns about the current voltage–weighted connections variable and whether it facilitates consistent treatment of similar connections when there are small differences in the ownership of assets. However, Powerlink did not support the use of end–user numbers as an alternative because 'it makes no difference whether a DNSP taking supply from a transmission network is supplying 100 x 1 MW customers or 100,000 x l kW customers, the output measure from the transmission system should look the same'. We note that the output measures have to be considered as a package as well as individually and the throughput and maximum demand variables capture the totals seen by the TNSP. This leaves scope for the inclusion of an end–user numbers variable that provides information on another aspect of the scale and complexity of the transmission task involved in providing the service demanded by consumers.

ElectraNet (2017, p.4) also did not support the use of downstream customer numbers because 'the number of downstream customers has no direct relationship to the transmission service being provided, or the efficient costs incurred by the TNSP'. As noted above, however, the transmission system exists to service downstream customers and the number, size and location of downstream customers will influence the number and size of exit points required by the TNSP.

CCP (2017, p.14) also questioned whether there was a direct link between TNSP costs and end–user numbers. It noted there may be no argument for 'TNSP costs to vary as a function of the final number of end use customers while the number of exit or entry points is held constant' and, conversely, noted 'costs would increase if the number of exit/entry points increased even if the number of end–customers and demand was unchanged'. However, CCP (2017, pp.6–7) earlier noted that 'the unique characteristics of economic benchmarking versus other benchmarking techniques based on the focus of economic benchmarking being on outputs that are provided to and valued by customers'. The CCP went on to note:

> 'From the perspective of the long–term interests of consumers, the focus on the efficiency of delivering the services provided to and valued by customers is more relevant than technical engineering benchmarking focussing on cost drivers.'

We agree with this summary and believe it supports the case for including a variable focusing on consumers such as the number of end–users.

Having assessed the arguments raised in submissions and discussed at the forum, we consider the suggestion to substitute the number of end–users for the current voltage–weighted connections output has merit and is worthy of further consideration. It directly reflects the services provided to end–users and focuses on a significant output while also linking closely to the NEL/NER. It thus scores strongly against all three of the output selection criteria whereas the current variable does not score well against the second selection criterion. It can be based on relatively uniform and unambiguous data and avoids many of the issues with construction of the current variable discussed in the following section. While the proposed end–user numbers variable does not differentiate the size of end–users (eg a smelter versus a household), AusNet has noted that this dimension would be captured by the throughput and maximum demand outputs, in combination with the number of end–users. We will, therefore, proceed to examine the effect adopting this change to the specification would have in section 2.4.

Another suggestion made at the forum was that it may be worth considering not including either a connections number–based or an end–user–based variable, as the throughput and ratcheted maximum demand variables may adequately capture scale effects other than network length. A similar option was also canvassed by AusNet (2017, p.9). We note that Economic Insights (2014a) considered a number of three, four and five output specifications. The main differences across these specifications were the inclusion or exclusion of energy throughput and the way system capacity was measured. The voltage–weighted connections output was included in all cases. We agree the specification where the connections output is excluded is also worthy of consideration for completeness. We will examine this further in section 2.4.

Before proceeding to quantify the effect of using the end–user number output, two further issues have to be considered. The first relates to how end–user numbers are measured and whether allowance would need to be made for the impact of interconnectors and special cases such as the Snowy Mountains Scheme. AusNet (2017, p.6) argued against making allowance for either of these factors as follows:

> 'Introducing explicit allowances for "special circumstances" (e.g. the Snowy Mountains Scheme) is not warranted because these differences are not expected to be material to the benchmarking results, and would also be accounted for in the other output measures. Introducing unnecessary and potentially complex adjustments to the model would also run counter to the simplicity benefits offered by using end-users to measure output.'

TransGrid (2017, p.3) agreed that it would introduce 'an additional level of estimation and annual variability' that was not warranted. We agree that one of the attractions of using end–user numbers (within the TNSP's primary service area) is that it can be based on robust data without the need for introducing additional estimation. Attempting to adjust for special cases would remove this advantage for likely little, if any, benefit.

The second issue that needs to be decided is, given that an end–user numbers variable only focuses on downstream users, does separate allowance need to be made for the entry side of the transmission network? CCP (2017, p.14) noted that while it may be desirable to capture 'some form of … entry costs', it noted that 'it is difficult to anticipate how that would be done'. AusNet (2017, p.7) suggested that one way of doing this could be to add the number of entry points to the number of end–users. However, we note that the number of entry points is miniscule compared to the number of end–users so this suggestion would have negligible impact. And, while TransGrid (2017, p.3) noted that including the upstream side may be worth examining, it noted that simply adding entry points to end–user numbers 'is not adding similar items together'. AusNet (2017, p.7) concluded:

> 'We note that the DNSP benchmarking model captures only end–user customer numbers in its outputs (i.e. it excludes the entry points to each distribution network from the relevant transmission network). This feature [has] not been identified as being problematic for that model.'

One advantage of the current voltage–weighted connections variable can be argued to be that it includes both the upstream and downstream sides. This needs to be weighed against other advantages and disadvantages relative to using the proposed end–user numbers alternative. We are of the view that, for the purposes of considering the alternative specification further and also to maintain broad comparability with the DNSP economic benchmarking specification, entry points should not be included separately. To the extent that some TNSPs face unusual circumstances with regard to entry points, this may be better handled by operating environment factor analysis.

2.3 Issues with the construction of the connection points output variable

If we retain the voltage–weighted connections output, there is still considerable debate about the way this variable should be constructed and measured.

In response to our issues paper question regarding whether there were better measures of connection point 'size' than voltage, AusNet (2017, pp.7–9) argued that the MVA of a connection point would be a better approximation to size than voltage. AusNet (2017, p.7) argued:

> 'For a given level of demand, high voltage stations typically require fewer assets that are relatively costly to maintain individually, whereas low voltage stations typically have more assets that are less costly to maintain individually, but collectively may be similarly costly. While high voltage electricity systems are generally the most efficient way to meet demand, it cannot be argued that voltage is a good proxy for the productive output nor the costs required at each terminal station. This, presumably, is why MVA capacity, and not voltage, is used to standardise input quantities for each TNSP.'

To illustrate its point, AusNet gave the example of two of its 66kV terminal stations, Thomastown and Terang. Thomastown serves around 159,000 end–users in Melbourne while Terang serves around 78,000 end–users in rural Victoria. Thomastown has five transformers, each of 150 MVA, while Terang has only two transformers, one of 125 MVA and one of 50 MVA. Thomastown serves maximum demand of around 510 MVA while Terang serves maximum demand of around 213 MVA. AusNet argued that on all measures of the 'productive capacity' of the two stations and of the end–users and maximum demand served, Thomastown is at least twice the size of Terang and yet they treated as being equal when voltage is used as the basis for weighting. It argued that data on the MVA capacity of terminal stations were readily available (to TNSPs) but would need to be added to the RIN data collection process.

As well as better covering the situation where exit points of similar voltage cover very different numbers of end–users, MVA–weighting would also better cover the situation where different types of end–users are supplied. For example, a much higher capacity exit point will be required to supply a large industrial customer compared to a small number of domestic and commercial consumers.

TransGrid (2017, p.3) agreed that a 'connections variable which reflected the supply capacity of connections (e.g. in MVA) would provide a much better approximation of the quantum of output provided'. However, ElectraNet (2017, p.4) stated that it was 'supportive of the [current] multiplicative method as a measure that is relatively simple and easy to understand'.

An issue that needs to be considered in the index number context relates to potential similarity of variables used on both the output and input sides if MVAs were used as the basis of weighting. TNSPs confirmed at the forum that a very high proportion of their MVA transformer capacity is likely to be tied up in entry and exit terminal stations. The only other transformers TNSPs would have would be changing voltages between transmission lines of different voltages within the TNSP's own system and this is not common. Since total transformer MVAs are used as the measure of transformer quantity on the input side, this would lead to some similarity of variables used to form components of both the output side and input side of the TFP calculation. However, on the output side MVAs would only be used as weights in forming the connections output so this would not be a problem as MVAs do not appear directly as an output.

We note that MVA capacity does in principle appear to be a better measure of terminal size than voltage. However, the benefits of collecting additional data through the RINs have to be weighed against the costs involved.

The next issue to be considered is the way connection points are measured and whether the voltage on the TNSP or the customer side of the connection should be used for weighting the connection point numbers. The current practice is to measure connection points using the definition AEMO uses in its Marginal Loss Factor (MLF) reports and to take the voltage at the TNSP side of the connection[2]. This approach has been applied consistently since 2015.

ElectraNet (2017, p.5) supported using the TNSP–side voltage as follows:

> ‘the low side / distribution voltage transformer rating is essentially arbitrary, being determined by local distribution network requirements, does not provide a meaningful measure for transmission scale services, and bears no direct relation to the costs involved in the servicing [of] a transmission connection point. For a TNSP the overwhelming majority of the equipment owned and maintained within each connection point will be at the high side / transmission voltage, which will determine the scale of the efficient costs involved. Therefore, use of the high side / transmission voltage more reasonably reflects the costs related to servicing the connection point owned and maintained by the transmission business and should be applied in the measure.’

AusNet (2017) and TransGrid (2017) concurred. Powerlink noted further complications regarding ownership of terminal station equipment and suggested:

> ‘If the AER's intention is to measure the complexity and cost of providing different transmission connections, Powerlink considers this could be best met by using a voltage weighting for the busbar owned by the TNSP that provides supply to the customer. If the TNSP only owns the step-down transformers but not the low voltage busbar, the voltage would then be the high voltage side of the transformer. If the customer owns the transformer the same voltage would be applied.’

None of the submissions saw any argument in favour of using the downstream voltage to be consistent with the AEMO Marginal Loss Factors. For example, CCP (2017, pp.15–16) argued as follows:

> ‘It is not clear that the treatment of connections for benchmarking should necessarily be the same as the treatment of connections for marginal loss factor reports. The questions to be considered in the context of benchmarking is whether connection at different levels of voltage provides a different level of service and/or entails significantly different levels of cost … The answers to these questions should guide the decision rather than harmonisation with the treatment for loss factors.’

[2] It was incorrectly stated in Economic Insights (2017) that the customer–side voltage is currently used.

Based on the arguments presented, we agree that the TNSP side voltage (ie upstream for exit points and downstream for entry points) best reflects the 'size' of the connection that the TNSP has to service.

The final issue relates to the way connections to multiple DNSPs at the one terminal station are treated. AusNet and TransGrid serve multiple DNSP customers at some of their connection points. Currently, only one DNSP connection is counted where multiple DNSPs are connected to the same station. This approach was adopted in 2015 in an attempt to provide consistency with jurisdictions that have fewer DNSPs. However, AusNet has claimed that it had to provide extra infrastructure and administration to accommodate its multiple DNSPs so it used extra inputs compared to states with few DNSPs but it received no credit for this on the output side.

AusNet (2016, pp.8–9) quoted the example of Templestowe Terminal Station (TSTS) that currently has connections to four DNSPs but these are currently only counted as one connection in measuring the connections output. AusNet submitted that this approach does not consistently measure inputs and outputs across jurisdictions and penalises AusNet for the historic decision to privatise Victorian distribution into five networks. The connection assets at TSTS include a configuration with multiple transformers and circuit breakers which are required to provide adequate security and service the load of the four DNSPs connected at TSTS. Accordingly, while the capacity of the transformers and capital cost of these assets is counted as an input in the AER's MTFP model, the associated outputs – service to four connections – are claimed not to have been counted as outputs. Furthermore, the existence of multiple connection points drives additional inputs for AusNet, including the operating costs associated with administering separate connection agreements with each DNSP. AusNet requested that all its DNSP connections be counted to ensure parity of treatment.

Not all stakeholders agreed with this proposition, including TransGrid (2017, p.4) – one of the TNSPs with multiple DNSP connections to terminal stations – which noted:

> 'This suggested change would introduce another arbitrary difference between TNSP outputs. It does not assist in the measurement of efficiency nor does it provide a better indication of the complexity or quantum of service provided.'

There was extensive debate of this issue at the forum with no agreement being reached. It was noted that the Templestowe Terminal Station used as an example by AusNet was actually quite old and its construction pre–dated the privatisation of the Victorian DNSPs. AusNet argued that additional modifications had been done to accommodate the multiple DNSPs. Others noted that the main additional cost would be paperwork related to additional connection contracts.

Given the lack of agreement on this issue in both submissions and the forum and given the preference to look at voltage from the TNSP side of downstream connection points discussed above, we are of the view to maintain the status quo on this issue. That is, if the voltage–weighted connections variable is retained then a terminal station should be counted as one exit point, regardless of the number of DNSPs that connect to that terminal station. The discussion of this issue at the forum served to highlight the complexities involved with using the voltage–weighted connections output and the lack of agreement over how it should be measured. All else equal, this lends some support to using the simpler alternative measure based on end–user numbers.

2.4 Options considered and quantitative implications

After assessing the arguments advanced in the preceding two sections, we believe there are four options worthy of further consideration. These are:

1) continue using the current voltage–weighted connections output
2) change to using the TNSP MVA rating of connections as the method of weighting
3) replace the voltage–weighted connections variable with the number of end–users, and
4) exclude the connections output.

The next step is to quantify the effects of changing from the status quo. We are unable to quantify the second option as we do not have data on the MVA rating of TNSP connections. These data would need to be collected from TNSPs by an expansion of the EBRINs.

To quantify the third option we substitute the total number of DNSP customers in the jurisdiction the TNSP operates in. To facilitate comparison of effects, we leave the weight applied to this output unchanged for now.

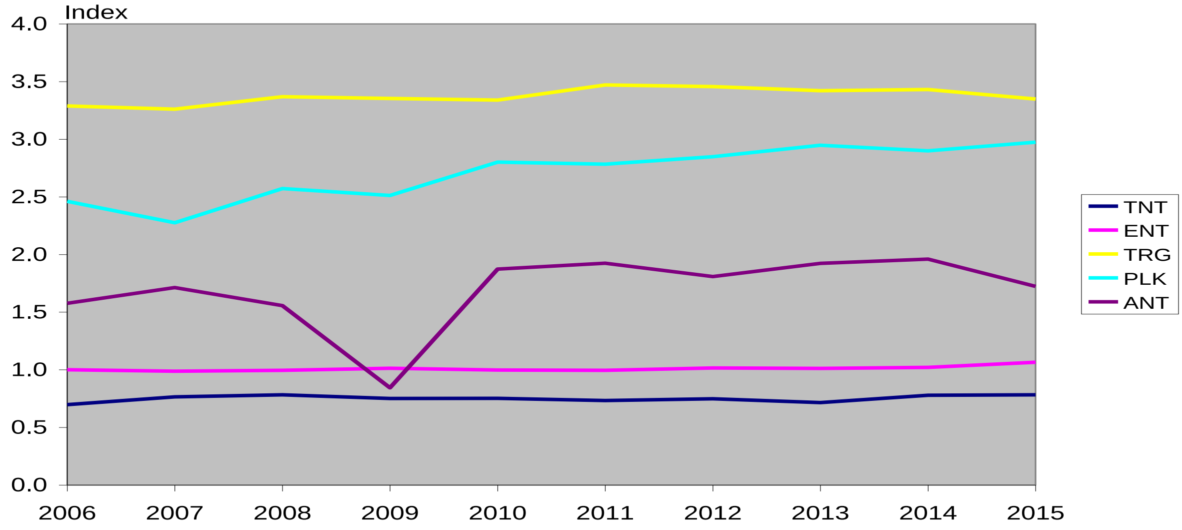
To quantify the fourth option we need to determine new weights for the other four outputs. Again, to facilitate comparisons, we reallocate the voltage–weighted connections output's weight proportionally across the other three non–reliability outputs while retaining the same treatment for reliability outputs.

In Figure 2 we present the multilateral output indexes for the three options we are currently able to quantify. In this and the following three figures we use the same vertical axis scale across each of the three options to facilitate comparisons. The first thing to observe from Figure 1 is that the output patterns and relativities are broadly similar across the three options. Compared to using the current voltage–weighted connections output in Figure 2(a), using end–user numbers in Figure 2(b) leads to relative increases in TRG's and ANT's outputs (relative to ENT's output in 2006 as that is used as the base observation for presentation purposes). It also leads to a relative decrease in TNT's output while PLK's relative output remains largely the same. This implies that TRG's and ANT's operations are less entry point and exit point intensive per end–user relative to TNT's output (although each entry and exit point for TRG and ANT would be expected to be considerably higher capacity compared to TNT, as would be picked up by MVA–weighting but not by the current voltage–weighting). This is to be expected given that TNT's network is more 'dendritic' and serves a more geographically diffuse end–user (and generator) base compared to NSW and Victoria. As noted earlier, we would expect the differences between an MVA–weighted entry and exit point output and the end–user numbers output to be smaller than those observed between current voltage–weighted entry and exit points output and the end–user numbers output.

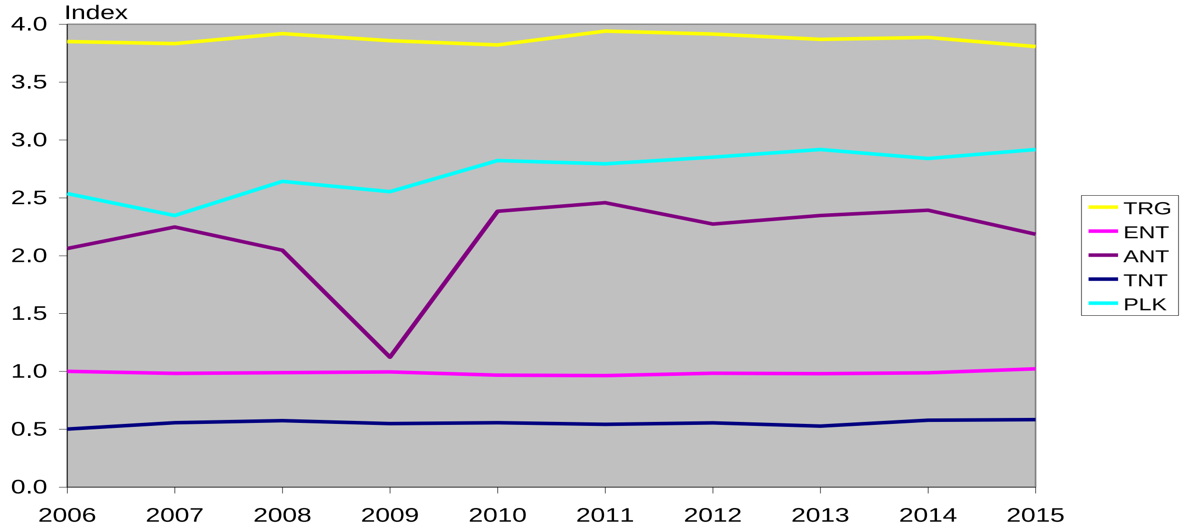
Excluding the connections output altogether in Figure 2(c) also leads to increases in the relative outputs of TRG and ANT and a decrease in the relative output of TNT, although to somewhat lesser extents than is the case in Figure 2(b).

Figure 2 Multilateral output index by TNSP, 2006 to 2015

a) Using voltage–weighted connections



b) Substituting end–user numbers for voltage–weighted connections



c) Excluding connections output altogether

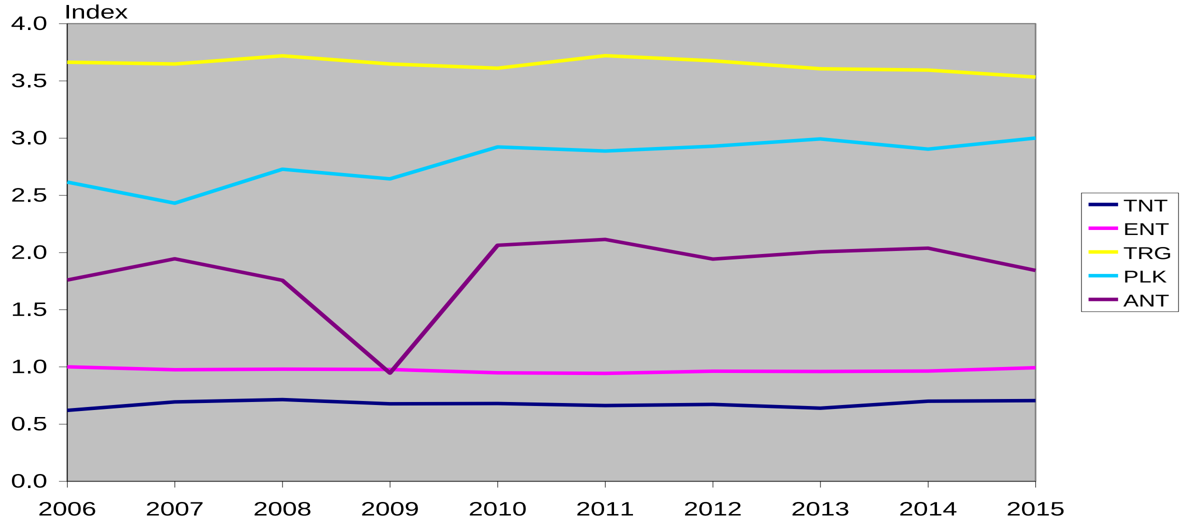
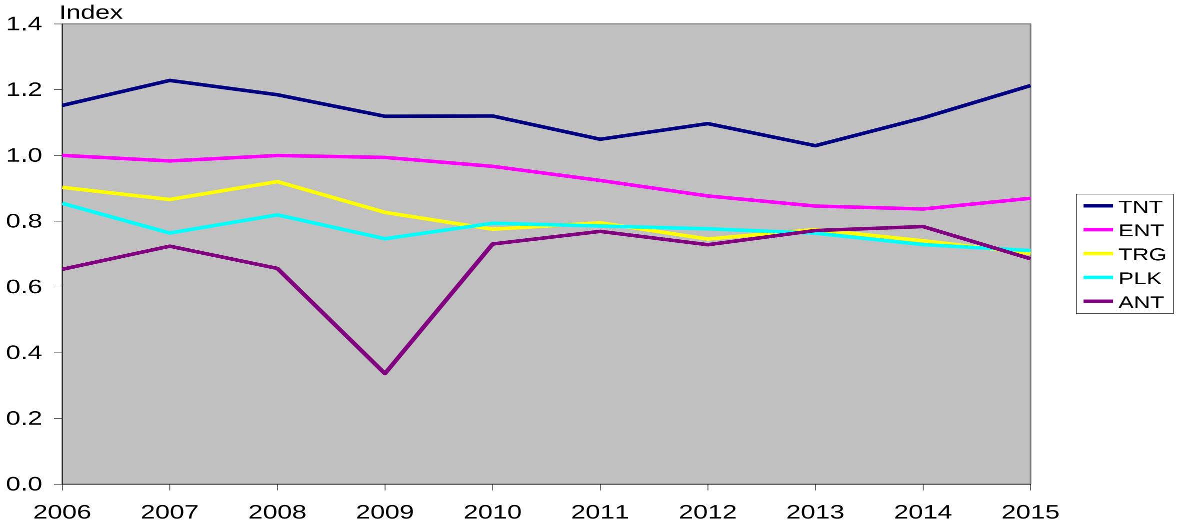
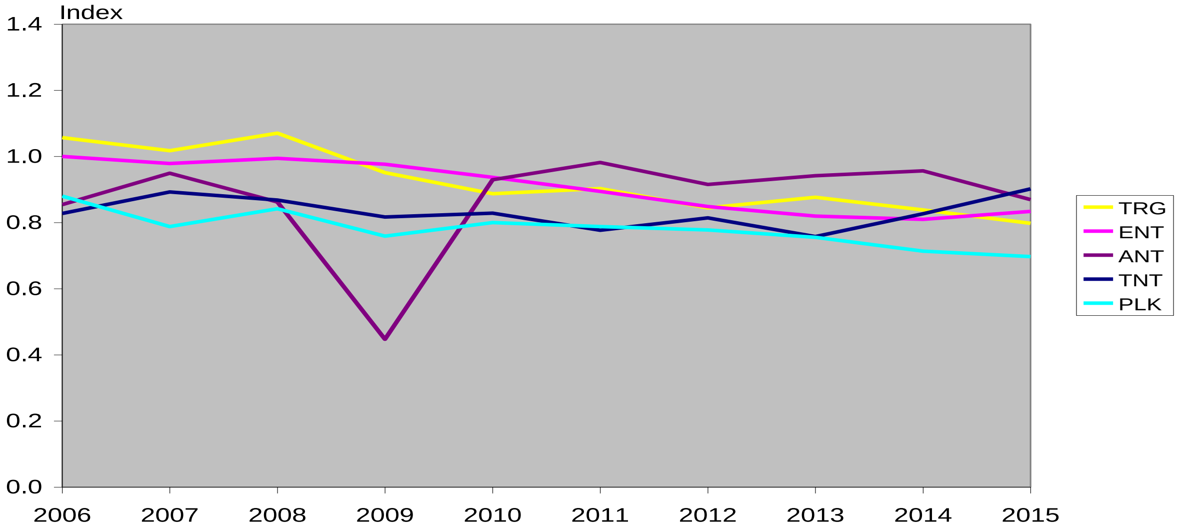


Figure 3 Multilateral total factor productivity index by TNSP, 2006 to 2015

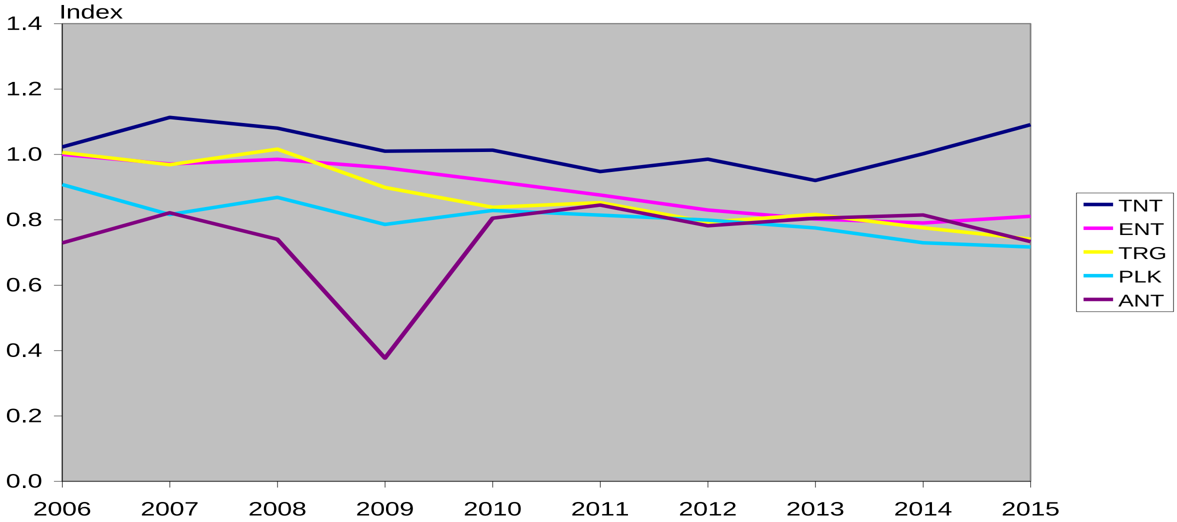
a) Using voltage–weighted connections



b) Substituting end–user numbers for voltage–weighted connections



c) Excluding connections output altogether



In Figure 3 we present MTFP results for the three options we are able to quantify. The effect of using end–user numbers in Figure 3(b) relative to voltage–weighted connections in Figure 3(a) is to greatly reduce the spread of MTFP scores. TNT is no longer an outlier lying well above the other TNSPs. And the smaller ENT is also brought back into the range of results for the other TNSPs. Using end–user numbers there are also changes in the relative performance of larger and smaller TNSPs over time as might be expected to occur in practice.

Excluding the connections output altogether in Figure 3(c) leads to a further compression in the spread of MTFP results excluding TNT but again leads to TNT being an outlier above the other TNSPs.

Average annual growth rates for MTFP and for opex MPFP are presented in table 1. Using the end–user numbers output leads to MTFP growth rates being up to 0.5 per cent per annum more negative for four of the TNSPs and being 0.4 per cent per annum higher for TNT compared to using the voltage–weighted connections output. Excluding the connections output altogether generally leads to larger differences in MTFP growth rates compared to using the voltage–weighted connections output with growth rates being up to 0.8 per cent per annum more negative for four of the TNSPs. These differences in growth rates are replicated for both opex MPFP and capital MPFP (because the input sides of those indexes also remain unchanged while only the output components change).

Table 1 Average annual growth rates of MTFP and opex MPFP, 2006–2015

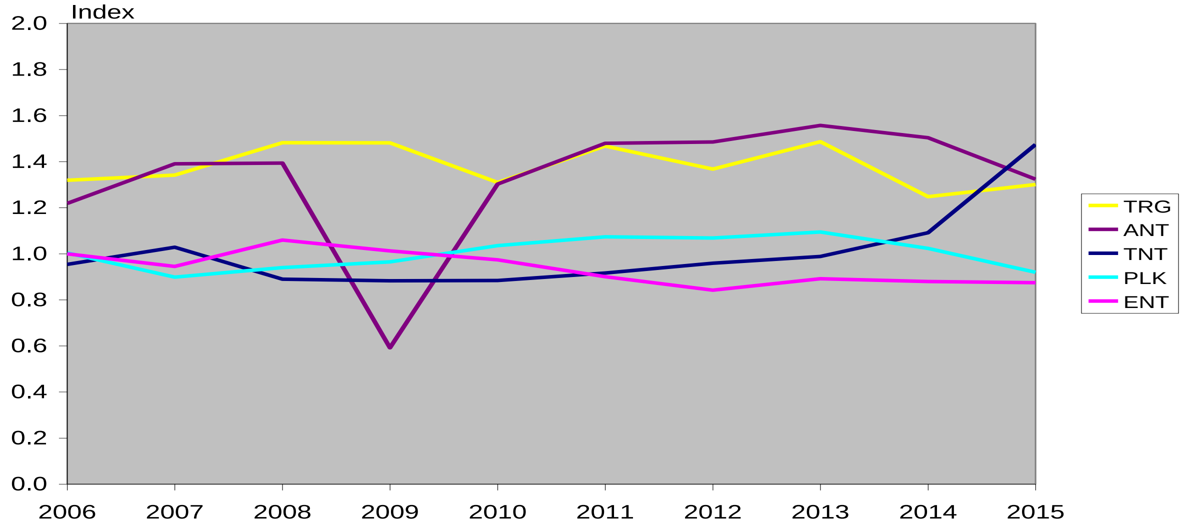
	MTFP Growth Rates			Opex MPFP Growth Rates		
	Voltage–Wtd Conns	End–user Nos	Excluding Conns.	Voltage–Wtd Conns	End–user Nos	Excluding Conns.
ENT	–1.55%	–2.02%	–2.33%	–1.49%	–1.96%	–2.27%
PLK	–2.05%	–2.59%	–2.63%	–0.97%	–1.52%	–1.55%
ANT	0.54%	0.20%	0.07%	0.92%	0.58%	0.45%
TNT	0.57%	0.95%	0.72%	4.84%	5.22%	4.98%
TRG	–2.80%	–3.13%	–3.40%	–0.16%	–0.49%	–0.76%

Source: Economic Insights calculations

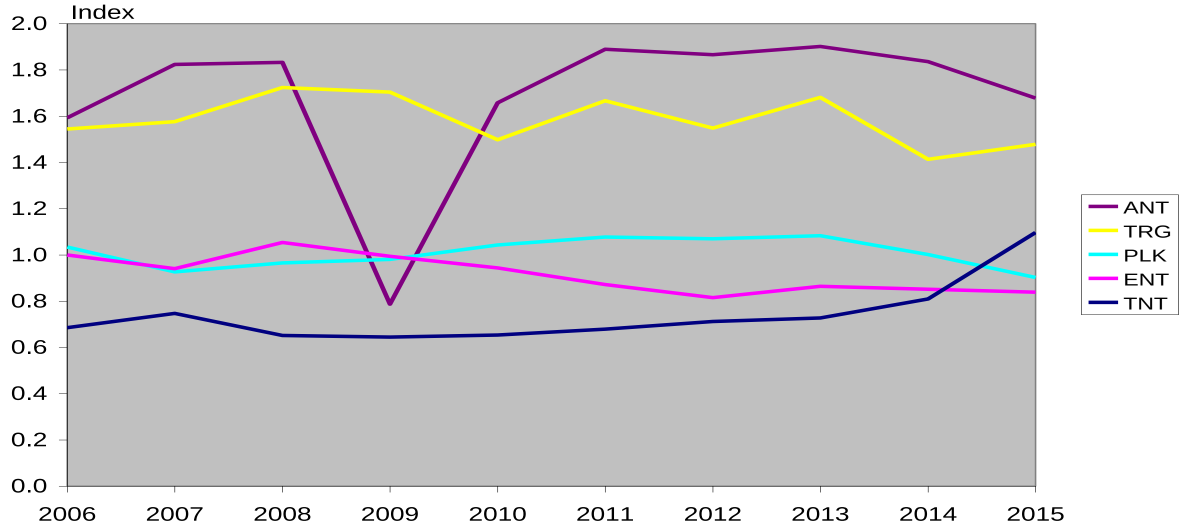
In Figure 4 we present opex MPFP results for the three options we are able to quantify. The effect of using end–user numbers in Figure 4(b) relative to voltage–weighted connections in Figure 4(a) is to increase the spread of opex MPFP scores somewhat. This is because the two TNSPs that previously performed best on this measure – ANT and TRG, the two largest TNSPs which also do best on this measure – have relative increases in their outputs using end–user numbers and the relative output of TNT is reduced using end–user numbers which puts it at the bottom of the opex MPFP range for most of the period, instead of being second lowest as was the case using the voltage–weighted connections. Again, we expect that voltage–weighted connections tends to understate output for the larger TNSPs and overstate it for the smaller TNSPs relative to what would be the case using MVA weighting which would more accurately reflect entry and exit point capacity.

Figure 4 Multilateral opex partial factor productivity index by TNSP, 2006 to 2015

a) Using voltage–weighted connections



b) Substituting end–user numbers for voltage–weighted connections



c) Excluding connections output altogether

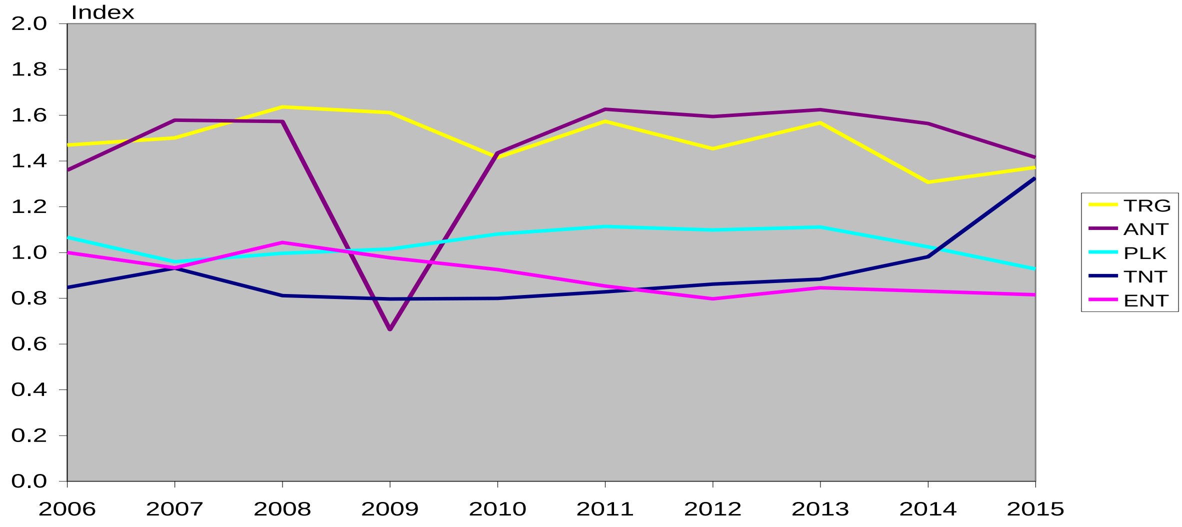
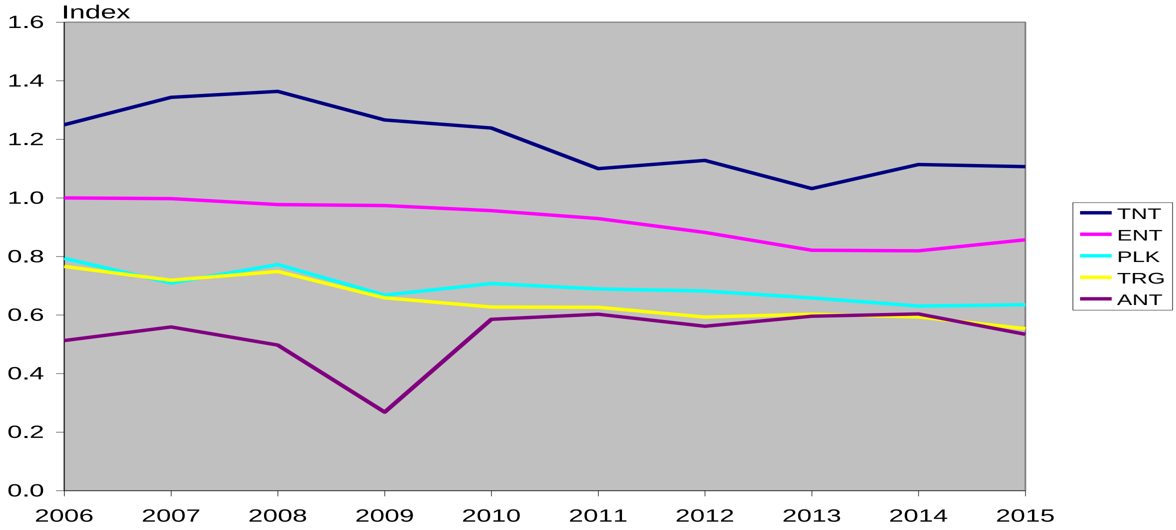
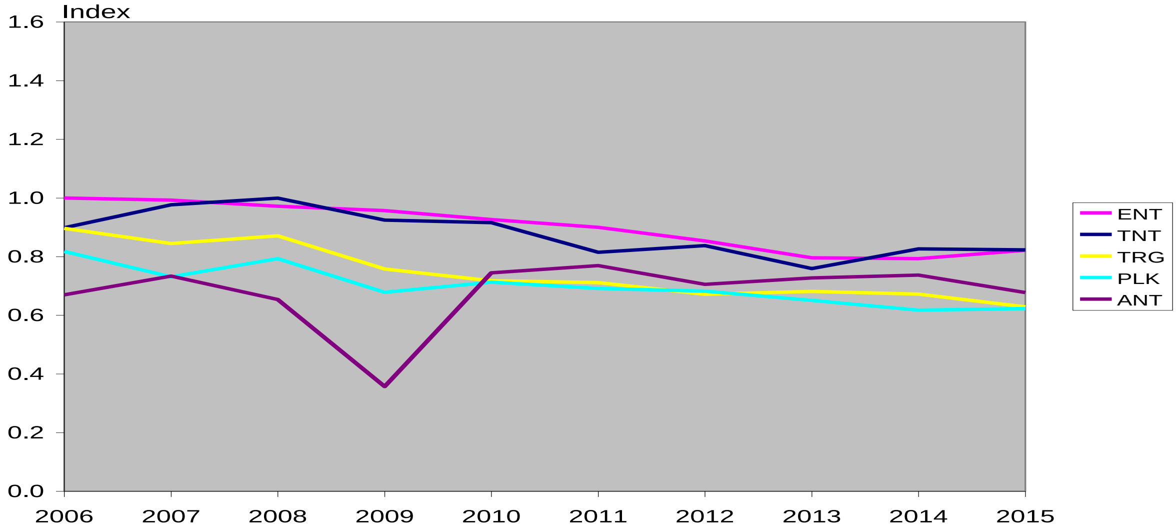


Figure 5 Multilateral capital partial factor productivity index by TNSP, 2006 to 2015

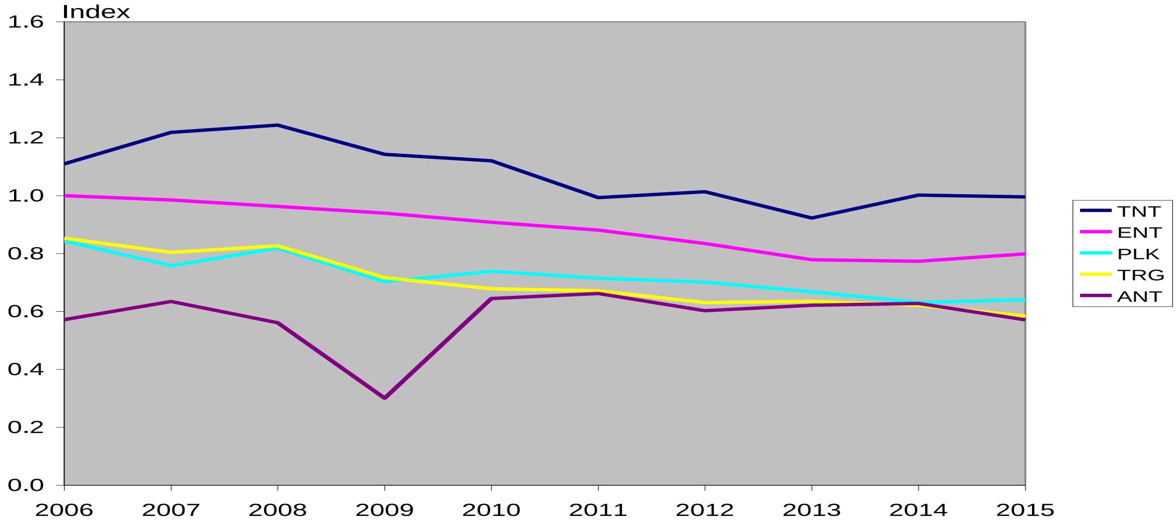
a) Using voltage–weighted connections



b) Substituting end–user numbers for voltage–weighted connections



c) Excluding connections output altogether



Excluding the connections output altogether in Figure 4(c) leads to a small increase in the spread of opex MPFP results compared to using the voltage–weighted connections output.

In Figure 5 we present capital MPFP results for the three options we are able to quantify. The effect of using end–user numbers in Figure 5(b) relative to voltage–weighted connections in Figure 5(a) is to considerably reduce the spread of capital MPFP scores. The two small TNSPs – TNT and ENT – are no longer outliers lying well above the three larger TNSPs. Using end–user numbers the highest capital MPFP result in 2015 is 32 per cent above that of the lowest capital MPFP in that year whereas the highest score using the voltage–weighted connections output was 110 per cent higher than the lowest score in 2015.

Excluding the connections output altogether in Figure 5(c) reduces the spread of capital MPFP results somewhat compared to using the voltage–weighted connections output but TNT and ENT still remain relative outliers above the three larger TNSPs.

2.5 Preferred options

Having reviewed each of the four options listed in section 2.4, each has a number of advantages and disadvantages. The current voltage–weighted connections measure has the advantage of attempting to adjust the number of entry and exit points for the relative ‘size’ of each connection point using accessible information and in a simple way. However, we accept the criticisms of the measure made by AusNet (2017) that the voltage of the connection point is not necessarily closely related to the capacity of the connection point and that the number of connection points does not necessarily reflect the complexity of the task the TNSP has to perform. Furthermore, Economic Insights (2013) noted that the measure does not score well against the second selection criterion, namely that the output should directly reflect a service provided to customers. And, while a case can be made for including allowance for entry points, it marks a departure from the framework currently used to measure DNSP outputs for economic benchmarking which focus on the end–user side of the network.

The second option listed above of replacing the TNSP–side voltage of the connection point as the means of weighting by the MVA capacity of the connection point overcomes one of the main shortcomings of the current method. It provides a better approximation to the capacity of the connection point but retains the other disadvantages of the first measure. All else equal, we expect the current voltage–weighted connections variable tends to understate capacity for the larger TNSPs and to overstate it for the smaller TNSPs. To implement this measure data on the MVA capacity of each connection point would be required. We believe there is a case, on balance, for extending the TNSP EBRINs to collect these data (including backcasting to 2006) to support further testing of this output specification and to support future refinement of TNSP economic benchmarking, including OEF development.

The third measure listed above of substituting jurisdictional end–user numbers for voltage–weighted connections has the advantage of focusing on the service provided to electricity customers. It, thus, scores more highly on the second selection criterion than either of the first two measures. It also uses robust data that is currently readily available. It provides a direct measure of the scale of the transmission task and a good proxy for the complexity of the task facing the TNSP. A disadvantage is that it provides less direct information on the operating environment facing the TNSP which may require a higher number of smaller entry and/or exit points than the operating environments faced by other TNSPs. That is, it is less directly related to the actual number of 'on–ramps' and 'off–ramps' to the freeway (to use the road analogy used in Economic Insights 2013). However, the output specification cannot take account of all OEFs. Unusual circumstances facing a TNSP such as the need to connect a larger number of smaller renewable energy generators than other TNSPs are likely to be best dealt with through the application of separate OEF analysis.

The end–user numbers measure also has the advantage of being the most similar to the current treatment of DNSP outputs. While the end–user numbers output is a proxy for system complexity and scale, it is likely to provide a better approximation to an MVA–weighted connections output variable than the current voltage–weighted connections variable. Although it does not fully capture the influence of large industrial customers, the influence of these customers on TNSP output will be captured through the throughput and ratcheted maximum demand outputs.

The fourth option listed above of simply excluding the connections output has the advantage of sidestepping many of the difficulties associated with the measurement and refinement of the current variable. However, we believe it is important to retain a measure of the scale and complexity of the TNSP's task that focuses on the provision of capacity rather than simply energy consumed or maximum demand observed. While using the ratcheted maximum demand variable provides some allowance for capacity that has had to be built to meet past demand, it does not address the likely future situation of falling throughput and demand but increases in the number of end–users that have to be served. Including either an end–user number or a connections–based output helps address this situation. Excluding the output would also mark a significant departure from having a broadly analogous specification to that currently used for DNSP economic benchmarking. Therefore, while excluding this output does not have a dramatic impact on the results obtained, we favour the retention of either an end–user number output or an improved version of the connections output.

On balance, we favour shifting to the end–user number output as the next phase of refinement in TNSP economic benchmarking. It can be implemented immediately as it draws on robust data that are currently available and better addresses the second selection criterion of focusing on customers. It has the practical benefit of removing the outlier status in the results of the two smaller TNSPs, TNT and ENT.

We also support expansion of the TNSP EBRIN data collection to include the MVA rating of each TNSP entry and exit point. This will allow further testing of the second specification listed above and provide useful options for the eventual development of improved entry and exit point capacity proxies and OEFs.

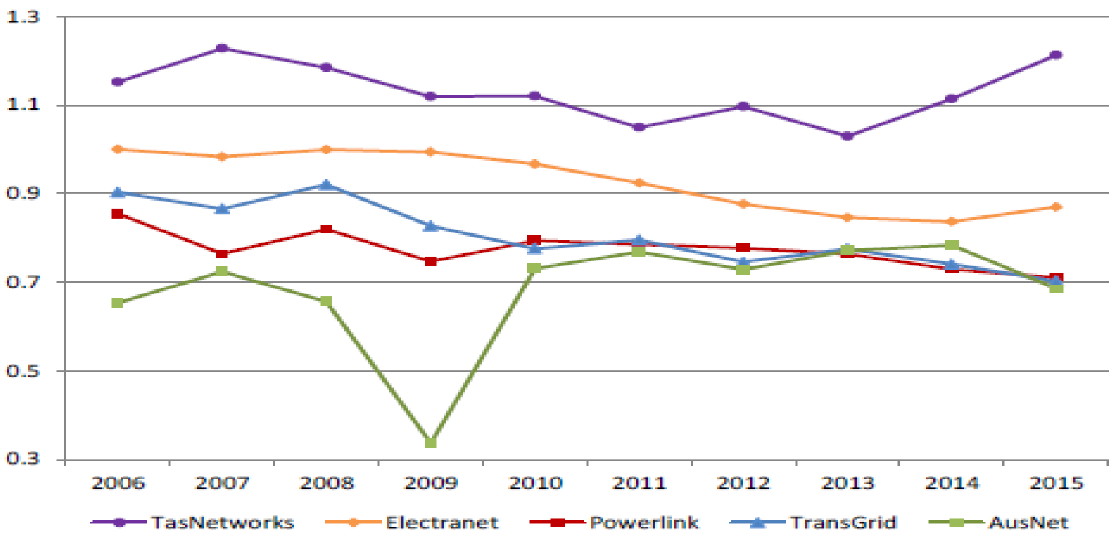
3 RELIABILITY OUTPUT WEIGHTING

The reliability output measure is a negative output variable that captures energy not supplied as a result of network outages (unsupplied energy). Unsupplied energy is typically a very small proportion of total energy, but the economic and social costs of transmission outages can be very large. The weight applied to unsupplied energy is currently based on the Australian Energy Market Operator's jurisdictional values of customer reliability (VCR) (AEMO 2014).

3.1 The problem raised

AusNet (2016, pp.4–6) submitted that the current MTFP model specification places too high a weight on reliability outcomes and these can 'swamp' the other outputs contained in the model. Unlike distribution, it states that transmission reliability incidents are of low probability and high consequence, and are often due to the failure of a major asset or external circumstance (eg a storm event). As such, it considers the current impact of major transmission outages on MTFP results are not reflective of underlying productivity achieved in a given year.

Figure 6 Multilateral total factor productivity index by TNSP, 2006 to 2015

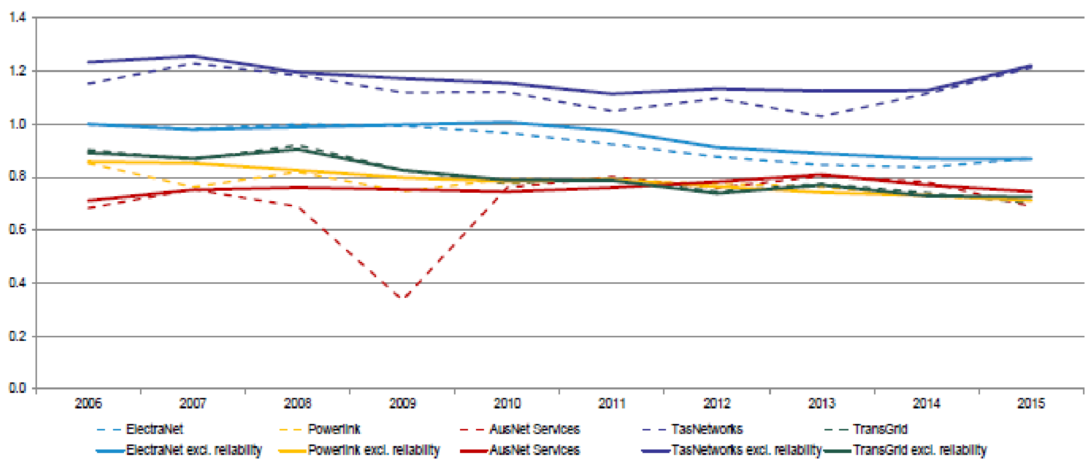


Source: AER (2016a)

To illustrate, Figure 6 shows that AusNet Services' MTFP results fell by 50 per cent in 2009 and total industry productivity also dropped by 13 per cent in that year. AusNet states this was the result of a transmission outage following the failure of AusNet's 500kV transformer at the South Morang Terminal Station. Similarly, AusNet states that its MTFP rank in 2015 declined from third to last largely as a result of a loss of supply incident involving an outage on a transmission line connecting a major 500kV customer.

AusNet compared MTFP results from the current model with one that excluded the reliability output. AusNet's modelling showed that excluding reliability makes the results considerably less volatile without changing the trajectory of each TNSP's productivity. AusNet's results are presented in figure 7. AusNet concluded that moderating the effects of reliability would result in a MTFP model that is more reflective of the underlying productivity achieved in any given year and, therefore, better achieves the intended purpose of benchmarking.

Figure 7 MTFP results by TNSP excluding the reliability output, 2006 to 2015



Source: AusNet (2016, p.6)

AusNet suggested that one solution could be to include a cap on the weight given to reliability in any one year or, alternatively, a cap on the included amount of energy not supplied. AusNet (2016, p.6) noted:

> 'It would also align with the principle applied by the AER when it introduced a cap on unplanned outages in version 5 of the transmission STPIS, which was in part to ensure that transmission networks continue to have an incentive to manage reliability following the occurrence of a major unplanned outage.'

Other TNSPs generally supported capping the influence of reliability outcomes on the productivity measures. For instance, Powerlink (2017, p.3) stated that it 'supports the proposal to cap the influence of unserved energy on the benchmarking results'. ElectraNet (2017, p.5) also supported considering a cap on both the weights given to reliability and the volume of unserved energy used in the model. And TasNetworks (2017, p.4) agreed that 'capping the impact of reliability outages would ensure that individual TNSP and industry productivity gains are not distorted by large one–off reliability events'. While ElectraNet (2017, pp.5–6) thought there should be consistency between the adjusted measures used in the AER's STPIS incentive scheme and the benchmarking analysis, TasNetworks (2017, p.4) thought this was not necessary as 'it may introduce unnecessary complexities'.

At the forum on the Issues Paper, a representative of the AER's CCP objected to the options of excluding reliability or reducing its significance as reliability is a major consideration for large users. Economic Insights does not favour excluding the transmission reliability output as reliability is an important requirement for TNSPs. However, we acknowledge that the current approach does appear to place too much weight on reliability in some relatively rare instances as evidenced by the very large impact of outages at one terminal station on the Victorian and industry productivity levels in 2009.

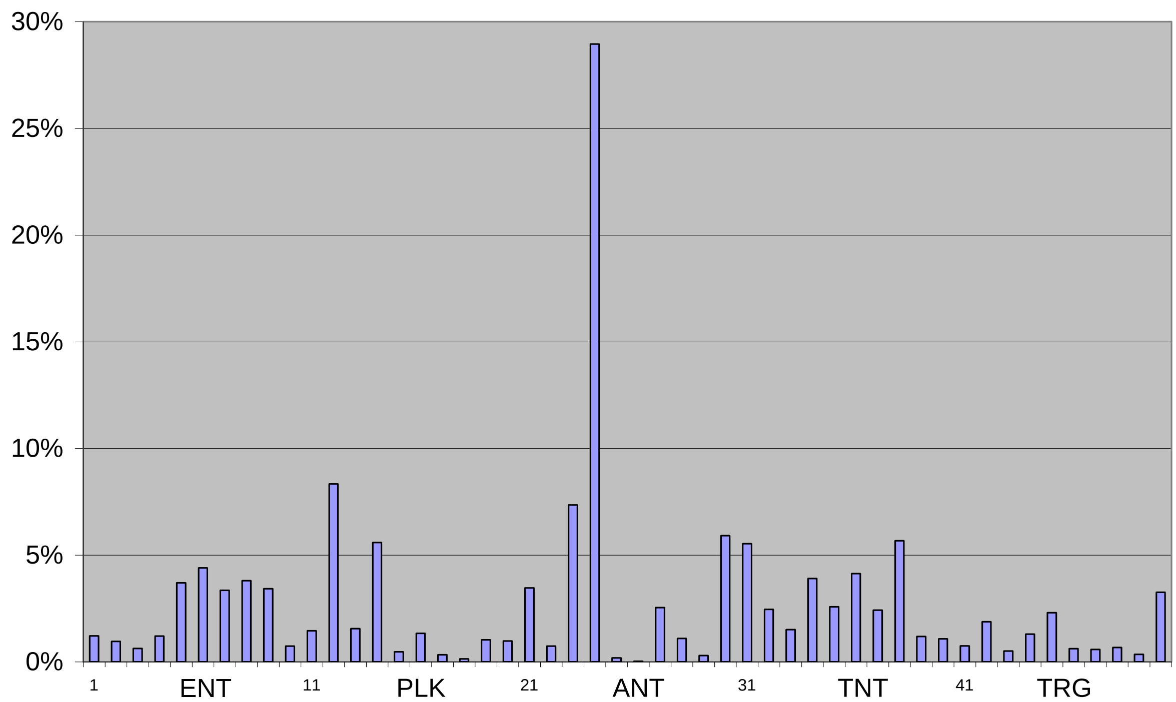
3.2 Options considered and quantitative implications

Capping the impact of outages on the productivity results appears to be the best way of retaining recognition of the importance of reliability while ensuring that one–off large events do not swamp the results. We believe there are two options worthy of further consideration:

1) cap the share given to reliability but retain the current energy not supplied due to outages (ENS) series, and
2) cap the ENS itself (based on capping the share at a specified value).

The current reliability output shares of gross revenue are plotted in Figure 8. There are 10 observations for each of the five TNSPs and the data are stacked by year (ie 2006 to 2015 for ENT, then 2006 to 2015 for PLK and so on). The average share for the 50 observations is 2.8 per cent. It can be seen that the share for ANT in 2009 of 28 per cent is an extreme outlier. Excluding this observation, the sample average is 2.2 per cent. The standard deviation of the sample including this outlier is 4.3 per cent, while excluding this observation it is 2.0 per cent. Given the extreme nature of the outlier, we exclude it in calculating a reasonable cap value. If a normal distribution of shares is assumed, the probability that a share would be less than 5.5 per cent is 95 per cent. There are another six observations with shares that exceed 5.5 per cent, although there are only two of these that exceed 6 per cent. We believe a cap value of 5.5 per cent for the share of the reliability output in total revenue is reasonable.

Figure 8 Shares of TNSP reliability output in gross revenue, 2006 to 2015

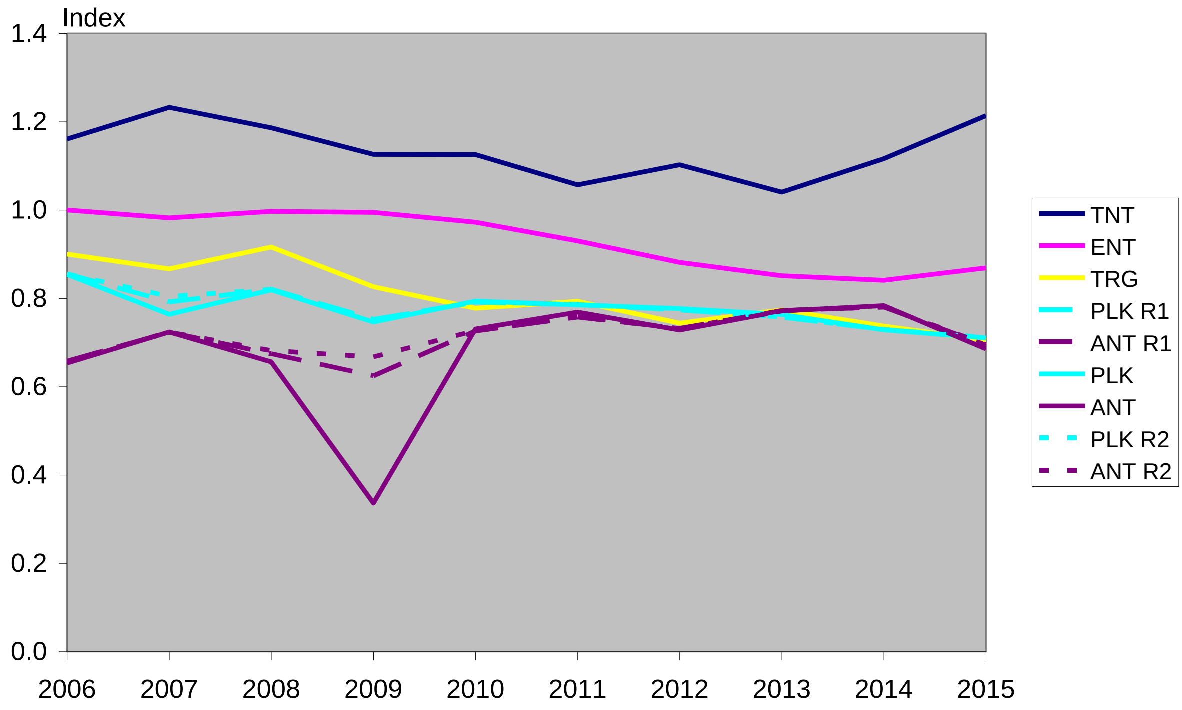


Source: Calculations based on Economic Insights (2016)

To implement this cap the first option above assumes that the ENS value remains unchanged but, for those observations where the share exceeds 5.5 per cent, the price of the reliability output falls to enable the cap to be achieved. That is, for these observations the price of outages becomes less than the AEMO jurisdictional VCR.

The second option above implements the cap by adjusting the ENS value for those observations where the share exceeds 5.5 per cent. That is, for these observations the price of outages remains at the AEMO jurisdictional VCR but the ENS is reduced to achieve the capped share.

Figure 9 Multilateral total factor productivity index by TNSP including adjusted reliability treatment using options 1 and 2, 2006 to 2015



Source: Calculations based on Economic Insights (2016)

Figure 9 presents the TNSP MTFP results using the current treatment (solid lines), option 1 which adjusts the price of energy not served to achieve the share cap (large dashed lines) and option 2 which adjusts energy not served to achieve the share cap (small dashed lines)[3]. For clarity of presentation, options 1 and 2 are only included for PLK and ANT. TNT also has active adjustments in two years but these are both very small and would not show clearly on the graph. ENT and TRG do not have adjustments made in any of the years included in figure 9.

Options 1 and 2 both reduce the magnitude of the major dip in ANT's MTFP in 2009 and the much smaller dips in PLK's MTFP in 2007 and ANT's MTFP in 2008. Option 1 produces somewhat less smoothing than option 2 as option 1 retains the original ENS series but gives it less weight whereas option 2 adjusts the ENS quantity itself while also giving it less weight.

Comparing figure 9 with figure 7 where the series excluding reliability altogether are plotted, it can be seen that in figure 7 ANT's MTFP is relatively constant from 2007 to 2010 when

[3] For the purposes of comparison we retain the current voltage–weighted connections output.

reliability is excluded whereas in all three cases presented in figure 9 ANT’s MTFP falls in 2009. Option 2 only produces a small dip in 2009 whereas option 1 produces a more marked – but still relatively modest – dip. The current treatment, on the other hand, produces a very large dip in 2009, one that is arguably implausibly seeing that it was a one–off outage at only one terminal station.

3.3 Preferred option

Based on the analysis presented in the preceding section, we believe there is a solid case for capping the share given to the reliability output in the TNSP productivity model. While it is important to retain the reliability output in the model in recognition of the vital tole of transmission in the electricity supply chain, the current treatment which leads to a one–off outage at one terminal station leading to reduction in ANT’s output for the entire year of 50 per cent and of the industry’s output by 13 per cent is not realistic. Instead, we favour adopting option 1 above which places a cap on the value of ENS as a share of gross revenue of 5.5 per cent with the cap taking effect by reducing the price of ENS in those years where the cap is binding. This has the advantage of recording somewhat more of a downturn in productivity in those years where the cap binds compared to the alternative of imposing the cap via changes in the ENS itself. Setting the cap at a share of 5.5 per cent is consistent with a 95 per cent probability of the cap not being binding. Or, in other words, outlier situations where the cap would bind have only a 5 per cent chance of occurring.

4 WEIGHTS FOR OUTPUTS OTHER THAN RELIABILITY

There has been general agreement that a 'functional' outputs approach is more appropriate than a 'billed' outputs approach for economic benchmarking used in a building blocks context. This is because NSP pricing structures have often evolved on the basis of convenience rather than on any strong relationship to underlying relative costs. As a result, observed revenue shares are of limited usefulness (in a building blocks context) in forming weights for index number economic benchmarking techniques that need to aggregate output quantities into a measure of total output. Rather, it is necessary to form output weights based on the weights implicitly used in building blocks determinations. These are generally taken to be cost–reflective output weights.

4.1 The problem raised and options considered

TransGrid has recently submitted a report by Frontier Economics (FE 2017) which contains a number of criticisms of the econometrically–based output shares used in the AER's TNSP economic benchmarking to date. Specifically, FE raised the following issues:

- the estimates have not been updated to include data for 2014 and 2015
- the estimates have not been updated to include data revisions for earlier years
- output shares are estimated for total costs and not separately for opex and capital
- there is a high degree of correlation among the included outputs
- the estimated cost function violates the monotonicity requirement for some observations, and
- the price index used to deflate total costs.

Economic Insights (2017b) provides a detailed response to the technical issues raised by FE (2017). We do not intend to repeat the technical discussion here. Rather, we concentrate on whether the weights for outputs other than reliability now need to be updated.

In keeping with the approach commonly adopted in network industry productivity studies using index number methods, estimates of the relevant cost–reflective output shares in Economic Insights (2014b) were formed from the first–order coefficients of a simple econometric cost function. However, the ability to form these estimates was significantly constrained by the small number of observations available at the time. We had only 40 observations available – 8 years for each of 5 TNSPs. At the best of times this would limit the sophistication of the cost function model that could be estimated. However, as noted in Economic Insights (2015a), NSPs are very stable entities that exhibit limited time–series variation in cost/output relationships. In this case, our 40 observations were more akin to the explanatory power of 5 observations because the main variation in the data comes from the cross–sectional dimension.

To address small numbers of observations, previous index number productivity studies have estimated a very simple Leontief cost function developed by Lawrence and Diewert (2006) which is less flexible but also less observation–demanding than the translog functional form. This method is used to estimate output cost shares for the DNSP MTFP analysis in Economic Insights (2014c). It is briefly outlined in appendix A. However, estimation of the Leontief cost function using the TNSP data available in 2014 led to over 40 per cent weight being placing on the voltage–weighted connections output, the output that was considered the least developed and settled of the TNSP outputs. Placing such a high weight on the least developed output was not considered desirable. A basic translog cost function, on the other hand, placed more even weight across the four outputs and was used instead (Economic Insights 2014b, p.9).

Contrary to what FE (2017) appears to assume to be the case, standard practice in functional output–based productivity index number studies has been to not update output shares annually. To do so would make it difficult to discern those changes due to genuine productivity improvement and those due to weight changes. Similarly, we note that regulators that make use of econometric models as their primary means of undertaking annual economic benchmarking typically do not update the parameters of their econometric models every year for the same reason (PEGR 2015, p.7).

A cautious approach involving infrequent updating of the output cost shares was generally supported by TNSPs. For example, ElectraNet (2017, p.7) noted:

> ‘While the information should be reviewed periodically and tested and updated as required in the interest of developing and improving the robustness of the model over time, a level of stability is also required to ensure meaningful efficiency comparisons and incentives over time.’

And AusNet (2017, p.12) noted:

> ‘It is generally considered good practice to use the latest information when developing regulatory decision making tools such as benchmarking. However, frequent updating makes measuring changes in productivity more difficult and may create uncertainty for businesses. Accordingly, we would support infrequent (e.g. five yearly) updates of the weights.’

The CCP (2017, p.18) was also of a similar view:

> ‘stability in the weights assigned to the outputs is desirable. While it is appropriate to review the weights periodically, the AER should be cautious in changing the weights on the basis of the latest data.’

The CCP (2017, p.19) also observed that it would be desirable to draw on other sources of information such as accounting–based cost allocation models to corroborate results from econometric modelling. While we agree this would be desirable, it is difficult to obtain such information on a consistent basis across TNSPs and a forensic study based on accounting and engineering data is outside the scope of this review.

This leaves econometric estimation as the most tractable way of deriving output cost share information. While this approach is not ideal in small sample situations, it is important to recognise that our primary method of analysis is the index number method. Being a non–parametric method, index number analysis is not affected by only having a small number of observations. Information is required on output cost shares and this is derived from the estimation of very simple cost functions. While this information is not unimportant, it is secondary to data on output and input quantities which are the primary drivers of productivity measures. While multicollinearity and degrees of freedom constraints affect the robustness of econometrically–derived output cost share estimates, the sensitivity of productivity results to output cost shares estimates will depend on how closely related movements in output quantities are. As FE (2017, p.12) notes, in this case the correlations between the (logged) output quantities are all quite high so, all else equal, one would not expect the economic benchmarking results to be particularly sensitive to the estimated output cost shares.

Table 2 Estimated output cost shares

	With voltage–weighted connections					
Output	2014 Leontief	2017 Leontief	2014 Translog	2017 Translog	Output	2017 Leontief
Energy	0.18	0.23	0.21	0.31	Energy	0.23
RMD	0.15	0.20	0.22	0.56	RMD	0.19
Connections	0.43	0.24	0.28	0.04	End–users	0.20
Circuit kms	0.24	0.33	0.29	0.09	Circuit kms	0.38

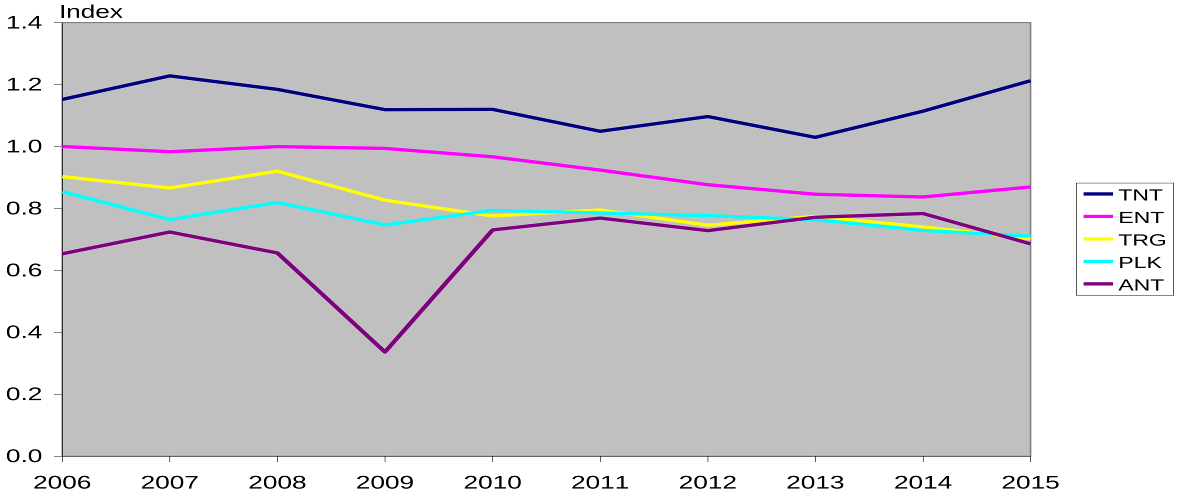
Source: Economic Insights cost function estimates

In table 2 we present output cost share estimates from a range of cost functions, model specifications and time periods. The first column of table 2 presents the output share estimates we obtained from the Leontief cost function in 2014. As noted above, this model placed by far the highest weight on the least developed output, voltage–weighted connections. The second column presents current estimates from this model using the revised connections variable (see Economic Insights 2015b) and two extra years of data. This model places roughly even weight on the first three outputs and more weight on circuit length. These results now seem very plausible without placing undue weight on the least developed output measure. The third column presents the 2014 translog cost function estimates currently used in TNSP economic benchmarking. And the fourth column presents translog estimates using the revised connections output and two extra years of data. The translog estimates in this case place minimal weight on the connections and circuit length outputs, in line with the first order coefficients on those variables being insignificant in the revised and updated model. Having a larger number of parameters to estimate, the translog model is more prone to multicollinearity problems and associated coefficient instability as variables and observation numbers are changed in what is still a very small sample for this type of model. Given the deterioration in performance of the translog model in this case we do not progress its results further. Instead, we switch back to using the updated simple Leontief cost function results, in line with the approach adopted in DNSP index number economic benchmarking.

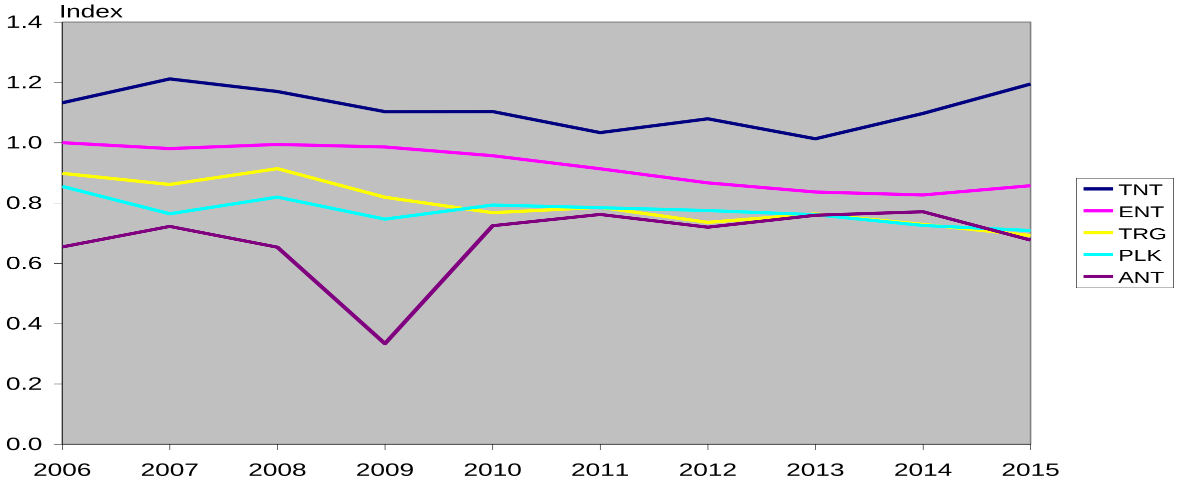
In the last column of table 2 we present Leontief cost function–based output cost shares for the model where voltage–weighted connections are replaced by end–user numbers. These results are broadly similar to the corresponding results in the second column with a minor transferring of weight towards line length and away from the end–users output relative to the model with voltage –weighted connections. The results are thus relatively stable despite the specification change.

Figure 10 Multilateral total factor productivity index by TNSP, 2006 to 2015

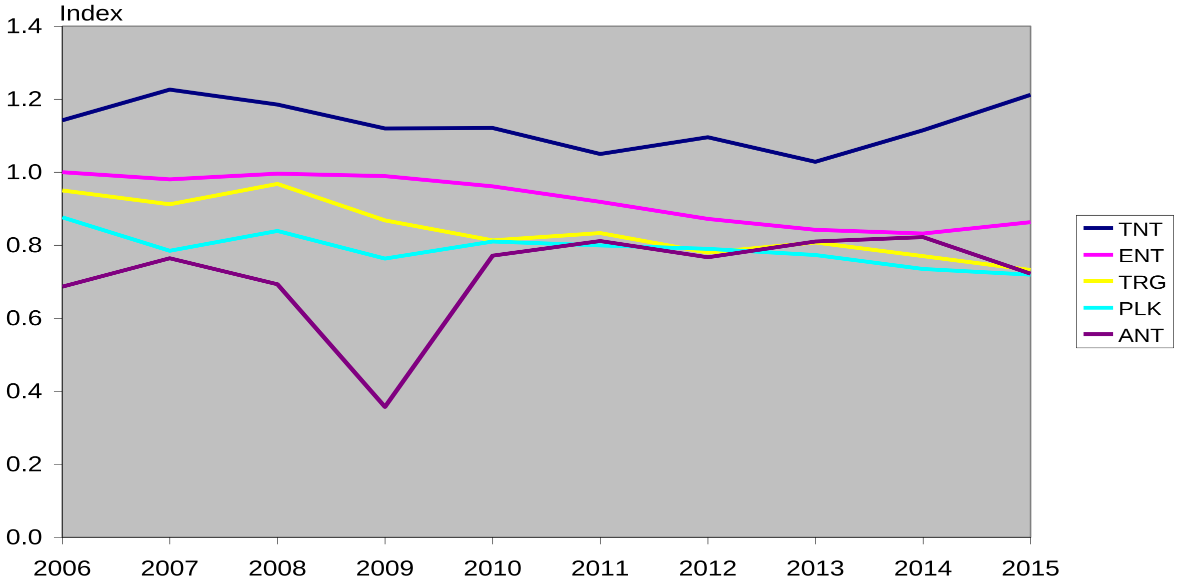
a) Using 2014 translog cost function weights



b) Using 2017 Leontief cost function weights



c) Using equal weights



To examine the sensitivity of the MTFP results to the choice of output cost shares, in figure 10 we present the TNSP MTFP indexes using the latest data with three different sets of output cost shares – those from the 2014 translog cost function, those from the 2017 Leontief cost function and a third set using equal weights of 25 per cent on all four non–reliability outputs. Again, for ease of comparison purposes, we use the current specification using the voltage–weighted connections output. From figure 10 it can be seen that the differences in MTFP results across the three different sets of output cost shares are not material.

4.2 Preferred option

Given that the current review of TNSP economic benchmarking is considering changes to the output specification suggested by TNSPs, it is timely to review the output cost shares used in TNSP economic benchmarking. In particular, if changes to the output specification are made as part of the review process then it will be necessary to re–estimate models from which output cost shares are derived. Based on the analysis presented above, the Leontief cost function–based shares using the latest data set, which includes a number of revisions relative to the 2014 data set used to estimate the shares currently used, appear to present the most plausible and stable results. Adopting this approach has the added advantage of being consistent with the approach adopted in the index number method component of the parallel economic benchmarking of DNSPs.

In line with practice adopted by other regulators presenting annual economic benchmarking results and the preference expressed by stakeholders in submissions, we recommend using the 2017 Leontief cost function–based shares presented in table 2 for a reasonable length of time to permit changes observed over time to be attributed more clearly to productivity changes.

5 'ADDITIVE' VERSUS MULTIPLICATIVE CAPACITY MEASURES

5.1 The issue raised

The FE (2017, p.21) report submitted by TransGrid claims that the TNSP economic benchmarking model does not adequately control for TNSP scale effects. It argues that the separate inclusion of the key system capacity variables of ratcheted maximum demand and line length on the output side does not mirror the 'multiplicative' inclusion of line capacity on the input side. It claims that this will potentially disadvantage large TNSPs relative to small TNSPs.

5.2 Analysis and options considered

Economic Insights (2014b, p.8) has previously examined including a multiplicative measure of system capacity based on installed downstream transformer capacity and line length on the output side. We did not favour this approach because increases over time in both transformer capacity and line length led to unrealistic rates of output growth and divergences between measured output levels for large and small NSPs. The measure of line capacity on the input side, on the other hand, involves multiplying line lengths by a constant MVA conversion factor applicable to the line's voltage level and is thus a different situation.

The difference in the two cases can be seen considering a simple example. Consider a TNSP that has y MVA of transformer capacity, z MVA of ratcheted maximum demand and x circuit kilometres of line with a weighted average MVA rating of, say, 200. Under the multiplicative system capacity output approach the TNSP's capacity output is yx MVA*kms while under the separate inclusion approach it is z MVAs and x kilometres. Its input measure is $200x$ MVAkms.

Now consider the situation of a TNSP of exactly twice the size. It has $2y$ MVA of transformer capacity, $2z$ MVA of ratcheted maximum demand and $2x$ circuit kilometres of line with a weighted average MVA rating of 200. All else equal and assuming constant returns to scale, the doubling of all variables should lead to its productivity remaining the same. Under the multiplicative system capacity output approach the larger TNSP's capacity output is $2y2x=4xy$ MVA*kms while under the additive approach it is $2z$ MVAs plus $2x$ kilometres. Its input measure is $200(2x)=400x=2(200x)$ MVAkms. That is, under the multiplicative output approach the larger TNSP's output is four times larger than the smaller TNSP's output compared to its input which is twice as large. Under the separate inclusion approach, the larger TNSP's output is double that of the smaller TNSP as required. Given that input has also doubled, productivity is the same for both TNSPs under the separate inclusion output approach as required but it is twice as high for the larger TNSP under the multiplicative approach.

This example disproves FE's (2017, p.23) claim that the current output and input specifications do not adequately control for TNSP scale effects.

The above example assumes the same configuration of lines for the larger TNSP as for the smaller TNSP. If the larger TNSP was to configure its lines to use a higher proportion of very high MVA capacity lines then it would potentially have a higher share of its total MVAkms on the input side in these very high capacity lines. However, it remains necessary to convert circuit line lengths to a common unit so that the line input can be legitimately summed to an aggregate level for each TNSP. If this was not done, to use an aeroplane example, we would be counting a Cessna and a Jumbo jet equally in summing up the number of planes to form a proxy for total capital input quantity.

AusNet (2017, p.14) made the following suggestion:

> 'One approach could be to add a scale efficiency factor to the MVA * km multiplicative calculation that would reflect the fact that the relationship between input cost and line capacity is not linear. The scale efficiency factor could be determined through expert engineering analysis of the operating and capital costs that are required to operate lines of different capacity.'

We do not favour this approach as it would introduce a degree of arbitrariness into the analysis. And, in any case, it needs to be remembered that productivity measures the quantity of outputs relative to the quantity of inputs and the current MVAkms measure on the input side measures the quantity of input capacity available.

Furthermore, as can be seen from figures 3 and 5 in section 2 above, much of the tendency for the current specification to 'favour' smaller TNSPs can be attributed to the voltage–weighted connections variable rather than differences between 'additive' and multiplicative approaches on the output and input sides, respectively. Changing to using jurisdictional end–user numbers instead of voltage–weighted connections removes much of the 'advantage' of the two smaller TNSPs, TNT and ENT.

In our economic benchmarking of DNSPs, concern was expressed that some DNSPs have more subtransmission lines of higher voltage than their peers due to the different system histories across States. This led to those DNSPs that inherited more and higher voltage subtransmission having relatively more of their MVAkms of line input tied up in these assets which accounted for relatively small proportions of their asset base. To address this concern we disaggregated lines and cables into separate subtransmission and distribution inputs, given that we also had the DNSP regulatory assets bases disaggregated along these lines (Economic Insights 2014c, pp.12–13). In practice, making this refinement led to little change in the DNSP MTFP results. A similar disaggregation could, in principle, be adopted for TNSPs although the split between very high voltage lines and lower voltage transmission lines would be somewhat arbitrary and would require a similar disaggregation of asset values which we do not currently have.

The CCP (2017, p.21) questioned the efficacy of such an approach as follows:

> 'In terms of a split between very high voltage lines and lower voltage transmission lines, we agree that such a split would be arbitrary, whereas the split between the DNSPs' subtransmission lines and cables and distribution lines and cables was able to be relatively clearly defined both conceptually and in the data. Moreover, with only 5 transmission businesses and of those, only one (AusNet),

> having 500 KV lines (if that was the split), the additional complexities may not add much to the outcome.'

Another approach to this issue has been adopted in our economic benchmarking of gas distribution businesses (for example Economic Insights 2012, 2015c) where pipeline lengths are separately included for services, low pressure, medium pressure and high pressure pipelines on the input side of productivity analysis. This requires data to be available or to be readily estimable for corresponding asset values. The greater diversity of TNSP line and cable capacities and the absence of disaggregated asset values make this approach less tractable for TNSPs.

It should be noted that this issue is only potentially of relevance to benchmarking total productivity levels across TNSPs. Currently, only TNSP opex MPFP growth rates are used in the AER's TNSP regulatory determinations. As illustrated in the example above, a move to include a multiplicative measure of capacity on the output side would distort measured productivity growth rates as well as productivity level comparisons.

And, finally, the CCP (2017, p.21) also noted:

> 'If the AER was considering using the benchmarking at some point for peer–to–peer comparison, then further analysis of this question may be warranted. While the practical use of the benchmarking is confined to trend analysis, such additional complexity does not seem warranted.'

5.3 Preferred option

Based on the analysis in the preceding section and the quantitative results from section 2, we do not believe a case has been made that our current treatment of the output and input specifications is inappropriate for an index number method productivity model or that a preferable or more tractable option has been identified. Consequently, we recommend retention of the 'additive' inclusion of ratcheted maximum demand and line length on the output side and the use of MVAkms to measure the quantity of line capacity on the input side.

6 PREFERRED SPECIFICATION FOR FUTURE TNSP ECONOMIC BENCHMARKING

Following assessment of the issues previously raised by stakeholders and discussed in the issues paper and subsequent submissions, we recommend making the following three changes to the TNSP economic benchmarking model:

1) substitution of jurisdictional end–user numbers for the current voltage–weighted connections output
2) adoption of revised output cost share weights derived from a Leontief cost function model applied to data for the 2006 to 2015 period, and
3) application of a cap of 5.5 per cent of gross revenue on the output share of energy not served with the cap being achieved by changes in the price of energy not served rather than its quantity.

We also recommend that the TNSP EBRINs be expanded to include data on the MVA capacity of transformers for each TNSP entry and exit point. This information will allow fuller assessment of a refined connections output using an improved weighting method and support future development of a more TNSP–specific output specification.

The move to using jurisdictional end–user numbers instead of the current voltage–weighted connections variable has the advantage of focusing on the service provided to electricity customers. It, thus, scores highly on the selection criterion requiring outputs to reflect services provided to customers. It also uses robust data that is currently readily available. It provides a direct measure of the scale of the transmission task and a good proxy for the complexity of the task facing the TNSP and has the advantage of being similar to the current treatment of DNSP outputs. It also has the practical benefit of removing the outlier status in the results of the two smaller TNSPs, TNT and ENT.

It needs to be recognised that the output specification cannot take account of all OEFs and unusual circumstances facing a TNSP such as the need to connect a larger number of smaller renewable energy generators than other TNSPs are likely to be best dealt with through the application of separate OEF analysis. Future refinement of a connections–based output using a transformer capacity weighting instead of a voltage weighting may assist with this.

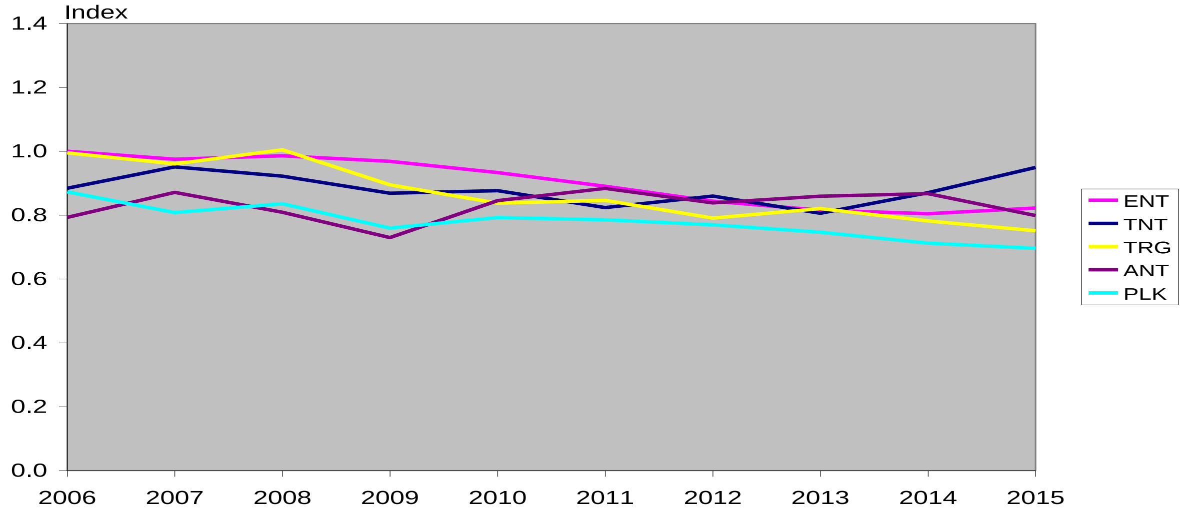
Given that changes are being made to the output specification, output cost shares need to be updated. Leontief cost function–based shares using the latest data set appear to present the most plausible and stable results and have the advantage of being consistent with the approach adopted in the index number method component of the parallel economic benchmarking of DNSPs. We recommend using these shares for a reasonable length of time to permit changes observed over time to be attributed more clearly to productivity changes.

And, we believe there is a solid case for capping the share given to the reliability output in the TNSP productivity model to avoid anomalous results. Setting the cap at a share of 5.5 per cent is consistent with a 95 per cent probability of the cap not being binding.

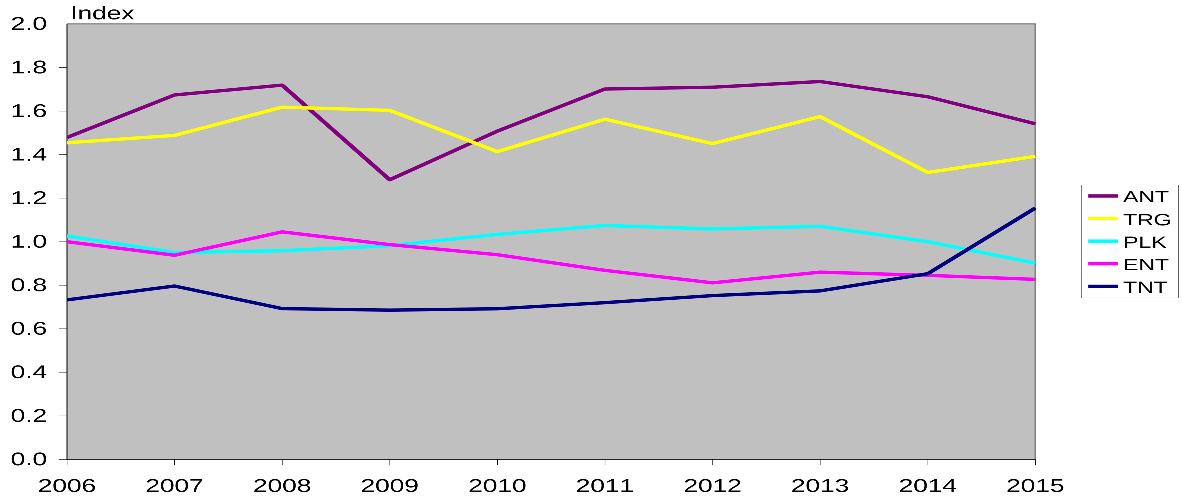
The TNSP economic benchmarking results for the period 2006 to 2015 using the specification recommended are presented in figure 11.

Figure 11 Multilateral productivity indexes by TNSP, 2006 to 2015

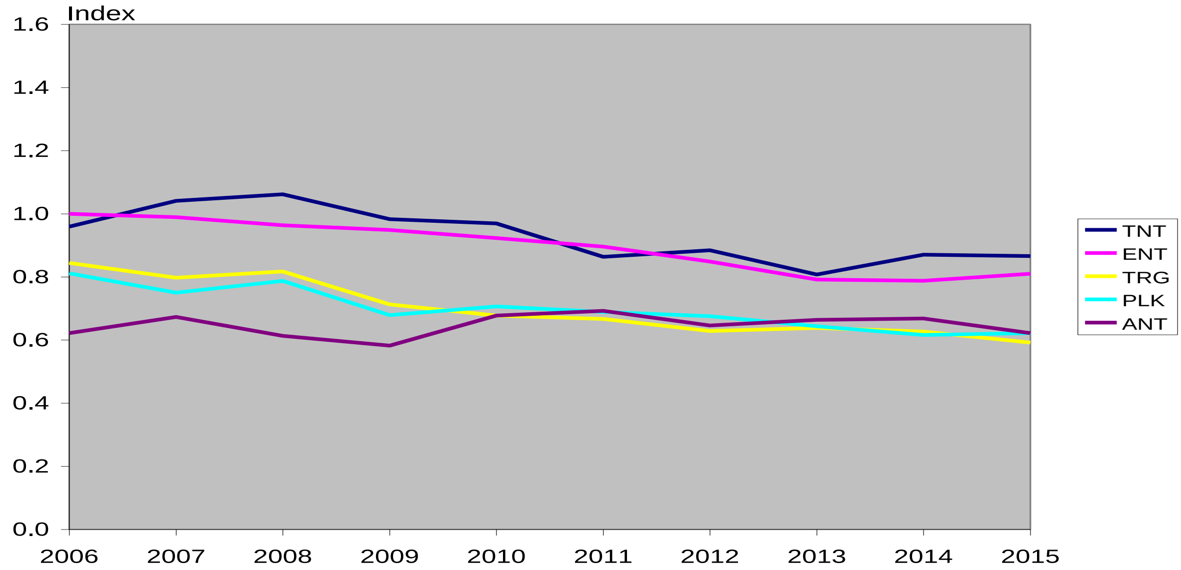
a) Multilateral total factor productivity



b) Multilateral opex partial factor productivity



c) Multilateral capital partial factor productivity



APPENDIX A: LEONTIEF OUTPUT COST SHARE WEIGHTS

The multi–output Leontief cost function method for deriving output cost share weights in small samples was developed by Lawrence and Diewert (2006). The multi–output Leontief functional form assumes that firms use inputs in fixed proportions for each output and is given by:

(A1) $$C(y^t, w^t, t) = \sum_{i=1}^{M} w_i^t \left[\sum_{j=1}^{N} (a_{ij})^2 y_j^t (1+b_i t)\right]$$

where there are M inputs and N outputs, w_i is an input price, y_j is an output and t is a time trend representing technological change. The input/output coefficients a_{ij} are squared to ensure the non–negativity requirement is satisfied, ie increasing the quantity of any output cannot be achieved by reducing an input quantity. This requires the use of non–linear regression methods. To conserve degrees of freedom a common rate of technological change for each input across the three outputs is imposed but this can be either positive or negative.

The estimating equations are the M input demand equations:

(A2) $$x_i^t = \sum_{j=1}^{N} (a_{ij})^2 y_j^t (1+b_i t)$$

where the i's represent the M inputs, the j's the N outputs and t is a time trend.

The input demand equations are estimated separately for each firm using non–linear regression. Given the limited number of observations and the absence of cross equation restrictions, each input demand equation is estimated separately.

Output cost shares for each output and each observation are then derived as follows:

(A3) $$h_j^t = \left\{\sum_{i=1}^{M} w_i^t [(a_{ij})^2 y_j^t (1+b_i t)]\right\} / \left\{\sum_{i=1}^{M} w_i^t \left[\sum_{j=1}^{N} (a_{ij})^2 y_j^t (1+b_i t)\right]\right\}.$$

A weighted average of the estimated output cost shares for each observation is then used to form an overall estimated output cost share where the weight for each observation, b, is given by:

(A4) $$s_b^t = C(b, y_b^t, w_b^t, t) / \sum_{b,t} C(b, y_b^t, w_b^t, t).$$

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