Quantonomics

QUANTITATIVE ECONOMICS

Memorandum

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Subject:	Opex Cost Function–Options to Address Performance Issues of Translog Models

1 Introduction

This memo examines options for further development of the opex cost function used in benchmarking distribution network service providers (DNSP), specifically focussed on:

- addressing shortcomings of the SFATLG model when using the latest dataset updates, specifically relating to the estimated total output elasticity for Australian DNSPs and some efficiency score estimates (eg, for AGD); and
- ameliorating the problem of monotonicity violations. This is directed to addressing the concerns of several DNSPs about the comparability of benchmarking scores between DNSPs, or from year to year for a given DNSP, when some TLG models may be excluded for monotonicity reasons from the average efficiency calculation.

Our approach to the first issue involves testing a modified specification of the opex cost model which adds an Australian DNSP-only time trend, that may be somewhat better behaved. In approaching the second issue, this memo takes two directions. Firstly, it considers the question of whether there would be merit in lowering the standard for defining a monotonicity violation to a 'significant monotonicity violation'. Secondly, it follows on from Quantonomics (2022a) which considered several so-called hybrid models, which are Translog models with constraints imposed by omitting selected higher-order terms. Responding to comments on the 2022 memo, we explore a hybrid model which seems to make intuitive sense.

This memo has the following parts:

- Section 2 discusses the definition of monotonicity violations, introducing the notion of statistically significant monotonicity violations. The implications of the alternative definition are examined.
- Section 3 examines a modification to the opex cost function in which an additional time trend variable, specific to the Australian jurisdiction, is included in the model. This allows the underlying time trend of opex to differ on average for Australian DNSPs compared to those in New Zealand and Ontario.

- Section 4 develops a Restricted Translog model that may be suitable to replace the full Translog models when the latter cannot be used because they violate economic principles, such as excessive monotonicity violations. This section includes a brief outline of the submissions to the 2022 memo.
- Section 5 discusses issues raised by Frontier Economics in recent advice prepared for Evoenergy and Ausgrid relating to the maximisation of the likelihood function in the SFATLG model.

2 Alternative definition of monotonicity violations

This section considers an alternative, lower standard, for defining monotonicity violations. This section and section 4 are both directed to the issue—raised by several stakeholders—of the comparability of benchmarking scores between DNSPs, or from year to year, when some TLG models may be excluded for monotonicity reasons from the average efficiency calculation.

At present, an observation is defined as a monotonicity violation if one or more of the estimated elasticities of real opex with respect to each output is negative. An alternative, lower standard, would be to define of a monotonicity violation as where an estimated elasticity of real opex with respect to any output is both negative and significantly different from zero [1] Hereafter, an observation that meets these two criteria is referred to as a 'significant monotonicity violation'. Under this definition, elasticities of real opex with respect to output may be regarded as effectively equal to zero in the case where they are not significantly different from zero at the 0.05 level of significance.

2.1 Comparison of Frequency

We have tested the monotonicity outcomes under this alternative definition, both with the dataset used in the 2022 benchmarking study, and the datasets used in the 2023 draft study. In the following tables, we compare the frequency of monotonicity violations as currently defined against the frequency of significant monotonicity violations. They are not separately shown by output, only whether an observation has a monotonicity violation or not.

Tables 2.1 and 2.2 present the frequency of monotonicity violations in models presented in the 2022 benchmarking review, for the long and short sample periods respectively. These comparisons show that the great majority of monotonicity violations are not significantly different from zero.

[1] We have used a two-tailed test at the 0.05 level of significance for the second arm of this definition. That is, an estimate is significantly different from zero if its absolute value is greater than 1.96 times the standard error of that estimate.

Table 2.1 Frequency of monotonicity violations by DNSP 2006-2021

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	0.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	0.0%	0.0%	0.0%
ERG	0.0%	0.0%	0.0%	0.0%
ESS	0.0%	0.0%	0.0%	0.0%
JEN	0.0%	0.0%	0.0%	0.0%
PCR	0.0%	0.0%	0.0%	0.0%
SAP	0.0%	0.0%	0.0%	0.0%
AND	0.0%	0.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	0.0%	0.0%	0.0%	0.0%
Total Australia	0.0%	0.0%	0.0%	0.0%
New Zealand	43.4%	14.8%	0.0%	0.0%
Ontario	0.4%	15.1%	0.0%	0.0%
Full sample	12.5%	12.1%	0.0%	0.0%

Table 2.2 Frequency of monotonicity violations by DNSP 2012-2021

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	70.0%	0.0%	0.0%
AGD	100.0%	100.0%	0.0%	100.0%
CIT	100.0%	100.0%	0.0%	0.0%
END	0.0%	100.0%	0.0%	0.0%
ENX	100.0%	100.0%	0.0%	0.0%
ERG	0.0%	20.0%	0.0%	0.0%
ESS	0.0%	0.0%	0.0%	0.0%
JEN	100.0%	100.0%	0.0%	0.0%
PCR	0.0%	70.0%	0.0%	0.0%
SAP	0.0%	10.0%	0.0%	0.0%
AND	50.0%	100.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	100.0%	100.0%	0.0%	30.0%
Australia	42.3%	66.9%	0.0%	10.0%
New Zealand	57.4%	62.1%	10.5%	10.5%
Ontario	8.1%	25.7%	0.0%	0.0%
Full sample	28.8%	44.1%	3.0%	5.0%

Tables 2.3 to 2.6 present the frequency of significant monotonicity violations in the models presented in the 2023 benchmarking review draft report. Tables 2.3 and 2.4 present the monotonicity results for models with the standard definition of opex, for the long and short periods respectively.

The frequency of monotonicity violations for Australian DNSPs in each model is as follows:

- *Standard opex long sample period*:
  - Monotonicity violations: LSETLG, 19.5 per cent; SFATLG, 29.4 per cent;
  - Significant monotonicity violations: 0.0 per cent for both models.
- *Standard opex short sample period:*
  - Monotonicity violations: LSETLG, 46.9 per cent; SFATLG, 72.7 per cent;
  - Significant monotonicity violations: LSETLG, 0.0 per cent; SFATLG 7.7 per cent.

This shows that the majority of observations that are monotonicity violations using the standard definition are not significantly different from zero. There are no significant monotonicity violations for Australian DNSPs in the long sample period, and comparatively few significant monotonicity violations for Australian DNSPs in the shorter sample period.

Table 2.3 Frequency of monotonicity violations by DNSP 2006-2022 (standard opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	23.5%	17.6%	0.0%	0.0%
CIT	76.5%	0.0%	0.0%	0.0%
END	0.0%	35.3%	0.0%	0.0%
ENX	0.0%	11.8%	0.0%	0.0%
ERG	0.0%	100.0%	0.0%	0.0%
ESS	0.0%	100.0%	0.0%	0.0%
JEN	52.9%	0.0%	0.0%	0.0%
PCR	0.0%	17.6%	0.0%	0.0%
SAP	0.0%	100.0%	0.0%	0.0%
AND	0.0%	0.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	100.0%	0.0%	0.0%	0.0%
Total Australia	19.5%	29.4%	0.0%	0.0%
New Zealand	40.9%	44.6%	0.0%	0.0%
Ontario	0.0%	50.6%	0.0%	2.9%
Full sample	15.4%	44.8%	0.0%	1.5%

Table 2.4 Frequency of monotonicity violations by DNSP 2012-2022 (standard opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	90.9%	0.0%	0.0%
AGD	100.0%	100.0%	0.0%	100.0%
CIT	100.0%	100.0%	0.0%	0.0%
END	36.4%	100.0%	0.0%	0.0%
ENX	100.0%	100.0%	0.0%	0.0%
ERG	0.0%	0.0%	0.0%	0.0%
ESS	0.0%	0.0%	0.0%	0.0%
JEN	100.0%	100.0%	0.0%	0.0%
PCR	0.0%	100.0%	0.0%	0.0%
SAP	0.0%	54.5%	0.0%	0.0%
AND	72.7%	100.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	100.0%	100.0%	0.0%	0.0%
Australia	46.9%	72.7%	0.0%	7.7%
New Zealand	58.4%	53.6%	0.0%	0.0%
Ontario	9.0%	17.2%	11.0%	0.0%
Full sample	30.6%	38.5%	3.2%	1.5%

Tables 2.5 and 2.6 show the monotonicity results for the models with opex defined according to ‘Option 5’, where opex for benchmarking purposes is defined to include capitalised corporate overheads (CCOs), for the long and short periods respectively. The frequency of monotonicity violations for Australian DNSPs in each model is as follows:

- *Standard opex long sample period*:
    - Monotonicity violations: LSETLG, 10.0 per cent; SFATLG, 42.1 per cent;
    - Significant monotonicity violations: 0.0 per cent for both models.
- *Standard opex short sample period:*
    - Monotonicity violations: LSETLG, 49.7 per cent; SFATLG, 74.1 per cent;
    - Significant monotonicity violations: LSETLG, 0.0 per cent; SFATLG 15.4 per cent.

This result again shows that only a small proportion of monotonicity violations are significantly different from zero. The monotonicity results using opex defined to include CCO does not have a large effect on the frequency of monotonicity violations.

Table 2.5 Frequency of monotonicity violations by DNSP 2006-2022 (option 5 opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	100.0%	0.0%	0.0%
CIT	29.4%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	0.0%	0.0%	0.0%
ERG	0.0%	100.0%	0.0%	0.0%
ESS	0.0%	100.0%	0.0%	0.0%
JEN	23.5%	41.2%	0.0%	0.0%
PCR	0.0%	5.9%	0.0%	0.0%
SAP	0.0%	100.0%	0.0%	0.0%
AND	0.0%	0.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	76.5%	100.0%	0.0%	0.0%
Total Australia	10.0%	42.1%	0.0%	0.0%
New Zealand	37.2%	38.4%	0.0%	0.0%
Ontario	0.0%	0.0%	0.0%	4.4%
Full sample	12.5%	51.3%	0.0%	2.3%

Table 2.6 Frequency of monotonicity violations by DNSP 2012-2022 (option 5 opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	54.5%	0.0%	0.0%
AGD	100.0%	100.0%	0.0%	100.0%
CIT	100.0%	100.0%	0.0%	0.0%
END	54.5%	100.0%	0.0%	0.0%
ENX	100.0%	100.0%	0.0%	100.0%
ERG	0.0%	0.0%	0.0%	0.0%
ESS	0.0%	9.1%	0.0%	0.0%
JEN	100.0%	100.0%	0.0%	0.0%
PCR	0.0%	100.0%	0.0%	0.0%
SAP	0.0%	100.0%	0.0%	0.0%
AND	90.9%	100.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	100.0%	100.0%	0.0%	0.0%
Australia	49.7%	74.1%	0.0%	15.4%
New Zealand	58.9%	52.6%	10.0%	0.0%
Ontario	9.3%	20.7%	0.0%	0.5%
Full sample	31.4%	40.3%	2.9%	3.3%

2.2 Summary conclusions

This section has raised the question of whether there would be merit in lowering the standard for defining a monotonicity violation to include only those observations with an estimated output elasticity that is both negative and significantly different from zero.

3 Alternative time trend specification

This section responds to the issue of the deterioration of the monotonicity performance of the TLG models with the sample extended to include 2022 data, by testing a modified model specification, which has an additional time trend term.

Firstly, there is an issue associated with the SFATLG model applied to the 2023 data which is manifested in the unreasonably low total output elasticity for Australian DNSPs. The SFATLG model produces a total output elasticity estimate for Australian DNSPs of 0.69. This is an anomaly since past studies have consistently shown that the total output elasticity is close to 1, and the estimate produced by the LSETLG model of 1.03 is consistent with this. The SFATLG also produces some anomalous efficiency scores in some cases.

Secondly, there is a deterioration in monotonicity performance. The deterioration in monotonicity performance is as follows. With both the 2022 data and the 2023 data, the monotonicity performance for the TLG models when using the short sample period has been especially poor. There are excessive monotonicity violations for many Australian DNSPs and there has been a relatively small deterioration in the 2023 data sample.[2] However, for the long sample periods the TLG models had no monotonicity violations in the 2022 study. The deterioration here is more significant because in the 2023 draft report there is a substantial number.[3] The LSETLG and SFATLG models have monotonicity violations in 19.5 per cent and 29.4 per cent of observations on Australian DNSPs, respectively.

3.1 Testing a modified model specification

The time trend in the models is intended to capture the effects of technical change on opex over time. However, it inevitably captures a range of other factors that vary over time but are

[2] For the short sample period models in the 2022 report, the LSETLG and SFATLG models had monotonicity violations in 28.8 per cent and 44.1 per cent of all observations, respectively. For Australian DNSPs the corresponding frequencies were 42.3 per cent and 66.9 per cent. In the 2023 draft report, in the short sample period and using standard opex, the LSETLG and SFATLG models had monotonicity violations in 30.6 per cent and 38.5 per cent of observations overall, respectively. For Australian DNSPs the corresponding frequencies were 46.9 per cent and 72.7 per cent, respectively.

[3] In the 2022 report, for the long sample period, the LSETLG and SFATLG models had monotonicity violations in 12.5 per cent and 12.1 per cent of observations overall, respectively. For Australian DNSPs the corresponding frequencies were 0.0 per cent in each case. In the 2023 draft report, again for the long sample period and using standard opex, the LSETLG and SFATLG models had monotonicity violations in 15.4 per cent and 44.8 per cent of observations overall, respectively. For Australian DNSPs the corresponding frequencies were 19.5 per cent and 29.4 per cent, respectively.

not explicitly accounted for in the model. For example, changes in technical or performance standards, regulatory frameworks and obligations, and/or environmental conditions. For this reason, the time trend effect may differ between jurisdictions.

This section presents a modified model specification which has a separate additional time trend for Australian DNSPs only. This variable is an interaction between the main time trend variable and a jurisdictional dummy variable for Australia. This is the only change to the model specification. This approach is a parsimonious way of introducing additional flexibility into the time trend specification. Parsimony is desirable to avoid undue multicollinearity, which may make inferences from the model less reliable.

Section 3.2 presents the results of this model using the standard definition of opex in both the long and short sample periods. Section 3.3 presents the results when opex is defined to include capitalised corporate overheads (CCOs).

3.2 Results – Standard opex

The LSE models use panel-corrected standard errors. The SFA models assume a truncated-normal distribution of inefficiencies.

3.2.1 Long-period results

The models that use the long sample period have 1,137 observations over 69 DNSPs. The two Cobb-Douglas (CD) models are presented in Table 3.1 and the two Translog (TLG) models in Table 3.2. The first observation to make is that the additional time trend variable for Australia is statistically significant in all regressions.

For the TLG models shown in Table 3.2, the hypothesis tests that the six higher-order output terms are jointly equal to zero requires the p-value of the null hypothesis to exceed 0.05. In the LSETLG model the p-value of the null hypothesis is 0.0000, and in the SFATLG model the corresponding p-value is 0.0006, meaning in both models the additional higher-order terms of the TLG model are jointly statistically significant.

Table 3.1 Aust. Time Trend Models, 2006 to 2022 (standard opex)

	LSECD			*SFACD*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.571	0.066	8.66	0.408	0.076	5.35
ln(CircLen)=x2	0.171	0.029	5.85	0.152	0.040	3.82
ln(RMDemand)=x3	0.231	0.060	3.86	0.414	0.065	6.33
ln(ShareUGC)	-0.135	0.023	-5.90	-0.134	0.033	-4.09
Year	0.013	0.002	7.85	0.014	0.001	15.10
New Zealand	-0.322	0.139	-2.33	0.056	0.094	0.60
Ontario	-0.170	0.136	-1.25	0.089	0.071	1.25
Aust. trend	-0.015	0.004	-3.62	-0.016	0.002	-8.66
AGD	-0.010	0.182	-0.05			

	LSECD			SFACD		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
CIT	-0.632	0.155	-4.08			
END	-0.231	0.150	-1.55			
ENX	-0.231	0.144	-1.60			
ERG	-0.160	0.159	-1.01			
ESS	-0.313	0.170	-1.85			
JEN	-0.337	0.157	-2.14			
PCR	-0.708	0.151	-4.70			
SAP	-0.481	0.155	-3.11			
AND	-0.395	0.154	-2.57			
TND	-0.458	0.160	-2.86			
UED	-0.487	0.152	-3.21			
Constant	10.147	0.137	73.86	9.492	0.087	108.77
Mu				0.333	0.058	5.75
R^2	0.992			n.a.		
N	1137			1137		

Table 3.2 Aust. Time Trend Models, 2006 to 2022 (standard opex)

	LSETLG			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.419	0.070	5.99	0.451	0.075	6.04
ln(CircLen)=x2	0.176	0.030	5.92	0.082	0.042	1.97
ln(RMDemand)=x3	0.359	0.058	6.15	0.410	0.071	5.74
x1*x1/2	-0.526	0.457	-1.15	0.992	0.449	2.21
x1*x2	0.327	0.110	2.96	-0.119	0.124	-0.96
x1*x3	0.181	0.353	0.51	-0.702	0.363	-1.93
x2*x2/2	-0.036	0.041	-0.89	0.030	0.068	0.45
x2*x3	-0.272	0.089	-3.04	0.112	0.096	1.17
x3*x3/2	0.148	0.274	0.54	0.449	0.307	1.46
ln(ShareUGC)	-0.123	0.027	-4.61	-0.117	0.039	-3.02
Year	0.015	0.002	9.01	0.014	0.001	13.00
New Zealand	-0.425	0.133	-3.20	0.161	0.068	2.36
Ontario	-0.31	0.131	-2.38	0.102	0.08	1.28
Aust. trend	-0.017	0.004	-4.21	-0.020	0.002	-9.14
AGD	-0.149	0.186	-0.80			
CIT	-0.659	0.149	-4.42			
END	-0.369	0.147	-2.51			
ENX	-0.369	0.147	-2.51			
ERG	-0.244	0.173	-1.41			
ESS	-0.496	0.183	-2.71			
JEN	-0.222	0.159	-1.39			
PCR	-0.829	0.149	-5.56			
SAP	-0.625	0.156	-4.00			
AND	-0.464	0.154	-3.01			

	LSETLG			*SFATLG*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
TND	-0.488	0.154	-3.18			
UED	-0.417	0.158	-2.64			
Constant	10.19	0.132	77.16	9.467	0.095	100.08
Mu				0.196	0.124	1.58
R^2	0.992			n.a.		
N	1137			1137		

Table 3.3 reports the output elasticities of all four models. In the LSECD and SFACD models, the average output elasticities are 0.97 in both cases. In the LSETLG and SFATLG models, the average output elasticities for the whole sample are 0.95 and 0.94 respectively. For Australian DNSPs, the average output elasticities in these models, are 1.06 and 1.07 respectively. This result implies that the average Australian DNSP is slightly larger than the most efficient scale, whereas overseas DNSPs are slightly smaller than the most efficient scale on average. This result is reasonable since the Australian DNSPs are on average larger than the sample average. Furthermore, in all the models, the average output elasticities for the individual outputs are positive, as required by the theory underlying the model specification.

Table 3.4 shows the frequency of monotonicity violations using the TLG specification with standard opex and the long sample period. For Australian DNSPs, with the LSETLG model 8.6 per cent of observations are monotonicity violations. With the SFATLG model 27.6 per cent of observations on Australian DNSPs are monotonicity violations. However, there are no significant monotonicity violations for Australian DNSPs in either model.

Table 3.3 Aust. Time Trend Models: Output elasticities, 2006 to 2022 (standard opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSECD				
Full sample	0.571	0.171	0.231	0.973
LSETLG by jurisdiction				
Australia	0.438	0.239	0.381	1.059
New Zealand	0.661	0.209	0.051	0.921
Ontario	0.280	0.134	0.518	0.932
Full sample	0.419	0.176	0.359	0.954
SFACD				
Full sample	0.408	0.152	0.414	0.974
SFATLG by jurisdiction				
Australia	0.841	0.118	0.111	1.070
New Zealand	0.446	0.064	0.462	0.972
Ontario	0.308	0.078	0.494	0.880
Full sample	0.451	0.082	0.410	0.943

Table 3.4 Aust. Time Trend Models: Monotonicity violations, 2006-2022 (standard opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	100.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	70.6%	0.0%	0.0%
ERG	17.6%	0.0%	0.0%	0.0%
ESS	94.1%	0.0%	0.0%	0.0%
JEN	0.0%	41.2%	0.0%	0.0%
PCR	0.0%	0.0%	0.0%	0.0%
SAP	0.0%	0.0%	0.0%	0.0%
AND	0.0%	47.1%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	0.0%	100.0%	0.0%	0.0%
Total Australia	8.6%	27.6%	0.0%	0.0%
New Zealand	38.4%	3.1%	0.6%	0.0%
Ontario	0.5%	3.5%	0.0%	0.0%
Full sample	12.8%	8.1%	0.2%	0.0%

The efficiency scores estimated by the four models are presented in Table 3.5. In the LSECD and SFACD models, the average output elasticities. The average efficiency score of the four models (irrespective of whether there are excessive monotonicity violations) is also shown.

Table 3.5 Aust. Time Trend Models: Efficiency scores, 2006-2022 (standard opex)

Sample	*LSECD*	*LSETLG*	*SFACD*	*SFATLG*	*Average*
EVO	0.493	0.437	0.503	0.486	0.480
AGD	0.497	0.507	0.492	0.547	0.511
CIT	0.927	0.844	0.950	0.938	0.915
END	0.621	0.632	0.634	0.631	0.629
ENX	0.620	0.632	0.626	0.687	0.641
ERG	0.578	0.557	0.591	0.562	0.572
ESS	0.674	0.717	0.616	0.629	0.659
JEN	0.690	0.545	0.663	0.716	0.654
PCR	1.000	1.000	0.966	0.977	0.986
SAP	0.797	0.816	0.784	0.797	0.798
AND	0.732	0.694	0.673	0.733	0.708
TND	0.779	0.711	0.793	0.713	0.749
UED	0.802	0.663	0.801	0.895	0.790
Australia	0.708	0.673	0.699	0.716	0.699

3.2.2 Short-period results

The models in this section all have 729 observations over 69 DNSPs. The LSE models use panel-corrected standard errors. The SFA models assume a truncated-normal distribution of inefficiencies. The two Cobb-Douglas (CD) models are presented in Table 3.6. The two Translog (TLG) models are presented in Table 3.7.

The additional time trend variable for Australia is statistically significant in all regressions. Again, the parameters on the jurisdictional indicators for New Zealand and Ontario are almost identical in every case. For the hypothesis tests that the six higher-order output terms are jointly equal to zero, in both the LSETLG and SFATLG models the p-value of the null hypothesis is 0.0000. This means that in both models the additional higher-order terms of the TLG model are jointly statistically significant.

Table 3.8 reports the output elasticities of all four models. In the LSECD and SFACD models, the average output elasticities are 0.98 and 0.96 respectively. In the LSETLG and SFATLG models, the average output elasticities for the whole sample are 0.96 and 0.97 respectively. For Australian DNSPs, the average output elasticities in these models, are both 1.04. An important problem with the SFTLG model is that the elasticity of output with respect to RMD is negative on average. This is inconsistent with economic theory, and means that the SFATLG model is not viable. There are also some smaller negative output weights for the overseas DNSPs in the LSETLG and SFATLG models.

Table 3.6 Aust. Time Trend Models, 2012 to 2022 (standard opex)

	LSECD			*SFACD*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.602	0.071	8.48	0.523	0.087	5.992
ln(CircLen)=x2	0.198	0.03	6.48	0.258	0.045	5.685
ln(RMDemand)=x3	0.179	0.067	2.67	0.182	0.086	2.124
ln(ShareUGC)	-0.135	0.025	-5.37	-0.021	0.040	-0.529
Year	0.011	0.002	4.34	0.010	0.001	6.607
New Zealand	-0.406	0.158	-2.57	-0.137	0.093	-1.469
Ontario	-0.233	0.155	-1.51	0.068	0.091	0.748
Aust. trend	-0.039	0.006	-6.93	-0.041	0.003	-13.974
AGD	-0.074	0.185	-0.40			
CIT	-0.550	0.162	-3.40			
END	-0.284	0.163	-1.74			
ENX	-0.237	0.162	-1.46			
ERG	-0.244	0.175	-1.40			
ESS	-0.342	0.176	-1.94			
JEN	-0.347	0.167	-2.08			
PCR	-0.751	0.166	-4.53			
SAP	-0.464	0.169	-2.74			
AND	-0.365	0.169	-2.17			

	LSECD			SFACD		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
TND	-0.482	0.183	-2.64			
UED	-0.504	0.169	-2.99			
Constant	10.346	0.156	66.19	9.836	0.100	98.07
Mu				0.355	0.065	5.50
R^2	0.995			n.a.		
N	729			729		

Table 3.7 Aust. Time Trend Models, 2012 to 2022 (standard opex)

	LSETLG			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.453	0.073	6.209	0.366	0.108	3.38
ln(CircLen)=x2	0.207	0.029	7.052	0.261	0.051	5.10
ln(RMDemand)=x3	0.303	0.061	4.958	0.340	0.095	3.59
x1*x1/2	-0.398	0.513	-0.775	0.787	0.577	1.36
x1*x2	0.281	0.116	2.418	0.307	0.155	1.98
x1*x3	0.106	0.390	0.271	-0.907	0.458	-1.98
x2*x2/2	0.016	0.040	0.402	0.011	0.073	0.15
x2*x3	-0.293	0.093	-3.135	-0.309	0.115	-2.69
x3*x3/2	0.239	0.297	0.804	1.042	0.377	2.76
ln(ShareUGC)	-0.114	0.026	-4.441	-0.002	0.053	-0.04
Year	0.013	0.002	5.399	0.012	0.002	7.72
New Zealand	-0.513	0.140	-3.664	-0.120	0.102	-1.17
Ontario	-0.344	0.137	-2.509	0.035	0.093	0.38
Aust. trend	-0.041	0.006	-7.198	-0.048	0.003	-14.37
AGD	-0.179	0.179	-1.000			
CIT	-0.606	0.144	-4.205			
END	-0.383	0.148	-2.582			
ENX	-0.335	0.154	-2.166			
ERG	-0.315	0.177	-1.775			
ESS	-0.512	0.181	-2.834			
JEN	-0.235	0.16	-1.475			
PCR	-0.831	0.155	-5.364			
SAP	-0.567	0.159	-3.571			
AND	-0.402	0.162	-2.475			
TND	-0.493	0.163	-3.022			
UED	-0.440	0.164	-2.689			
Constant	10.375	0.138	75.134	9.671	0.156	61.97
Mu				0.450	0.114	3.96
R^2	0.995			n.a.		
N	729			729		

Table 3.8 Aust. Time Trend Models: Output elasticities, 2012 to 2022 (standard opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSECD				
Full sample	0.602	0.198	0.179	0.979
LSETLG by jurisdiction				
Australia	0.480	0.260	0.302	1.042
New Zealand	0.674	0.292	-0.037	0.928
Ontario	0.320	0.140	0.492	0.952
Full sample	0.453	0.207	0.303	0.963
SFACD				
Full sample	0.523	0.258	0.182	0.964
SFATLG by jurisdiction				
Australia	0.915	0.323	-0.202	1.035
New Zealand	0.750	0.342	-0.088	1.004
Ontario	-0.056	0.192	0.782	0.918
Full sample	0.366	0.261	0.340	0.966

Table 3.9 shows the frequency of monotonicity violations using the TLG specification with standard opex and the short sample period. For Australian DNSPs, with the LSETLG model 15.4 per cent of observations are monotonicity violations. With the SFATLG model 77.6 per cent of observations on Australian DNSPs are monotonicity violations. While there are no significant monotonicity violations for Australian DNSPs in the LSETLG model, in the SFATLG model, 36.4 per cent of the observations for Australian DNSPs are significant monotonicity violations. These results again highlight the poor performance of the SFATLG model in the short sample period.

The efficiency scores estimated by the four models are presented in Table 3.10. In the LSECD and SFACD models, the average output elasticities. The average efficiency score of the four models is also shown.

Table 3.9 Aust. Time Trend Models: Monotonicity violations, 2012-2022 (standard opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	100.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	54.5%	0.0%	0.0%
ENX	0.0%	100.0%	0.0%	0.0%
ERG	100.0%	100.0%	0.0%	72.7%
ESS	100.0%	100.0%	0.0%	100.0%
JEN	0.0%	54.5%	0.0%	0.0%
PCR	0.0%	100.0%	0.0%	100.0%
SAP	0.0%	100.0%	0.0%	100.0%
AND	0.0%	100.0%	0.0%	100.0%
TND	0.0%	100.0%	0.0%	0.0%
UED	0.0%	100.0%	0.0%	0.0%
Total Australia	15.4%	77.6%	0.0%	36.4%
New Zealand	60.8%	67.5%	15.8%	15.8%
Ontario	0.0%	65.3%	0.0%	8.2%
Full sample	20.4%	68.3%	4.5%	15.9%

Table 3.10 Aust. Time Trend Models: Efficiency scores, 2012-2022 (standard opex)

Sample	*LSECD*	*LSETLG*	*SFACD*	*SFATLG*	*Average*
EVO	0.472	0.436	0.535	0.438	0.470
AGD	0.508	0.521	0.525	0.475	0.507
CIT	0.818	0.798	0.864	0.730	0.802
END	0.627	0.639	0.672	0.581	0.630
ENX	0.598	0.609	0.647	0.601	0.614
ERG	0.603	0.597	0.596	0.502	0.574
ESS	0.664	0.727	0.642	0.691	0.681
JEN	0.668	0.551	0.662	0.547	0.607
PCR	1.000	1.000	0.954	0.959	0.978
SAP	0.750	0.768	0.800	0.761	0.770
AND	0.680	0.651	0.667	0.712	0.678
TND	0.764	0.713	0.789	0.653	0.730
UED	0.782	0.677	0.780	0.673	0.728
Australia	0.687	0.668	0.702	0.640	0.674

3.3 Results – Option 5 opex

3.3.1 Long-period results

The models in this section all have 1,137 observations over 69 DNSPs. The LSE models use panel-corrected standard errors. The SFA models assume a truncated-normal distribution of inefficiencies. The two Cobb-Douglas (CD) models are presented in Table 3.11. The two Translog (TLG) models are presented in Table 3.12.

Table 3.11 Aust. Time Trend Models, 2006 to 2022 (option 5 opex)

	LSECD			*SFACD*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.566	0.067	8.41	0.413	0.072	5.70
ln(CircLen)=x2	0.173	0.030	5.78	0.142	0.043	3.33
ln(RMDemand)=x3	0.234	0.061	3.85	0.414	0.064	6.51
ln(ShareUGC)	-0.133	0.023	-5.66	-0.144	0.030	-4.75
Year	0.013	0.002	7.70	0.014	0.001	15.67
New Zealand	-0.510	0.129	-3.94	-0.088	0.093	-0.95
Ontario	-0.357	0.126	-2.83	-0.055	0.084	-0.66
Aust. trend	-0.015	0.004	-3.70	-0.016	0.002	-8.57
AGD	-0.187	0.178	-1.05			
CIT	-0.504	0.138	-3.65			
END	-0.317	0.144	-2.21			
ENX	-0.359	0.133	-2.69			
ERG	-0.141	0.154	-0.92			
ESS	-0.313	0.165	-1.90			
JEN	-0.412	0.149	-2.76			
PCR	-0.727	0.141	-5.17			
SAP	-0.668	0.148	-4.50			
AND	-0.531	0.143	-3.72			
TND	-0.545	0.158	-3.44			
UED	-0.669	0.145	-4.62			
Constant	10.338	0.128	80.92	9.639	0.096	100.80
Mu				0.296	0.057	5.18
R^2	0.992			n.a.		
N	1137			1137		

The additional time trend variable for Australia is statistically significant in all regressions. The results for hypothesis tests that the six higher-order output terms are jointly significantly different from zero are as follows. In the LSETLG model the p-value of the null hypothesis is 0.0000, and in the SFATLG model the corresponding p-value is 0.0001, meaning in both models the additional higher-order terms of the TLG model are jointly statistically significant.

Table 3.12 Aust. Time Trend Models, 2006 to 2022 (option 5 opex)

	LSETLG			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.420	0.071	5.892	0.433	0.068	6.337
ln(CircLen)=x2	0.177	0.031	5.802	0.099	0.033	3.022
ln(RMDemand)=x3	0.356	0.059	5.992	0.412	0.070	5.883
x1*x1/2	-0.455	0.464	-0.980	1.075	0.408	2.638
x1*x2	0.306	0.113	2.710	-0.163	0.107	-1.523
x1*x3	0.132	0.358	0.369	-0.774	0.344	-2.247
x2*x2/2	-0.028	0.042	-0.662	0.072	0.056	1.291
x2*x3	-0.259	0.091	-2.835	0.130	0.094	1.377
x3*x3/2	0.181	0.279	0.649	0.504	0.296	1.702
ln(ShareUGC)	-0.119	0.027	-4.356	-0.114	0.037	-3.129
Year	0.015	0.002	8.777	0.014	0.001	12.992
New Zealand	-0.612	0.125	-4.910	0.024	0.079	0.310
Ontario	-0.496	0.122	-4.071	-0.011	0.086	-0.126
Aust. trend	-0.017	0.004	-4.275	-0.019	0.002	-8.711
AGD	-0.327	0.184	-1.777			
CIT	-0.534	0.134	-3.985			
END	-0.453	0.142	-3.182			
ENX	-0.496	0.138	-3.585			
ERG	-0.235	0.172	-1.367			
ESS	-0.504	0.181	-2.783			
JEN	-0.304	0.153	-1.984			
PCR	-0.849	0.140	-6.042			
SAP	-0.813	0.151	-5.377			
AND	-0.603	0.144	-4.170			
TND	-0.574	0.153	-3.757			
UED	-0.605	0.153	-3.965			
Constant	10.380	0.123	84.075	9.591	0.098	97.691
Mu				0.172	0.128	1.34
R^2	0.992			n.a.		
N	1137			1137		

Table 3.13 reports the output elasticities of all four models. In the LSECD and SFACD models, the average output elasticities are 0.972 and 0.969 respectively. In the LSETLG and SFATLG models, the average output elasticities for the whole sample are 0.954 and 0.944 respectively. For Australian DNSPs, the average output elasticities in these models, are 1.059 and 1.044 respectively. This result is reasonable since the Australian DNSPs are on average larger than the sample average. Furthermore, in all the models, the average output elasticities for the individual outputs are positive, as required by the theory underlying the model specification.

Table 3.14 shows the frequency of monotonicity violations using the TLG specification with 'option 5' opex and the long sample period. For Australian DNSPs, with the LSETLG model 5.9 per cent of observations are monotonicity violations. With the SFATLG model 30.3 per cent of observations on Australian DNSPs are monotonicity violations. However, there are no significant monotonicity violations for any DNSPs in either model.

Table 3.13 Aust. Time Trend Models: Output elasticities, 2006 to 2022 (option 5 opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSECD				
Full sample	0.566	0.173	0.234	0.972
LSETLG by jurisdiction				
Australia	0.443	0.242	0.373	1.059
New Zealand	0.657	0.214	0.052	0.923
Ontario	0.283	0.133	0.516	0.931
Full sample	0.420	0.177	0.356	0.954
SFACD				
Full sample	0.413	0.142	0.414	0.969
SFATLG by jurisdiction				
Australia	0.762	0.172	0.110	1.044
New Zealand	0.428	0.103	0.463	0.995
Ontario	0.313	0.069	0.497	0.878
Full sample	0.433	0.099	0.412	0.944

Table 3.14 Aust. Time Trend Models: Monotonicity violations, 2006-2022 (option 5 opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	100.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	76.5%	0.0%	0.0%
ERG	0.0%	0.0%	0.0%	0.0%
ESS	76.5%	0.0%	0.0%	0.0%
JEN	0.0%	64.7%	0.0%	0.0%
PCR	0.0%	0.0%	0.0%	0.0%
SAP	0.0%	0.0%	0.0%	0.0%
AND	0.0%	52.9%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	0.0%	100.0%	0.0%	0.0%
Total Australia	5.9%	30.3%	0.0%	0.0%
New Zealand	36.2%	9.6%	0.0%	0.0%
Ontario	0.0%	10.5%	0.0%	0.0%
Full sample	11.4%	14.1%	0.0%	0.0%

The efficiency scores estimated by the four models are presented in Table 3.15. In the LSECD and SFACD models, the average output elasticities. The average efficiency score of the four models is also shown.

Table 3.15 Aust. Time Trend Models: Efficiency scores, 2006-2022 (option 5 opex)

Sample	*LSECD*	*LSETLG*	*SFACD*	*SFATLG*	*Average*
EVO	0.483	0.428	0.487	0.451	0.462
AGD	0.583	0.593	0.566	0.564	0.577
CIT	0.800	0.730	0.836	0.775	0.785
END	0.664	0.673	0.668	0.622	0.657
ENX	0.692	0.703	0.679	0.689	0.691
ERG	0.557	0.541	0.556	0.572	0.557
ESS	0.661	0.709	0.603	0.663	0.659
JEN	0.730	0.580	0.704	0.718	0.683
PCR	1.000	1.000	0.963	0.971	0.984
SAP	0.943	0.966	0.907	0.931	0.936
AND	0.822	0.782	0.750	0.791	0.786
TND	0.834	0.760	0.851	0.755	0.800
UED	0.944	0.784	0.940	0.963	0.908
Australia	0.747	0.711	0.732	0.728	0.730

3.3.2 Short-period results

The models in this section all have 729 observations over 69 DNSPs. The LSE models use panel-corrected standard errors. The SFA models assume a truncated-normal distribution of inefficiencies. The two Cobb-Douglas (CD) models are presented in Table 3.16. The two Translog (TLG) models are presented in Table 3.17.

The additional time trend variable for Australia is statistically significant in all regressions. The results for hypothesis tests that the six higher-order output terms are jointly significantly different from zero are as follows. In both the LSETLG and SFATLG models the p-value of the null hypothesis is 0.0000, meaning in both models the additional higher-order terms of the TLG model are jointly statistically significant.

Table 3.16 Aust. Time Trend Models, 2012 to 2022 (option 5 opex)

	LSECD			*SFACD*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.600	0.070	8.58	0.516	0.083	6.25
ln(CircLen)=x2	0.197	0.030	6.59	0.244	0.042	5.85
ln(RMDemand)=x3	0.181	0.067	2.73	0.200	0.083	2.42
ln(ShareUGC)	-0.136	0.025	-5.49	-0.037	0.041	-0.91
Year	0.011	0.002	4.36	0.010	0.001	6.85
New Zealand	-0.610	0.132	-4.61	-0.263	0.085	-3.11
Ontario	-0.436	0.128	-3.40	-0.084	0.090	-0.93

	LSECD			SFACD		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
Aust. trend	-0.041	0.005	-7.63	-0.041	0.003	-14.30
AGD	-0.260	0.162	-1.61			
CIT	-0.444	0.132	-3.36			
END	-0.366	0.139	-2.64			
ENX	-0.378	0.132	-2.86			
ERG	-0.251	0.152	-1.66			
ESS	-0.382	0.154	-2.48			
JEN	-0.373	0.134	-2.79			
PCR	-0.779	0.139	-5.60			
SAP	-0.661	0.145	-4.56			
AND	-0.523	0.141	-3.71			
TND	-0.577	0.166	-3.48			
UED	-0.701	0.144	-4.88			
Constant	10.549	0.130	80.96	9.979	0.097	102.68
Mu				0.320	0.057	5.57
R^2	0.995			n.a.		
N	729			729		

Table 3.17 Aust. Time Trend Models, 2012 to 2022 (option 5 opex)

	LSETLG			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.451	0.072	6.30	0.359	0.108	3.33
ln(CircLen)=x2	0.207	0.029	7.16	0.254	0.052	4.86
ln(RMDemand)=x3	0.305	0.060	5.08	0.348	0.096	3.61
x1*x1/2	-0.379	0.505	-0.75	0.960	0.570	1.68
x1*x2	0.272	0.115	2.37	0.234	0.150	1.56
x1*x3	0.089	0.383	0.23	-1.035	0.458	-2.26
x2*x2/2	0.019	0.040	0.48	0.063	0.074	0.85
x2*x3	-0.285	0.092	-3.09	-0.285	0.113	-2.52
x3*x3/2	0.252	0.292	0.87	1.149	0.383	3.00
ln(ShareUGC)	-0.114	0.025	-4.52	-0.002	0.048	-0.03
Year	0.013	0.002	5.42	0.012	0.002	7.78
New Zealand	-0.716	0.118	-6.08	-0.284	0.085	-3.33
Ontario	-0.547	0.114	-4.78	-0.126	0.098	-1.29
Aust. trend	-0.042	0.005	-7.79	-0.048	0.003	-14.52
AGD	-0.360	0.160	-2.25			
CIT	-0.501	0.119	-4.23			
END	-0.464	0.128	-3.64			
ENX	-0.470	0.130	-3.61			
ERG	-0.327	0.160	-2.04			
ESS	-0.554	0.165	-3.35			
JEN	-0.265	0.133	-2.00			
PCR	-0.856	0.133	-6.42			

	LSETLG			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
SAP	-0.763	0.139	-5.48			
AND	-0.557	0.140	-3.96			
TND	-0.589	0.150	-3.94			
UED	-0.636	0.144	-4.40			
Constant	10.578	0.116	91.48	9.882	0.122	80.78
Mu				0.385	0.076	5.08
R^2	0.995			n.a.		
N	729			729		

Table 3.18 reports the output elasticities of all four models. In the LSECD and SFACD models, the average output elasticities are 0.98 and 0.96 respectively. In the LSETLG and SFATLG models, the average output elasticities for the whole sample are both 0.96. For Australian DNSPs, the average output elasticities in these models, are 1.04 and 0.99 respectively. An important problem with the SFTLG model is that the elasticity of output with respect to RMD is negative on average. This is inconsistent with economic theory, and means that the SFATLG model is not viable. We are less concerned about some small negative average output elasticities for New Zealand or Ontario DNSPs.

Table 3.18 Aust. Time Trend Models: Output elasticities, 2012 to 2022 (option 5 opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSECD				
Full sample	0.600	0.197	0.181	0.979
LSETLG by jurisdiction				
Australia	0.466	0.261	0.313	1.040
New Zealand	0.672	0.291	-0.035	0.928
Ontario	0.323	0.139	0.490	0.953
Full sample	0.451	0.207	0.305	0.963
SFACD				
Full sample	0.516	0.244	0.200	0.960
SFATLG by jurisdiction				
Australia	0.856	0.331	-0.198	0.989
New Zealand	0.728	0.372	-0.087	1.013
Ontario	-0.034	0.159	0.796	0.921
Full sample	0.359	0.254	0.348	0.961

Table 3.19 shows the frequency of monotonicity violations using the TLG specification with 'option 5' opex and the short sample period. For Australian DNSPs, with the LSETLG model 15.4 per cent of observations are monotonicity violations. With the SFATLG model 77.6 per cent of observations on Australian DNSPs are monotonicity violations. While there are no significant monotonicity violations for Australian DNSPs in the LSETLG model, in the

SFATLG model, 32.9 per cent of the observations for Australian DNSPs are significant monotonicity violations. These results again highlight the poor performance of the SFATLG model in the short sample period. The efficiency scores estimated by the four models are presented in Table 3.20. In the LSECD and SFACD models, the average output elasticities. The average efficiency score of the four models is also shown.

Table 3.19 Aust. Time Trend Models: Monotonicity violations, 2012-2022 (option 5 opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	100.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	36.4%	0.0%	0.0%
ENX	0.0%	100.0%	0.0%	0.0%
ERG	100.0%	100.0%	0.0%	27.3%
ESS	100.0%	100.0%	0.0%	100.0%
JEN	0.0%	72.7%	0.0%	0.0%
PCR	0.0%	100.0%	0.0%	100.0%
SAP	0.0%	100.0%	0.0%	100.0%
AND	0.0%	100.0%	0.0%	100.0%
TND	0.0%	100.0%	0.0%	0.0%
UED	0.0%	100.0%	0.0%	0.0%
Total Australia	15.4%	77.6%	0.0%	32.9%
New Zealand	61.2%	64.1%	15.8%	15.8%
Ontario	0.0%	61.5%	0.0%	3.7%
Full sample	20.6%	65.4%	4.5%	12.9%

Table 3.20 Aust. Time Trend Models: Efficiency scores, 2012-2022 (option 5 opex)

Sample	*LSECD*	*LSETLG*	*SFACD*	*SFATLG*	*Average*
EVO	0.459	0.425	0.511	0.441	0.459
AGD	0.595	0.609	0.603	0.525	0.583
CIT	0.715	0.701	0.757	0.675	0.712
END	0.661	0.676	0.700	0.601	0.659
ENX	0.670	0.680	0.699	0.631	0.670
ERG	0.590	0.589	0.572	0.519	0.567
ESS	0.672	0.739	0.647	0.740	0.700
JEN	0.666	0.554	0.668	0.580	0.617
PCR	1.000	1.000	0.944	0.958	0.975
SAP	0.888	0.911	0.921	0.899	0.905
AND	0.774	0.741	0.750	0.809	0.769
TND	0.817	0.766	0.842	0.726	0.787
UED	0.925	0.802	0.916	0.802	0.861
Australia	0.726	0.707	0.733	0.685	0.713

3.4 Conclusions

This section presents the opex cost function results when an additional time trend variable is added for Australian DNSPs over and above the general time trend applying to all DNSPs in the sample. Tables 3.21 and 3.22 show, for long and short sample periods respectively, a summary comparison of the monotonicity outcomes compared to the standard model specification using data up to 2022.

Our main observations are:

(1) For the long sample period, this time trend specification has some advantages over the standard specification:

- In all models, the additional time trend term is statistically significantly different from zero.
- This specification appears to satisfactorily address some of the concerns with the performance of the usual specification of the SFATLG model using the data sample ending 2022.
  - The efficiency score for AGD is much more reasonable;
  - The output weights for Australian DNSP now sum to close to 1.0, which is consistent between models;
  - The output weights are consistently positive using country averages.
- As shown in Table 3.21, there is a marginal improvement in the monotonicity performance in the long-period application of the model.

Table 3.21 Comparison of monotonicity violations: Long sample period

	Monotonicity violations		*Significant monotonicity violations*	
Model	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
A. Standard opex				
All observations				
- Standard specification	15.4%	44.8%	0.0%	1.5%
- Additional trend model	12.8%	8.1%	0.2%	0.0%
Australian DNSPs				
- Standard specification	19.5%	29.4%	0.0%	0.0%
- Additional trend model	8.6%	27.6%	0.0%	0.0%
B. 'Option 5' opex				
All observations				
- Standard specification	12.5%	51.3%	0.0%	2.3%
- Additional trend model	11.4%	14.1%	0.0%	0.0%
Australian DNSPs				
- Standard specification	10.0%	42.1%	0.0%	0.0%
- Additional trend model	5.9%	30.3%	0.0%	0.0%

(2) For TLG models using the short sample period, this alternative time trend specification is not viable.

- The shortcomings of the SFATLG model are *not* satisfactorily ameliorated in the short sample period. The output weight for RMD is negative for Australian DNSPs on average.
- As shown in Table 3.22, there is a deterioration of the monotonicity performance in the short-period application of the model.

(3) For CD models using the short sample period, the alternative time trend specification appears to be viable.

Table 3.22 Comparison of monotonicity violations: Short sample period

	Monotonicity violations		*Significant monotonicity violations*	
Model	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
A. Standard opex				
All observations				
- Standard specification	30.6%	38.5%	3.2%	1.5%
- Additional trend model	20.4%	68.3%	4.5%	15.9%
Australian DNSPs				
- Standard specification	46.9%	72.7%	0.0%	7.7%
- Additional trend model	15.4%	77.6%	0.0%	36.4%
B. 'Option 5' opex				
All observations				
- Standard specification	31.4%	40.3%	2.9%	3.3%
- Additional trend model	20.6%	65.4%	4.5%	12.9%
Australian DNSPs				
- Standard specification	49.7%	74.1%	0.0%	15.4%
- Additional trend model	15.4%	77.6%	0.0%	32.9%

Our suggestions are:

a) Including an additional time-trend term for Australian DNSPs can be considered for the CD and TLG models when using the *long* sample period (for both definitions of opex).

b) It can also be considered for the CD models when using the *short* sample period (again, for both definitions of opex).

c) However, when using the short sample period, including an additional Australian DNSP time-trend in the TLG models *is not feasible* (for either definition of opex).

4 Restricted Translog Specification

This section examines a restricted translog specification. This follows on from analysis of 'hybrid' models carried out in 2022 (Quantonomics 2022a). Two submissions were received to the 2022 memo 'Opex Cost Function Development' from Ausgrid and AusNet. Section 4.1 briefly summarises the main points. Section 4.2 describes the specification tested here, while sections 4.3 and 4.4 present the results and the conclusions respectively.

4.1 Stakeholder responses to 2022 memo

Ausgrid suggested that the hybrid models do not resolve the problem of the comparability of benchmarking scores when some model is excluded for monotonicity reasons. This is because of variation when a hybrid specification is substituted for a Translog model. In our view, if a TLG model is excluded due to excessive monotonicity, it would be preferable to replace it with an estimate drawn from a TLG model restricted to satisfy the requirement that it does not have excess monotonicity violations.

AusNet observed that the hybrid models presented in that memo had limitations since in some models the higher-order terms were not statistically significant. They also argued that the hybrid models tested needed to make intuitive sense. Both AusNet and Ausgrid suggested further exploring the robust regression method. Both DNSPs also suggested that perhaps it may be better just to rely only on the Cobb-Douglas models, given the monotonicity issues with the Translog model and because they do not improve on the fit of the Cobb-Douglas models. Ausgrid stated: "The best way to reduce the monotonicity violations in the Translog models would be to get better data (i.e., with fewer 'outliers') to have more comparability in the dataset. Because the scope to procure more comparable data is limited, this option is not considered realistic at least in the short term."

4.2 Motivation of this analysis

Monotonicity violations sometimes arise in benchmarking applications of the Translog model due to complex issues such as multicollinearity between the output variables, the effects of influential observations on the nonlinear shape of the function, and inadequate sample size. Kumbhakar, Wang and Horncastle (2015, 107) suggest "imposing more structure in the estimation process" to address this issue. For example, in benchmarking Ontario DNSPs, Pacific Economic Group (PEG) excludes the output interaction terms from the Translog model to satisfy output regularity (Lowry and Getachew 2009, 336).

The Quantonomics (2022a) memo considered several hybrid models, in which some of the parameters of the Translog model are constrained to zero; although others could be tested. In its submission in response to the 2022 memo, AusNet stated:

> "We agree that other alternatives could be explored when there are monotonicity violations in the translog opex cost function models e.g., the hybrid models in the

> memorandum. However, for the alternatives to be an improvement on the base model, the inputs/results from the alternatives need to make intuitive sense – the AER should consider how the hybrid model makes intuitive sense if it is to be adopted. Non-violation of monotonicity should not be the only criteria."

In choosing the Restricted Translog (RTL) specification tested here, we have considered the following criteria:

- the meaningful economic interpretation of the functional form and parameters, including parameters having the correct signs;
- the extent to which the model reduces monotonicity errors for Australian DNSPs, or mitigates other model shortcomings.
- joint significance tests of groups of related explanatory variables added to a model, and
- goodness-of-fit.

In the early consultations on the benchmarking output specifications, electricity networks were likened to a road network with connectivity and capacity dimensions. RMD and Circuit Length variables were viewed as representing proxies for different aspects of network capacity. It is reasonable to expect a comparatively simple relationship between costs and connectivity (ie, customer numbers) whereas network capacity and its effect on costs may be a comparatively complex function of RMD and Circuit Length and the interaction between them. This suggests a model that restricts the higher-order (including interaction) terms on the customer number output, while not imposing restrictions on the higher-order terms for RMD and Circuit Length. This corresponds to the following function form (not including the inefficiency effects or the stochastic disturbance, which differ between the LSE and SFA forms):

$$c_{it} = \alpha_0 + \alpha_z z + \alpha_t t + \alpha_{1t} d_1 t + \sum_{k=2,3} \gamma_k d_k + \sum_{i=1}^{3} \beta_i y_i + \frac{1}{2}\beta_{22} y_2^2 + \frac{1}{2}\beta_{33} y_3^2 + \beta_{23} y_2 y_3 \quad (4.1)$$

where c_{it} is log real opex for DNSP i in period t. The log outputs are: y_1 = log of customer numbers; y_2 = log of circuit length; y_3 = log of RMD. The other variables are: d_1, d_2 and d_3 are jurisdictional dummy variables; t = time period; and z is the log share of underground cables in circuit length. This model is referred to as RTL.

4.3 RTL Results

All LSE models presented here use the panel-corrected standard errors estimator, and all SFA models assume a truncated-normal distribution of inefficiencies.

4.3.1 Long Period, Standard Opex

The two RTL models using the long sample period and standard opex are presented in Table 4.1. Testing the hypothesis test that the three higher-order output terms are jointly equal to zero, in the LSE version the p-value of the null hypothesis is 0.0000 and in the SFA version it is 0.1866. This means that these additional variables are jointly statistically significant in the LSE model but are not statistically significant in the SFA model.

Table 4.1 RTL Models, 2006 to 2022 (standard opex)

	LSERTL			*SFARTL*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.520	0.067	7.721	0.438	0.077	5.72
ln(CircLen)=x2	0.161	0.030	5.325	0.119	0.055	2.16
ln(RMDemand)=x3	0.271	0.057	4.759	0.401	0.07	5.73
x1*x1/2	0.098	0.032	3.094	0.004	0.049	0.09
x2*x2/2	-0.090	0.028	-3.193	0.045	0.05	0.92
x3*x3/2	0.149	0.028	5.409	-0.08	0.061	-1.33
ln(ShareUGC)	-0.090	0.027	-3.292	-0.11	0.039	-2.84
Year	0.013	0.002	8.053	0.014	0.001	13.45
New Zealand	-0.406	0.142	-2.853	0.158	0.087	1.81
Ontario	-0.264	0.140	-1.894	0.102	0.094	1.09
Aust. trend	-0.017	0.004	-4.007	-0.016	0.002	-8.31
AGD	-0.189	0.191	-0.988			
CIT	-0.719	0.159	-4.522			
END	-0.343	0.157	-2.188			
ENX	-0.363	0.152	-2.388			
ERG	-0.293	0.177	-1.655			
ESS	-0.475	0.195	-2.433			
JEN	-0.304	0.161	-1.886			
PCR	-0.746	0.158	-4.725			
SAP	-0.590	0.167	-3.539			
AND	-0.399	0.158	-2.522			
TND	-0.419	0.164	-2.554			
UED	-0.488	0.156	-3.134			
Constant	10.185	0.141	72.069	9.502	0.105	90.34
Mu				0.287	0.091	3.15
R^2	0.992			n.a.		
N	1137			1137		

Output elasticities are reported in Table 4.2. The average output elasticities for the whole sample are 0.95 and 0.96 in the LSERTL and SFARTL models respectively. For Australian DNSPs, the average output elasticities in these models are 1.07 and 1.00 respectively, which are slightly larger than the sample average. In both models, the average output elasticities for the individual outputs are positive, as required by the theory underlying the models.

Table 4.2 RTL Model Output elasticities, 2006 to 2022 (standard opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSERTL by jurisdiction				
Australia	0.520	0.211	0.340	1.072
New Zealand	0.520	0.266	0.119	0.905
Ontario	0.520	0.084	0.328	0.933
Full sample	0.520	0.161	0.271	0.952
SFARTL by jurisdiction				
Australia	0.438	0.207	0.357	1.002
New Zealand	0.438	0.082	0.482	1.002
Ontario	0.438	0.106	0.373	0.917
Full sample	0.438	0.119	0.401	0.958

Table 4.3 shows the frequency of monotonicity violations associated with the models in Table 4.1. It shows that in the LSERTL model monotonicity violations account for 4.0 per cent of all observations, but none of these are for Australian DNSPs. With the SFARTL model there are no monotonicity violations. Neither model has any significant monotonicity violations for Australian DNSPs. Table 4.4 shows the efficiency scores estimated using the RTL models with standard opex over the long sample period.

Table 4.3 RTL Model: Frequency of monotonicity violations, 2006-2022 (standard opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSERTL*	*SFARTL*	*LSERTL*	*SFARTL*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	0.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	0.0%	0.0%	0.0%
ERG	0.0%	0.0%	0.0%	0.0%
ESS	0.0%	0.0%	0.0%	0.0%
JEN	0.0%	0.0%	0.0%	0.0%
PCR	0.0%	0.0%	0.0%	0.0%
SAP	0.0%	0.0%	0.0%	0.0%
AND	0.0%	0.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	0.0%	0.0%	0.0%	0.0%
Total Australia	0.0%	0.0%	0.0%	0.0%
New Zealand	11.5%	0.0%	0.0%	0.0%
Ontario	1.3%	0.0%	0.0%	0.0%
Full sample	4.0%	0.0%	0.0%	0.0%

Table 4.4 RTL Model Efficiency scores, 2006-2022 (standard opex)

Sample	*LSERTL*	*SFARTL*
EVO	0.474	0.494
AGD	0.573	0.470
CIT	0.973	0.902
END	0.669	0.619
ENX	0.682	0.623
ERG	0.636	0.622
ESS	0.762	0.659
JEN	0.643	0.644
PCR	1.000	0.975
SAP	0.856	0.822
AND	0.707	0.675
TND	0.721	0.762
UED	0.772	0.764
Australia	0.728	0.695

4.3.2 Short Period, Standard Opex

The two RTL models in this section use standard opex and the short sample period, and are presented in Table 4.5. Testing the hypothesis test that the three higher-order output terms are jointly equal to zero, in the LSE version the p-value of the null hypothesis is 0.0000 and in the SFA version it is 0.0037. This means that these additional variables are jointly statistically significant in both models.

Output elasticities are reported in Table 4.6. The average output elasticities for the whole sample are 0.96 in both the LSERTL and SFARTL models. For Australian DNSPs, the average output elasticities in these models are 1.05 and 0.98 respectively, which are similar to or slightly larger than the sample average. In both models, the average output elasticities for the individual outputs are positive, as required by the theory underlying the models.

Table 4.5 RTL Models, 2012 to 2022 (standard opex)

	LSERTL			*SFARTL*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.561	0.068	8.31	0.503	0.099	5.09
ln(CircLen)=x2	0.190	0.030	6.40	0.248	0.052	4.80
ln(RMDemand)=x3	0.211	0.058	3.60	0.207	0.086	2.39
x1*x1/2	0.136	0.030	4.55	0.175	0.049	3.61
x2*x2/2	-0.139	0.027	-5.20	-0.151	0.046	-3.26
x3*x3/2	0.195	0.027	7.11	0.138	0.053	2.58
ln(ShareUGC)	-0.084	0.027	-3.09	0.033	0.048	0.69
Year	0.011	0.002	4.66	0.009	0.001	6.38
New Zealand	-0.498	0.149	-3.34	-0.145	0.106	-1.37
Ontario	-0.306	0.146	-2.10	0.045	0.090	0.50

	LSERTL			SFARTL		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
Aust. trend	-0.040	0.005	-7.35	-0.041	0.003	-14.14
AGD	-0.207	0.181	-1.14			
CIT	-0.657	0.153	-4.29			
END	-0.356	0.158	-2.26			
ENX	-0.324	0.159	-2.05			
ERG	-0.350	0.181	-1.93			
ESS	-0.493	0.191	-2.58			
JEN	-0.309	0.158	-1.96			
PCR	-0.760	0.162	-4.69			
SAP	-0.534	0.169	-3.17			
AND	-0.345	0.162	-2.14			
TND	-0.428	0.174	-2.46			
UED	-0.497	0.159	-3.12			
Constant	10.370	0.148	70.12	9.823	0.118	83.14
Mu				0.359	0.086	4.17
R^2	0.995			n.a.		
N	729			729		

Table 4.7 shows the frequency of monotonicity violations using the RTL specification with standard opex and the short sample period. The LSERTL model has monotonicity violations in 17.7 per cent of all observations, but none of these are for Australian DNSPs. The SFARTL model has monotonicity violations in 15.1 per cent of all observations and 15.4 per cent of the observations on Australian DNSPs. Neither model has any significant monotonicity violations for Australian DNSPs.

Table 4.8 shows the efficient scores estimated using the RTL models with standard opex over the short sample period.

Table 4.6 RTL Model Output elasticities, 2012 to 2022 (standard opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSERTL by jurisdiction				
Australia	0.561	0.234	0.257	1.052
New Zealand	0.561	0.343	0.011	0.916
Ontario	0.561	0.088	0.304	0.953
Full sample	0.561	0.190	0.211	0.962
SFARTL by jurisdiction				
Australia	0.503	0.353	0.128	0.984
New Zealand	0.503	0.422	0.050	0.976
Ontario	0.503	0.111	0.323	0.938
Full sample	0.503	0.248	0.207	0.958

Table 4.7 RTL Model: Frequency of monotonicity violations, 2012-2022 (standard opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSERTL*	*SFARTL*	*LSERTL*	*SFARTL*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	0.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	0.0%	0.0%	0.0%
ERG	0.0%	100.0%	0.0%	0.0%
ESS	0.0%	100.0%	0.0%	0.0%
JEN	0.0%	0.0%	0.0%	0.0%
PCR	0.0%	0.0%	0.0%	0.0%
SAP	0.0%	0.0%	0.0%	0.0%
AND	0.0%	0.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	0.0%	0.0%	0.0%	0.0%
Total Australia	0.0%	15.4%	0.0%	0.0%
New Zealand	51.2%	26.3%	0.0%	0.0%
Ontario	5.8%	8.8%	9.6%	0.0%
Full sample	17.7%	15.1%	2.7%	0.0%

Table 4.8 RTL Model Efficiency scores, 2012-2022 (standard opex)

Sample	*LSERTL*	*SFARTL*
EVO	0.468	0.514
AGD	0.575	0.497
CIT	0.902	0.894
END	0.668	0.635
ENX	0.647	0.615
ERG	0.664	0.679
ESS	0.766	0.800
JEN	0.637	0.612
PCR	1.000	0.955
SAP	0.798	0.840
AND	0.661	0.646
TND	0.717	0.732
UED	0.769	0.712
Australia	0.713	0.702

4.3.3 Long Period, Option 5 Opex

The two RTL models shown in Table 4.5 use the long sample period and opex includes CCO (ie, 'Option 5' opex). Testing the hypothesis test that the three higher-order output terms are jointly equal to zero, in the LSE version the p-value of the null hypothesis is 0.0000 and in the SFA version it is 0.1617. This means that these additional variables are jointly statistically significant in the LSE model but not in the SFA model.

Table 4.9 RTL Models, 20062 to 2022 (option 5 opex)

	LSERTL			*SFARTL*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.514	0.069	7.47	0.418	0.075	5.57
ln(CircLen)=x2	0.164	0.031	5.28	0.114	0.061	1.88
ln(RMDemand)=x3	0.274	0.058	4.72	0.422	0.069	6.11
x1*x1/2	0.101	0.033	3.09	0.038	0.048	0.79
x2*x2/2	-0.091	0.029	-3.15	0.013	0.049	0.26
x3*x3/2	0.148	0.028	5.25	-0.063	0.06	-1.05
ln(ShareUGC)	-0.087	0.028	-3.11	-0.125	0.037	-3.42
Year	0.013	0.002	7.88	0.014	0.001	14.06
New Zealand	-0.593	0.133	-4.46	0.008	0.085	0.10
Ontario	-0.452	0.130	-3.47	-0.040	0.097	-0.41
Aust. trend	-0.017	0.004	-4.08	-0.016	0.002	-8.08
AGD	-0.364	0.188	-1.94			
CIT	-0.589	0.142	-4.14			
END	-0.428	0.152	-2.82			
ENX	-0.49	0.142	-3.45			
ERG	-0.282	0.174	-1.62			
ESS	-0.485	0.192	-2.52			
JEN	-0.378	0.153	-2.46			
PCR	-0.768	0.148	-5.18			
SAP	-0.781	0.161	-4.84			
AND	-0.537	0.147	-3.65			
TND	-0.508	0.163	-3.12			
UED	-0.668	0.149	-4.48			
Constant	10.376	0.132	78.67	9.629	0.103	93.46
Mu				0.249	0.121	2.06
R^2	0.992			n.a.		
N	1137			1137		

Output elasticities are reported in Table 4.10. The average output elasticities for the whole sample are 0.95 and 0.96 in the LSERTL and SFARTL models respectively. For Australian DNSPs, the average output elasticities in these models are 1.07 and 0.98 respectively. In both models, the average output elasticities for the individual outputs are positive, as required by the theory underlying the models.

Table 4.10 RTL Model Output elasticities, 2006 to 2022 (option 5 opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSERTL by jurisdiction				
Australia	0.514	0.218	0.339	1.071
New Zealand	0.514	0.271	0.122	0.907
Ontario	0.514	0.085	0.333	0.932
Full sample	0.514	0.164	0.274	0.952
SFARTL by jurisdiction				
Australia	0.418	0.217	0.340	0.975
New Zealand	0.418	0.115	0.478	1.012
Ontario	0.418	0.075	0.422	0.916
Full sample	0.418	0.114	0.422	0.955

Table 4.11 shows the frequency of monotonicity violations using the RTL specification with option 5 opex and the long sample period. The LSERTL and SFARTL models have monotonicity violations in 3.9 per cent and 1.5 per cent of all observations respectively. Neither model has any monotonicity violations for Australian DNSPs. Neither model has any significant monotonicity violations.

Table 4.11 RTL Model: Frequency of monotonicity violations, 2006-2022 (option 5 opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSERTL*	*SFARTL*	*LSERTL*	*SFARTL*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	0.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	0.0%	0.0%	0.0%
ERG	0.0%	0.0%	0.0%	0.0%
ESS	0.0%	0.0%	0.0%	0.0%
JEN	0.0%	0.0%	0.0%	0.0%
PCR	0.0%	0.0%	0.0%	0.0%
SAP	0.0%	0.0%	0.0%	0.0%
AND	0.0%	0.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	0.0%	0.0%	0.0%	0.0%
Total Australia	0.0%	0.0%	0.0%	0.0%
New Zealand	11.1%	0.0%	0.0%	0.0%
Ontario	1.3%	2.9%	0.0%	0.0%
Full sample	3.9%	1.5%	0.0%	0.0%

Table 4.12 shows the efficient scores estimated using the RTL models with option 5 opex over the short sample period.

Table 4.12 RTL Model Efficiency scores, 2006-2022 (option 5 opex)

Sample	*LSERTL*	*SFARTL*
EVO	0.458	0.471
AGD	0.659	0.508
CIT	0.826	0.786
END	0.703	0.623
ENX	0.748	0.642
ERG	0.607	0.602
ESS	0.744	0.678
JEN	0.668	0.669
PCR	0.988	0.973
SAP	1.000	0.942
AND	0.784	0.745
TND	0.761	0.818
UED	0.893	0.871
Australia	0.757	0.718

4.3.4 Short Period, Option 5 Opex

The models in this section use 'Option 5 opex', and have 729 observations over 69 DNSPs. The LSE models use panel-corrected standard errors. The SFA models assume a truncated-normal distribution of inefficiencies. The two RTL models are presented in Table 4.13. Testing the hypothesis test that the three higher-order output terms are jointly equal to zero, in the LSE version the p-value of the null hypothesis is 0.0000 and in the SFA version it is 0.0008. This means that these additional variables are jointly statistically significant in both models.

Table 4.13 RTL Models, 2012 to 2022 (option 5 opex)

	LSERTL			*SFARTL*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.560	0.067	8.41	0.490	0.096	5.08
ln(CircLen)=x2	0.189	0.029	6.51	0.237	0.055	4.28
ln(RMDemand)=x3	0.212	0.058	3.69	0.231	0.087	2.65
x1*x1/2	0.136	0.029	4.62	0.202	0.049	4.08
x2*x2/2	-0.140	0.026	-5.29	-0.178	0.047	-3.76
x3*x3/2	0.195	0.027	7.25	0.146	0.054	2.73
ln(ShareUGC)	-0.084	0.027	-3.17	0.018	0.049	0.37
Year	0.011	0.002	4.68	0.010	0.002	6.45
New Zealand	-84.526	10.387	-8.14	-84.273	5.815	-14.49
Ontario	-84.334	10.385	-8.12	-84.101	5.812	-14.47
Aust. trend	-0.042	0.005	-8.09	-0.042	0.003	-14.48
AGD	-0.393	0.159	-2.47			
CIT	-0.552	0.125	-4.41			
END	-0.439	0.135	-3.25			
ENX	-0.465	0.131	-3.55			

	LSERTL			*SFARTL*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ERG	-0.356	0.161	-2.21			
ESS	-0.533	0.173	-3.08			
JEN	-0.337	0.126	-2.67			
PCR	-0.787	0.138	-5.72			
SAP	-0.730	0.147	-4.97			
AND	-0.504	0.136	-3.70			
TND	-0.522	0.158	-3.30			
UED	-0.695	0.136	-5.11			
Constant	72.635	9.438	7.70	74.421	5.743	12.96
Mu				0.331	0.098	3.40
R^2	0.995			n.a.		
N	729			729		

Output elasticities are reported in Table 4.14. The average output elasticities for the whole sample are 0.96 in both the LSERTL and SFARTL models. For Australian DNSPs, the average output elasticities in these models are 1.05 and 0.95 respectively. In both models, the average output elasticities for the individual outputs are positive, as required by the theory underlying the models.

Table 4.14 RTL Model Output elasticities, 2012 to 2022 (option 5 opex)

Sample	*Customer numbers*	*Circuit length*	*RMD*	*Total Output*
LSERTL by jurisdiction				
Australia	0.560	0.233	0.259	1.051
New Zealand	0.560	0.343	0.013	0.915
Ontario	0.560	0.088	0.305	0.953
Full sample	0.560	0.189	0.212	0.962
SFARTL by jurisdiction				
Australia	0.490	0.351	0.110	0.951
New Zealand	0.490	0.441	0.059	0.990
Ontario	0.490	0.081	0.371	0.942
Full sample	0.490	0.237	0.231	0.958

Table 4.15 shows the frequency of monotonicity violations using the RTL specification with option 5 opex and the short sample period. The LSERTL model has monotonicity violations in 17.4 per cent of all observations, but none for Australian DNSPs. The SFARTL model they represent 23.5 per cent of all observations, and 30.8 per cent of Australian DNSP observations. Neither model has any significant monotonicity violations for Australian DNSPs.

Table 4.15 RTL Model: Frequency of monotonicity violations, 2012-2022 (option 5 opex)

	Monotonicity violations		*Significant monotonicity violations*	
Sample	*LSERTL*	*SFARTL*	*LSERTL*	*SFARTL*
Australian DNSPs				
EVO	0.0%	0.0%	0.0%	0.0%
AGD	0.0%	0.0%	0.0%	0.0%
CIT	0.0%	0.0%	0.0%	0.0%
END	0.0%	0.0%	0.0%	0.0%
ENX	0.0%	0.0%	0.0%	0.0%
ERG	0.0%	100.0%	0.0%	0.0%
ESS	0.0%	100.0%	0.0%	0.0%
JEN	0.0%	0.0%	0.0%	0.0%
PCR	0.0%	100.0%	0.0%	0.0%
SAP	0.0%	100.0%	0.0%	0.0%
AND	0.0%	0.0%	0.0%	0.0%
TND	0.0%	0.0%	0.0%	0.0%
UED	0.0%	0.0%	0.0%	0.0%
Total Australia	0.0%	30.8%	0.0%	0.0%
New Zealand	50.2%	25.4%	0.0%	0.0%
Ontario	5.8%	19.6%	10.0%	0.0%
Full sample	17.4%	23.5%	2.9%	0.0%

Table 4.16 shows the efficient scores estimated using the RTL models with option 5 opex over the short sample period.

Table 4.16 RTL Model Efficiency scores, 2012-2022 (option 5 opex)

Sample	*LSERTL*	*SFARTL*
EVO	0.455	0.491
AGD	0.674	0.537
CIT	0.79	0.786
END	0.706	0.634
ENX	0.724	0.631
ERG	0.649	0.656
ESS	0.775	0.825
JEN	0.638	0.614
PCR	1.000	0.939
SAP	0.945	0.951
AND	0.753	0.720
TND	0.767	0.782
UED	0.911	0.819
Australia	0.753	0.722

4.4 Conclusions

This section presents the opex cost function results when the higher-order terms relating to customer numbers are constrained to zero. In other respects the specification is the same as the TLG models presented in section 3—ie, including the additional time trend variable for Australian DNSPs.

The monotonicity results when the RTL specification is applied to the long sample period are shown in Table 4.17. There are no monotonicity violations for Australian DNSPs, which is an improvement to the standard model. However, in other respects the RTL specification has mixed results when applied to the long sample period. When applied to the long-period the higher-order terms for RMD and Circuit length are only jointly significant in the LSE version of the model. In the SFA version they are not jointly significantly different from zero. This outcome is sufficient to conclude that this model is not suitable for use with the long sample period.

Table 4.17 Comparison of monotonicity violations: Long sample period

	Monotonicity violations		*Significant monotonicity violations*	
Model	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
A. Standard opex				
All observations				
- Standard specification	15.4%	44.8%	0.0%	1.5%
- RTL & additional trend	4.0%	0.0%	0.0%	0.0%
Australian DNSPs				
- Standard specification	19.5%	29.4%	0.0%	0.0%
- RTL & additional trend	0.0%	0.0%	0.0%	0.0%
B. 'Option 5' opex				
All observations				
- Standard specification	12.5%	51.3%	0.0%	2.3%
- RTL & additional trend	3.9%	1.5%	0.0%	0.0%
Australian DNSPs				
- Standard specification	10.0%	42.1%	0.0%	0.0%
- RTL & additional trend	0.0%	0.0%	0.0%	0.0%

The monotonicity performance of the RTL specification when applied to the short sample period is shown in Table 4.18. This specification substantially improves on the standard TLG specification in terms of the amount of monotonicity violations. Nevertheless, it does not remove all of the monotonicity violations. The LSE versions of the RTL model have none for Australian DNSPs, but the SFA-RTL models do have monotonicity violations for Australian DNSPs. The SFA-RTL model with ordinary opex has monotonicity violations in 15.4 per cent of observations for Australian DNSPs, and with 'Option 5' opex in 30.8 per cent. In both cases, none of these monotonicity violations are significantly different from zero.

Table 4.18 Comparison of monotonicity violations: Short sample period

	Monotonicity violations		*Significant monotonicity violations*	
Model	*LSETLG*	*SFATLG*	*LSETLG*	*SFATLG*
A. Standard opex				
All observations				
- Standard specification	30.6%	38.5%	3.2%	1.5%
- RTL & additional trend	17.7%	15.1%	2.7%	0.0%
Australian DNSPs				
- Standard specification	46.9%	72.7%	0.0%	7.7%
- RTL & additional trend	0.0%	15.4%	0.0%	0.0%
B. 'Option 5' opex				
All observations				
- Standard specification	31.4%	40.3%	2.9%	3.3%
- RTL & additional trend	17.4%	23.5%	2.9%	0.0%
Australian DNSPs				
- Standard specification	49.7%	74.1%	0.0%	15.4%
- RTL & additional trend	0.0%	30.8%	0.0%	0.0%

In the short sample period, the additional higher order terms in the RTL model are jointly statistically significant in both the LSE and SFA versions. The averages of output elasticities by jurisdiction also have the correct sign. We note that the OEF for the share of underground cables in total circuit length is not statistically significant in the SFATL model. Overall, the RTL model has promise as a substitute for the TLG model in the shorter sample period. However, whether it is seen as a satisfactory substitute or not will depend on the definition adopted for monotonicity violations, and specifically whether the weaker concept of significant monotonicity violations is regarded as satisfactory or not. If not, then the RTL model will not be adequate, and only the CD models will be fully satisfactory for the short sample period.

5 Issues Raised by Frontier Economics

In its note 'Mis-estimation of SFA models', Frontier (2023) notes concerns about the SFATLG models in the draft 2023 benchmarking report in relation to their convergence and the results. The AER was aware of this and we understand that it noted these issues when circulating the draft report. Frontier also makes certain observations and criticisms relating to the SFATLG model which we briefly discuss in this section.

The truncated-normal distribution of inefficiencies in the SFA model is flexible in that it can take different shapes depending on the value of the parameter mu. Frontier finds that the pattern of inefficiencies over all DNSPs in the sample, can differ between SFA models. Specifically, it suggests that (using Option 5 opex) in the SFATLG models, the value of mu should be negative, whereas for the CD models it should be positive (Frontier Economics 2023, 3). This is inconsistent with the 2022 benchmarking report, where both SFACD and

SFATLG models in both the long and short sample periods had positive values for mu (Quantonomics 2022b Appendix C). It is also inconsistent with all of the SFA models presented in sections 3 and 4 above. Although the 2023 benchmarking report, for the SFATLG long-period model, has an atypical estimated mu of –0.82 under 'Option 5' opex modelling, it is not statistically significantly different from zero. In our view, Frontier's conclusion on this point is in error.

Frontier claims that it found for the short sample period, a fitted SFATLG model with a higher value of the log likelihood function than the corresponding model presented in the draft 2023 benchmarking report. The model it estimates has a "very large negative mu" (-843.26). However, Frontier notes that its model did not converge. This is after 1,000 iterations, which should suggest there is a significant problem with the model in terms of its nonconvergence to a maximum of the log likelihood function. We disagree with Frontier's claim that "the fact that the SFA estimation did not converge does not mean that efficiency has been mis-estimated". Since the model did not converge after 1,000 iterations, it is possible that it would never converge, with mu increasing to infinity. This appears to be a case outside the domain of values for which the program converges to a feasible solution. If the likelihood maximisation problem has no solution, then it would appear to be mis-estimated. For example, it may need to be re-estimated with different parameter starting values or using a different maximum likelihood algorithm.

In response to the general observation made by the AER that there are shortcomings with the SFATLG model, Frontier has correctly highlighted difficulties with the convergence of the SFATG model to a stable and economically sensible solution. However, as we have seen, the details of its analysis are flawed. Frontier then draws unwarranted strong conclusions that there is a "serious misspecification of the SFA-TLG models" and "the misspecification problem affects all of the econometric benchmarking models used by the AER", which "makes them unreliable for the purposes of setting allowed revenues for DNSPs". These assertions do not follow from the narrow convergence issues unsatisfactorily explored by Frontier, and no other arguments or tests are provided to support these strong assertions.

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