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QUANTITATIVE ECONOMICS

Memorandum

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Subject:	Electricity Distribution Opex Cost Function: Potential Misspecification Issues

1 Introduction

The AER's econometric opex cost function Translog models have exhibited declining performance in terms of the frequency of monotonicity violations (MVs) in recent annual benchmarking reports (ABRs). A potential explanation for this issue is the existence of omitted variables; ie, when models fail to incorporate all of the appropriate explanatory variables. To explore this possibility, two types of omitted variables are examined; firstly, more flexible time trend specifications; and second, whether circuit length measurement inconsistencies in Ontario should be controlled for.

As highlighted by previous research (Quantonomics 2023; Frontier Economics 2023), differences in the underlying time trends of opex partial productivity between jurisdictions may be an important omission.

In theory, the time-trend element of the standard opex cost function specification represents technical change because the model assumes time-invariant inefficiency, and implicitly assumes there are no important omitted operating environment factors (OEFs). In actuality, the inefficiency of DNSPs has likely changed over time, given the length of the sample periods. Further, given the difficulties of including all relevant OEFs (because some are not measured or not consistently measured between jurisdictions or because the effects of OEFs are complex and may not be captured by a single metric) it is likely that changes in OEFs over time have an unmeasured influence on real opex. Hence, the time-trend component will, in practice, reflect the combined effects of technical change, changes in cost inefficiency over time and the effect of changes over time in omitted OEFs.

As noted in Economics Insight (2021), differences in economic regulatory regimes may lead to varying rates of efficiency improvements across jurisdictions. Also, changes over time in technical regulation standards may give rise to changes in observed productivity. If these effects are significant, they could result in differences in opex efficiency trends between jurisdictions, which can be captured to some extent by including jurisdiction-specific time trends in the models.

This view is supported by observed trends. The AER's opex partial factor productivity (PFP) index analysis of the Australian DNSP industry finds an average Opex PFP growth rate of 0.3 per cent per annum from 2006 to 2023, including a substantial decrease in the period up to 2012, and an equally substantial improvement after 2012 (Quantonomics 2024, 15). A recent study of productivity trends of the New Zealand electricity DNSP industry (CEPA 2024) finds that between 2008 and 2023, the average opex partial productivity as measured using econometric analysis fell by between 1.2 and 2.2 per cent per year. In 2013, Pacific Economics Group (PEG) carried out a study of Rate Setting Parameters and Benchmarking for the Ontario Energy Board. It presented an output index and an Opex quantity index for 2002 to 2011 (PEG 2013:63,65). Between these two years, the Ontario electricity distribution industry's Opex PFP average rate of change was 0.0 per cent per annum.[1] This difference in trends between Australia, New Zealand and Ontario suggests that the assumption of a uniform trend may be unsatisfactory. Further, a growing divergence between jurisdictions caused by such trends may explain why the issue of monotonicity violations in the Translog models has worsened in recent years.

This memo examines whether jurisdiction-specific time trends would be appropriate in the opex cost function benchmarking models. The first set of omitted variables tested and reported in section 2, is separate time trends for each jurisdiction: Australia, New Zealand and Ontario. A variation on the same theme, using an additional time trend for Australia only, was tested in Quantonomics (2023) *'Opex Cost Function-Options to Address Performance Issues of Translog Models'* and found to be strongly significant. Section 3 of this memo updates that analysis.

We further investigate whether a potential inconsistency in the measurement of circuit length for Ontario DNSPs, compared to data from Australian and New Zealand DNSPs, may need to be controlled for. To address this, Ontario circuit length interaction terms have been incorporated into the standard models. The results are briefly described in section 5 and presented in more detail in Appendix B. They do not provide sufficiently strong support for including such interaction terms.

The primary aim of this analysis is to assess the statistical significance of the additional variables and determine whether their inclusion enhances the performance of the models in terms of MVs, goodness-of-fit and other key properties. The baseline for comparison is the standard Opex function model in ABR24 (Quantonomics 2024). The same dataset is used in this analysis.

2 Jurisdiction-specific Time Trends

In Appendix A, Tables A1.1 to A1.4 present the econometric results when incorporating separate jurisdictional time trends, for both the long and short sample periods. These tables present the LSECD, LSETLG, SFACD, and SFATLG versions of the jurisdictional time

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[1] Subsequent regulatory decisions by the Ontario Energy Board adopt this parameter in setting the X-factor's 'productivity factor' component.

trend models. For convenience, model specifications with separate time trends for each of the three countries in the sample are referred to in this memo as Jurisdictional Time Trend (JTT) models.

Variables *yr_1, yr_2* and *yr_3* capture the time trends for Australia, New Zealand and Ontario, respectively. These variables are interactions of the indicator variable for each country with the time trend variable (*yr)* from the standard model. They replace the single time-trend variable in the standard model. The coefficients on the three time-trend variables inversely reflect the underlying trend in opex partial productivity (hereafter 'Opex PFP') for each jurisdiction. A negative value means that, on average, Opex PFP has been improving. In the standard models, the coefficient of *yr* represents the inverse trend in Opex PFP for all DNSPs in the sample. The positive value of *yr* found in standard models means that, on average over all jurisdictions and DNSPs, Opex PFP is deteriorating. Since technical change is generally taken to have a positive effect, the deterioration in Opex PFP will be either due to increased inefficiency (if regulation is ineffective in some jurisdictions) or changes in OEFs that increase costs (eg, increased technical standards or compliance obligations).

2.1 Interpreting Jurisdictional Time Trends

2.1.1 Opex PFP Trends

Table 2.1 summarises the estimates for the jurisdictional rates of change in Opex PFP from the four model specifications and the two sample periods. Negative values of coefficients on *yr_1, yr_2* or *yr_3* mean that Opex PFP for the corresponding jurisdiction (Australia, New Zealand and Ontario respectively) has been improving, and positive coefficient values imply decreasing Opex PFP.

Table 2.1 Estimated Rates of Change in Opex PFP: JTT Models

	Long–period			*Short period*		
	Aust.	*NZ*	*Ontario*	*Aust.*	*NZ*	*Ontario*
LSECD	0.2%*	–2.6%	–0.4%	2.6%	–2.8%	0.2%*
LSETLG	0.1%*	–2.8%	–0.6%	2.5%	–2.9%	0.0%*
SFACD	0.5%	–2.5%	–0.4%	3.1%	–2.8%	0.6%
SFATLG	0.7%	–2.4%	–0.3%	3.1%	–2.8%	0.5%
Average	0.4%	–2.6%	–0.4%	2.8%	–2.8%	0.3%

Note: * Not significantly different from zero.

Estimated trends in Opex PFP for *Australian* DNSPs are:

- In the LSECD and LSETLG models, the coefficient on *yr_1* is not statistically significant in the long period and is negative and significant in the short period.[2]

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[2] Unless otherwise stated, statistical significance refers to the 0.05 level of significance (ie, 95 per cent confidence).

Insignificance of the coefficient on *yr_1* in the long sample period means that the average rate of change over that period is so close to zero that we cannot reject that Australian DNSPs' Opex PFP did not change, on average, over the long period. However, in the short period from 2012 to 2023, Opex PFP is estimated to have increased at an average annual rate of 2.6 per cent in the LSECD model and 2.5 per cent in the LSETLG model.

- In the SFACD and SFATLG models, the coefficient on *yr_1* is negative and statistically significant in both periods. The estimated average annual rate of change in Opex PFP for Australian DNSPs over the long period is 0.5 per cent in the SFACD model and 0.7 per cent in the SFATLG model. In the short period, the rate of increase in Opex PFP is much higher, averaging 3.1 per cent per annum in both the SFACD and SFA TLG models.

Averaged across the four econometric models, the average annual rate of change in Opex PFP for Australian DNSPs over the long period is 0.4 per cent. In the short period, it is 2.8 per cent. On average, the Opex PFP of Australian DNSPs has been improving over the full period, but most strongly from 2012 to 2023. These results can be compared to the productivity index analysis in Quantonomics (2024), where the Opex PFP index is available separately for Australian DNSPs. The JTT model Opex PFP trend for Australian DNSPs is consistent with the index-based Opex PFP trend for the Australian DNSP industry, which is estimated to increase by 0.3 per cent per annum in the period 2006 to 2023, and 2.5 per cent per annum over the period 2012 to 2023 (Quantonomics 2024, 15).

Estimated trends in *New Zealand* DNSPs' Opex PFP are:

- In all four models the coefficient on *yr_2* is positive and statistically significant in both the long and short periods, implying a decreasing trend in Opex PFP which appears to be consistent between the long and short periods.
- In the LSECD and LSETLG models, the average annual rate of change in Opex PFP over the long period is –2.6 per cent and –2.8 per cent respectively. Over the short period, that average annual rate of change is –2.8 per cent and –2.9 per cent respectively.
- In the SFACD and SFATLG models, the average annual rate of change in Opex PFP over the long period is –2.5 per cent and is –2.4 per cent respectively. Over the short period it is –2.8 per cent in both models.

Over the long period, the estimated average annual rate of change in Opex PFP for NZ DNSPs, when averaged across the four econometric models, is –2.6 per cent. In the short period, the average annual rate of change in Opex PFP is –2.9 per cent.

The rate of decline in Opex PFP of New Zealand DNSPs estimated by the JTT models over the longer period (ie, 2006 to 2023) is larger than those recently estimated by Cambridge

Economic Policy Associates (CEPA 2024) for the New Zealand electricity distribution industry from 2008 to 2023. CEPA's estimated Opex PFP time trend using index analysis was –1.4 per cent per annum (averaged over various output specifications). Using econometric analysis, the estimated Opex PFP time trends were between –1.2 and –2.2 per cent per year for various output specifications. The JTT model estimates of the rate of decline in Opex PFP of New Zealand DNSPs over the shorter sample period (ie, 2012 to 2023) are similar to CEPA's estimate of –2.1 per cent per annum for the New Zealand electricity distribution industry from 2014 to 2023 (using index analysis and averaged over various output specifications). Differences from the CEPA results are to be expected because that study uses a larger number of DNSPs than are used in our sample, which excludes the smaller New Zealand DNSPs.[3] Further, CEPA uses a range of output specifications and calculates average rates of change over different periods.

Estimated trends in Opex PFP for *Ontario* DNSPs are:

- In the LSECD and LSETLG models, the coefficient on *yr_3* is positive and statistically significant in the long period, but is not statistically significant in the short period. This indicates that the average rate of change over the short period is close to zero. In the SFACD and SFATLG models, the coefficients on *yr_3* have different signs in the long and short periods, both statistically significant. They indicate that although there was an overall decline in Opex PFP over the long period, this decline was concentrated in the first half of that period, and it improved in the second half.
- In the LSECD and LSETLG models the average annual rate of change in Opex PFP for Ontario DNSPs over the long period is –0.4 per cent and –0.6 per cent respectively. In the period after 2012, it was 0.2 per cent and 0.0 per cent respectively.
- In the SFACD and SFATLG models, the average annual rate of change in Opex PFP in the long period is –0.4 per cent and –0.3 per cent respectively. In the short period, the average rate of change in Opex PFP is 0.6 per cent and 0.5 per cent respectively.

On average over all four models, the Ontario DNSPs' average annual rate of increase in Opex PFP is –0.4 per cent for the long period, and 0.3 per cent for the short period. As previously noted, although an up-to-date study is not available, PEG has previously found that there was no growth in Ontario electricity Opex PFP between 2002 and 2011 (PEG 2013, 63,65).

2.1.2 Comparison & statistical significance of separate trends

Table 2.2 shows the estimated rates of Opex PFP change obtained from the standard opex cost function models, which are constrained to be uniform across the three jurisdictions (Quantonomics 2024, 144–51). These estimates are approximately equal to the weighted average of the rates of Opex PFP changes for the three jurisdictions in the corresponding

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[3] There are 29 New Zealand DNSPs included in the Commerce Commission's disclosure data, of which 19 are used in the AER benchmarking analysis.

models in Table 2.1.[4] The weighted average long-period rate of Opex PFP change across three jurisdictions and four models from Table 2.1 is –0.9 per cent. The weighted average short-period rate of Opex PFP change across three jurisdictions and three models (excluding SFATLG) from Table 2.1 is –0.2 per cent. These can be compared to the bottom row of Table 2.2.

Table 2.2 Estimated Rates of Change in Opex PFP: Standard Models

	Long–period	*Short period*
LSECD	–1.0%	–0.3%*
LSETLG	–1.2%	–0.6%
SFACD	–1.0%	–0.2%*
SFATLG	–1.0%	NA
Average	–1.1%	–0.4%

Note: * Not significantly different from zero.

In the standard models, Table 2.2 shows that the coefficient on the time trend variable is significantly different from zero in five of the seven models successfully estimated. In the JTT models, the hypothesis that the coefficients on the three jurisdictional time trend effects are all equal to zero is rejected in all eight models.[5]

It remains to test whether the standard model is a valid approximation to the more flexible JTT model. The standard model with a single time trend is equivalent to constraining the coefficients on the three jurisdictional time trend variables to be equal. The validity of this restriction can be tested.

In the LSECD, LSETLG, SFACD and SFATLG models, in both the long and short periods, the Wald test for the null hypothesis that the coefficients on the jurisdiction time trend variables (*yr_1*, *yr_2*, and *yr_3*) are equal to each other consistently yields a p-value of 0.000. Since this is below the 0.05 significance level, the null hypothesis is rejected in every model. This suggests that the coefficients of the jurisdiction time trend variables are not statistically equal to each other, indicating significant differences in trends between the jurisdictions. This is consistent with findings reported by Frontier Economics (2023, 82).

2.2 Output Elasticities, Weights & Monotonicity

2.2.1 Output elasticities

Table 2.3 shows the elasticities of opex with respect to each output. On average across the four econometric models, the customer numbers output has the highest elasticity in both the long and short periods, followed by circuit length and RMD. The relative sizes of the output

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[4] The weights being based on the number of DNSPs in the sample from each jurisdiction, namely 13 from Australia, 19 from New Zealand and 29 from Ontario.

[5] The hypothesis was tested using a Wald test.

elasticities in the JTT models differ from the standard models. In the long-period JTT models, the average elasticity of the customer numbers output is 0.61; for the circuit length output it is 0.19; and for RMD, 0.15. For comparison, in the standard long-period models, the average elasticity of the customer numbers output is 0.37; for the circuit length output it is 0.19; and for RMD, 0.39 (Quantonomics 2024, 39). In short, RMD has a smaller weight and customer numbers has a larger weight compared to the standard models.

Table 2.3 shows the short-period JTT SFACD model does not satisfy the monotonicity requirement because the RMD output elasticity is negative, although it is not statistically significantly different from zero. In the SFATLG models for both the long and short periods, the RMD output elasticity is positive (although not significantly different from zero). We have calculated the average weights for the short period with and without the SFACD estimates.

Table 2.3 JTT Models: Output Cost Elasticities

	Long Period (2006-2023)				*Short Period (2012-2023)*			
	Cust.	*Circuit Length*	*RMD*	*Total*	*Cust.*	*Circuit Length*	*RMD*	*Total*
LSECD	0.615	0.219	0.132	0.966	0.588	0.252	0.128	0.968
LSETLG								
- AUS	0.455	0.268	0.291*	1.015	0.392*	0.298	0.310*	1.000
- NZ	0.707	0.252	–0.027*	0.931	0.665	0.318	–0.054*	0.929
- Ontario	0.341	0.172	0.431	0.943	0.310	0.189	0.455	0.955
*- Average***	0.479	0.217	0.258	0.955	0.438	0.252	0.266	0.956
SFACD	0.629	0.183	0.143	0.955	0.721	0.268	–0.049*	0.940
SFATLG								
- AUS	0.754	0.222	0.067*	1.042	0.674	0.289	–0.029*	0.935
- NZ	0.575	0.241	0.120*	0.936	0.701	0.405	–0.156*	0.951
- Ontario	0.774	0.069*	0.062*	0.906	0.520	0.052*	0.354	0.926
*- Average***	0.708	0.155	0.081*	0.944	0.610	0.213	0.113*	0.936
Average 4 models	0.608	0.194	0.154	0.955	0.589	0.246	0.115	0.950
*Average of 3 models****					0.545	0.239	0.170	0.954

Note: * Not significantly different from zero. ** Evaluated at the sample mean. *** Excludes the SFACD model.

The sum of the elasticities of cost with respect to all outputs (or 'total output elasticity'), is also called the elasticity of scale (Coelli et al. 2005, 274). If it is less than one, then opex increases less than proportionately with total output, and there are economies of scale. With constant returns to scale, the scale elasticity equals one.[6]

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[6] More accurately, what is being measured here is the economies of expansion. Energy networks are recognised as having economies of scale, which means that when more energy is delivered through a fixed network, average cost per unit of energy delivered will decrease. However, increases in demand can also be associated with an extension of the energy network, or changes in customer density on parts of the network, requiring reinforcement etc, and there are not necessarily economies of expansion (Torres and Morrison Paul 2006). The actual relationship between average costs and scale will depend on the balance of spatial extension and demand density aspects of output expansion.

Table 2.3 also shows the elasticities of opex with respect to total output. Similar to previously established results from standard models, the total output elasticities are close to 1, which suggests near-constant returns to scale.

To evaluate the stability of the total output elasticities in the JTT models compared to the standard model, the standard deviation of the total output elasticities values across the four models are calculated for both JTT and standard models in long and short periods. The standard deviation is used to measure the extent to which the values deviate from their mean. A higher standard deviation indicates greater variability in the total output elasticities across the four models, while a lower standard deviation suggests more consistency in the total output elasticity estimates.

The results indicate that, for the long period, the standard deviation of the total output cost elasticities is 0.9 per cent in the JTT models and 1.7 per cent in the standard models, suggesting that there is more consistency in the total output elasticity estimates of the JTT models compared to the standard models. For the short period, the JTT models show a standard deviation of 1.4 per cent, while the standard models have 0.8 per cent, suggesting that the JTT models produce less consistent estimates of the total output elasticity. Overall, the findings are mixed, with low variability of total output elasticities in both the JTT and standard models.

2.2.2 Monotonicity violations

As explained in the introduction, there is a concern that the standard Translog models have had worsening monotonicity performance. This section considers whether the monotonicity performance of the JTT Translog models represents an improvement over the standard Translog models. As already mentioned in section 2.2.1, the SFACD model in the short period presents monotonicity violations due the negative value of the RMD output.

The established practice in accounting for monotonicity violations (MVs) in the annual benchmarking analysis is to predict each output elasticity at each observation, and if any of the predicted output elasticities are negative, then there is an MV at that observation. By contrast, Lau (1978, 446) suggests that the hypothesis of monotonicity can be tested by using a one-tailed statistical test of the null hypothesis that each output elasticity is greater than zero. If the null hypothesis is rejected for any output, then the model does not satisfy monotonicity. Although Lau suggests that this test is carried out at the sample mean, we apply the test at each observation to determine whether there is a statistically significant monotonicity violation (SMV) at that observation. We then calculate the frequency of SMVs. These are reported alongside the frequency of MVs.

Tables 2.4 and 2.5 present the frequencies of MVs and SMVs for the JTT Translog models in both the long period. Tables 2.6 and 2.7 present the corresponding information for the short-period JTT Translog models. Figure 2.1 compares the frequency of MVs in the JTT Translog models with those from the standard models. The main points to note are:

- There is a substantial reduction in the frequency of MVs in the JTT models compared to the standard models.
- In the long sample LSETLG model, the frequency of MVs decreased from 22.2 per cent in the standard version to 7.7 per cent in the JTT version for Australian DNSPs, and from 21.9 per cent to 19.6 per cent for the total sample. In the long sample SFATLG model, MVs decreased from 79.5 per cent in the standard version to 28.6 per cent in the JTT version for Australian DNSPs, and from 45.5 per cent to 15.9 per cent for the total sample. In the short sample LSETLG model, MVs decreased from 48.7 per cent in the standard version to 3.2 per cent in the JTT version for Australian DNSPs, and from 36.6 per cent to 18.9 per cent for the total sample.[7]
- Using the AER's criteria for excluding efficiency scores, in the long sample JTT LSETLG model, only one DNSP (ESS) is excluded due to excessive MVs, compared to three (AGD, CIT, and UED) excluded in the standard LSETLG model. In the long sample JTT SFATLG model, four DNSPs (AGD, CIT, JEN and UED) are excluded from the sample mean efficiency due to excessive MVs, compared to all DNSPs being excluded in the standard SFATLG model. In the short sample JTT LSETLG model, no DNSPs' efficiency scores are excluded due to excessive MVs, while in the standard LSETLG model, six (AGD, CIT, END, ENX, JEN and UED) are excluded. In the short sample JTT SFATLG model, the efficiency scores of six DNSPs (ERG, ESS, PCR SAP, AND and TND) are excluded, whereas the standard SFATLG model could not be calculated.
- In summary, the number of Australian DNSPs that have an efficiency score excluded when calculating the average efficiency score across models is considerably reduced.
- The only JTT model that has any SMVs for Australian DNSPs is the short-period SFATLG model.

2.3 Consistency with Expected Parameter Estimates

The estimated parameters must align with economic theory. Accordingly, it is expected that the main coefficients on all outputs (Customer Numbers, Circuit Length, and RMD) are non-negative, thereby satisfying the monotonicity criterion.[8] This aspect was addressed in Section 2.2. Additionally, the OEF variable, Underground Cable Share, is anticipated to negatively impact opex implying a negative coefficient.[9] This outcome was observed in all models, except in the SFACD and SFATLG models for the short period, where the variable was positive, although statistically not different from zero.

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[7] Since the standard SFATLG did not converge in the short sample, a comparison cannot be made with the short sample JTT SFATLG model.

[8] Since the output data is centred at the mean values of the output variables, in the Translog results, the coefficients on the main variables are equal to the elasticities of cost to the outputs evaluated at the sample mean.

[9] Underground cables require more capital but less maintenance than overhead lines.

Table 2.4 LSETLG Model: Frequency of Monotonicity Violations (%) - Long Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.00	0.00	7.69	7.69	0.00	0.00	0.00	0.00
NZ	0.00	0.00	57.60	57.60	0.00	0.00	7.60	7.60
Ontario	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	19.58	19.58	0.00	0.00	2.37	2.37
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- JEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- TND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.5 SFATLG Model: Frequency of Monotonicity Violations (%) - Long Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.00	0.00	28.63	28.63	0.00	0.00	0.00	0.00
NZ	0.00	0.00	5.56	5.56	0.00	0.00	0.00	0.00
Ontario	0.00	12.26	8.05	17.05	0.00	0.00	0.00	0.00
Total	0.00	5.83	11.66	15.94	0.00	0.00	0.00	0.00
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	66.67	66.67	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- JEN	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	5.56	5.56	0.00	0.00	0.00	0.00
- TND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00

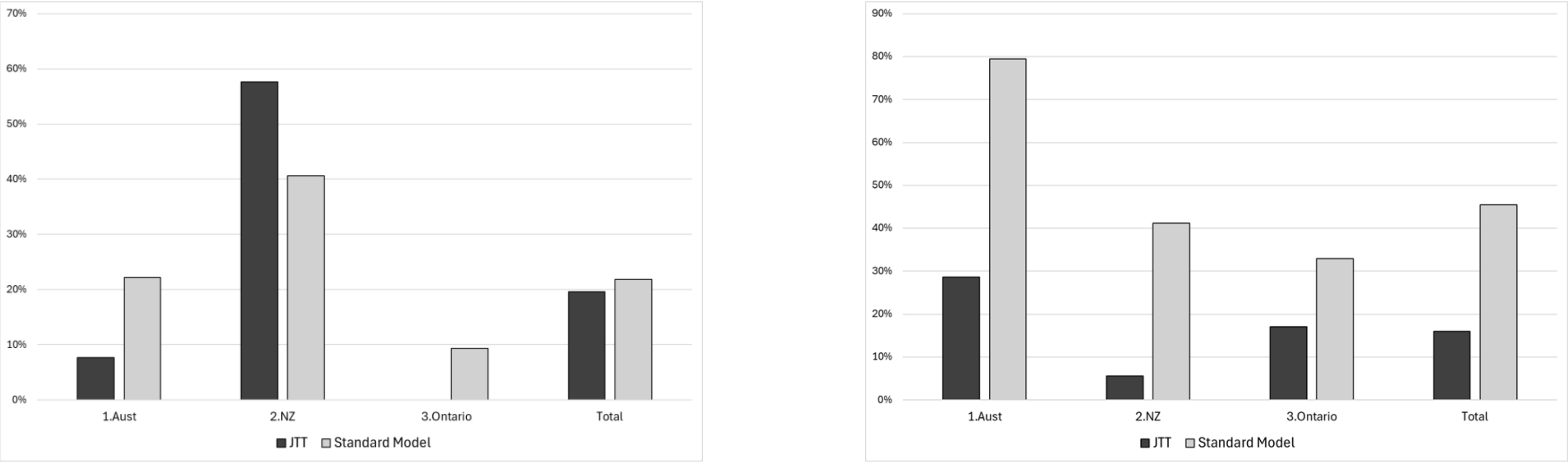
Table 2.6 LSETLG Model: Frequency of Monotonicity Violations (%) - Short Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.00	0.00	3.21	3.21	0.00	0.00	0.00	0.00
NZ	0.00	0.00	58.33	58.33	0.00	0.00	16.23	16.23
Ontario	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	18.85	18.85	0.00	0.00	5.05	5.05
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	41.67	41.67	0.00	0.00	0.00	0.00
- JEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- TND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.7 SFATLG Model: Frequency of Monotonicity Violations (%) - Short Period

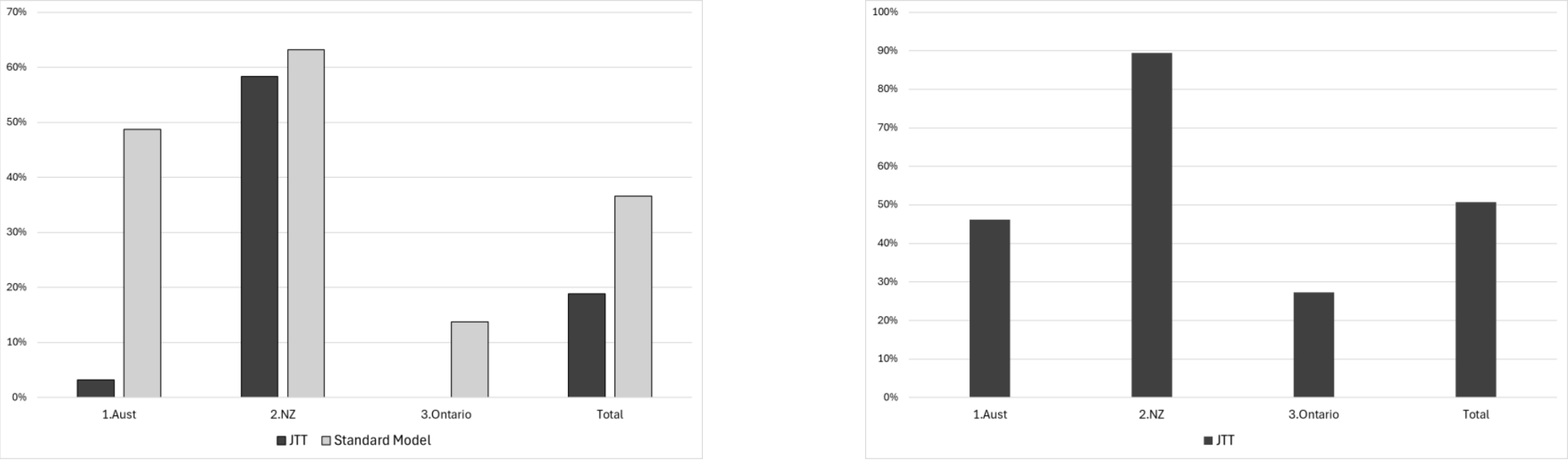
	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.00	0.00	46.15	46.15	0.00	0.00	7.69	7.69
NZ	0.00	0.00	89.47	89.47	0.00	0.00	14.91	14.91
Ontario	0.00	23.85	3.45	27.30	0.00	0.00	0.00	0.00
Total	0.00	11.34	39.34	50.68	0.00	0.00	6.28	6.28
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	100.00	100.00	0.00	0.00	100.00	100.00
- JEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- TND	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 2.1 Frequency of Monotonicity Violations (MVs), JTT Compared to Standard Models



LSETLG Long Period

SFATLG Long Period



LSETLG Short Period

SFATLG Short Period

2.4 Convergence & Reliability of SFATLG Models

2.4.1 Long-period

The standard SFATLG models raised problematic estimation issues in both the short and long periods. In the long period, the standard SFATLG model produced anomalous efficiency scores for some DNSPs and understated efficiency on average. In contrast, the long-period JTT SFATLG model produces sensible efficiency scores. This comparison is shown in Table 2.8.

The *standard* SFATLG long-period model produces many anomalies in efficiency scores, as can be seen by comparing them against the average of the four other efficiency score estimates from the other three standard opex models and the index-based Opex multilateral PFP results. For example, the *standard* SFATLG efficiency score for AGD is 53 per cent below the four-model average; for END it is 33 per cent below the comparator; for ENX it is 40 per cent below, and for ERG it is 35 per cent higher. The correlation coefficient between the *standard* SFATLG efficiency scores and the average efficiency scores of the four other standard models is only 0.70. In contrast, the correlation coefficients between the other four estimates and the four-model average are all between 0.92 and 0.98.

Table 2.8 Australian DNSP average opex efficiency scores, long period (2006-2023)

	Standard Models			*JTT Models*		
	SFATLG	*Average - Other Models**	*Diff. (%)*	*SFATLG*	*Average - Other Models**	*Diff. (%)*
EVO	0.549	0.504	8.8%	0.480	0.494	–2.9%
AGD	0.265	0.562	–52.8%	0.611	0.563	8.5%
CIT	0.707	0.783	–9.7%	0.816	0.753	8.3%
END	0.458	0.684	–33.1%	0.655	0.667	–1.9%
ENX	0.405	0.680	–40.4%	0.717	0.684	4.9%
ERG	0.784	0.583	34.5%	0.612	0.553	10.6%
ESS	0.761	0.668	13.9%	0.709	0.665	6.6%
JEN	0.743	0.653	13.8%	0.756	0.663	14.1%
PCR	0.965	0.976	–1.1%	0.962	0.978	–1.6%
SAP	0.908	0.968	–6.2%	0.969	0.963	0.6%
AND	0.738	0.769	–4.0%	0.788	0.789	–0.1%
TND	0.976	0.844	15.7%	0.745	0.815	–8.5%
UED	0.749	0.843	–11.2%	0.972	0.859	13.2%
Average	0.693	0.732	–5.3%	0.753	0.727	3.7%

Note: * Includes SFACD, LSECD, LDETLG and Opex MPFP.

This problem does not arise with the JTT SFATLG long-period model. Table 2.9 shows that it does not produce large anomalies in efficiency scores. The correlation coefficient between the JTT SFATLG efficiency scores and the average efficiency scores of the four other models is 0.94. This is similar to the correlation coefficients between the other four estimates and the four-model average for the JTT models, which are between 0.94 and 0.99.

This improvement is related to the following observations about parameters of the distribution of inefficiency:

- In the JTT SFATLG long-period model, the variance of inefficiency (*sigma_u2* = 0.072) is not greatly higher than that for the JTT SFACD long-period model (*sigma_u2* = 0.052). The standard SFATLG long-period model has a much higher inefficiency variance (*sigma_u2* = 6.611).
- The parameters *lnsigma2,* and *lgtgamma* imply that, in the long period, about 84.4 per cent of the total variance in the composite error is due to inefficiency, with the remainder due to random noise. This contrasts with the standard SFATLG, where 99.8 per cent of the total variance is due to inefficiency.
- The *mu* parameter, which normally represents the mode of the distribution of inefficiencies,[10] is positive but not statistically significant in the JTT SFATLG model in both the long and short periods. However, the standard SFATLG model has a very large negative *mu* (–18.544). The expected value is equal to or greater than zero.[11]

2.4.2 Short period

In the short period, the standard SFATLG model did not successfully converge. However, the JTT SFATLG model successfully converges in the short period. This is a considerable improvement.

The short-period JTT SFATLG model also mainly produces typical average inefficiency levels, although it is not fully reliable in this respect. Table 2.9 compares the efficiency scores of the short-period JTT SFATLG against the average of the four other efficiency score estimates from the other three JTT opex models and the index-based Opex multilateral PFP results over the short period. The SFATLG model produces a large anomaly for CIT, 30 per cent above the average of the other estimates. The correlation coefficient between the short-period JTT SFATLG efficiency scores and the average efficiency scores of the four other models is 0.89. This is below the correlation coefficients between the other four estimates and the four-model average for the JTT models, which are between 0.95 and 0.99. These observations suggest the short-period JTT SFATLG model is not fully reliable.

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[10] Technically, it is equal to the mean of the truncated-normal distribution before truncation.

[11] A μ value equal to zero will imply a bunching of businesses close to the full efficiency frontier. If $\mu > 0$ there will be a bunching of businesses at an efficiency level that is less than fully efficient. In both these cases, the frequency of firms decreases at lower levels of efficiency. In contrast, a large negative μ implies a near-uniform distribution of efficiency scores over the range of feasible values from 0 to 1.

Table 2.9 Australian DNSP average opex efficiency scores, short period (2012-2023)

	JTT Models		
	SFATLG	*Average - Other Models**	*Diff. (%)*
EVO	0.595	0.515	15.6%
AGD	0.635	0.609	4.3%
CIT	0.940	0.725	29.7%
END	0.716	0.707	1.2%
ENX	0.709	0.697	1.7%
ERG	0.580	0.613	–5.4%
ESS	0.780	0.713	9.4%
JEN	0.733	0.644	13.8%
PCR	0.975	0.990	–1.5%
SAP	0.970	0.946	2.6%
AND	0.823	0.775	6.2%
TND	0.823	0.840	–2.0%
UED	0.957	0.876	9.3%
Average	0.787	0.742	6.1%

Note: * Includes SFACD, LSECD, LDETLG and Opex MPFP.

2.5 Goodness of Fit

Table 2.10 presents goodness-of-fit statistics for the JTT models in comparison to the corresponding standard models. The Pseudo-adjusted-R² statistic is used here to provide a common basis for comparing the goodness of fit for panel-corrected LSE and SFA models.[12] It penalises less parsimonious models by adjusting for degrees of freedom.[13] The results indicate that including jurisdictional time trend variables improves the goodness of fit across all models and periods compared to the standard models.

Table 2.10 Pseudo-adjusted-R^2

	Jurisdictional Time Trend Models		*Standard Models*	
	Long Period	*Short Period*	*Long Period*	*Short Period*
LSECD	0.9805	0.9836	0.9787	0.9805
LSETLG	0.9832	0.9870	0.9813	0.9842
SFACD	0.9927	0.9960	0.9910	0.9930
SFATLG	0.9927	0.9961	0.9917	NA
Average	0.9873	0.9889*	0.9857	0.9859*

Notes: * Average over three models (excluding SFATLG).

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[12] The pseudo–adjusted R^2 statistic is defined here as: $adj.R^2 = 1 - (1 - r^2)\,(N - 1)/(N - k)$, where r is the correlation coefficient between the actual and predicted values of the dependent variable; N is the number of observations; and k is the number of parameters in the model (including the intercept).

[13] However, Greene questions whether this penalty on increasing model size is sufficient to ensure the $\bar{R}^2$ "criterion will necessarily lead the analyst to the correct model (assuming it is among the ones considered) as the sample size increases" (Greene 2012, 179).

Goodness-of-fit is an important diagnostic for model selection (Greene 2012, 179–80). These results indicate that the JTT models consistently improve on the standard models allowing for the loss of degrees of freedom due to including more explanatory variables.

2.6 Efficiency scores

2.6.1 Long Period

Table 2.11 and Figure 2.2 present the efficiency scores for the four models in the long period. The averages are calculated using only the DNSPs that do not exhibit excessive monotonicity violations. Figure 2.3 compares the JTT long period efficiency scores with those of the standard model.

The averages of efficiency scores indicate that:

- PCR (0.984) and SAP (0.956) have the highest average efficiency scores.
- UED (0.901), AND (0.819), TND (0.807) and CIT (0.770) also had an efficiency score above the average.
- Several DNSPs are below average but not the lowest in terms of opex efficiency. These include JEN (0.697), ENX (0.696), ESS (0.668) and END (0.664).
- The three DNSPs with lowest opex efficiency are EVO (0.492), AGD (0.574) and ERG (0.562).
- The overall average efficiency scores are similar between models. The average efficiency scores for each model are: LSECD (0.750), LSETLG (0.723) SFACD (0.745) and SFATLG (0.737).

As noted in section 2.3.1, incorporating jurisdiction-specific time trends addresses the unusually low efficiency scores observed for AGD, END, and ENX in the standard SFATLG model. As a result, the efficiency scores from the JTT SFATLG model align more closely with the other three models for the long period, as also observed in Figure 2.3.[14]

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[14] The standard deviations of the log differences in JTT efficiency scores compared to the standard model efficiency scores in the long period are 1.2 per cent for LSECD, 5.4 per cent for LSETLG, 5.8 per cent for SFACD, and 31.8 per cent for SFATLG.

Table 2.11 JTT Models: Efficiency Scores -Long Period (2006-2023)

	LSECD		*LSETLG*		*SFACD*		*SFATLG*		*AVERAGE*	
	Eff	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*
EVO	0.503	13	0.469	13	0.515	13	0.480	13	0.492	13
AGD	0.576	11	0.572	11	0.575	11	0.611*	12	0.574	11
CIT	0.766	6	0.734	6	0.811	6	0.816*	4	0.770	6
END	0.666	10	0.671	9	0.665	9	0.655	10	0.664	10
ENX	0.691	8	0.683	8	0.692	8	0.717	8	0.696	8
ERG	0.553	12	0.554	12	0.530	12	0.612	11	0.562	12
ESS	0.677	9	0.722*	7	0.619	10	0.709	9	0.668	9
JEN	0.728	7	0.611	10	0.751	7	0.756*	6	0.697	7
PCR	1.000	1	1.000	1	0.973	1	0.962	3	0.984	1
SAP	0.955	2	0.963	2	0.935	3	0.969	2	0.956	2
AND	0.856	4	0.817	3	0.814	5	0.788	5	0.819	4
TND	0.845	5	0.802	5	0.837	4	0.745	7	0.807	5
UED	0.935	3	0.804	4	0.964	2	0.972*	1	0.901	3
AVG	0.750		0.723		0.745		0.737		0.738	

*Notes: Excluded from the average due excessive monotonicity violations

Figure 2.2 JTT Model Efficiency Scores (Exc. MV) -Long Period (2006-2023)

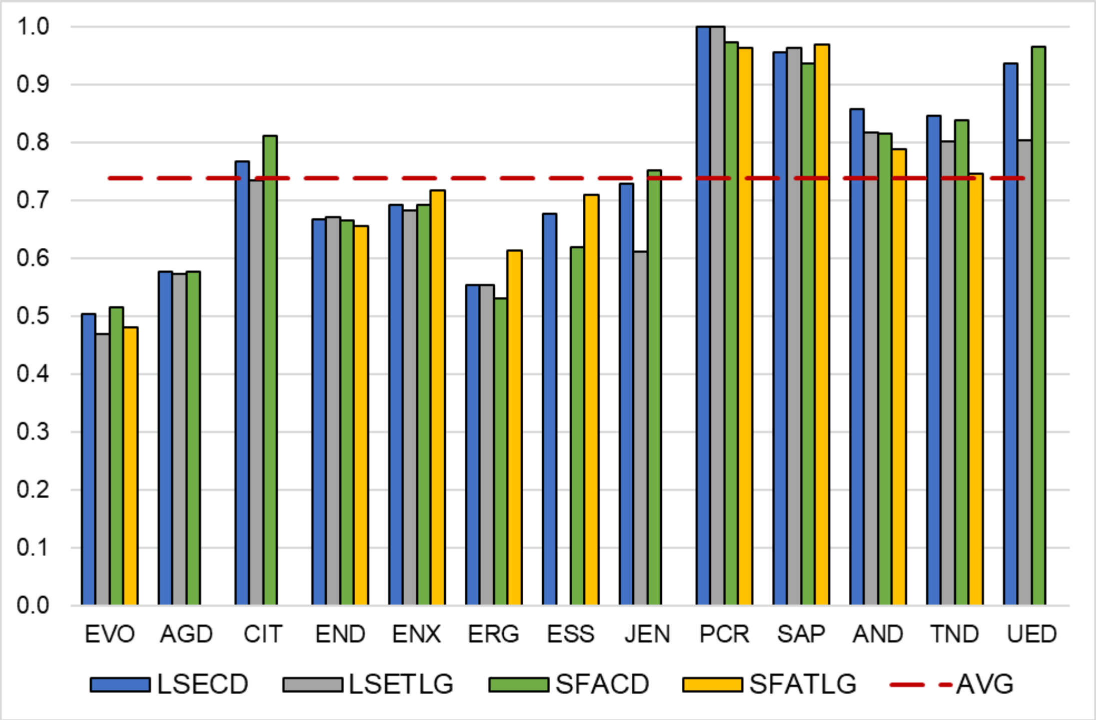
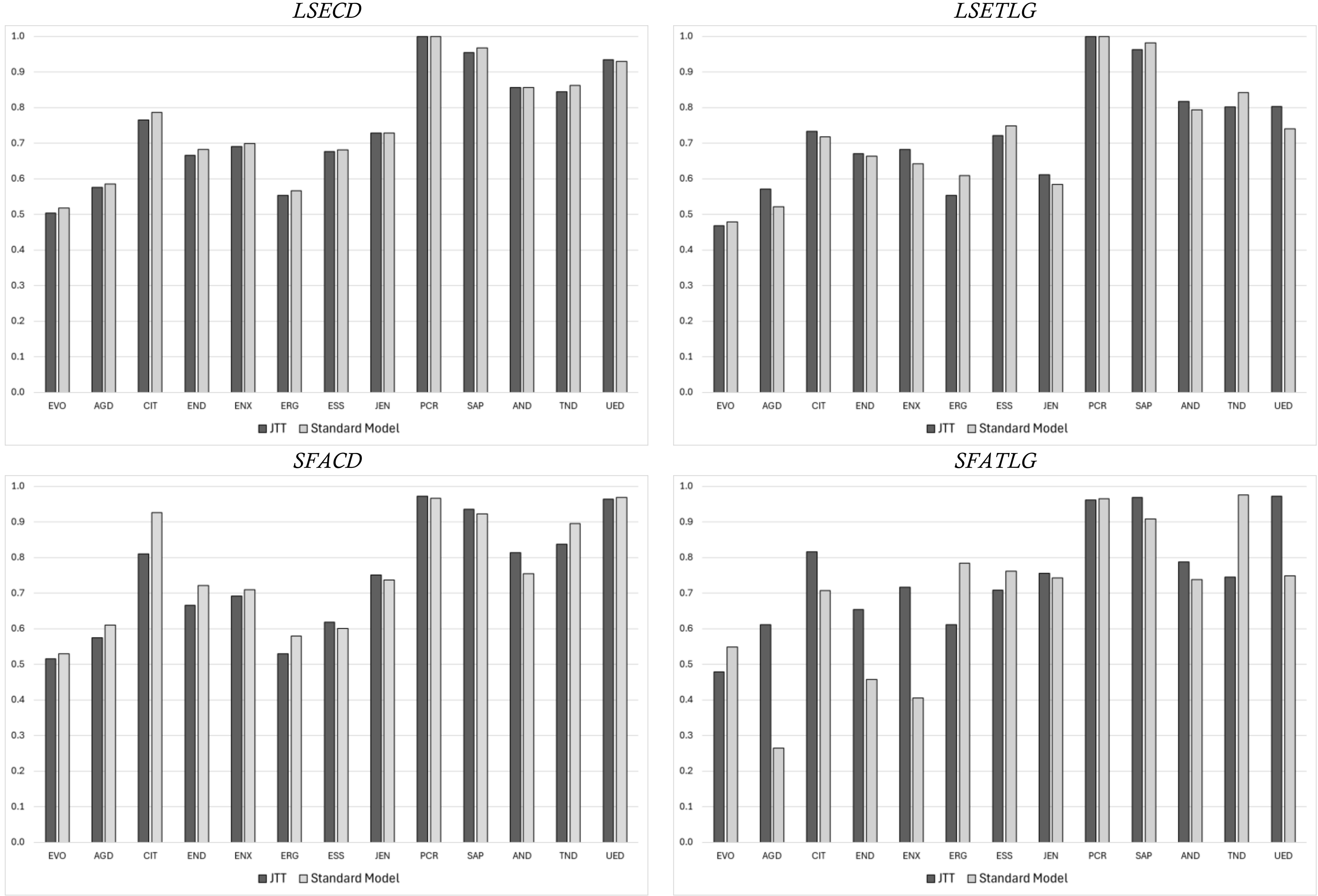


Figure 2.3 Efficiency Scores Comparison - Long Period (2006-2023)



LSECD

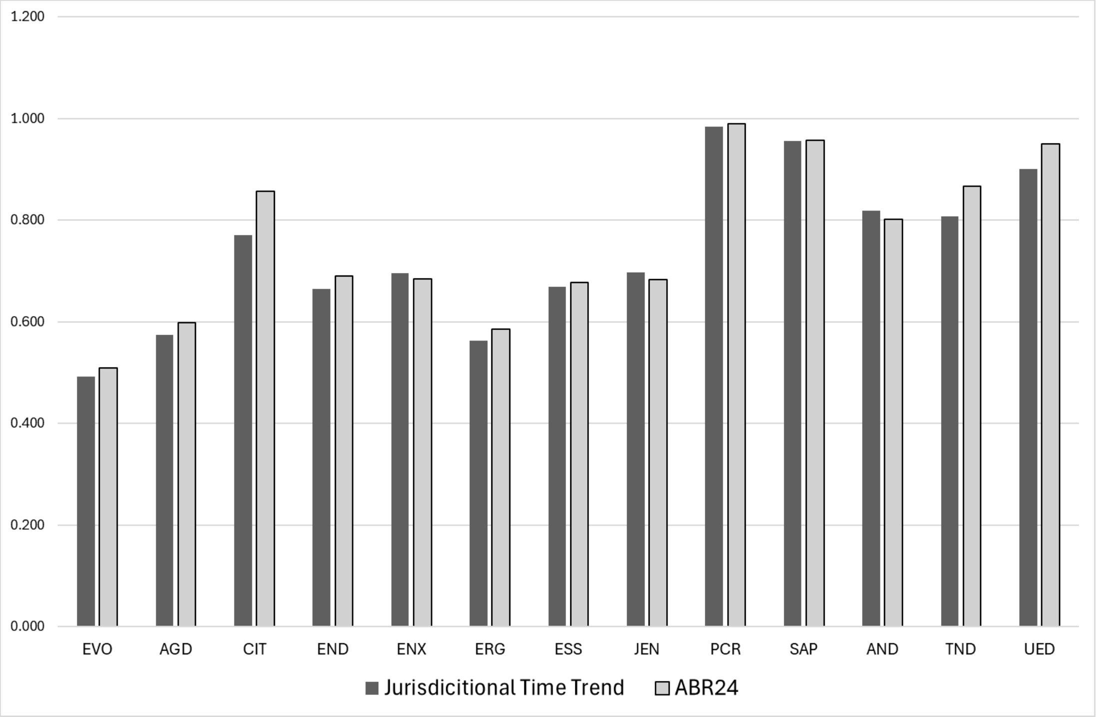
LSETLG

SFACD

SFATLG

Figure 2.4 compares the average efficiency scores of the JTT models with those of the standard models, excluding the DNSPs' efficiency scores with excessive monotonicity violations.

Figure 2.4 Average of Efficiency Scores (Exc. MV) - Long Period (2006-2023)



Note: The standard deviation of the log difference between the JTT and standard model efficiency scores is 3.8 per cent.

The effects of using the JTT models instead of the standard models on the average econometric efficiency scores in the long period are:

- DNSPs experiencing an increase in the average efficiency scores include AND (from 0.801 to 0.819, a 2.2 per cent increase), JEN (from 0.683 to 0.697, a 2.0 per cent increase), and ENX (from 0.684 to 0.696, a 1.8 per cent increase).
- DNSPs experiencing a *decrease* in average efficiency scores include CIT (from 0.857 to 0.770, a 10.1 per cent *decrease*), TND (from 0.867 to 0.807, a 6.9 per cent *decrease*), UED (from 0.950 to 0.901, a 5.1 per cent *decrease*), AGD (from 0.598 to 0.574, a 3.9 per cent *decrease*), ERG (from 0.585 to 0.562, a 3.9 per cent *decrease*), END (from 0.690 to 0.664, a 3.7 per cent *decrease*), EVO (from 0.509 to 0.492, a 3.4 per cent *decrease*), ESS (from 0.677 to 0.668, a 1.3 per cent *decrease*).
- The DNSPs with negligible differences in average efficiency scores include PCR (from 0.989 to 0.984, a 0.5 per cent *decrease*) and SAP (from 0.957 to 0.956, a 0.1 per cent *decrease*).

- In the ranking of average efficiency scores, END falls from 7th to 10th, CIT from 5th to 6th, and TND from 4th to 5th. ESS would rise from 10th to 9th, JEN and AND from 9th to 7th and 6th to 4th, respectively. The other DNSPs retain their ranking positions.

2.6.2 Short Period

Table 2.12 and Figure 2.5 present the efficiency scores for the four models in the short period. The averages are calculated using only the DNSPs' efficiency scores that do not exhibit excessive monotonicity violations, with the SFACD model being excluded from the average calculation due to excessive monotonicity violations.

Table 2.12 JTT Models: Efficiency Scores -Short Period (2012-2023)

	LSECD		*LSETLG*		*SFACD**		*SFATLG*		*AVERAGE*	
	Eff	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*
EVO	0.489	13	0.476	13	0.559	12	0.595	12	0.520	13
AGD	0.593	12	0.599	11	0.622	11	0.635	11	0.609	12
CIT	0.698	6	0.717	7	0.759	6	0.940	4	0.785	6
END	0.675	8	0.695	8	0.707	9	0.716	9	0.695	8
ENX	0.673	9	0.672	9	0.716	8	0.709	10	0.685	9
ERG	0.601	11	0.634	10	0.549	13	0.580*	13	0.618	11
ESS	0.696	7	0.761	6	0.659	10	0.780*	7	0.729	7
JEN	0.665	10	0.590	12	0.736	7	0.733	8	0.663	10
PCR	1.000	1	1.000	1	0.967	1	0.975*	1	1.000	1
SAP	0.908	3	0.929	2	0.945	3	0.970*	2	0.919	2
AND	0.804	5	0.771	5	0.827	5	0.823*	6	0.788	5
TND	0.845	4	0.824	3	0.844	4	0.823*	5	0.835	4
UED	0.910	2	0.820	4	0.961	2	0.957	3	0.896	3
AVG	0.735		0.730		0.758		0.755		0.749	

Notes: *Excluded from the average due to excessive monotonicity violations

The averages of efficiency scores indicate that:

- PCR (1.000) and SAP (0.919) have the highest average efficiency scores .
- UED (0.896), TND (0.835), AND (0.788) and CIT (0.785) also had an efficiency score above the average.
- Several DNSPs are below average but not the lowest in terms of opex efficiency. These include ESS (0.729), END (0.695), ENX (0.685) and JEN (0.663).
- The three DNSPs with lowest opex efficiency are EVO (0.520), AGD (0.609) and ERG (0.618).

Figure 2.5 JTT Model Efficiency Scores (Exc. MV) -Short Period (2012-2023)

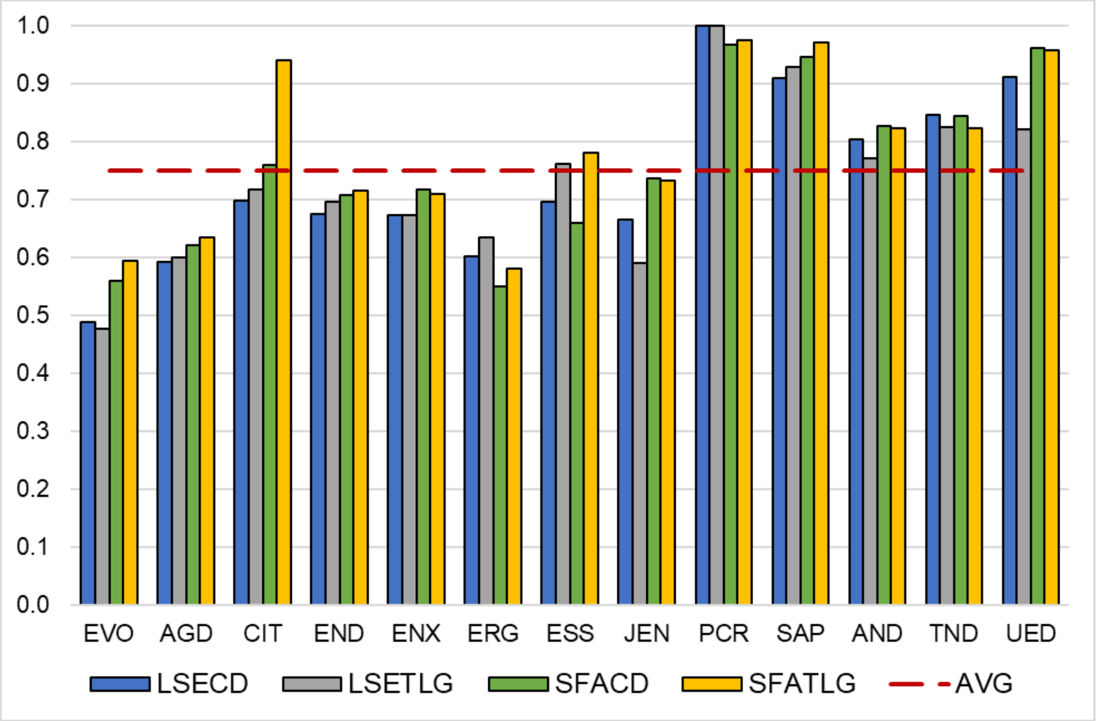


Figure 2.5 indicates that, overall, the efficiency scores are generally comparable across the models, with a few notable exceptions:

- The average efficiency score for EVO in the LSECD and LSETLG models is 0.482. In the SFACD and SFATLG models, the average is 0.577, 19.6 per cent of difference.
- The CIT efficiency score in the SFATLG model is 0.940, which is 29.8 per cent higher than the average score across the LSECD, LSETLG and SFACD models (0.724).
- The ESS efficiency score in the LSETLG model is 0.761, 12.2 per cent higher than the average score for the LSECD and SFACD models (0.678).
- The average efficiency score for JEN in the SFACD and SFATLG models is 0.734. In the LSECD model, it is 0.665, which is 9.4 per cent lower the SFA models, and in the LSETLG model, it is also 0.590, which is 19.7 per cent lower than in the SFA models.
- The UED efficiency score in the LSETLG model is 0.820, which is 13.1 per cent lower than the average efficiency score across the LSECD, LSETLG and SFACD models (0.943).

Figure 2.6 compares the efficiency scores of the JTT model with those of the standard model in the short period. The figure indicates that the models are closely aligned, particularly the LSECD model.[15]

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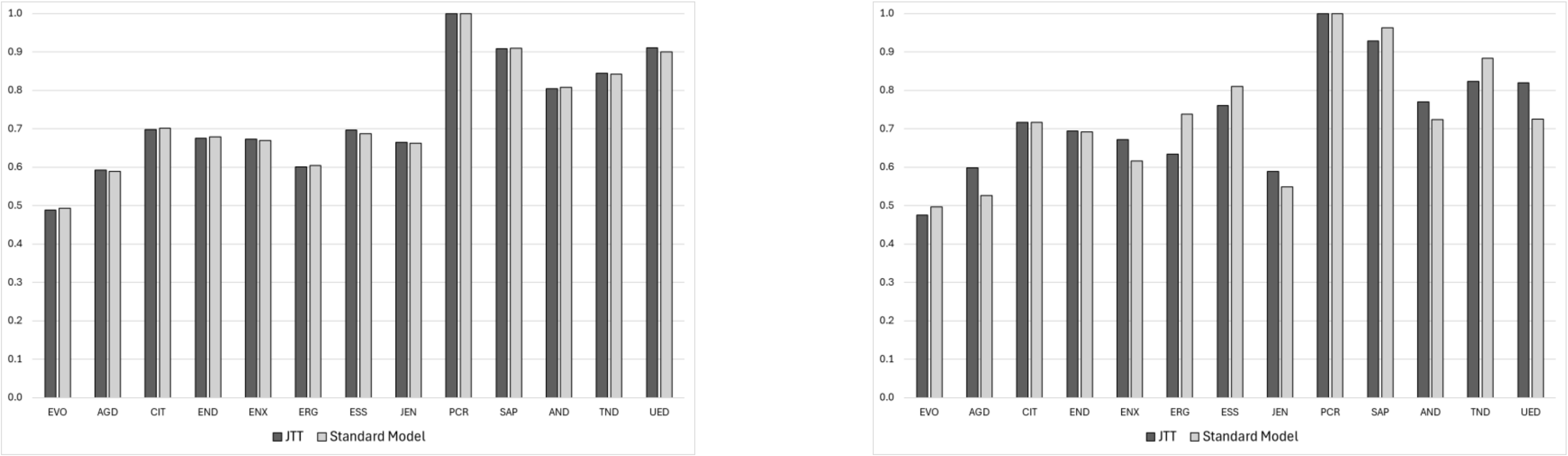
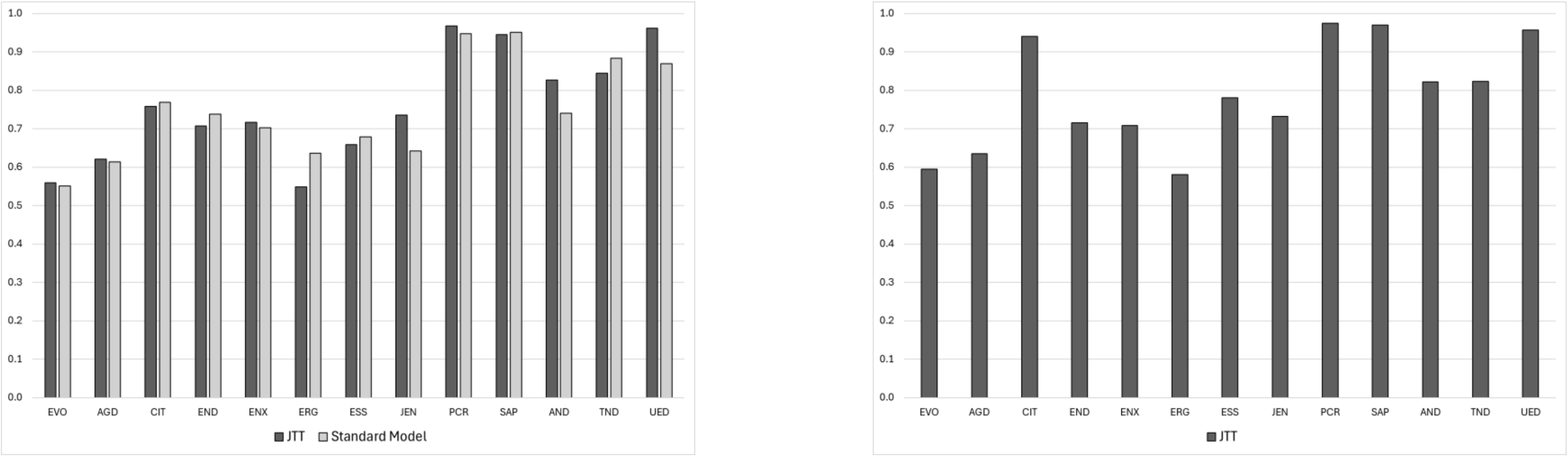
[15] The standard deviations of the log differences in JTT efficiency scores compared to the standard model efficiency scores in the short period are 0.7 per cent for LSECD, 8.3 per cent for LSETLG and 7.5 per cent for SFACD.

Figure 2.6 Efficiency Scores Comparison - Short Period (2012-2023)



LSECD

LSETLG

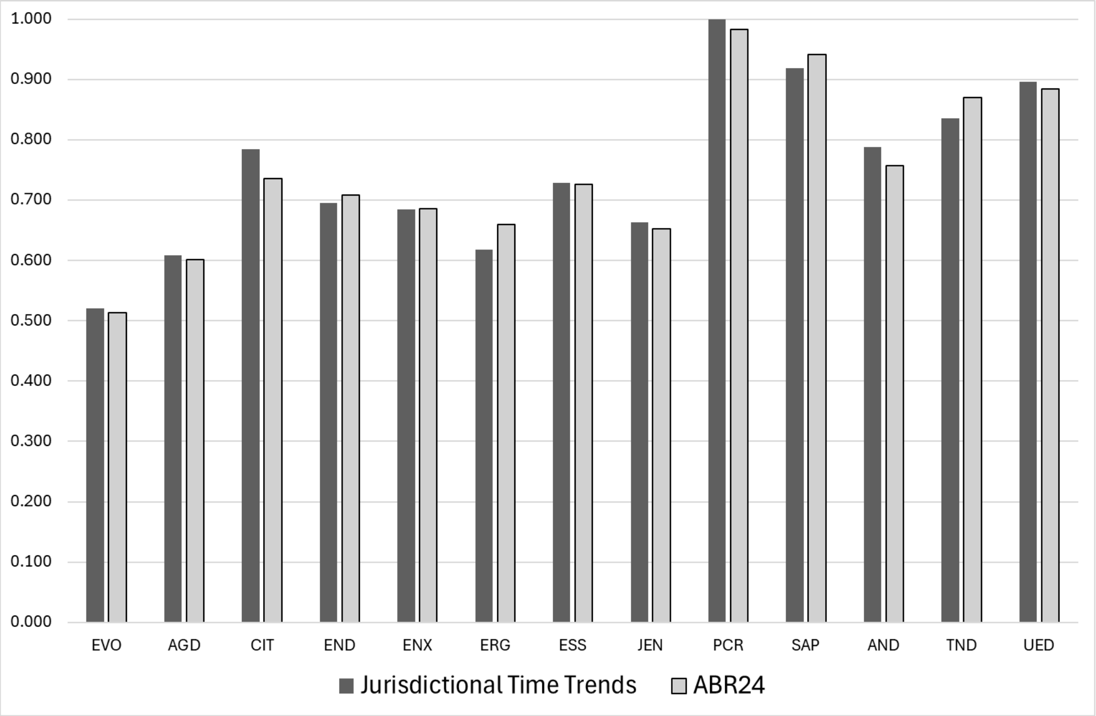


SFACD

SFATLG

Figure 2.7 contrasts the average efficiency scores of the JTT models with those of the standard models, excluding models with excessive monotonicity violations

Figure 2.7 Average of Efficiency Scores (Exc. MV) - Short Period (2012-2023)



Notes: The standard deviation of the log difference between the JTT and standard model efficiency scores is 3.2 per cent.

The effect of using the JTT models instead of the standard models on the average econometric efficiency scores in the short period is as follows:

- DNSPs experiencing an increase in average efficiency scores include CIT (from 0.736 to 0.785, a 6.7 per cent increase), AND (from 0.757 to 0.788, a 4.1 per cent increase), PCR (from 0.982 to 1.000, a 1.8 per cent increase), JEN (from 0.652 to 0.663, a 1.7 per cent increase), UED (from 0.885 to 0.896, a 1.3 per cent increase), AGD (from 0.601 to 0.609, a 1.3 per cent increase) and EVO (from 0.514 to 0.520, a 1.2 per cent increase).
- DNSPs experiencing a *decrease* in average efficiency scores include ERG (from 0.660 to 0.618, a 6.3 per cent *decrease*), TND (from 0.870 to 0.835, a 4.0 per cent *decrease*), SAP (from 0.942 to 0.919, a 2.4 per cent *decrease*) and END (from 0.708 to 0.695, a 1.9 per cent *decrease*).
- DNSPs with negligible changes in average efficiency scores include and ENX (from 0.686 to 0.685, a 0.2 per cent *decrease*) and ESS (from 0.726 to 0.729, a 0.4 per cent *decrease*).

- In the ranking of average efficiency scores, ERG falls from 10th to 11th and JEN rises from 11th to 10th. The rankings for other DNSPs remain unchanged.

2.7 Concluding Comments

The results of the analysis indicate that the JTT models outperform the standard models across several key metrics. First, estimation results show that the hypothesis that the jurisdictional time trend variables are equal to each other (a constraint imposed in the standard model) is consistently rejected, as established using a Wald test. The values of the jurisdictional trends in Opex PFP align well with trends previously identified in results of Törnqvist Opex PFP indexes for Australian DNSPs in ABR 2024 and some of the recent New Zealand productivity results. Second, the SFATLG model in the long period produces more robust inefficiency parameters compared to standard model and the efficiency scores are more reasonable, indicating that the previously identified issues with this model are resolved. Third, the convergence of the SFATLG model in the short period highlights a key improvement over the standard model, which does not converge. Fourth, the JTT models display higher Pseudo-Adjusted-R^2 values than the corresponding standard models, indicating a better fit. And fifth, the JTT models produce much fewer monotonicity violations than the corresponding standard models.

On the other hand, the JTT SFACD model in the short period presented a poor performance, failing to meet the monotonicity requirement due to the negative coefficient on the log of RMD (although not statistically significantly different from zero). This is an important shortcoming. In addition, the coefficient on the share of undergrounding in the SFACD and SFATLG short period models is of the unexpected sign (positive).

These findings suggest that jurisdictional time trend variables are likely omitted variables. An alternative method of incorporating divergent time trends between Australian and overseas DNSPs is examined in chapter 3, with a view to addressing the issue highlighted with the JTT SFACD model in the short period.

3 Australian Time Trend

This section presents a simpler version of the JTT model in which the time trends for New Zealand and Ontario are restricted to be the same. The rationale for this variation is that since we are only benchmarking Australian DNSPs, estimating the distinct trends in Opex PFP in New Zealand and Ontario has no practical purpose, and a model which estimates an average trend for both jurisdictions may be sufficient.

Appendix A, Tables A2.1 to A2.4, presents the econometric results for the Australian Time Trend (ATT) models, including the LSECD, LSETLG, SFACD, and SFATLG versions. These models incorporate separate Australian time trends for long and short periods.

3.1 Interpreting Time Trends

3.1.1 Opex PFP Trends

Table 3.1 provides a summary of the estimated jurisdictional rates of change in Opex PFP across the four model specifications and two sample periods. In this specification, *yr* captures the time trend for both New Zealand and Ontario. Unlike the JTT model, the time trend for Australia is equal to the *total* of the coefficients in *yr* and *yr_1*. Negative values indicate an improvement in Opex, whereas positive values indicate a decline in Opex PFP.

Table 3.1 Estimated Rates of Change in Opex PFP: ATT Models

	Long period		*Short period*	
	Aust.	*NZ & Ontario*	*Aust.*	*NZ & Ontario*
LSECD	0.1%	–1.3%	2.5%	–1.1%
LSETLG	0.1%	–1.5%	2.6%	–1.2%
SFACD	0.3%	–1.3%	2.6%	–1.2%
SFATLG	0.4%	–1.3%	3.2%	–1.2%
Average	0.2%	–1.4%	2.7%	–1.2%

The variables *yr* and *yr_1* are significant in all models for both the long and short periods. Estimated trends in Opex PFP for *Australian* DNSPs are:

- In the LSECD and LSETLG models, productivity improvement is minimal, at only 0.1 per cent per year. However, from 2012 to 2023, Opex PFP is estimated to have increased at an average annual rate of 2.5 per cent in the LSECD model and 2.6 per cent in the LSETLG model.
- In the SFACD and SFATLG models, the estimated average annual growth rate of Opex PFP for Australian DNSPs over the long period is 0.3 per cent in the SFACD model and 0.4 per cent in the SFATLG model. For the short period, however, the growth rate of Opex PFP is substantially higher, averaging 2.6 per cent per year in the SFACD model and 3.2 per cent per year in the SFATLG model.

Across the four econometric models, the average annual rate of change in Opex PFP for Australian DNSPs over the long period is 0.2 per cent, compared to 2.7 per cent over the short period. Overall, Opex PFP for Australian DNSPs has shown improvement over the full period, with the strongest gains occurring from 2012 to 2023. These results are closely aligned with those found in the JTT specification.

Estimated trends in Opex PFP for *New Zealand* and *Ontario* DNSPs are:

- In the LSECD and LSETLG models, the average annual rate of change in Opex PFP over the long period is –1.3 per cent and –1.5 per cent, respectively. For the short period, the average annual rate of change is –1.1 per cent in the LSECD model and –1.2 per cent in the LSETLG model.

- In the SFACD and SFATLG models, the average annual rate of change in Opex PFP over the long period is –1.3 per cent in both models, while in the short period it is –1.2 per cent in both models.

Over the long period, the estimated average annual rate of change in Opex PFP for NZ and Ontario DNSPs, when averaged across the four econometric models, is –1.4 per cent. In the short period, the average annual rate of change in Opex PFP is –1.2 per cent.

To compare the annual rates of change in Opex PFP for New Zealand and Ontario with those from the JTT models, we calculate the weighted average of coefficients of *yr_2* and *yr_3* in the JTT specifications, which is –1.3 in the long period and –0.9 in the short period. On average in the long period, the ATT models indicate a similar decrease in annual rates of change in Opex PFP for New Zealand and Ontario compared to the JTT models. In the short period, the rate of decline in the Opex PFP of the overseas DNSPs in the ATT models is slightly larger.

3.1.2 Comparison & statistical significance of separate trends

Using data from Table 2.1 in Section 2.1.1, the JTT models show a weighted average Opex PFP change of –0.9 per cent for the long period and –0.1 per cent for the short period across three jurisdictions. The ATT models report similar figures, with –1.1 per cent for the long period and –0.1 per cent for the short period. These results are not very different from those found in the standard models, which show –1.1 per cent for the long period and –0.4 per cent for the short period. It should be noted, however, that the short period result does not include the SFATLG model.

The ATT model assumes that the NZ and Ontario time trends are equal. The validity of this restriction can be tested. In the LSECD, LSETLG, SFACD and SFATLG models, in both the long and short periods, the Wald test for the null hypothesis—stating that the NZ and Ontario time trend coefficients (yr_2 and yr_3) are equal—consistently yields a p-value of 0.000. Since this is below the 0.05 significance threshold, the null hypothesis is rejected for all models. This result indicates that the more restrictive specification of the time trends in the ATT models compared to the JTT models does not capture the distinct time-trend effects of the overseas DNSPs as the JTT model does. This is a drawback of the ATT model compared to the JTT model.

In the ATT models, the hypothesis that the coefficients for *yr* and *yr_1* are all zero is rejected across all eight models. Additionally, the test for whether these coefficients are statistically equal, suggesting no difference in time trends between Australia and other jurisdictions, is also rejected in all models. This confirms that the coefficients for *yr* and *yr_1* are not statistically equal, indicating significant differences in trends of Opex PFP between Australia and overseas jurisdictions. [16]

3.2 Output Elasticities, Weights & Monotonicity

3.2.1 Output elasticities

Table 3.2 shows the elasticities of opex with respect to each individual output. On average across the four models, in the long period, the customer numbers variable exhibits the highest elasticity followed by RMD and circuit length. In the short period, RMD exhibits the highest elasticity followed by circuit length and customer numbers. This contrasts with the JTT models, where the customer numbers variable shows the highest elasticity in both the long and short periods, followed by circuit length and RMD.

Table 3.2 ATT Models: Individual Output Cost Elasticities

	Long Period (2006-2023)				*Short Period (2012-2023)*			
	Cust.	*Circuit Length*	*RMD*	*Total*	*Cust.*	*Circuit Length*	*RMD*	*Total*
LSECD	0.540	0.230	0.194	0.964	0.554	0.265	0.148	0.967
LSETLG								
- AUS	0.389*	0.287	0.338	1.014	0.464	0.304	0.241*	1.010
- NZ	0.676	0.236	0.027*	0.938	0.677	0.317	–0.059*	0.935
- Ontario	0.195*	0.204	0.538	0.937	0.209*	0.216	0.525	0.950
*- Average***	0.386	0.231	0.336	0.954	0.409	0.266	0.283	0.958
SFACD	0.327	0.156	0.484	0.966	0.347	0.337	0.266	0.950
SFATLG								
- AUS	0.553	0.214	0.152*	0.919	0.637	0.462	–0.166*	0.932
- NZ	0.436	0.143*	0.486	1.064	0.746	0.413	–0.109*	1.050
- Ontario	0.145*	0.093*	0.686	0.924	–0.490	0.348	1.075	0.934
*- Average***	0.323	0.134	0.510	0.967	0.135*	0.392	0.442	0.970
Average 4 models	0.394	0.188	0.381	0.963	0.361	0.315	0.285	0.961

Note: * Not significantly different from zero. ** Evaluated at the sample mean.

Unlike the short-period JTT SFACD model, Table 3.2 shows that the short-period ATT SFACD model satisfies the monotonicity requirement, as the RMD output elasticity, alongside with the other outputs, are positive. The ATT total-output elasticities are similar to those of the JTT models for the LSE specifications. However, there are notable differences in the SFA models. In the long period, the total output elasticity in the ATT SFACD is 18.6 per cent lower than in the JTT model, whereas in the short period, the total output elasticity in the ATT SFATLG model is 3.6 per cent higher than in the JTT model.

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[16] The hypothesis was tested using Wald test.

3.2.2 Monotonicity violations

Tables 3.3 and 3.6 present the frequency of MVs and SMVs for the ATT Translog models in both the long and short periods. Figure 3.1 compares the frequency of MVs in the ATT Translog models with those from the JTT models.

The results, when compared to the standard and JTT models in the long sample, show that:

- In the long sample LSETLG model, the frequency of MVs decreased from 22.2 per cent in the standard version to 7.7 per cent in the JTT and further to 3.4 per cent in the ATT for Australian DNSPs. For the total sample, MVs declined from 21.9 per cent in the standard version to 19.6 per cent in the JTT and to 17.2 per cent in the ATT. In the short sample LSETLG model, MVs decreased from 48.7 per cent in the standard version to 3.2 per cent in the JTT version and to 10.9 per cent in the ATT version for Australian DNSPs. For the total sample, MVs reduced from 36.6 per cent in the standard version to 18.9 per cent in the JTT and to 24.7 per cent in the ATT.
- Using the AER's criteria for excluding efficiency scores, in the long sample ATT LSETLG model, no DNSPs are excluded due to excessive MVs. In contrast, in the JTT LSETLG model only one DNSP (ESS) is excluded, while the standard version excludes three DNSPs (AGD, CIT, and UED). In the short sample ATT LSETLG model, only one DNSP (ESS) is excluded due to MVs, while the JTT version does not exclude any DNSPs. In contrast, the standard version excludes six DNSPs (AGD, CIT, END, ENX, JEN, and UED).
- In the long sample SFATLG model, MVs decreased from 79.5 per cent in the standard version to 28.6 per cent in the JTT and to 30.3 per cent in the ATT for Australian DNSPs. For the total sample, MVs decreased from 45.5 per cent in the standard version to 15.9 per cent in the JTT and to 20.5 per cent in the ATT. In the short sample SFATLG model, MVs are 46.2 per cent in the JTT version and 75.6 per cent in the ATT for Australian DNSPs. For the total sample, MVs are 50.7 per cent in the JTT version and 82.8 per cent in the ATT. This model does not converge in the standard.
- For the long sample SFATLG model, the ATT version excludes four DNSPs (AGD, JEN, AND, and UED) due to excessive MVs. Similarly, the JTT version excludes four DNSPs (AGD, CIT, JEN, and UED) from the sample mean efficiency due to excessive MVs, whereas the standard version excludes all DNSPs. version. In the short sample SFATLG model, the ATT version excludes 10 DNSPs due to MVs, and since the majority are excluded, all are to be excluded. For comparison, the JTT version excludes the efficiency scores of six DNSPs (ERG, ESS, PCR, SAP, AND, and TND) due to MVs.

Overall, the ATT models show an improvement in reducing MVs compared to the standard models in both the LSETLG and SFATLG specifications. However, compared to the JTT models, the ATT shows a reduction in MVs only for the LSETLG long period model.

Table 3.3 ATT LSETLG Model: Frequency of Monotonicity Violations (%) - Long Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.00	0.00	3.42	3.42	0.00	0.00	0.00	0.00
NZ	0.00	0.00	42.40	42.40	0.00	0.00	0.29	0.29
Ontario	6.90	0.00	0.00	6.90	0.00	0.00	0.00	0.00
Total	3.28	0.00	13.93	17.21	0.00	0.00	0.09	0.09
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	44.44	44.44	0.00	0.00	0.00	0.00
- JEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- TND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.4 ATT SFATLG Model: Frequency of Monotonicity Violations (%) - Long Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.85	0.00	29.49	30.34	0.00	0.00	0.00	0.00
NZ	9.94	0.00	0.29	10.23	0.00	0.00	0.00	0.00
Ontario	22.41	0.38	0.00	22.80	0.00	0.00	0.00	0.00
Total	13.93	0.18	6.38	20.49	0.00	0.00	0.00	0.00
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	72.22	72.22	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	44.44	44.44	0.00	0.00	0.00	0.00
- ERG	11.11	0.00	0.00	11.11	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- JEN	0.00	0.00	66.67	66.67	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	11.11	11.11	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	88.89	88.89	0.00	0.00	0.00	0.00
- TND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00

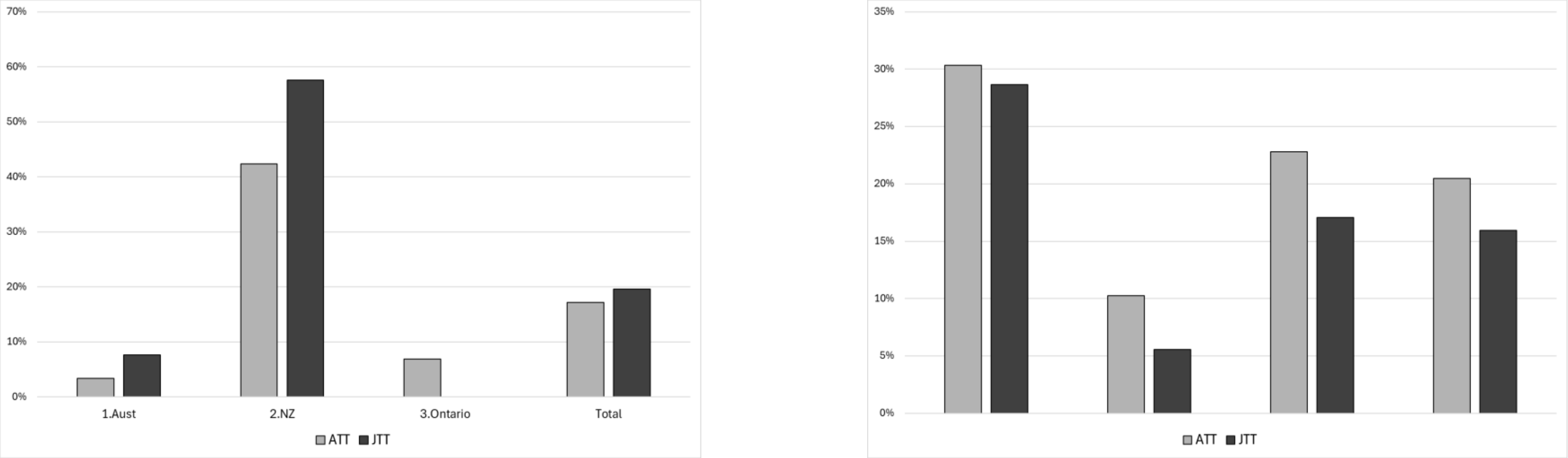
Table 3.5 ATT LSETLG Model: Frequency of Monotonicity Violations (%) - Short Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.00	0.00	10.90	10.90	0.00	0.00	0.00	0.00
NZ	0.00	0.00	61.40	61.40	0.00	0.00	15.79	15.79
Ontario	6.90	0.00	0.00	6.90	0.00	0.00	0.00	0.00
Total	3.28	0.00	21.45	24.73	0.00	0.00	4.92	4.92
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- JEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	8.33	8.33	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	33.33	33.33	0.00	0.00	0.00	0.00
- TND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.6 ATT SFATLG Model: Frequency of Monotonicity Violations (%) - Short Period

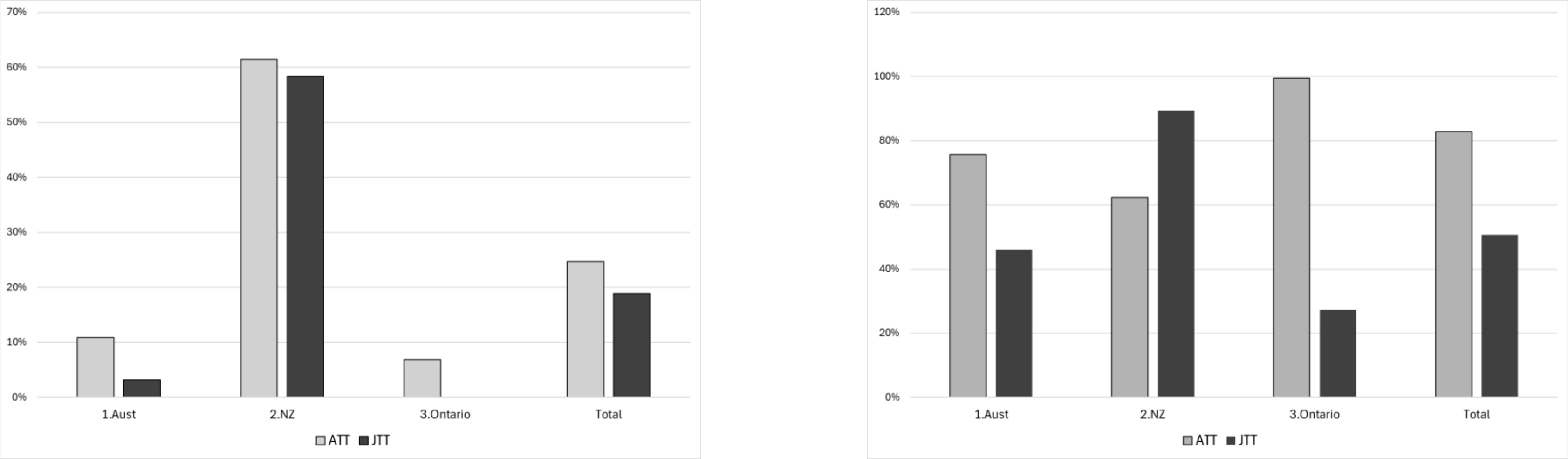
	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	8.33	0.00	67.31	75.64	0.00	0.00	26.92	26.92
NZ	0.00	0.00	62.28	62.28	0.00	0.00	16.67	16.67
Ontario	96.55	0.00	2.87	99.43	56.03	0.00	0.00	56.03
Total	47.68	0.00	35.11	82.79	26.64	0.00	10.93	37.57
Aust:								
- EVO	8.33	0.00	0.00	8.33	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	58.33	58.33	0.00	0.00	0.00	0.00
- CIT	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	8.33	8.33	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	100.00	100.00	0.00	0.00	100.00	100.00
- JEN	0.00	0.00	66.67	66.67	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	100.00	100.00	0.00	0.00	100.00	100.00
- SAP	0.00	0.00	100.00	100.00	0.00	0.00	50.00	50.00
- AND	0.00	0.00	100.00	100.00	0.00	0.00	100.00	100.00
- TND	0.00	0.00	41.67	41.67	0.00	0.00	0.00	0.00
- UED	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00

Figure 3.1 Frequency of Monotonicity Violations



LSETLG Long Period

SFATLG Long Period



LSETLG Short Period

SFATLG Short Period

3.3 Consistency with Expected Parameter Estimates

The main coefficients on all outputs are non-negative and statistically significant, with the exception of the short period SFATLG model where Customer numbers is positive but not statistically significant. The underground cable share variable is negative, as expected, in most models except the SFACD and SFATLG models in the short period, where it has a positive coefficient, although not statistically significant. These results are broadly consistent with the JTT specification.

3.4 Convergence & Reliability of SFATLG Models

The ATT SFATLG long period model demonstrates consistency in efficiency scores, mirroring the performance of the JTT model with no significant anomalies detected. Notably, the correlation between the ATT SFATLG efficiency scores and the average efficiency of the four other models is 0.92. This correlation is comparable to the range of 0.94 to 0.98 observed between the other ATT models and the four-model average.

In the short period analysis, the ATT SFATLG model, similar to the JTT model, shows convergence and represents an improvement over the standard model. However, the deviation between the average of the other models and the ATT SFATLG efficiency scores in the short period is greater than in the long period. Despite this, the correlation between the ATT SFATLG short period efficiency scores and the four-model average remains at 0.92, identical to the long period correlation.

Table 3.7 Australian DNSP average opex efficiency scores - ATT Model

	Long Period			*Short Period*		
	SFATLG	*Average – Other Models**	*Diff. (%)*	*SFATLG*	*Average – Other Models**	*Diff. (%)*
EVO	0.532	0.505	5.3%	0.490	0.517	–5.2%
AGD	0.510	0.574	–11.1%	0.475	0.607	–21.7%
CIT	0.872	0.778	12.1%	0.610	0.717	–14.9%
END	0.631	0.690	–8.6%	0.615	0.716	–14.1%
ENX	0.638	0.694	–8.1%	0.604	0.698	–13.5%
ERG	0.611	0.569	7.4%	0.505	0.619	–18.4%
ESS	0.675	0.662	2.0%	0.703	0.705	–0.3%
JEN	0.787	0.655	20.2%	0.530	0.620	–14.5%
PCR	0.972	0.976	–0.4%	0.953	0.976	–2.4%
SAP	0.948	0.973	–2.6%	0.938	0.952	–1.5%
AND	0.818	0.778	5.1%	0.839	0.760	10.4%
TND	0.854	0.835	2.3%	0.760	0.837	–9.2%
UED	0.968	0.852	13.6%	0.693	0.845	–18.0%
Average	0.755	0.734	2.9%	0.670	0.736	–9.0%

Note: * Includes SFACD, LSECD, LDETLG and Opex MPFP.

Overall, the average difference in the long period is 2.9 per cent, indicating a slight overestimation of efficiency by the ATT SFATLG model compared to the other models. In contrast, the short period average difference is –9.0 per cent, demonstrating a tendency for higher negative deviations in the short-period analysis.

3.5 Goodness of Fit

Table 3.8 provides a comparative overview of the goodness-of-fit statistics for the ATT models against their corresponding JTT models, measured by Pseudo-adjusted-R^2 statistics.

Table 3.8 Pseudo-adjusted-R^2

	Australia Time Trend Models		*Jurisdictional Time Trend Models*	
	Long Period	*Short Period*	*Long Period*	*Short Period*
LSECD	0.9793	0.9821	0.9805	0.9836
LSETLG	0.9820	0.9855	0.9832	0.9870
SFACD	0.9917	0.9946	0.9927	0.9960
SFATLG	0.9920	0.9952	0.9927	0.9961
Average	0.9863	0.9894	0.9873	0.9907

When comparing the ATT models against the JTT models, it is evident that both groups exhibit high levels of goodness-of-fit. The JTT models display marginally higher average pseudo-adjusted-R^2 values in both the long and short periods, with averages of 0.9873 and 0.9907 respectively, compared to 0.9863 and 0.9894 for the ATT models in the long and short periods. This suggests that the JTT models may provide a marginally better fit.

3.6 Efficiency scores

3.6.1 Long Period

Table 3.9 and Figure 3.2 present the efficiency scores for the four models in the long period.

The average efficiency scores show that:

- The average opex efficiency score is 0.749 for the long sample, which is higher than the 0.738 observed in the JTT models.
- PCR (0.985) and SAP (0.960) have the highest average efficiency scores, consistent with the JTT results.
- The three DNSPs with the lowest opex efficiency are EVO (0.516), ERG (0.578), and AGD (0.589), similar to the findings in the JTT models.

As observed in the JTT models, the inclusion of Australia-specific time trend also addresses the unusually low efficiency scores for AGD, END, and ENX seen in the standard SFATLG model. Consequently, the efficiency scores from the ATT SFATLG model align more closely with the patterns observed in the other three models for the long period compared to the standard SFATLG model.

Table 3.9 ATT Models: Efficiency Scores -Long Period (2006-2023)

	LSECD		*LSETLG*		*SFACD*		*SFATLG*		*AVERAGE*	
	Eff	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*
EVO	0.522	13	0.471	13	0.539	13	0.532	12	0.516	13
AGD	0.588	11	0.562	11	0.617	10	0.510*	13	0.589	11
CIT	0.787	6	0.714	7	0.909	4	0.872	4	0.821	5
END	0.687	9	0.676	9	0.729	8	0.631	10	0.681	9
ENX	0.703	8	0.680	8	0.724	9	0.638	9	0.686	8
ERG	0.568	12	0.559	12	0.574	12	0.611	11	0.578	12
ESS	0.683	10	0.718	6	0.605	11	0.675	8	0.670	10
JEN	0.729	7	0.594	10	0.737	7	0.787*	7	0.687	7
PCR	1.000	1	1.000	1	0.967	1	0.972	1	0.985	1
SAP	0.974	2	0.972	2	0.947	3	0.948	3	0.960	2
AND	0.858	5	0.819	3	0.767	6	0.818*	6	0.815	6
TND	0.865	4	0.812	4	0.887	5	0.854	5	0.855	4
UED	0.931	3	0.778	5	0.966	2	0.968*	2	0.892	3
AVG	0.761		0.720		0.767		0.748		0.749	

*Notes: Excluded from the average due excessive monotonicity violations

Figure 3.2 ATT Model Efficiency Scores (Exc. MV) -Long Period (2006-2023)

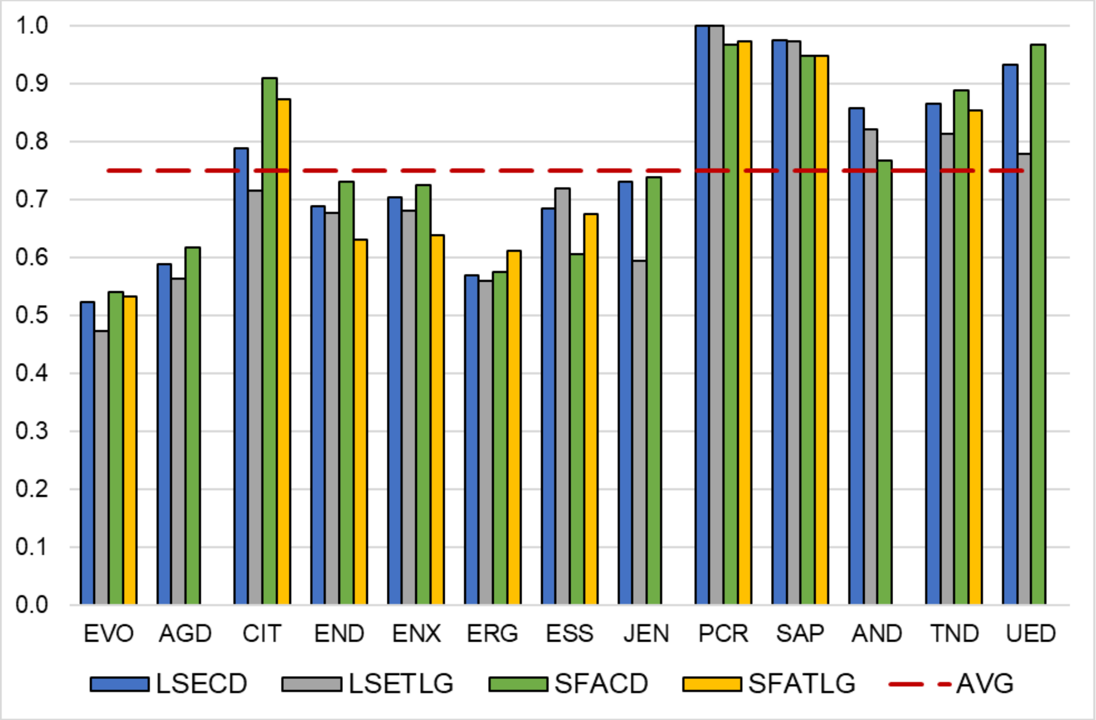


Figure 3.3 compares the efficiency scores of the ATT model with those of the JTT model and standard model for the long period. Overall, with a few exceptions, the efficiency scores from the ATT models are generally consistent with those from the standard and JTT models. Notably, in the SFACD model, the ATT scores align more closely with the standard model than with the JTT model. As previously mentioned, the problematic efficiency scores observed in the standard SFATLG model using the ABR24 dataset for the long sample are corrected in the ATT version of the SFATLG model.

3.6.2 Short Period

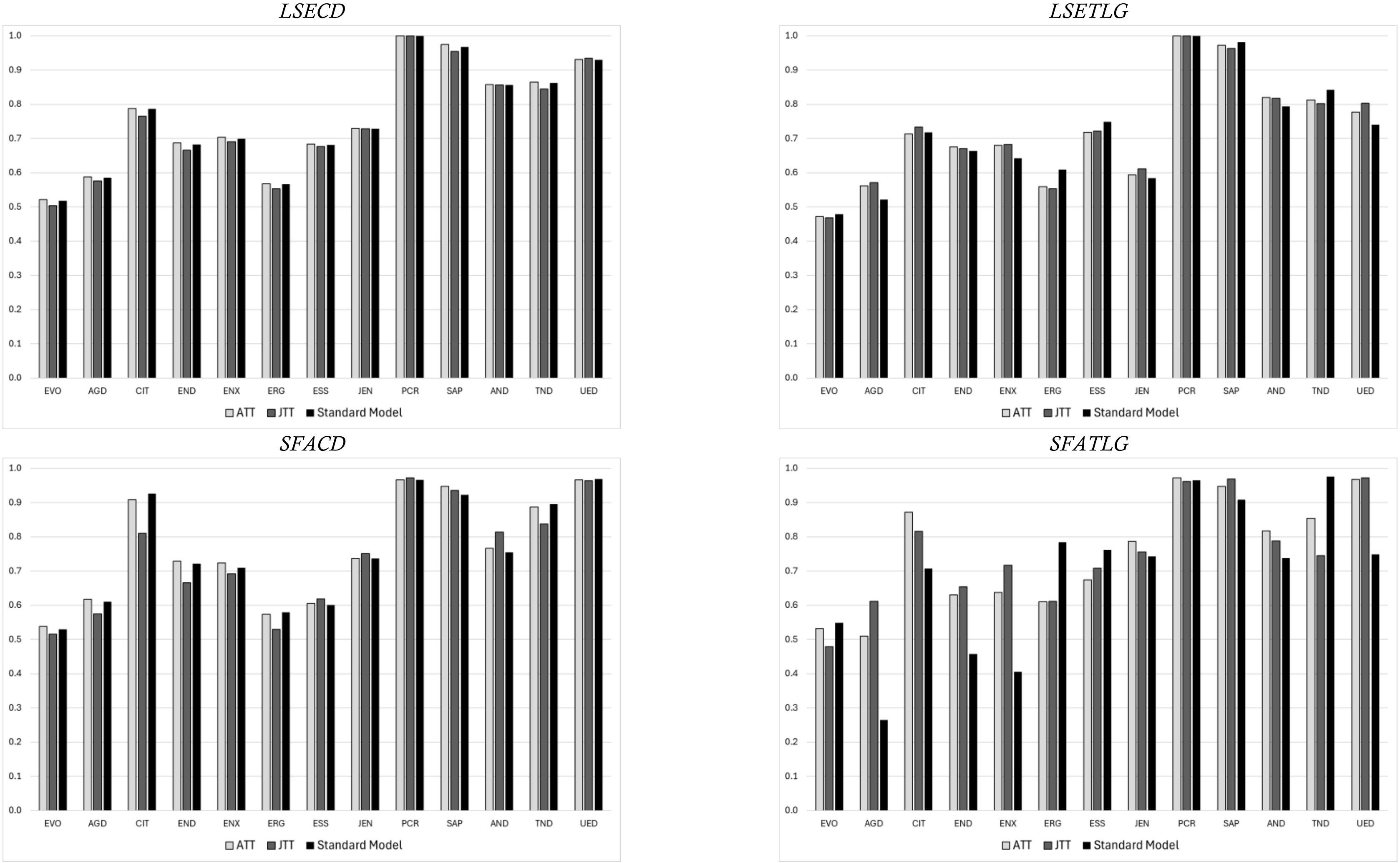
Table 3.10 and Figure 3.4 present the efficiency scores for the four models in the short period. The averages are calculated using only the DNSPs' efficiency scores that do not exhibit excessive monotonicity violations.

Table 3.10 ATT Models: Efficiency Scores -Short Period (2012-2023)

	LSECD		*LSETLG*		*SFACD*		*SFATLG**		*AVERAGE*	
	Eff	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*
EVO	0.498	13	0.466	13	0.570	13	0.490	12	0.511	13
AGD	0.596	12	0.594	11	0.617	11	0.475	13	0.602	12
CIT	0.702	6	0.687	7	0.755	5	0.610	8	0.715	6
END	0.686	8	0.685	8	0.743	6	0.615	7	0.705	7
ENX	0.678	9	0.671	9	0.717	8	0.604	9	0.689	8
ERG	0.607	11	0.612	10	0.591	12	0.505	11	0.603	11
ESS	0.694	7	0.744*	6	0.644	10	0.703	5	0.669	9
JEN	0.665	10	0.582	12	0.647	9	0.530	10	0.631	10
PCR	1.000	1	1.000	1	0.915	2	0.953	1	0.972	1
SAP	0.920	2	0.921	2	0.964	1	0.938	2	0.935	2
AND	0.810	5	0.789	5	0.743	7	0.839	3	0.781	5
TND	0.849	4	0.804	4	0.848	4	0.760	4	0.834	4
UED	0.903	3	0.811	3	0.856	3	0.693	6	0.857	3
AVG	0.739		0.719		0.739		0.670		0.731	

Notes: *Excluded from the average due excessive monotonicity violations

Figure 3.3 Efficiency Scores Comparison - Long Period (2006-2023)



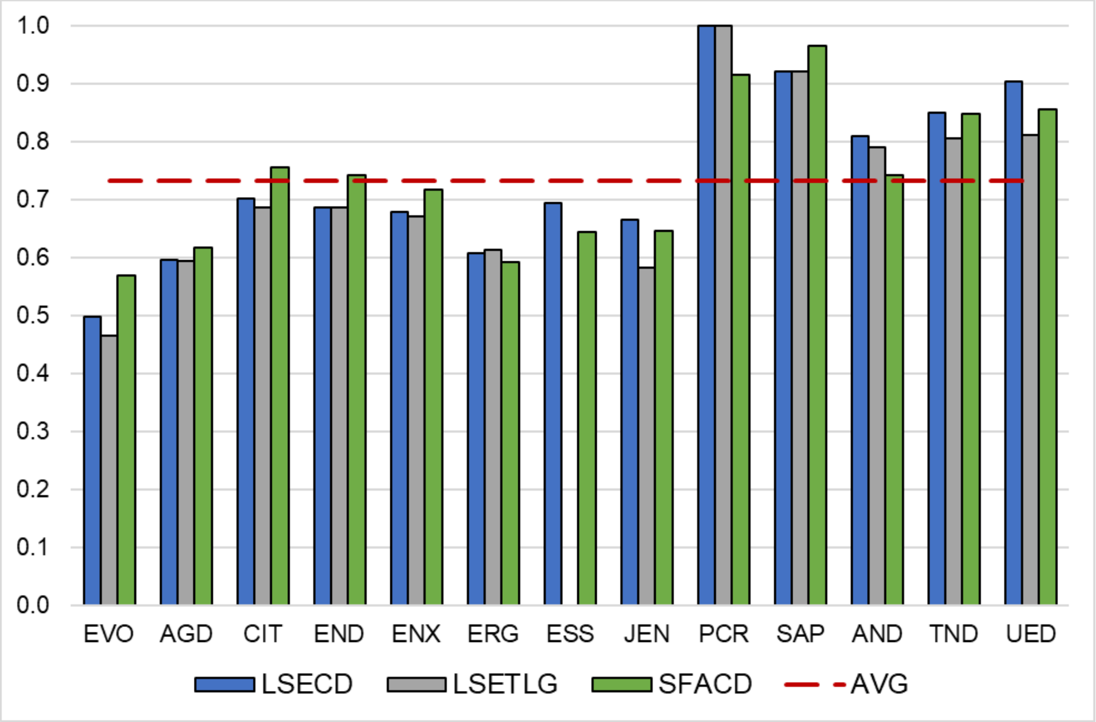
LSECD

LSETLG

SFACD

SFATLG

Figure 3.4 ATT Model Efficiency Scores (Exc. MV) -Short Period (2012-2023)

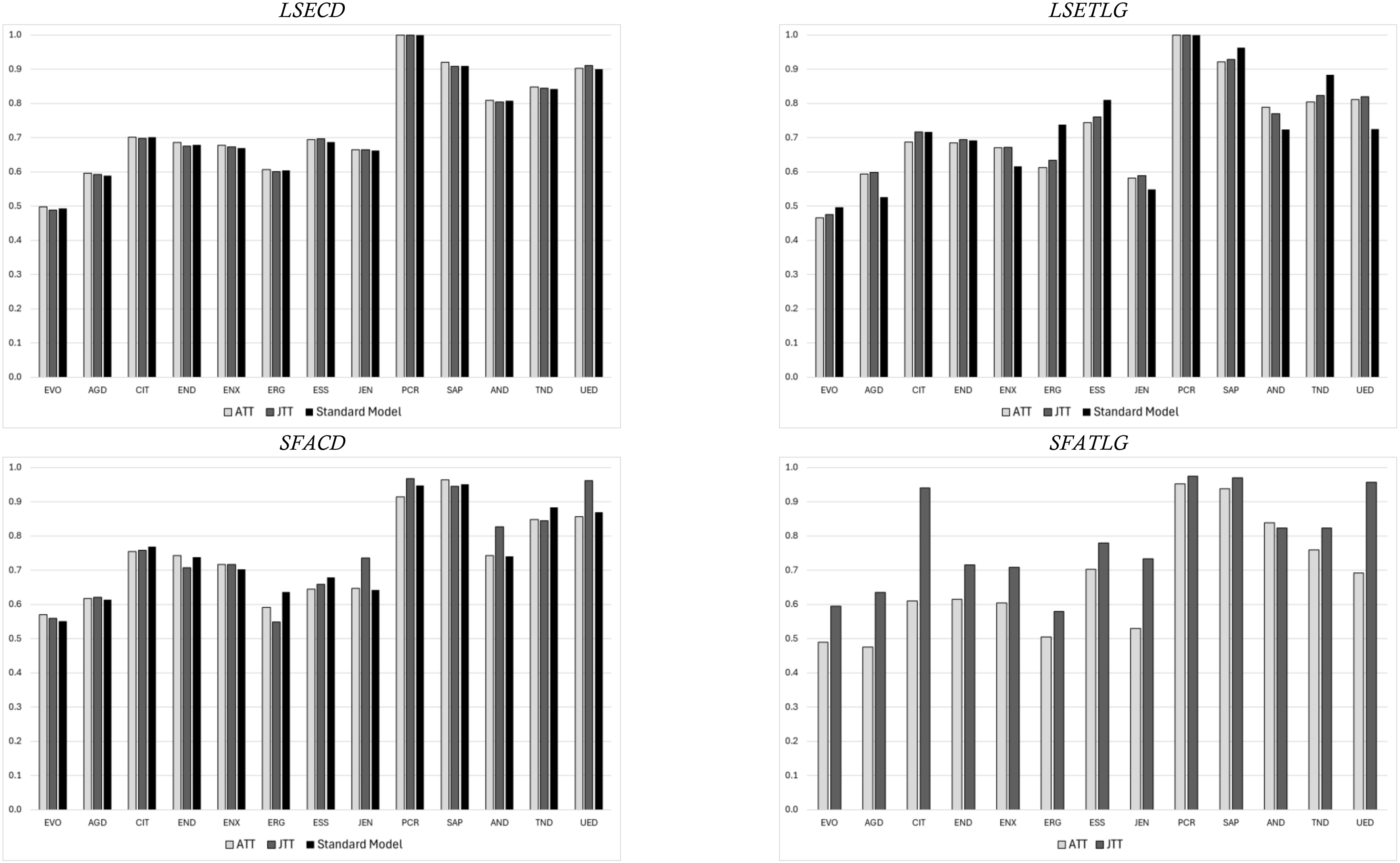


The averages of efficiency scores indicate that:

- The sample average opex efficiency score is 0.731 for the short sample, which is lower than the 0.751 observed in the JTT models.
- PCR (0.972) and SAP (0.935) have the highest average efficiency scores, consistent with the JTT results.
- The three DNSPs with the lowest opex efficiency are EVO (0.511), AGD (0.602), and ERG (0.603), similar to the findings in the JTT model.

Figure 3.5 compares the efficiency scores of the ATT model with those of the JTT model for the long period. Overall, the efficiency scores from the ATT models are generally consistent with those from the standard and JTT models, with the exception of the SFATLG model. In the SFATLG model, there are significant discrepancies between the ATT and JTT scores, particularly for CIT, UED, and JEN, highlighting the instability of the short-period SFATLG model.

Figure 3.5 Efficiency Scores Comparison - Short Period (2012-2023)



LSECD

LSETLG

SFACD

SFATLG

3.7 Concluding Comments

The analysis results indicate that the ATT models, like the JTT model, outperform standard models across several key metrics. The jurisdictional trends in Opex PFP align with findings from Frontier Economics (2023a) and from the Opex PFP indices for Australian DNSPs in ABR 2024 (Quantonomics 2024), with the JTT model showing a closer match. The ATT SFATLG model using the long sample provides more reliable inefficiency parameters than the standard model, leading to more credible efficiency scores, while the ATT SFATLG model also shows convergence in the short period. The ATT models exhibit substantially fewer monotonicity violations than standard models, although they still exceed those in the JTT model. Additionally, the ATT models yield higher Pseudo-Adjusted R^2 values than standard models, indicating a better fit, although the JTT models have a slightly better fit than the ATT models.

One advantage of the ATT models over the JTT model is that the SFACD short period model meets the monotonicity condition for the RMD output. On the other hand, the SFATLG ATT short period model has more MVs than the corresponding JTT model, sufficient to exclude all of the efficiency scores of this model. The output weights calculated using the ATT models differ substantially from the JTT-based output weights, and are more similar to the output weights from the standard model.

These findings reinforce the conclusions in Section 2, suggesting that variables capturing differing time trends across jurisdictions are likely omitted variables. This finding recommends to account for different time-trends in future standard models. Some ongoing issues with the SFATLG model, in the short period in regard to the frequency of MVs are partly mitigated but remain an important issue to be resolved despite the introduction of time trends.

4 Insights and Alternatives for Time-Trend Modelling

In this section, we discuss the findings from the time-trend models. Then we explore some initial thoughts around possible alternative methods for incorporating varying time trends into the econometric models, including a previous illustrative approach raised by Frontier Economics. This is not a definitive list and further consideration is required of the possible time trend options that may assist with improving the performance of the econometric models, along with any appropriate empirical testing of these options.

4.1 Concluding Observations on Specific Time Trend Variables

Omitting relevant explanatory variables in cost functions is a form of misspecification which can result in biased estimates of the relationship between output quantities and costs. When key variables are omitted, the remaining included variables may capture part of their influence, potentially leading to incorrect parameter estimates. The results in this memo suggest that incorporating different jurisdictional time trends, overall, leads to improvements over the standard models.

The JTT and ATT specifications tested here outperform the standard models across several key metrics, including successful convergence, reduced monotonicity violations in most cases, especially for Australian DNSPs, and slightly improved model fit. However, limitations remain. Notably, the JTT short-period SFACD model has a negative coefficient on the RMD parameter which is a monotonicity violation. The ATT short-period SFATLG models have an excessive number of monotonicity violations.

Regarding the model estimates of efficiency scores, we observe the following:

- The standard, JTT, and ATT LSECD models yield highly consistent efficiency scores across both long and short periods, with no issues observed in any of these models.
- The standard, JTT, and ATT LSETLG models yield highly consistent efficiency scores across both long and short periods, with no issues observed in any of these models. The JTT and ATT LSETLG models show consistent efficiency scores over both periods, though they differ somewhat from the standard LSETLG model. Notably, the MVs significantly decreased in the JTT and ATT LSETLG models compared to the standard models, and the models do not present SMVs for Australian DNSPs across both models and both periods. These changes in efficiency scores may reflect the impact of addressing SMVs through the inclusion of jurisdictional time trends.
- In the SFACD models in both long and short period, there is some divergence between the JTT and ATT models, with the ATT models occasionally aligning more closely with the standard model. The SFACD models in the short period under JTT are problematic due to the negative coefficient on RMD, suggesting potential issues in the SFA model specifications that were not resolved by including time trend variables and may instead have been highlighted.
- For the SFATLG models in the long period, both JTT and ATT models effectively addressed the unreasonable efficiency scores seen in the standard. This improvement may relate to the absence of SMVs and the significant reduction in MVs for Australian DNSPs and the overall sample compared to the standard model. However, there is some volatility in efficiency scores between the JTT and ATT models in the SFATLG long and short periods, indicating that unresolved issues with the SFATLG model may remain despite the introduction of different time trends.

The frequency of monotonicity violations is substantially reduced in the alternative time trend specifications considered here compared to the standard models. In the long period, the JTT version of SFATLG has fewer monotonicity violations than the ATT version, whereas the ATT version of the LSETLG model have fewer MVs than the JTT version. In the short period, the frequency of MV is also reduced compared to the standard models, but the short-period SFATLG models continue to have serious performance issues. The JTT models have fewer

MVs than the ATT models in the short period. The continuing difficulties with the short-period Translog models (especially the SFATLG model in this data sample) raises a question about alternative approaches to the Translog in the short period (see section 5).

For the output weights, the analysis shows that the JTT models allocate more weight to the RMD output over the customer numbers output compared to the standard and ATT models. The ATT model also assigns more weight to customer numbers than to RMD relative to the standard model, though the ATT model's weights differ only slightly from those in the standard model.

Overall, this investigation confirms the value of including time trend variables but indicates that unresolved issues, particularly with the short-period SFATLG model, may have underlying causes beyond time trends alone.

The improvement in model metrics through the inclusion of jurisdictional time trends may help explain why model issues have been escalating, even as more data becomes available. The analysis shows that differences in jurisdictional time trends have intensified in recent periods, with the short period exhibiting greater variation than the long period. This trend is likely linked to improvements in Australian efficiency following the initial impact of benchmarking analysis implementation. As these jurisdictional differences grow, omitting them increasingly distorts the regression coefficients.

While monotonicity performance shows broadly improved performance in the JTT and ATT models compared to the standard models, we note that some monotonicity violations remain. We consider this is to some extent an inherent feature of the model specification and Translog cost function. In particular, while the causes of excessive monotonicity violations are complex, 'multicollinearity' is almost certainly one important factor. Especially in a panel dataset, the output variables are correlated with each other, and this correlation is greatly increased in the TLG model, which includes squared values and interactions of the same variables. This leads to imprecision in output elasticities calculated *at specific observations*, and in certain ranges of observations where one or other of the output weights may be insignificantly different from zero, this can lead to a proliferation of statistically insignificant monotonicity violations. This is indicated by the scarcity of statistically significant monotonicity violations compared to the frequency of MVs as usually defined by the AER.

4.2 Time-varying inefficiency and DNSP-specific trends

As explained in section 1, the time trend effect (ie, $\lambda.t$ in equation 4.1 below) in the standard opex econometric models actually reflects the combined effect of technical change (also referred to as frontier shift), inefficiency changes over time of the average DNSP in the sample (historical "catch-up"), and any systematic trend effects due to omitted OEFs. The time trend is also assumed to be the same across the 3 jurisdictions. The models examined in sections 2 and 3 allow more flexibility by allowing systematic differences in the time trend between jurisdictions. As discussed in section 4.1, the current models' assumption of a uniform time trend across jurisdictions may be a source of misspecification.

As presented in section 1, the design of both the current models and the models presented in this memo implicitly assume that inefficiency of each DNSP does not vary over time (i.e. the U_i term in equation 4.1 is assumed to be constant over time). This might have been a reasonable assumption at the commencement of the AER's benchmarking program. However, there is evidence that Australian DNSPs' inefficiency has varied over time, as indicated in the upward trend in the distribution TFP results since 2015, which is mainly due to opex productivity. The current models, and models in section 2 and 3 do not, however, enable us to separate the effects of time-varying inefficiency from technical change (or from changes over time in omitted OEFs), which are currently all conflated in $\lambda.t$. This may be a source of potential misspecification. This will be desirable if we want to ascertain the changes in efficiency scores over time.

Addressing this issue will be one focus of the next phase of the AER's consultation. This section discusses some initial thoughts in relation to alternative approaches that are designed to address it.

For convenience, we also assume in the discussion that technical change is net of the effect of omitted OEFs. However, further separation into pure technical change and the impact of omitted OEFs remains an area for further consideration and research.

Section 4.2.1 describes an approach previously put forward for discussion by Frontier Economics (2023a, 74-81) for estimating different trends in the efficiency of individual Australian DNSPs in LSE models. Section 4.2.2 briefly discusses the challenges in separately identifying the effects of technical change and time-varying inefficiency currently captured in the time trend. Section 4.2.3 briefly describes some approaches that may be available to estimate trends in the inefficiency of individual DNSPs (or for classes of similar DNSPs) separately , specifically in the context of SFA models.

4.2.1 Frontier Economics' model

For illustrative purposes, Frontier Economics has previously presented a simple model with time-varying efficiencies for each Australian DNSP using only the LSE versions of the opex econometric models. It is useful to consider this model in the present context, as it aids in illustrating the issues and challenges of accounting for time varying inefficiency.

In discussing this possibility, and other issues relating to DNSP-specific efficiency trends and separating the effects of technical change and time-varying inefficiency, in this and the following sections it will be useful to start with and refer to a generic cost function model. In this model, opex is a function of outputs, jurisdictional differences, the time trend (as a proxy for technical change but also capturing other factors that change over time that impact opex), inefficiency for each DNSP, and random error. In mathematical form, this can be expressed in the following equation (4.1):

$$c_{it} = f(\boldsymbol{x}_{it}; \boldsymbol{\beta}) + \lambda.t + U_{it} + \varepsilon_{it} \tag{4.1}$$

where c_{it} is the log of real opex for DNSP i in period t; $f(.)$ is a functional form (eg, Cobb-Douglas or Translog); $\boldsymbol{x}_{it}$ is a set of explanatory variables for DNSP i in period t, including the logs of outputs, OEF variables, and the static jurisdictional dummy variables; t is a time variable used as a proxy for technical change; $\boldsymbol{\beta}$ and λ are parameters to be estimated;[17] U_{it} is a measure of inefficiency for DNSP i in period t; and ε_{it} is a normally-distributed stochastic disturbance.

In the standard LSE models, $U_i = \sum_{n=2}^{13} \delta_n D_i^n$, where D_i^n is an indicator variable for DNSP n (where $D_i^n = 1$ if $n = i$, and equals 0 otherwise).[18] In the standard SFA model, the inefficiency term is a random effect drawn from a truncated-normal distribution: $U_i \sim \mathcal{N}^+(\mu, \sigma_u^2)$.[19] The t subscript has been dropped here because U_{it} does not vary over time in the standard models.

In the JTT model explored in section 2 of this memo, the term $\lambda.t$ has been generalised to differentiate between the 3 jurisdictions, i.e.:

$$(\lambda_1 I_1 + \lambda_2 I_2 + \lambda_3 I_3)t \tag{4.2}$$

where I_j is a dummy variable for each of the two overseas jurisdictions, and λ_j are parameters to be estimated. The ATT specification explored in section 3 is an intermediate case where $\lambda_2 = \lambda_3$.

Like the standard models, in the JTT and ATT models presented in this paper, $U_{it} = U_i$ because it does not vary over time; i.e. each DNSP's level of inefficiency is assumed not to vary from year to year over the sample period. Thus, in the standard models, the inefficiency term, U_{it}, captures each DNSP's inefficiency on a period-average basis. However, any changing over time in that inefficiency is, effectively, captured in the time trend ($\lambda.t$).

Broadly, time-varying inefficiency can be introduced into the LSE model by allowing U_{it} to vary over time. Frontier Economics' illustrative model allows the rate of change to differ between DNSPs by including Australian DNSP-specific time trends into the inefficiency term, as follows:

$$U_{it} = \sum_{n=1}^{13} D_i^n \, (\delta_n + b_n t) \tag{4.3}$$

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[17] Including the intercept parameter.

[18] DNSP 1 has been arbitrarily chosen as the base firm so that $\delta_1 = 0$. The choice of base has no effect because the inefficiency score is calculated relative to the minimum δ.

[19] The way that each DNSP's efficiency scores are obtained from the estimated U_i also differs between the LSE and SFA models.

where the δ_n's and b_n's are parameters to be estimated, and n is an index of the Australian DNSPs in the sample. Frontier Economics incorporates this into the standard model (4.1), while retaining a generic $\lambda.t$ term for a common rate of technical change for all countries. More specifically, by incorporating DNSP-specific time trends for each Australian DNSP, the estimated value of λ in effect represents the average time trend for the 2 remaining jurisdictions (New Zealand and Ontario).

In short, Frontier Economics' model allows for a specific time trend for each Australian DNSP, rather than for Australian DNSPs to be grouped together as a whole. However, the model does not decompose each Australian DNSP's time trend further into separate estimates of technical change and efficiency change.[20] This topic is briefly discussed further in section 4.2.2.

We also note that equation (4.3) cannot be combined with the JTT specification of (4.2) or with the ATT case as specified in this paper because they both include a separate time trend for Australian DNSPs resulting in the 'dummy variable trap'.[21] However, if (4.3) is summed over DNSPs 2 through 13, it can be combined with either of the jurisdictional time trend specifications considered here.

Frontier Economics' illustrative differentiation of the time trend of individual DNSPs is a useful direction for further research. Perhaps the most important limitation and area for further exploration at this stage is that Frontier Economics does not formulate a corresponding SFA model. This is discussed in section 4.2.3.

4.2.2 Decomposition of Opex PFP change into technical change and technical efficiency

We have noted that the LSE-based model put forward for illustration by Frontier Economics is not designed to separate the effects of technical change and efficiency change for Australian DNSPs. Models that incorporate time-varying efficiency of individual DNSPs often seek to separate the effects of time-varying inefficiency (or 'catch-up'), which are firm-specific, from the effects of technical change ('frontier shift), which are common to the DNSPs. As explained above, these two effects (as well changes in omitted OEFs over time) are currently conflated in the time trend term because the estimated inefficiency terms is time-invariant. However, there is an issue of identification or multicollinearity when an econometric model seeks to use the time variable (years) as a proxy for both technical change and changes in inefficiency. This

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[20] If instead, (4.3) is summed over DNSPs 2 through 13 and an Australia-specific time trend term is included, this does not alter this result, because the time-trend of the base DNSP is subsumed in the jurisdiction-specific time trend.

[21] When there is a set of binary variables representing all the categories of a categorical variable (eg, jurisdiction) then one should be excluded (eg, the standard models include only two jurisdictional dummies, excluding that for Australia). If all were included they would sum to one at every observation, and have perfect multicollinearity with the constant term (Greene 2012, 192). Alternatively, the regression constant could be excluded. Likewise, if there is a set of binary variables multiplied against the time trend variable (eg, Australian DNSP-specific time trends) then one would need to be excluded if there is an overall time trend for Australia, to avoid perfect multicollinearity. Alternatively, the overall time trend for Australia could be excluded.

is a challenge for the simpler LSE models, and as discussed further in section 4.2.3, these challenges are compounded in SFA models.

The Essential Services Commission has also observed this challenge: "The effects of technology change and changes in technical efficiency are, in practice, difficult to disentangle using models that seek to identify each effect through a steady time-related trend" (ESC 2012, 36).

For these reasons, if we wish to measure time-varying inefficiency distinct from the effects of technical change on opex, it *may* be desirable to have some measure of technical change (frontier shift) that can be used in place of t in equation (4.1). This would leave the time variable to be used for identifying changes in efficiency. A number of regulators develop estimates of frontier shift that may be relevant. For example, the Dutch Authority for Consumers and Markets uses a weighted average of Total Factor Productivity trends in several comparator industries (Economic Insights 2020). Developing an alternative measure of technical change may be feasible although there are likely to be a range of conceptual and practical issues to be encountered when evaluating such an option.

4.2.3 Firm-specific Time-varying Inefficiency in SFA Models

Related issues can arise in SFA models that assume time-varying inefficiency specifications (eg, Battese and Coelli 1992). The starting point of SFA time-varying inefficiency models is usually to generalise the stochastic inefficiency term as:

$$U_{it} = \eta_{it} U_i \tag{4.4}$$

where U_i has the same truncated normal distribution as in the time-invariant case. In Battese and Coelli's approach, $\eta_{it} = \exp[-\eta(t - T_i)]$ where η is a decay parameter to be estimated, and T_i is the last period in the sample for firm *i*. Here η is the uniform rate of change of inefficiency applicable to all firms in the sample. If the inefficiencies of firms actually change at different rates, the estimated η should approximate an average rate of change of inefficiency.

The time-varying decay SFA model can be estimated when $\lambda.t$ is included directly (as in equation 4.1). However, there can be a question over the reliability of the separation of the trends into technical change and changes in efficiency due to the correlation between $\lambda.t$ and $U_i \cdot \exp[-\eta(t - T_i)]$, since t appears as a variable in both.

A generalization of the Battese & Coelli time-varying inefficiency model to admit different trends in inefficiency for individual firms has been developed by Cuesta (2000) in the context of a production function. Here the expression for η_{it} is:

$$\eta_{it} = \exp[-\xi_i(t - T)] \tag{4.5}$$

where ξ_i is a firm-specific rate of decay of inefficiency, in place of the constant η in the Battese & Coelli model. A key shortcoming of this approach is the large number of ξ_i parameters to be estimated since there is a different parameter for every DNSP. To simplify this model, it may be desirable to restrict the variation of time trends to a limited set of groups or classes of firms.

We are not aware of any software that implements this approach. It may be feasible to implement using Stata's maximum likelihood function programming routine (*ml*). This would involve programming the log-likelihood function. The log-likelihood function is the same as in Battese and Coelli's model (see Battese and Coelli 1992, 165), except that the vector of η_{it}'s is calculated according to (4.5) rather than the simpler expression used in Battese and Coelli's approach. It remains uncertain whether any specific difficulties might arise with implementing this approach.

5 Ontario Circuit Length Interaction Terms

We have examined a potential inconsistency in the measurement of Ontario DNSPs' circuit length compared to data from Australia and New Zealand. This potential inconsistency also affects the share of underground cables in total circuit length. A summary of the purpose and findings are summarised in this section. Appendix B presents a summary of the results.

5.1 Inconsistency in Ontario's Circuit Length data

The data for Ontario DNSPs is derived from two sources: PEG published Excel workbooks and the Ontario Energy Board (OEB) Yearbooks. Before 2019, both PEG and the Yearbooks provided data on Ontario DNSPs' overhead and underground lines without distinguishing between primary and secondary lines.[22] Reporting of secondary circuit lengths was not obligatory and our understanding is that in most cases only primary circuit lengths were reported. From 2019 onwards, PEG and OEB have reported separate data fields for primary and secondary circuit lengths, although reporting secondary circuit lengths remains optional, and several DNSPs do not report them (OEB 2023, 98). The ABR dataset has continued to include only primary circuits for Ontario DNSPs before and after 2019.

Secondary lines may include low-voltage lines and may also include distributor-owned service lines, although there is limited information on this. The definition of secondary circuits appears to vary between Ontario DNSPs, as does ownership and the method of data collection (Canadian Electricity Association 2017, 4). Of the 29 Ontario DNSPs in ABR24 dataset, 16 do not provide information on secondary lengths.[23] It is possible that some of these 16 DNSPs do not differentiate between primary and secondary lines, and report data on all circuits under the primary lines category.

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[22] Primary lines are those operating at voltages higher than 750 V but not exceeding 50,000 V phase-to-phase. Secondary lines are those operating at 750 V or lower (ESA 2018, 18).

[23] Specifically Hydro One Networks, Hydro Ottawa, London Hydro, Elexicon Energy, Enova Power, Burlington Hydro, Oakville Hydro, GrandBridge, Synergy North, Newmarket Tay, PUC Distribution, North Bay, Westario Power, Welland Hydro, Festival Hydro and ERTH Power.

It remains uncertain whether data for combined primary and secondary circuit lengths would be more comparable with the Australian and New Zealand definition given the lack of clarity and potential inconsistency of definitions of secondary lines. Moreover, any attempt to reconstruct data for secondary circuit lengths would face fundamental difficulties.

- A comparison of primary circuit length data reported before and since 2019 highlights whether the previously reported data included secondary lines or not. However, if the DNSP reported only primary circuit length previously, past secondary circuit lengths cannot now be obtained;
- If there has been any inconsistency over time in whether a DNSP reported primary or both primary and secondary circuit length, it may be difficult to remedy those inconsistencies;
- Since the reporting of secondary circuit length remains optional, for 16 Ontario DNSPs there are still lack data for secondary circuit length after 2019. For those, it is not certain whether they either (a) have no secondary circuits; or (b) they have elected not to report their secondary circuits, or (c) they have reported their secondary circuits combined within their primary circuit length reported data.

For these reasons, there does not appear to be a reliable alternative way of measuring circuit length (CL) and the underground cables share (UGS) for Ontario to contrast with the existing method of using only primary circuits.

Given these challenges of reconstructing the data, we have thus adopted an econometric approach. We test the potential effects of potential differences in the measurement of circuit length between Ontario on the one hand and Australia and New Zealand on the other. It does this by defining two additional interaction variables: [24]

- an interaction of the Ontario dummy variable with CL; and
- an interaction of the Ontario dummy variable with UGS.

Together these are the ‘Ontario Interaction Terms’ (OIT). They are designed to capture the specific impact of circuit length and UGS in the Ontario sample on opex, which can be statistically tested whether each differs from zero. This is equivalent to testing whether the effects of CL and UGS on the opex of Ontario DNSPs is statistically different from their effects on the opex of Australia and New Zealand DNSPs.

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[24] Interaction terms are variables formed by the product of two variables, one or both of which may also enter the model directly. The interaction of a dummy variable representing one category of the data with an explanatory variable allows the marginal effect of that explanatory variable to be different for that category.

5.2 Concluding comments

Including interaction terms for Ontario circuit length and underground cables in the econometric models yields poor results overall. Although these terms are statistically significant in some models, the significance is inconsistent across models. Moreover, there are discrepancies in coefficient signs for affected variables. For example, in the LSETLG models, Underground Cable Share (*lz1)* has a positive coefficient—contrary to the expected negative relationship with opex as shown in the standard models. Two further important deficiencies of the OIT models are: (a) that the SFATLG models fail to converge in both periods; (b) estimated efficiency scores show marked differences to the standard model estimates, with some clearly anomalous efficiency scores. These results suggest that, on the basis of the current data sample, including Ontario interaction terms does not significantly improve model performance. Further, the inconsistency in the significance of the added interaction terms does not support the hypothesis of systematic differences in Ontario circuit length variables which the addition of the interaction terms seeks to test.

6 Final Comments

The findings presented in this memo show that incorporating different time trends for the jurisdictions enhances the performance of econometric opex cost function models by several key metrics, including better model fit, convergence of the SFATLG model, and reduced monotonicity violations in most cases. However, limitations remain, which include:

- the JTT short-period SFACD model presents monotonicity violations in the form of a negative coefficient on RMD, although not statistically significantly different from zero,
- the ATT short-period SFATLG models also presents an excess of monotonicity violations,
- generally, the short-period Translog models (especially the SFATLG model) can sometimes be unstable; eg, producing excessive monotonicity violations or unusual efficiency scores.
- the variation in output weights across the JTT and standard and ATT models.

In short, the analysis confirms the value of including time trend variables but indicates there are unresolved issues; for example, with the short-period Translog models. Further, that there may be benefit in considering extensions of the models to include time varying inefficiency.

Key issues for stakeholder comment that arise from this analysis include:

(a) *Whether jurisdictional time trend models such as tested in sections 2 and 3 are the most appropriate way of including flexible time trends or whether there are better alternatives. For example, DNSP-specific time trends models discussed in section 4.2, or other possible options and, if so, what those options might be.*

(b) *Whether the jurisdictional time trend models are a step forward but remain incomplete due to their lack of accounting for time varying inefficiency.*

(c) *The challenges of incorporating time varying inefficiency, and whether suitable approaches exist for addressing these.*

(d) *Whether the potential issue with the measurement of Ontario circuit length has been adequately tested and whether stakeholders agree with the conclusion that there is no evidence of systematic differences in the effects of circuit length on Opex for Ontario DNSPs.*

Appendix A: Opex Cost Function Regression Results

In all models shown in this Appendix, *ly1* refers to the log of customer numbers, *ly2* to the log of circuit length, l*y3* to the log of RMD and *lz1* to log of share of underground cables.

A1 Jurisdictional Time Trend Model Results

Table A1.1 JTT LSECD Model Estimates

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.615	0.071	8.690	0.588	0.068	8.590
ly2	0.219	0.033	6.620	0.252	0.030	8.360
ly3	0.132	0.061	2.170	0.128	0.064	2.020
lz1	–0.096	0.024	–4.070	–0.093	0.023	–4.090
yr_1	–0.002	0.003	–0.490	–0.026	0.004	–6.400
yr_2	0.026	0.003	9.420	0.028	0.004	7.080
yr_3	0.004	0.002	2.040	–0.002	0.002	–0.620
jur2	–56.683	8.692	–6.520	–110.166	11.464	–9.610
jur3	–11.247	7.570	–1.490	–49.540	9.359	–5.290
d2	–0.135	0.164	–0.830	–0.193	0.135	–1.430
d3	–0.420	0.128	–3.290	–0.356	0.109	–3.280
d4	–0.280	0.131	–2.140	–0.324	0.111	–2.910
d5	–0.317	0.122	–2.600	–0.320	0.108	–2.960
d6	–0.095	0.141	–0.670	–0.207	0.125	–1.660
d7	–0.296	0.150	–1.980	–0.354	0.127	–2.790
d8	–0.370	0.138	–2.680	–0.309	0.110	–2.790
d9	–0.686	0.129	–5.320	–0.716	0.115	–6.230
d10	–0.640	0.139	–4.620	–0.620	0.123	–5.060
d11	–0.531	0.130	–4.070	–0.498	0.113	–4.410
d12	–0.518	0.144	–3.600	–0.548	0.133	–4.120
d13	–0.619	0.134	–4.610	–0.622	0.118	–5.260
_cons	13.700	6.680	2.050	62.909	8.188	7.680
rho	0.753			0.638		
N	1,098			732		
R^2	0.9918			0.9948		
PseudoR^2	0.9805			0.9836		

Table A1.2 JTT LSETLG Model Estimates

	Long Period (2006-2023)			Short Period (2012-2023)		
	Coeff	std. err.	t-ratio	Coeff	std. err.	t-ratio
ly1	0.479	0.079	6.060	0.438	0.074	5.950
ly2	0.217	0.033	6.560	0.252	0.028	9.000
ly3	0.258	0.066	3.900	0.266	0.063	4.250
ly11	–0.285	0.498	–0.570	–0.008	0.530	–0.020
ly12	0.251	0.116	2.160	0.175	0.118	1.480
ly13	–0.005	0.396	–0.010	–0.223	0.407	–0.550
ly22	–0.014	0.041	–0.330	0.032	0.038	0.840
ly23	–0.222	0.095	–2.330	–0.198	0.096	–2.070
ly33	0.285	0.315	0.900	0.497	0.313	1.590
lz1	–0.098	0.026	–3.720	–0.085	0.023	–3.740
yr_1	–0.001	0.003	–0.420	–0.025	0.004	–5.660
yr_2	0.028	0.003	10.170	0.029	0.004	7.700
yr_3	0.006	0.002	3.000	0.000	0.002	0.220
jur2	–59.655	8.838	–6.750	–109.713	11.446	–9.590
jur3	–14.892	7.803	–1.910	–51.268	9.806	–5.230
d2	–0.198	0.174	–1.140	–0.230	0.142	–1.630
d3	–0.448	0.129	–3.470	–0.410	0.105	–3.900
d4	–0.359	0.133	–2.690	–0.379	0.109	–3.480
d5	–0.376	0.132	–2.850	–0.345	0.115	–3.000
d6	–0.167	0.163	–1.020	–0.288	0.138	–2.090
d7	–0.432	0.170	–2.530	–0.469	0.144	–3.250
d8	–0.265	0.149	–1.790	–0.215	0.121	–1.770
d9	–0.758	0.135	–5.610	–0.743	0.120	–6.220
d10	–0.720	0.145	–4.960	–0.669	0.124	–5.380
d11	–0.556	0.139	–3.990	–0.482	0.125	–3.870
d12	–0.537	0.145	–3.720	–0.549	0.128	–4.300
d13	–0.539	0.149	–3.630	–0.545	0.130	–4.190
_cons	13.357	6.949	1.920	60.519	8.843	6.840
rho	0.749			0.613		
N	1,098			732		
R^2	0.9922			0.9952		
$PseudoR^2$	0.9831			0.9870		

Table A1.3 JTT SFACD Model Estimates

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.629	0.075	8.380	0.721	0.091	7.880
ly2	0.183	0.038	4.870	0.268	0.040	6.630
ly3	0.143	0.072	1.990	–0.049	0.087	–0.560
lz1	–0.088	0.035	–2.470	0.009	0.043	0.210
yr_1	–0.005	0.002	–2.750	–0.031	0.002	–13.510
yr_2	0.025	0.001	18.390	0.028	0.002	15.950
yr_3	0.004	0.001	3.750	–0.006	0.002	–4.110
jur2	–59.199	4.100	–14.440	–119.877	5.428	–22.080
jur3	–18.440	3.624	–5.090	–49.468	4.938	–10.020
_cons	19.369	3.505	5.530	72.512	4.649	15.600
/mu	0.202	0.095	2.130	0.228	0.073	3.140
/lnsigma2	–2.727	0.326	–8.360	–2.893	0.320	–9.050
/lgtgamma	1.348	0.412	3.270	1.881	0.374	5.030
sigma2	0.065	0.021		0.055	0.018	
gamma	0.794	0.067		0.868	0.043	
sigma_u2	0.052	0.021		0.048	0.018	
sigma_v2	0.013	0.001		0.007	0.000	
N	1,098			732		
LLH	695.218			643.570		
PseudoR^2	0.9927			0.9960		

Table A1.4 JTT SFATLG Model Estimates

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.708	0.077	9.160	0.610	0.089	6.830
ly2	0.155	0.034	4.510	0.213	0.037	5.780
ly3	0.081	0.078	1.050	0.113	0.080	1.420
ly11	0.659	0.418	1.570	–0.107	0.526	–0.200
ly12	–0.258	0.099	–2.600	0.131	0.138	0.950
ly13	–0.372	0.359	–1.030	–0.001	0.439	0.000
ly22	0.165	0.050	3.320	0.163	0.069	2.380
ly23	0.121	0.095	1.270	–0.287	0.101	–2.830
ly33	0.246	0.309	0.800	0.256	0.368	0.700
lz1	–0.041	0.035	–1.170	0.047	0.038	1.240
yr_1	–0.007	0.002	–3.480	–0.031	0.003	–11.950
yr_2	0.024	0.001	17.390	0.028	0.002	15.980
yr_3	0.003	0.001	2.310	–0.005	0.002	–2.770
jur2	–62.150	4.625	–13.440	–120.336	5.949	–20.230
jur3	–19.860	4.325	–4.590	–53.134	6.185	–8.590
_cons	23.393	3.920	5.970	72.901	5.262	13.850
/mu	0.080	0.160	0.500	0.049	0.185	0.270
/lnsigma2	–2.459	0.452	–5.440	–2.524	0.562	–4.490
/lgtgamma	1.685	0.539	3.130	2.322	0.624	3.720
sigma2	0.085	0.039		0.080	0.045	
gamma	0.844	0.071		0.911	0.051	
sigma_u2	0.072	0.039		0.073	0.045	
sigma_v2	0.013	0.001		0.007	0.000	
N	1,098			732		
LLH	701.939			656.480		
PseudoR^2	0.9927			0.9961		

A2 Australian Time Trend Model Results

Table A2.1 ATT LSECD Model Estimates

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.540	0.077	7.010	0.554	0.076	7.260
ly2	0.230	0.036	6.370	0.265	0.034	7.780
ly3	0.194	0.066	2.950	0.148	0.069	2.130
lz1	-0.086	0.026	-3.240	-0.080	0.026	-3.050
yr	0.013	0.002	7.470	0.011	0.002	4.590
yr_1	-0.014	0.004	-3.610	-0.036	0.005	-7.160
jur2	-28.751	7.861	-3.660	-73.237	10.179	-7.200
jur3	-28.517	7.859	-3.630	-72.980	10.176	-7.170
d2	-0.120	0.184	-0.650	-0.180	0.164	-1.100
d3	-0.412	0.144	-2.850	-0.343	0.135	-2.540
d4	-0.275	0.148	-1.860	-0.320	0.139	-2.300
d5	-0.299	0.138	-2.170	-0.308	0.134	-2.300
d6	-0.085	0.161	-0.530	-0.197	0.155	-1.270
d7	-0.270	0.169	-1.590	-0.332	0.156	-2.130
d8	-0.335	0.156	-2.150	-0.289	0.137	-2.110
d9	-0.651	0.147	-4.430	-0.697	0.143	-4.880
d10	-0.625	0.157	-3.990	-0.614	0.152	-4.050
d11	-0.497	0.147	-3.390	-0.486	0.140	-3.470
d12	-0.506	0.164	-3.090	-0.533	0.164	-3.250
d13	-0.579	0.153	-3.800	-0.595	0.147	-4.050
_cons	13.099	7.201	1.820	62.039	9.224	6.730
rho	0.787			0.717		
N	1,098			732		
R^2	0.9914			0.9948		
PseudoR^2	0.9793			0.9821		

Table A2.2 ATT LSETLG Model Estimates

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.386	0.082	4.700	0.409	0.082	5.020
ly2	0.231	0.035	6.540	0.266	0.032	8.410
ly3	0.336	0.069	4.850	0.283	0.070	4.070
ly11	-0.145	0.536	-0.270	0.262	0.563	0.460
ly12	0.278	0.126	2.210	0.186	0.125	1.500
ly13	-0.171	0.427	-0.400	-0.467	0.435	-1.070
ly22	-0.044	0.046	-0.960	0.014	0.041	0.330
ly23	-0.213	0.103	-2.070	-0.193	0.102	-1.900
ly33	0.432	0.341	1.270	0.702	0.337	2.090
lz1	-0.096	0.029	-3.260	-0.080	0.026	-3.020
yr	0.015	0.002	8.610	0.012	0.002	5.670
yr_1	-0.016	0.004	-4.030	-0.038	0.005	-7.300
jur2	-32.626	7.999	-4.080	-76.607	10.439	-7.340
jur3	-32.453	7.994	-4.060	-76.380	10.430	-7.320
d2	-0.176	0.191	-0.930	-0.243	0.162	-1.500
d3	-0.415	0.143	-2.910	-0.388	0.123	-3.160
d4	-0.360	0.148	-2.440	-0.386	0.127	-3.030
d5	-0.366	0.145	-2.530	-0.365	0.134	-2.730
d6	-0.171	0.180	-0.950	-0.273	0.162	-1.690
d7	-0.421	0.188	-2.240	-0.468	0.167	-2.800
d8	-0.231	0.163	-1.420	-0.223	0.139	-1.610
d9	-0.752	0.149	-5.030	-0.764	0.138	-5.520
d10	-0.723	0.160	-4.510	-0.682	0.145	-4.700
d11	-0.553	0.152	-3.640	-0.528	0.143	-3.700
d12	-0.544	0.160	-3.390	-0.546	0.149	-3.670
d13	-0.500	0.163	-3.080	-0.555	0.150	-3.710
_cons	12.689	7.373	1.720	61.665	9.703	6.360
rho	0.777			0.676		
N	1,098			732		
R^2	0.9918			0.9953		
$PseudoR^2$	0.9820			0.9855		

Table A2.3 ATT SFACD Model Estimates

	Long Period (2006-2023)			Short Period (2012-2023)		
	Coeff	std. err.	t-ratio	Coeff	std. err.	t-ratio
ly1	0.327	0.073	4.480	0.347	0.108	3.210
ly2	0.156	0.040	3.930	0.337	0.061	5.540
ly3	0.484	0.073	6.630	0.266	0.089	2.970
lz1	-0.104	0.031	-3.390	0.061	0.052	1.170
yr	0.013	0.001	14.060	0.008	0.001	5.960
yr_1	-0.016	0.002	-9.070	-0.037	0.003	-13.940
jur2	-32.783	3.617	-9.060	-75.742	5.428	-13.950
jur3	-32.697	3.614	-9.050	-75.444	5.425	-13.910
_cons	16.100	3.527	4.570	68.806	5.298	12.990
/mu	0.138	0.167	0.830	0.283	0.071	3.960
/lnsigma2	-2.485	0.469	-5.290	-3.020	0.253	-11.950
/lgtgamma	1.493	0.575	2.590	1.351	0.323	4.180
sigma2	0.083	0.039		0.049	0.012	
gamma	0.816	0.086		0.794	0.053	
sigma_u2	0.068	0.039		0.039	0.012	
sigma_v2	0.015	0.001		0.010	0.001	
N	1,098			732		
LLH	629.759			643.570		
PseudoR^2	0.9917			0.9946		

Table A2.4 ATT SFATLG Model Estimates

	Long Period (2006-2023)			Short Period (2012-2023)		
	Coeff	std. err.	t-ratio	Coeff	std. err.	t-ratio
ly1	0.323	0.075	4.280	0.135	0.112	1.210
ly2	0.134	0.033	4.100	0.393	0.061	6.490
ly3	0.510	0.082	6.220	0.442	0.097	4.540
ly11	1.407	0.439	3.210	1.272	0.590	2.150
ly12	-0.167	0.117	-1.430	0.418	0.180	2.320
ly13	-1.169	0.369	-3.170	-1.560	0.471	-3.310
ly22	0.083	0.052	1.600	-0.055	0.080	-0.690
ly23	0.127	0.108	1.170	-0.342	0.135	-2.530
ly33	0.888	0.315	2.820	1.716	0.393	4.370
lz1	-0.078	0.039	-2.020	0.081	0.056	1.440
yr	0.013	0.001	11.780	0.012	0.002	7.540
yr_1	-0.017	0.002	-7.810	-0.044	0.003	-14.150
jur2	-34.756	4.434	-7.840	-89.268	6.287	-14.200
jur3	-34.729	4.432	-7.840	-89.024	6.288	-14.160
_cons	18.198	4.215	4.320	75.624	5.982	12.640
/mu	-0.180	0.504	-0.360	0.408	0.118	3.450
/lnsigma2	-1.654	0.779	-2.120	-2.861	0.259	-11.040
/lgtgamma	2.487	0.849	2.930	1.696	0.323	5.260
sigma2	0.191	0.149		0.057	0.015	
gamma	0.923	0.060		0.845	0.042	
sigma_u2	0.177	0.149		0.048	0.015	
sigma_v2	0.015	0.001		0.009	0.001	
N	1,098			732		
LLH	643.107			568.294		
PseudoR^2	0.9920			0.9952		

Appendix B: Ontario Interaction Terms

This appendix presents the findings of examining a potential inconsistency in the measurement of Ontario DNSPs' circuit length compared to data from Australia and New Zealand DNSPs. This also affects the ratio of underground cables in total circuit length. The issue is briefly outlined in section 5.

Testing whether this potential issue is something that should be controlled for involves incorporating variables designed to capture the effect of any systematic difference of measurement of the circuit length variables between jurisdictions (hereafter the 'Ontario Interaction Terms'). This approach aims to determine whether any inconsistency of measurement might be affecting the econometric models, and whether including Ontario Interaction Terms (OITs) improves the models. The results are presented in this appendix.

B.1 Ontario Interaction Terms Models Results

Tables B.1 to B.3 present the econometric results when incorporating the Ontario Interaction Terms for both long and short periods. Variable *ont_ly2* represents the interaction between the Ontario dummy and CL, and variable *ont_lz1* represents the interaction between the Ontario dummy and UGS. For convenience, these models are referred to as "Ontario Interaction Terms (OIT) models".

Estimation Results

A key finding is that the OIT SFATLG model failed to converge in both the long and short periods. This outcome is less favourable compared to the ABR24 model, where only the SFATLG model in the short period failed to converge.

In terms of the statistical significance of the variables *ont_ly2* and *ont_lz1* across the models, the results are as follows:

- The coefficient for *ont_ly2* is positive and statistically significant only in the LSECD model for both the long and short periods. In contrast, for the LSETLG and SFACD models, it is not statistically significant.
- The coefficient for *ont_lz1* is negative and statistically significant across all valid models, except in the LSECD model for the short period.

Regarding the consistency of coefficient estimates with expectations, the OEF variable, Underground Cable Share (*lz1*), shows a positive and statistically significant coefficient in the Ontario CL LSETLG model for both long and short periods. It is also positive, though statistically insignificant, in the short period model for Ontario CL SFACD. This consists of an inconsistency with the expected signal of the coefficient for this variable.

Table B.1 OIT LSECD Opex Cost Function Models

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.484	0.080	6.050	0.524	0.084	6.220
ly2	0.186	0.050	3.690	0.174	0.054	3.230
ly3	0.233	0.066	3.540	0.192	0.072	2.680
lz1	–0.024	0.037	–0.640	–0.067	0.042	–1.610
yr	0.010	0.002	6.300	0.003	0.002	1.620
jur2	–0.344	0.129	–2.660	–0.372	0.144	–2.580
jur3	–0.259	0.129	–2.000	–0.211	0.144	–1.460
ont_ly2	0.065	0.029	2.200	0.090	0.030	2.990
ont_lz1	–0.104	0.035	–2.930	–0.043	0.038	–1.120
d2	0.032	0.194	0.160	–0.016	0.199	–0.080
d3	–0.412	0.143	–2.880	–0.379	0.152	–2.490
d4	–0.140	0.158	–0.890	–0.163	0.167	–0.980
d5	–0.131	0.149	–0.880	–0.116	0.161	–0.720
d6	0.228	0.192	1.190	0.117	0.202	0.580
d7	0.082	0.203	0.400	0.017	0.213	0.080
d8	–0.270	0.157	–1.720	–0.268	0.161	–1.660
d9	–0.386	0.168	–2.290	–0.450	0.176	–2.550
d10	–0.410	0.171	–2.400	–0.361	0.179	–2.020
d11	–0.284	0.159	–1.790	–0.285	0.168	–1.690
d12	–0.337	0.169	–2.000	–0.385	0.184	–2.090
d13	–0.458	0.158	–2.900	–0.517	0.170	–3.050
_cons	–9.045	3.107	–2.910	3.540	4.316	0.820
rho	0.778			0.720		
N	1,098			732		
R^2	0.9914			0.9947		
PseudoR^2	0.9792			0.9809		

Table B.2 OIT LSETLG Opex Cost Function Models

	Long Period (2006–2023)			*Short Period (2012–2023)*		
	Coeff	*std. err.*	*t–ratio*	*Coeff*	*std. err.*	*t–ratio*
ly1	0.306	0.084	3.640	0.188	0.089	2.120
ly2	0.282	0.054	5.230	0.411	0.056	7.330
ly3	0.341	0.068	4.980	0.341	0.071	4.840
ly11	–0.089	0.533	–0.170	–0.318	0.540	–0.590
ly12	0.008	0.138	0.060	–0.150	0.140	–1.080
ly13	–0.004	0.420	–0.010	0.291	0.418	0.700
ly22	0.196	0.066	2.970	0.378	0.071	5.320
ly23	–0.207	0.102	–2.030	–0.240	0.098	–2.450
ly33	0.290	0.335	0.860	0.115	0.327	0.350
lz1	0.148	0.060	2.470	0.323	0.073	4.460
yr	0.010	0.002	6.070	0.002	0.002	1.180
jur2	–0.386	0.130	–2.960	–0.414	0.137	–3.020
jur3	–0.503	0.135	–3.740	–0.583	0.142	–4.120
ont_ly2	0.017	0.037	0.480	–0.009	0.034	–0.260
ont_lz1	–0.315	0.062	–5.070	–0.473	0.072	–6.520
d2	0.095	0.204	0.460	0.159	0.195	0.820
d3	–0.483	0.146	–3.300	–0.450	0.146	–3.080
d4	–0.119	0.168	–0.710	–0.099	0.165	–0.600
d5	–0.048	0.162	–0.300	0.071	0.160	0.450
d6	0.191	0.218	0.880	0.074	0.207	0.360
d7	0.029	0.220	0.130	0.058	0.212	0.270
d8	–0.078	0.169	–0.460	0.113	0.167	0.670
d9	–0.220	0.188	–1.170	–0.024	0.187	–0.130
d10	–0.432	0.180	–2.410	–0.352	0.172	–2.050
d11	–0.094	0.173	–0.540	0.176	0.178	0.990
d12	–0.189	0.182	–1.040	–0.055	0.187	–0.290
d13	–0.228	0.173	–1.320	–0.046	0.178	–0.260
_cons	–9.125	3.262	–2.800	5.776	4.253	1.360
rho	0.774			0.688		
N	1,098			732		
R^2	0.9919			0.9953		
PseudoR^2	0.9832			0.9860		

Table B.3 OIT SFACD Opex Cost Function Models

	Long Period (2006–2023)			*Short Period (2012–2023)*		
	Coeff	*std. err.*	*t–ratio*	*Coeff*	*std. err.*	*t–ratio*
ly1	0.274	0.075	3.670	0.141	0.129	1.100
ly2	0.174	0.036	4.830	0.377	0.064	5.880
ly3	0.535	0.075	7.110	0.411	0.098	4.200
lz1	–0.074	0.036	–2.060	0.118	0.063	1.870
yr	0.011	0.001	11.650	0.002	0.001	1.440
jur2	0.041	0.112	0.370	–0.192	0.119	–1.610
jur3	–0.110	0.105	–1.060	–0.172	0.133	–1.290
ont_ly2	0.003	0.043	0.070	0.018	0.044	0.410
ont_lz1	–0.200	0.047	–4.310	–0.232	0.070	–3.310
_cons	–11.635	1.855	–6.270	5.850	2.985	1.960
/mu	0.128	0.152	0.840	0.370	0.085	4.380
/lnsigma2	–2.444	0.436	–5.600	–3.116	0.178	–17.460
/lgtgamma	1.473	0.538	2.740	0.913	0.257	3.550
sigma2	0.087	0.038		0.044	0.008	
gamma	0.814	0.082		0.714	0.053	
sigma_u2	0.071	0.038		0.032	0.008	
sigma_v2	0.016	0.001		0.013	0.001	
N	1,098			732		
LLH	599.632			458.315		
PseudoR^2	0.9912			0.9931		

Monotonicity Violations

In the OIT specification, the Cobb-Douglas models do not have any monotonicity violations. For the Translog models, Tables B.4 and B.5 present the frequency of MVs and SMVs for the OIT LSETLG model in both the long and short periods. Figures A.1 and A.2 compare the frequency of MVs in the OIT LSETLG with those from the standard models.

The analysis reveals mixed results. In the long period, MVs decreased in the OIT LSETLG model compared to the standard model. For Australian DNSPs, MVs decreased from 22.2 per cent to 0 per cent, and from 21.9 per cent to 16.4 per cent for the total sample. No DNSPs are excluded in the OIT model, whereas AGD, CIT, and UED are excluded in the standard model. This also represents a slight improvement over the JTT LSETLG model in the long period.

In contrast, in the short period, MVs worsened in the OIT LSETLG model. For Australian DNSPs, MVs increased from 48.7 per cent to 89.1 per cent, and from 36.6 per cent to 50.5 per cent for the total sample. The entire OIT short-period LSETLG sample is excluded, while only six DNSPs are excluded in the standard model. This reflects a significant deterioration compared to the JTT LSETLG model in the short period.

Table B.4 LSETLG Model: Frequency of Monotonicity Violations (%) - Long Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NZ	0.00	0.00	37.43	37.43	0.00	0.00	0.00	0.00
Ontario	0.00	6.90	0.00	6.90	0.00	0.00	0.00	0.00
Total	0.00	3.28	11.66	14.94	0.00	0.00	0.00	0.00
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- CIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- END	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ENX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ERG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- ESS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- JEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- PCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- SAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- TND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- UED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.5 LSETLG Model: Frequency of Monotonicity Violations (%) - Short Period

	MVs				*Significant MVs*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	81.41	7.69	0.00	89.10	0.00	0.00	0.00	0.00
NZ	12.72	0.00	60.09	70.61	0.00	0.00	15.79	15.79
Ontario	6.32	13.79	0.00	20.11	0.00	3.45	0.00	3.45
Total	24.32	8.20	18.72	50.55	0.00	1.64	4.92	6.56
Aust:								
- EVO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
- AGD	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- CIT	0.00	100.00	0.00	100.00	0.00	0.00	0.00	0.00
- END	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- ENX	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- ERG	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- ESS	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- JEN	58.33	0.00	0.00	58.33	0.00	0.00	0.00	0.00
- PCR	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- SAP	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- AND	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- TND	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
- UED	100.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00

Figure B.1 Frequency of Monotonicity Violations: OIT LSETLG - Long Period

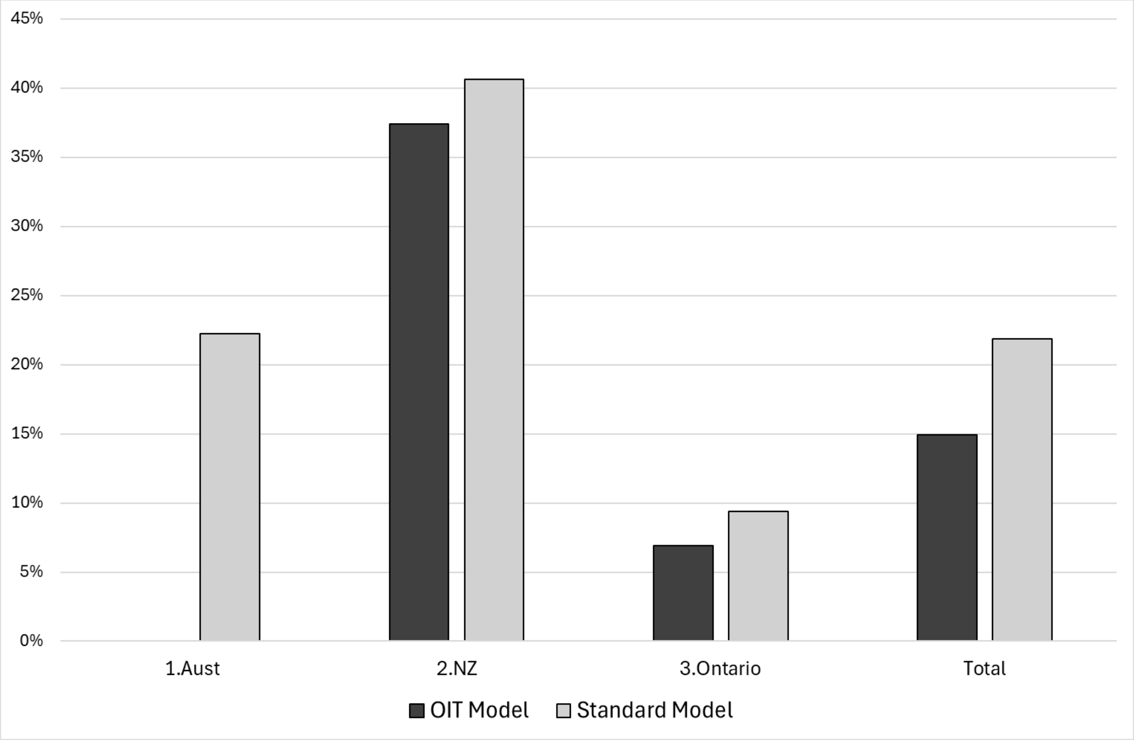
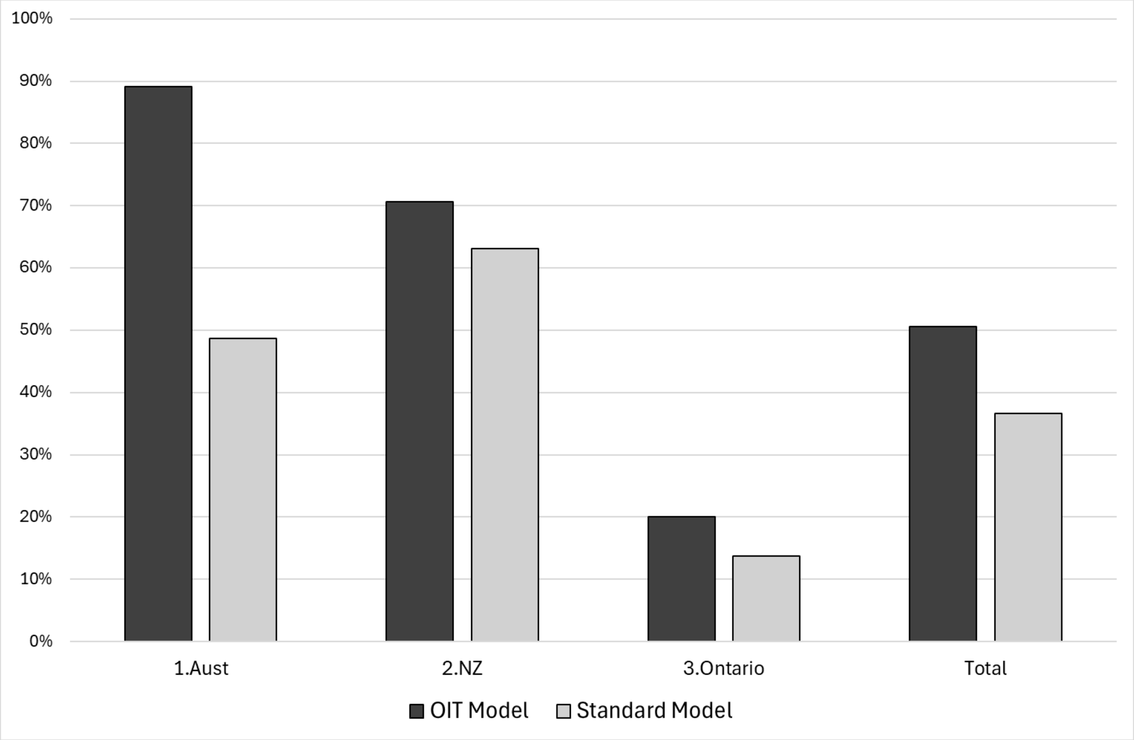


Figure B.2 Frequency of Monotonicity Violations: OIT LSETLG - Short Period



B.2 Efficiency Scores

Tables B.6 and B.57 present OIT efficiency scores for the long and short periods. Figures B.3 and B.4 compare the efficiency scores of the OIT and standard models. These figures show large inconsistencies between the LSE models of the OIT and the standard specifications in both long and short periods.

Table B.6 OIT Models: Efficiency Scores –Long Period (2006–2023)

	LSECD		*LSETLG*		*SFACD*		*AVERAGE*	
	Eff	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*
EVO	0.632	10	0.617	10	0.544	13	0.598	11
AGD	0.613	11	0.561	12	0.636	10	0.603	10
CIT	0.955	2	1.000	1	0.921	4	0.959	1
END	0.728	8	0.695	6	0.753	7	0.725	8
ENX	0.721	9	0.647	9	0.745	8	0.704	9
ERG	0.503	13	0.509	13	0.576	12	0.530	13
ESS	0.583	12	0.599	11	0.596	11	0.593	12
JEN	0.829	7	0.667	8	0.725	9	0.740	7
PCR	0.930	4	0.768	4	0.961	2	0.887	4
SAP	0.953	3	0.950	2	0.963	1	0.955	2
AND	0.840	6	0.677	7	0.760	6	0.759	6
TND	0.886	5	0.745	5	0.877	5	0.836	5
UED	1.000	1	0.774	3	0.960	3	0.911	3
AVG	0.782		0.708		0.771		0.754	

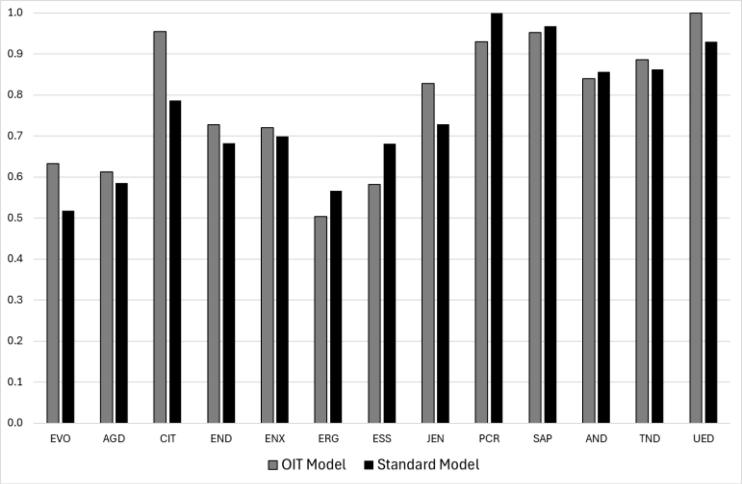
Table B.7 OIT Models: Efficiency Scores –Short Period (2012–2023)

	LSECD		*LSETLG**		*SFACD*		*AVERAGE*	
	Eff	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*
EVO	0.596	11	0.638	7	0.578	12	0.587	11
AGD	0.606	10	0.544	12	0.580	10	0.593	10
CIT	0.871	4	1.000	1	0.749	5	0.810	5
END	0.702	8	0.704	3	0.727	6	0.714	7
ENX	0.670	9	0.594	9	0.678	7	0.674	9
ERG	0.530	13	0.592	10	0.563	13	0.547	13
ESS	0.586	12	0.602	8	0.580	11	0.583	12
JEN	0.779	7	0.570	11	0.598	9	0.689	8
PCR	0.935	2	0.654	6	0.829	2	0.882	3
SAP	0.855	5	0.907	2	0.930	1	0.892	1
AND	0.793	6	0.535	13	0.671	8	0.732	6
TND	0.876	3	0.674	4	0.808	3	0.842	4
UED	1.000	1	0.668	5	0.775	4	0.887	2
AVG	0.754		0.668*		0.697		0.726	

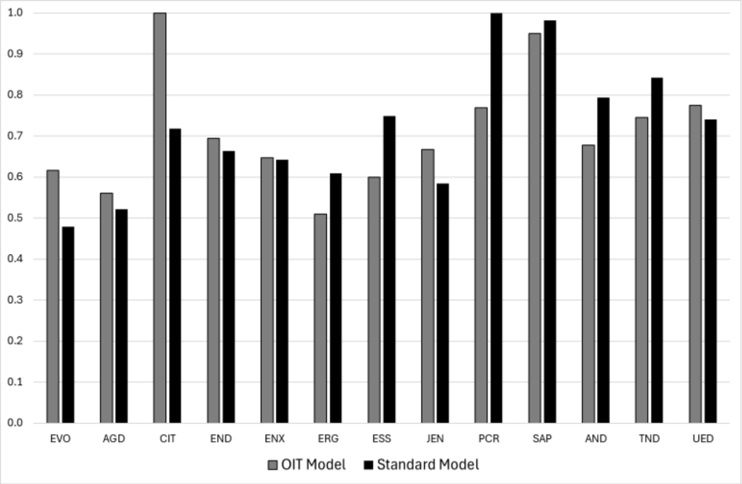
* Model excluded from the average due monotonicity violations.

Figure B.3 Efficiency Scores Comparison - Long Period (2006-2023)

LSECD



LSETLG



SFACD

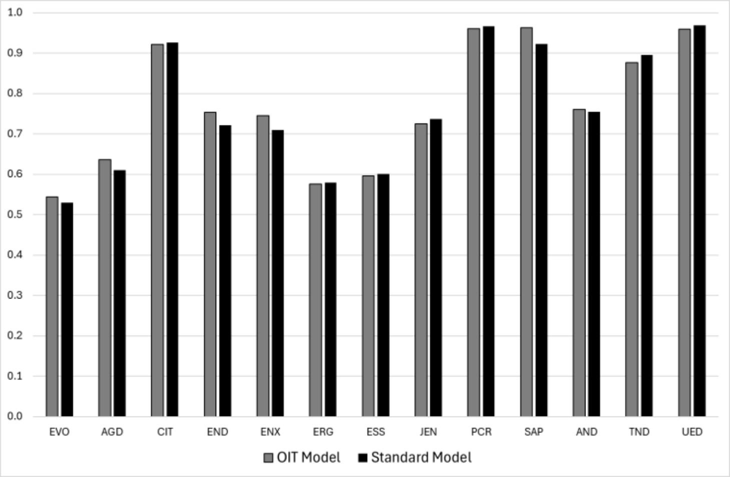
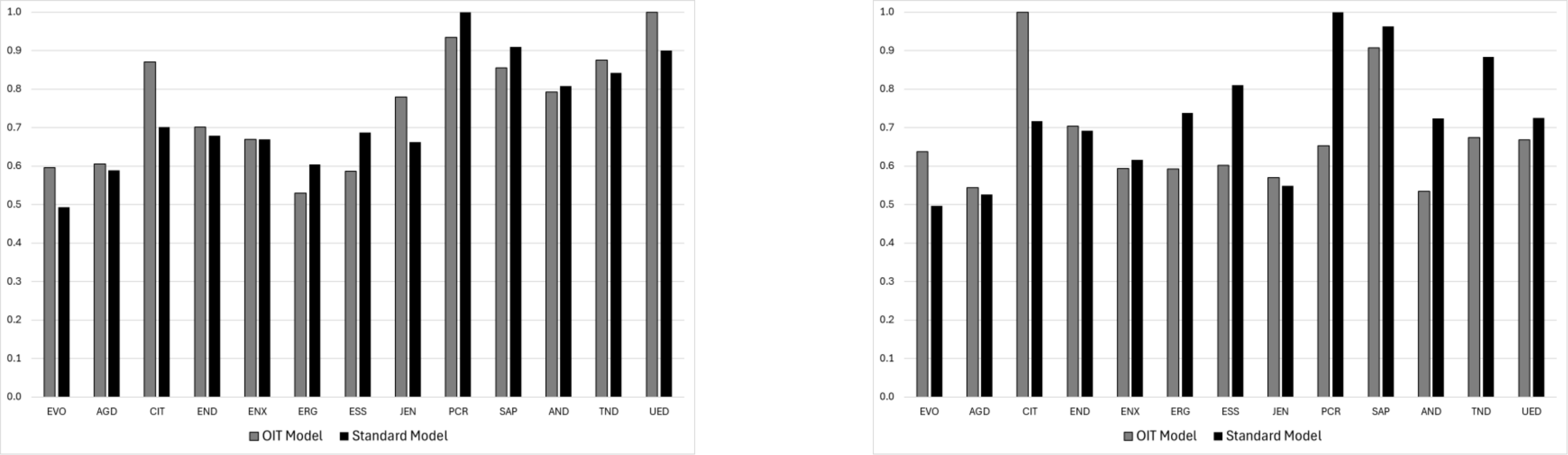
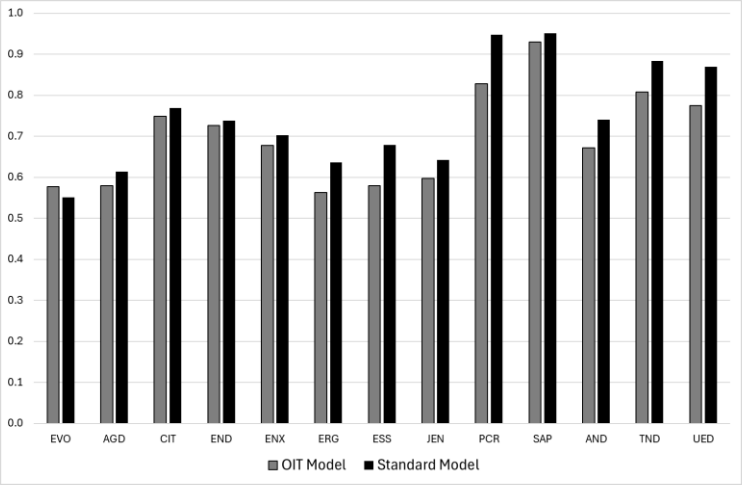


Figure B.4 Efficiency Scores Comparison - Short Period (2012-2023)



LSECD

LSETLG



SFACD

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