Attachment A: Opportunities for Refining Current Models

1 October 2025

Attachment to: Quantonomics (1 October 2025) *"Electricity Distribution Benchmarking Opex Model Development- Phase 2"*, Prepared for Australian Energy Regulator by Valentin Zelenyuk, Michael Cunningham, Alice Giovani and Joseph Hirschberg.

Contents

This attachment documents the empirical investigation of the opportunities for refining the current models discussed in section 2.1 of the *"Electricity Distribution Benchmarking Opex Model Development- Phase 2"* draft report (hereafter "Phase 2 draft report").

1 Standard SFA using Half Normal distribution of inefficiencies

The standard SFA approach in Quantonomics (2024) is implemented using a truncated normal distribution for the inefficiency term. Similarly, the jurisdictional time trends presented in Quantonomics (2023) also employ a truncated normal distribution for inefficiency. In this section, we present the results of the standard model when the inefficiency term is assumed to follow a half-normal distribution.

1.1 Estimation results

Tables 1.1 and 1.2 present the estimation results of the SFA Half Normal models for both the long and short periods, using Cobb-Douglas and Translog specifications.

Table 1.1 SFA Half Normal Models – Cobb-Douglas

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.280	0.075	3.75	0.283	0.100	2.83
ly2	0.122	0.039	3.13	0.244	0.039	6.22
ly3	0.560	0.074	7.55	0.428	0.106	4.02
lz1	-0.139	0.032	-4.41	-0.037	0.044	-0.84
yr	0.010	0.001	11.5	0.002	0.001	1.64
jur2	0.029	0.089	0.32	-0.064	0.078	-0.83
jur3	0.092	0.070	1.32	0.125	0.082	1.53
_cons	-11.250	1.849	-6.09	5.157	2.968	1.74
/mu	0	(omitted)		0	(omitted)	
/lnsigma2	-2.111	0.178	-11.86	-2.230	0.185	-12.05
/lgtgamma	1.849	0.212	8.71	1.980	0.220	8.98
sigma2	0.121	0.022		0.108	0.020	
gamma	0.864	0.025		0.879	0.023	
sigma_u2	0.105	0.022		0.094	0.020	
sigma_v2	0.016	0.001		0.013	0.001	
LLH	589.94			450.80		
# Iterations	6			6		
BIC	-1,109.9			-835.6		
Pseudo Adjusted R^2	0.991			0.993		
# Parameters	10			10		
N	1,098			732		

Table 1.2 SFA Half Normal Models – Translog

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.318	0.086	3.680	-0.021	0.167	-0.130
ly2	0.147	0.051	2.850	0.487	0.093	5.250
ly3	0.483	0.081	5.930	0.410	0.115	3.560
ly11	1.087	0.480	2.260	-0.447	0.685	-0.650
ly12	-0.266	0.118	-2.250	0.539	0.208	2.590
ly13	-0.981	0.398	-2.460	-0.855	0.543	-1.580
ly22	0.095	0.063	1.510	0.092	0.105	0.880
ly23	0.288	0.110	2.620	-0.273	0.143	-1.910
ly33	0.580	0.339	1.710	0.895	0.450	1.990
lz1	-0.120	0.044	-2.690	0.071	0.070	1.020
yr	0.010	0.001	9.150	0.005	0.002	2.700
jur2	0.009	0.075	0.110	-0.306	0.092	-3.340
jur3	0.026	0.086	0.300	-0.095	0.213	-0.450
_cons	-10.252	2.241	-4.570	0.251	3.760	0.070
/mu	0.000	(omitted)		0.000	(omitted)	
/lnsigma2	-1.502	0.237	-6.350	0.200	0.275	0.730
/lgtgamma	2.612	0.265	9.870	4.865	0.296	16.430
sigma2	0.223	0.053		1.221	0.335	
gamma	0.932	0.017		0.992	0.002	
sigma_u2	0.207	0.053		1.212	0.336	
sigma_v2	0.015	0.001		0.009	0.001	
LLH	610.7			488.3		
# Iterations	7			11		
BIC	-1,109.4			-871.1		
Pseudo Adjusted R^2	0.991			0.995		
# Parameters	16			16		
N	1,098			732		

1.2 Consistency with economic theory or industry knowledge

Tables 1.1 and 1.2 show that the main output variables are statistically significant and display the expected positive signs across all models. The OEF variable is negative and statistically significant in the long-period models but not significant in the short-period models. The time trend variable is statistically significant and positive in all models, except for the Cobb-Douglas specification in the short period. These results are consistent with those obtained under the Truncated-Normal specification. However, it is worth noting that the SFATLG short-period model under the Truncated-Normal distribution did not converge.

Table 1.3 presents the output elasticities for the Half-Normal models in both the long and short periods. The sum of these elasticities varies across models. In the long-period models, the total output elasticity for the full sample is close to one, indicating nearly constant returns to scale.

A similar result is observed for the Cobb-Douglas model in the short period. However, the Translog model in the short period yields a lower total elasticity of 0.876.

The output weights in the long-period Cobb-Douglas and Translog models follow a consistent pattern, with the highest weight assigned to RMD, followed by customer numbers and then CL, closely aligned with the results from the Truncated-Normal models. In the short-period Cobb-Douglas specification, RMD continues to receive the highest weight, while customer numbers and CL have similar weights. This contrasts with the Truncated-Normal Cobb–Douglas short-period model, where CL and RMD have similar weights and customer numbers receive a lower weight. The lower, and in some cases negative, output elasticities observed in the Half-Normal SFATLG short-period model are reflected in the high number of monotonicity violations reported in Table1.4.

Table 1.3 Output elasticities

	Long Period				*Short Period*			
Sample	*Cust.*	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
CD								
Full Sample	0.280	0.122	0.560	0.963	0.283	0.244	0.428	0.955
TLG								
Australia	0.088	0.345	0.265	0.697	-1.221	1.194	-0.174	-0.200
New Zealand	0.447	0.079	0.641	1.167	1.082	0.400	0.132	1.613
Ontario	0.337	0.102	0.478	0.917	-0.205	0.226	0.854	0.875
Full sample	0.318	0.147	0.483	0.948	-0.021	0.487	0.410	0.876

Table 1.4 Monotonicity Violations (%)

	Long Period				*Short Period*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	42.7	0.0	17.5	60.3	100.0	0.0	75.0	100.0
NZ	7.0	27.8	0.0	34.8	15.8	0.0	19.7	27.6
Ontario	10.3	26.8	0.0	37.2	44.5	35.3	3.4	79.9
Total	16.2	21.4	3.7	41.3	47.4	16.8	23.8	67.9
Aus DNSPs:								
- EVO	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0
- AGD	0.0	0.0	50.0	50.0	100.0	0.0	100.0	100.0
- CIT	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0
- END	94.4	0.0	0.0	94.4	100.0	0.0	83.3	100.0
- ENX	38.9	0.0	0.0	38.9	100.0	0.0	100.0	100.0
- ERG	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- ESS	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- JEN	0.0	0.0	77.8	77.8	100.0	0.0	16.7	100.0
- PCR	50.0	0.0	0.0	50.0	100.0	0.0	100.0	100.0
- SAP	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- AND	0.0	0.0	0.0	0.0	100.0	0.0	100.0	100.0
- TND	72.2	0.0	0.0	72.2	100.0	0.0	75.0	100.0
- UED	0.0	0.0	100.0	100.0	100.0	0.0	100.0	100.0

Both the long- and short-period Translog models exhibit a high proportion of monotonicity violations, consistent with the results from the Truncated-Normal specification. In the Half-Normal SFATLG model for the long period, 60.3 per cent of Australian DNSPs and 41.3 per cent of the total sample display MVs. This is somewhat lower than the corresponding figures under the Truncated-Normal specification, which show 79.5 per cent for the Australian sample and 45.4 per cent for the total sample. In the short-period half-normal SFATLG model, MVs occur in 100 per cent of the Australian DNSPs and 67.9 per cent of the total sample. These cannot be compared to the truncated-normal model, which did not converge.

1.3 Specification Tests

Tables 1.1 and 1.2 show the LLH value, the number of iterations, BIC and the pseudo-adjusted R^2. All models converged after relatively few iterations (on average, eight). This contrasts with the results from the Truncated SFA models reported in Quantonomics (2024), which typically required around 17 iterations to converge and failed to converge altogether for the Translog model in the short period. This outcome is expected, as the Half-Normal specification simplifies the optimisation process.

The Half-Normal and Truncated-Normal models display similar performance in terms of goodness-of-fit. On average, the pseudo-adjusted R^2 is 0.9925 for the Half-Normal models and 0.9926 for the Truncated-Normal models. The average BIC is –981.5 and –982.5, respectively. Additional diagnostic statistics are presented in Table 2.5.

Table 1.5 Diagnostic Statistics

	Long Period		*Short Period*	
	Stat.	*p-value**	*Stat.*	*p-value**
CD				
Normality of residuals				
IQR (% severe outliers)(1)	0.18		0.27	
Shapiro–Wilk W test(2)	0.983	0.000	0.976	0.000
Multicollinearity				
Average VIF(3)	25.0		25.9	
Condition number(3)	1084.2		1619.5	
TLG				
Normality of residuals				
IQR (% severe outliers)	0.09		0.14	
Shapiro–Wilk W test	0.986	0.000	0.979	0.000
Multicollinearity				
Average VIF	714.1		717.5	
Condition number	1641.0		2427.5	
Joint parameter tests				
Higher-order output terms	36.0	0.000	113.04	0.000

Note: * Null hypothesis is rejected in these tests, if the p-value is less than 0.05. Equivalently, the reported statistic exceeds the critical value for that statistic; (1) Severe outliers comprise about 0.0002% of the normal population; (2) The null hypothesis is that residuals are normally distributed; (3) Collinearity is potentially a problem if VIF>10 or the Condition number > 30;

Normality tests reject the assumption of normally distributed residuals. Multicollinearity is moderate in the Cobb–Douglas models but elevated in the Translog models. Functional form tests support the use of the Translog specification, as the joint tests confirm that the higher-order output terms are jointly significant in both the long and short periods.

1.4 Efficiency Scores

Table 1.6 presents the efficiency scores and corresponding rankings for all Australian DNSPs. Figure 1.1 compares the efficiency scores from the Half-Normal and Truncated-Normal models in the long period for each DNSP. Figure 1.2 presents the same comparison for the short period. On average, the efficiency scores are broadly consistent across models, with the exception of the short-period Translog specification, which produces lower average efficiency scores and notably misaligned rankings.

For the long-period Cobb–Douglas model, the efficiency scores are highly consistent across the Half-Normal and Truncated-Normal specifications for all DNSPs. In the long-period Translog model, the efficiency scores for EVO, ERG, ESS, JEN, PCR, SAP, AND, and TND are also closely aligned between the two specifications. However, for AGD, CIT, END, ENX, and UED, the Half-Normal Translog model produces moderately higher efficiency scores.

For the short-period Cobb–Douglas model, the efficiency scores under the Half-Normal specification are generally higher, with the exception of ERG, ESS, and SAP, where the scores are closely aligned across both specifications. The short-period Translog model under the Half-Normal specification cannot be directly compared to its Truncated-Normal counterpart, as the latter failed to converge. Nevertheless, the Half-Normal Translog model in the short period appears to produce unreliable and unusually low efficiency scores

Table 1.6 Efficiency Scores

	Long Period				*Short Period*			
	CD	*rank*	*TLG*	*rank*	*CD*	*rank*	*TLG*	*rank*
EVO	0.532	13	0.553	10	0.581	13	0.504	6
AGD	0.615	10	0.305	13	0.664	11	0.029	13
CIT	0.936	3	0.772	5	0.861	5	0.314	8
END	0.725	8	0.496	11	0.782	6	0.136	11
ENX	0.712	9	0.443	12	0.744	8	0.074	12
ERG	0.577	12	0.766	6	0.636	12	0.755	3
ESS	0.597	11	0.750	8	0.677	10	0.948	2
JEN	0.741	7	0.756	7	0.701	9	0.303	9
PCR	0.966	2	0.964	2	0.969	1	0.613	4
SAP	0.921	4	0.914	3	0.959	2	0.602	5
AND	0.754	6	0.737	9	0.768	7	0.418	7
TND	0.897	5	0.968	1	0.921	4	0.964	1
UED	0.973	1	0.794	4	0.956	3	0.174	10
AUS	0.765		0.709		0.786		0.449	

Table 1.1 Efficiency Scores – Long Period

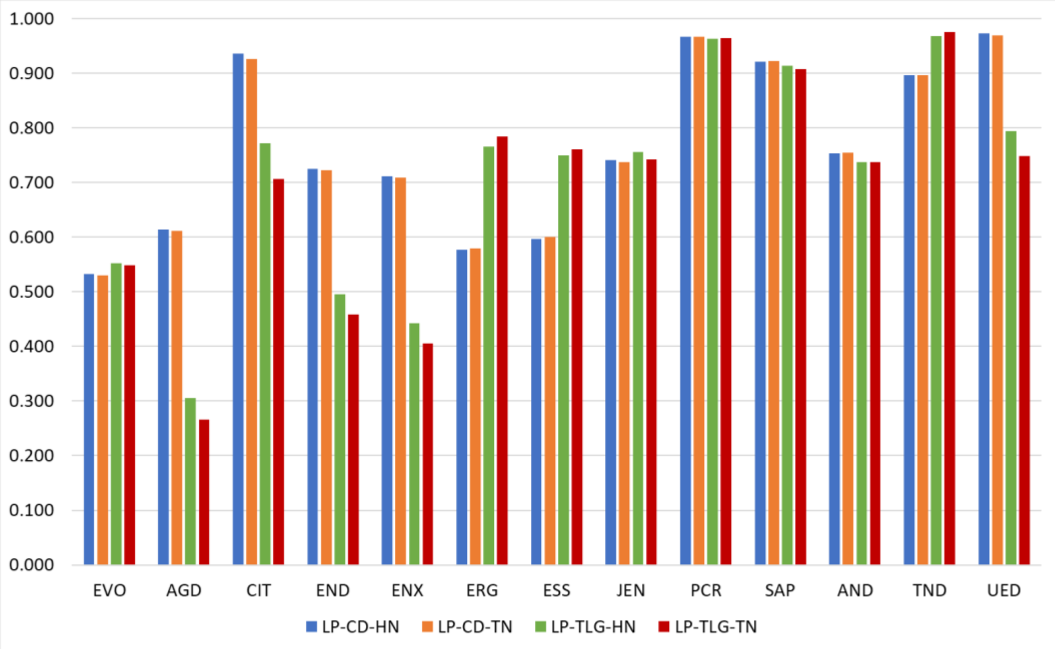
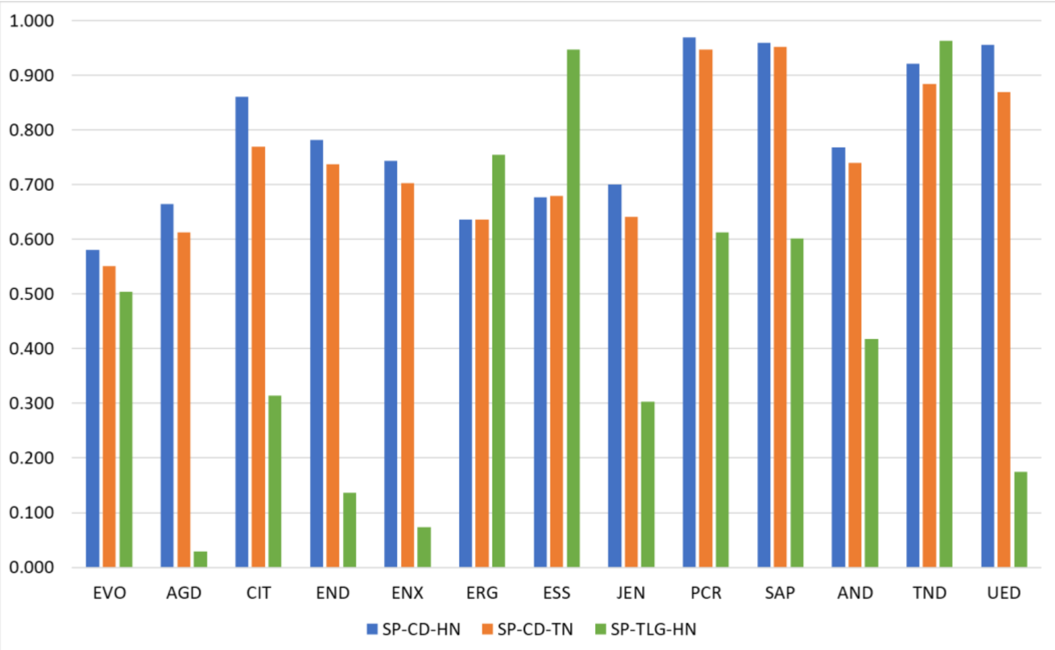


Table 1.2 Efficiency Scores – Short Period



1.5 Conclusion

The Half-Normal specification resolved the convergence issue in the short-period SFATLG model. However, this gain is limited, as the resulting efficiency scores are not considered reliable. For the other SFA and LSE modes, the half normal produced somewhat aligned output elasticities and efficiency scores. However, it did not address the problem of monotonicity violations.

2 Alternative methods of estimating the LSE models

2.1 Fixed Effects Model

As presented in Section 2 of the Phase 2 draft report, the current LSE approach, is applied using the Stata command **xtpcse** and includes fixed effects only for Australian DNSPs. Here, we present the results of the fixed effects model estimated using Stata's command **xtreg *y xlist*, fe**. This implicitly includes fixed effects for all of the DNSPs in the sample (although our interest is limited to the inefficiencies of the Australian DNSPs).

2.1.1 Estimation results

Tables 2.1.1 and 2.1.2 present the estimation results of the Fixed Effects model for both the long and short periods, using Cobb-Douglas and Translog specifications.

2.1.2 Consistency with economic theory or industry knowledge

Tables 2.1.1 shows that, for the Cobb-Douglas Model:

- The coefficient on customer numbers is not statistically significant in either the long or short period. It is positive in the long period and negative in the short period, indicating monotonicity violations. The coefficient on circuit length is positive but only statistically significant in the short period. The coefficient on RMD is positive and statistically significant in both periods. The coefficient on the share of underground circuit length is negative and statistically significant in the long period, but negative and not statistically significant in the short period.
- The time trend is positive and statistically significant in the long period, and not statistically significant in the short period. The within R^2 is higher in the long period compared to the short period, indicating that the explanatory variables account for more of the variation in opex within DNSPs over the long period Both models have high between and overall R^2, showing that the regressors explain most of the variation in average opex across DNSPs.
- The long-period model shows a strong negative correlation between fixed effects and regressors. The short-period model has a moderate positive correlation.
- The rho value is high in both models, indicating that the majority of the variation in opex is due to DNSP-specific (unobserved) factors.

Table 2.1.1 Fixed Effects Cobb-Douglas Models

	Long Period (2006-2023)			Short Period (2012-2023)		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.222	0.133	1.67	-0.233	0.240	-0.97
ly2	0.177	0.100	1.77	0.472	0.153	3.09
ly3	0.694	0.086	8.05	0.564	0.148	3.81
lz1	-0.212	0.051	-4.20	0.114	0.093	1.23
yr	0.011	0.002	7.37	0.004	0.003	1.44
_cons	-12.159	3.031	-4.01	3.106	5.160	0.60
sigma_u	0.275			0.304		
sigma_e	0.128			0.114		
rho	0.821			0.877		
R^2						
Within	0.358			0.109		
Between	0.980			0.960		
Overall	0.971			0.954		
Correlation u_i and X	-0.722			0.503		
BIC	-1418.06			-1133.18		
Pseudo Adj R^2	0.971			0.953		
# Parameters	6			6		
N	1,098			732		

For the Translog model, as shown in Table 2.1.2:

- The coefficient on customer numbers is not statistically significant in either the long or short period. It is positive in the long period and negative in the short period, indicating monotonicity violations. The coefficient on circuit length is positive and statistically significant in both periods. The coefficient on RMD is positive in both periods but and statistically significant only in the long period.
- The coefficient on the share of underground circuit length is negative and statistically significant in the long period, and negative but not statistically significant in the short period. The time trend is positive and statistically significant in both periods.
- The within R^2 is slightly higher in the long period compared to the short period. The between R^2 is considerably higher in the long period than in the short period and the overall R^2 shows a similar pattern: high in the long period but much lower in the short period.
- The correlation between fixed effects and regressors is negative in both models.
- The rho value is high in both models, indicating that the majority of the variation in opex is due to DNSP-specific (unobserved) factors.

These results suggest that the Fixed Effects model fails to produce reliable coefficients for the three main outputs, particularly due to lack of statistical significance and monotonicity issues. This indicates that the standard LSE model is more appropriate.

Table 2.1.2 Fixed Effects Translog Models

	Long Period (2006-2023)			Short Period (2012-2023)		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.166	0.135	1.23	-0.223	0.206	-1.09
ly2	0.496	0.128	3.88	1.123	0.169	6.63
ly3	0.323	0.104	3.11	0.197	0.144	1.37
ly11	0.611	0.553	1.1	-1.153	0.705	-1.64
ly12	-0.124	0.166	-0.74	0.853	0.210	4.06
ly13	-0.888	0.424	-2.09	-0.836	0.544	-1.54
ly22	0.200	0.119	1.68	0.336	0.155	2.16
ly23	0.392	0.121	3.24	-0.193	0.157	-1.23
ly33	0.295	0.362	0.81	0.628	0.470	1.34
lz1	-0.120	0.052	-2.33	0.040	0.080	0.50
yr	0.011	0.002	7.06	0.005	0.002	2.33
_cons	-11.1885	3.056	-3.66	0.225	4.518	0.05
sigma_u	0.7077			1.449		
sigma_e	0.1223			0.095		
rho	0.9710			0.996		
R^2						
Within	0.4207			0.389		
Between	0.7990			0.491		
Overall	0.7934			0.489		
Correlation u_i and X	-0.5387			-0.761		
BIC	-1489.73			-1369.30		
Pseudo Adj R^2	0.791			0.481		
# Parameters	12			12		
N	1,098			732		

Table 2.1.3 presents the output elasticities for the Fixed Effects models in the long and short period.

Table 2.1.3 Output elasticities

	Long Period				Short Period			
Sample	*Cust.*	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
<u>*CD*</u>								
Full Sample	0.222	0.177	0.694	1.093	-0.232	0.472	0.563	0.803
<u>*TLG*</u>								
Australia	-0.489	1.344	-0.006	0.848	-2.056	3.033	-0.650	0.327
New Zealand	0.536	0.270	0.689	1.495	1.359	0.819	0.148	2.327
Ontario	0.218	0.263	0.230	0.711	-0.439	0.465	0.609	0.636
Full sample	0.166	0.496	0.323	0.985	-0.223	1.123	0.197	1.096

The sum of these elasticities varies across models. It exceeds one in the Cobb–Douglas specification for the long period but is only 0.803 in the short period. Some output elasticities are negative, indicating violations of monotonicity, and the values also show inconsistencies when compared to the standard LSE model.

Table 2.1.4 presents the frequency of monotonicity violations (MVs) in the Fixed Effects Translog models. As noted earlier, the Cobb-Douglas models exhibit MVs for customer numbers in the short period. The Translog models also show significant issues, with MVs occurring in both periods. In the long period, 95.7 per cent of Australian observations and 64.5 per cent of the total sample are affected. In the short period, the problem is more pronounced, with 100 per cent of Australian observations and 73.1 per cent of the total sample showing violations. This also represents a deterioration compared to the standard LSETLG models.

Table 2.1.4 Fixed Effects Frequency of Monotonicity Violations (%)

	Long Period				*Short Period*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	88.9	0.0	50.9	95.7	100.0	0.0	93.6	100.0
NZ	9.9	31.9	5.3	41.8	15.8	3.1	24.6	32.0
Ontario	28.0	36.8	13.2	65.3	46.6	41.4	12.6	87.9
Total	35.3	27.4	18.8	64.5	48.4	20.6	33.6	73.1
Aus DNSPs:								
- EVO	44.4	0.0	11.1	44.4	100.0	0.0	41.7	100.0
- AGD	100.0	0.0	100.0	100.0	100.0	0.0	100.0	100.0
- CIT	100.0	0.0	100.0	100.0	100.0	0.0	75.0	100.0
- END	100.0	0.0	100.0	100.0	100.0	0.0	100.0	100.0
- ENX	100.0	0.0	100.0	100.0	100.0	0.0	100.0	100.0
- ERG	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- ESS	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- JEN	11.1	0.0	100.0	100.0	100.0	0.0	100.0	100.0
- PCR	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- SAP	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- AND	100.0	0.0	50.0	100.0	100.0	0.0	100.0	100.0
- TND	100.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
- UED	100.0	0.0	100.0	100.0	100.0	0.0	100.0	100.0

2.1.3 Specification Tests

Tables 2.1.1 and 2.1.2 show the BIC and Pseudo Adjusted R^2 goodness-of-fit statistic for each model. Notably, the Pseudo Adjusted R^2 is very low in the short period models, especially in the Translog Model. Other diagnostic statistics are shown in Table 2.1.5.

Residual diagnostic tests indicate there are no severe outliers in the CD models, while the TLG models show slightly higher rates (4.8 per cent in the long period and 6.2 per cent in the short period). The Shapiro–Wilk test rejects the null hypothesis of normality for the TLG residuals in both periods, and for the CD model in the long period but not in the short period ($p = 0.071$).

Multicollinearity is moderate in the CD models. In contrast, the TLG models present severe multicollinearity, largely due to the inclusion of interaction and squared terms. Functional form tests support the TLG specification, as the joint tests confirm that the higher-order output terms are jointly significant in both periods.

Table 2.1.5 Diagnostic Statistics

	Long Period		*Short Period*	
	Stat.	*p-value**	*Stat.*	*p-value**
CD				
Normality of residuals				
IQR (% severe outliers)(1)	0.00		0.00	
Shapiro–Wilk W test(2)	0.980	0.000	0.996	0.071
Multicollinearity				
Average VIF(3)	24.10		24.95	
Condition number(3)	947.51		1418.82	
TLG				
Normality of residuals				
IQR (% severe outliers)	4.37		6.15	
Shapiro–Wilk W test	0.928	0.000	0.900	0.000
Multicollinearity				
Average VIF	821.59		829.92	
Condition number	1592.13		2365.40	
Joint parameter tests				
Higher-order output terms	18.65	0.0000	50.31	0.000

Note: * Null hypothesis is rejected in these tests, if the p-value is less than 0.05. Equivalently, the reported statistic exceeds the critical value for that statistic; (1) Severe outliers comprise about .0002% of the normal population; (2) The null hypothesis is that residuals are normally distributed; (3) Collinearity is potentially a problem if VIF>10 or the Condition number > 30;

2.1.4 Efficiency Scores

Table 2.1.6 presents the efficiency scores and corresponding rankings for all Australian DNSPs and the three jurisdictions.

The efficiency scores are generally very low, and the rankings are neither consistent across jurisdictions nor aligned with those observed in other standard models. This suggests that the model fails to produce reliable efficiency estimates.

Table 2.1.6 Fixed Effects Models: Efficiency Scores

	Long Period				Short Period			
	CD	*rank*	*TLG*	*rank*	*CD*	*rank*	*TLG*	*rank*
EVO	0.600	1	0.188	3	0.679	5	0.029	7
AGD	0.383	3	0.457	1	0.907	1	0.480	1
CIT	0.320	9	0.244	2	0.588	10	0.113	3
END	0.334	5	0.175	7	0.634	8	0.050	6
ENX	0.329	7	0.182	5	0.732	3	0.074	4
ERG	0.344	4	0.016	12	0.669	7	0.000	12
ESS	0.332	6	0.013	13	0.689	4	0.000	13
JEN	0.403	2	0.175	6	0.766	2	0.066	5
PCR	0.224	13	0.030	10	0.516	11	0.002	10
SAP	0.247	12	0.029	11	0.450	13	0.001	11
AND	0.322	8	0.062	8	0.673	6	0.006	8
TND	0.281	10	0.052	9	0.455	12	0.004	9
UED	0.268	11	0.185	4	0.629	9	0.116	2
AUS	0.337		0.139		0.645		0.072	
NZ	0.502		0.146		0.382		0.024	
ONT	0.467		0.165		0.542		0.069	
Total	0.450		0.154		0.514		0.056	

2.1.5 Conclusions

The results of this analysis show that the coefficients obtained from this model differ substantially from those in the standard model presented in the 2024 benchmarking report (Quantonomics 2024: Appendix C). This underscores that expanding the fixed effects specification from Australian DNSPs only to all DNSPs significantly affects the parameter estimates overall. Further, the model produces unreliable efficiency scores.

3 Four & Five Outputs Specifications

The standard econometric opex cost function used in the ABR incorporates three outputs: customer numbers, circuit length, and ratcheted maximum demand (RMD). In contrast, the TFP index analysis includes five outputs—the same three, plus energy delivered and customer minutes off supply (CMOS). The exclusion of the latter two variables from the econometric analysis (Economic Insights 2014) was primarily due to concerns about data availability and reliability for international DNSPs. Additionally, there were concerns about potential multicollinearity arising from their inclusion. However, recent analysis indicates that the standard model may be affected by omitted variable bias. In this section, we test the inclusion of energy delivered and CMOS. We find that data for international DNSPs are available, and therefore data limitations do not pose a constraint if the data is sufficiently consistent between jurisdictions.

Section 3.1 outlines the methodological approach and provides descriptive statistics for the two additional variables. Sections 3.2, 3.3 and 3.4 present the econometric results from models that include: (i) all five output variables, (ii) only energy delivered, and (iii) only customer minutes off supply (CMOS).

3.1 Methodological Approach and Descriptive Statistics

3.1.1 Energy Delivered

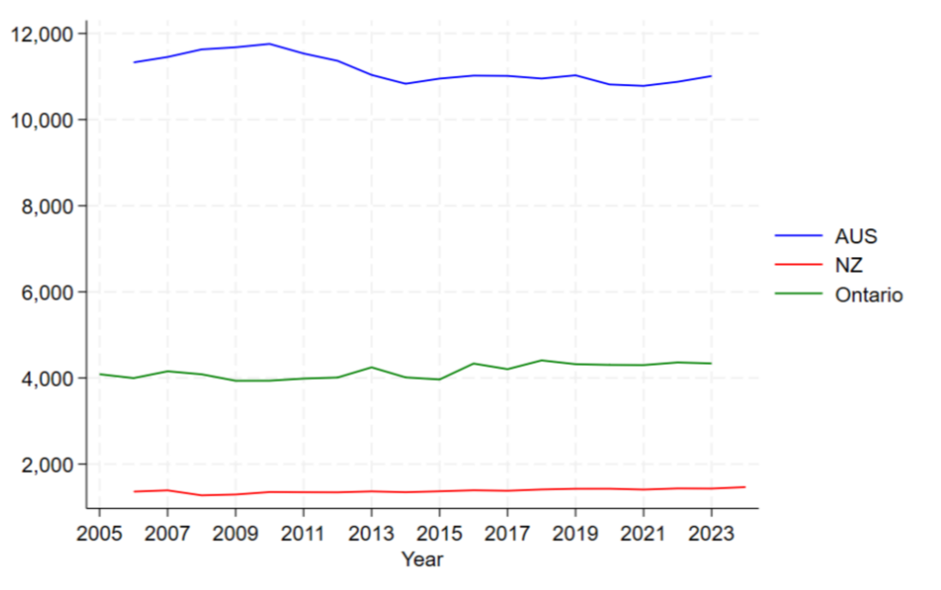
Energy Delivered refers to the amount of electricity supplied by a DNSP to its customers over a given year. For Australian DNSPs, the data are sourced from the AER dataset and reported in gigawatt-hours (GWh). Across all years, the average energy delivered is 11,171 GWh per DNSP, which equates to 0.424 GWh per kilometre of circuit length and 0.015 GWh per customer.

For New Zealand DNSPs, data from 2008 to 2024 are drawn from the NZCC workbooks under the item Energy delivered to ICPs in disclosure year (originally reported in MWh and converted to GWh). For 2006 and 2007, estimates were derived from the NZ Gazette, calculated as the difference between Total Electricity Entering and Energy Loss. The average across all years is 1,379 GWh per DNSP, 0.185 GWh/km of circuit length, and 0.015 GWh per customer.

For Ontario DNSPs, data are sourced from the PEG workbook under the label Delivery Volume (originally reported in kWh and converted to GWh). The average energy delivered across all years is 4,156 GWh per DNSP, 1.118 GWh/km of circuit length, and 0.023 GWh per customer.

When combining all jurisdictions, the overall average energy delivered is 4,714 GWh per DNSP, 0.682 GWh/km of circuit length, and 0.019 GWh per customer. Figure 5.1 presents the average energy delivered for each country.

Figure 3.1 Energy Delivered (GWh) per DNSP by Country



3.1.2 Customer Minutes off-supply (CMOS)

Customer Minutes Off Supply (CMOS) is defined as:

$$CMOS\ (min/year) = SAIDI\ (min/cust/year) \times Customers \tag{3.1}$$

where CMOS is Customer Minutes Off-supply and SAIDI is the System Average Interruption Duration Index. The latter is defined in the next section.

If SAIDI and customer numbers are available for international DNSPs, their respective CMOS values can be derived directly using Equation 5.1. The AER (2018: 6) defines SAIDI as the total duration of all sustained interruptions (measured in minutes), divided by the number of customers. Momentary interruptions—those lasting three minutes or less—are excluded from this measure. However, SAIDI is occasionally defined in terms of hours rather than minutes. For example, Okorie et al. (2015) defines it as:

$$SAIDI = \frac{Sum\ of\ all\ customers\ minutes\ interrupted}{Total\ number\ of\ customers\ served} = \frac{\sum_i r_i N_i}{N_T} \tag{3.2}$$

where r_i is the restoration time for interruption i, in hours; N_i is the number of customers interrupted in interruption i; and N_T is the total number of customers served.

New Zealand CMOS

In line with the AER, the New Zealand Commerce Commission also reports SAIDI in minutes (NZCC, 2024: 37-38). These data were sourced from the NZCC Disclosures workbooks, which provide a detailed breakdown of SAIDI by interruption class, including:

- Class A – Planned interruptions by Transpower
- Class B – Planned interruptions on the network
- Class C – Unplanned interruptions on the network
- Class D – Unplanned interruptions by Transpower
- Class E – Unplanned interruptions from EDB-owned generation
- Class F – Unplanned interruptions from generation owned by others
- Class G – Unplanned interruptions caused by another disclosing entity
- Class H – Planned interruptions caused by another disclosing entity
- Class I – Interruptions caused by other parties not listed above
- Total – All categories combined

For the purposes of this exercise, and to align with the AER's treatment of unplanned interruptions, we selected the following interruption classes: C, D, E, F, G, and I. New Zealand's CMOS was then calculated by multiplying SAIDI by the number of customers.

Ontario CMOS

For Ontario, SAIDI is reported in hours rather than minutes (OEB 2025, p. 15). Accordingly, to ensure consistency across jurisdictions, the Ontario SAIDI values were converted to minutes by multiplying by 60 for all years.

For the period 2015–2022, the OEB dataset provides a breakdown of SAIDI by cause, as follows:

- Cause: Unknown/Other
- Cause: Scheduled Outage
- Cause: Loss of Supply
- Cause: Tree Contacts
- Cause: Lightning
- Cause: Defective Equipment
- Cause: Adverse Weather
- Cause: Adverse Environment
- Cause: Human Element
- Cause: Foreign Interference

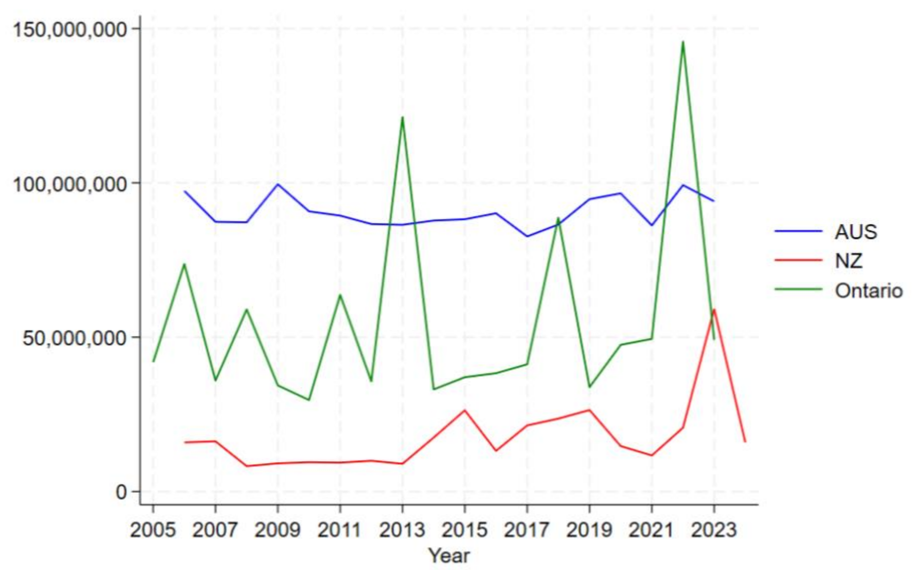
To align with the AER definition, SAIDI was calculated as the sum of all categories excluding "Cause: Scheduled Outage". A key challenge was the absence of disaggregated SAIDI data for uncontrollable interruptions in the Ontario dataset prior to 2014. To address this, we calculated the average ratio of uncontrollable to total SAIDI across the full Ontario dataset (where disaggregated data were available), and applied these ratios to estimate uncontrollable values for the earlier years based on the reported total SAIDI. Ontario's CMOS was then calculated by multiplying SAIDI by the number of customers.

Descriptive Statistics

For Australian DNSPs in total, the average CMOS across all years is 90,610,400 minutes per year, which equates to 2,015.15 minutes per kilometre of circuit length per year and 117.27 minutes per customer per year (i.e. SAIDI). For New Zealand DNSPs in total, the average CMOS is 17,788,319 minutes per year, corresponding to 2,235.11 minutes per kilometre of circuit length per year and 211.84 minutes per customer per year (SAIDI). For Ontario DNSPs in total, the average CMOS is 55,759,346 minutes per year, equating to 7,224.54 minutes per kilometre of circuit length per year and 173.99 minutes per customer per year (SAIDI).

When combining all jurisdictions, ie, considering the entire sample, the average CMOS is 50,914,325 minutes per year, which translates to 4,589.13 minutes per kilometre of circuit length per year and 174.33 minutes per customer per year (SAIDI). Figure 5.2 presents the average CMOS for each country.

Figure 3.2 CMOS per year per DNSP by Country



3.2 Estimation Results with Five Outputs

In this specification, all five output variables were included in the four models. Tables 3.2.1 to 3.2.4 present the estimation results for the LSE and SFA models for both the long and short periods. Interestingly, unlike in the standard models where the SFATLG specification for the short period failed to converge, in this extended specification it achieves convergence.

Table 3.2.1 Estimation Results – LSE Models (2006-2023)

	LSECD			LSETLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.503	0.075	6.668	0.299	0.082	3.661
ln(CircLen)	0.206	0.034	6.074	0.227	0.035	6.467
ln(RMDemand)	0.154	0.071	2.172	0.282	0.075	3.748
ln(Energy)	0.080	0.044	1.806	0.129	0.052	2.483
ln(CMOS)	0.018	0.004	4.055	0.011	0.006	1.869
x1*x1/2				-0.285	0.535	-0.531
x1*x2				0.296	0.127	2.330
x1*x3				-0.383	0.468	-0.819
x1*x4				0.264	0.238	1.109
x1*x5				-0.029	0.036	-0.829
x2*x2/2				-0.044	0.045	-0.972
x2*x3				-0.023	0.129	-0.176
x2*x4				-0.197	0.085	-2.310
x2*x5				0.004	0.009	0.419
x3*x3/2				0.798	0.476	1.677
x3*x4				-0.367	0.229	-1.607
x3*x5				0.007	0.041	0.161
x4*x4/2				0.370	0.183	2.018
x4*x5				0.009	0.032	0.264
x5*x5/2				0.007	0.006	1.166
ln(ShareUGC)	-0.093	0.025	-3.691	-0.110	0.028	-3.879
Year	0.010	0.002	6.276	0.013	0.002	7.614
New Zealand	-0.416	0.124	-3.346	-0.469	0.124	-3.788
Ontario	-0.213	0.123	-1.735	-0.332	0.123	-2.706
AGD	-0.141	0.180	-0.784	-0.043	0.184	-0.232
CIT	-0.434	0.137	-3.181	-0.401	0.138	-2.909
END	-0.293	0.144	-2.027	-0.307	0.144	-2.123
ENX	-0.311	0.133	-2.344	-0.252	0.142	-1.784
ERG	-0.108	0.156	-0.691	-0.248	0.180	-1.377
ESS	-0.273	0.164	-1.670	-0.423	0.188	-2.246
JEN	-0.358	0.150	-2.388	-0.202	0.158	-1.274
PCR	-0.665	0.140	-4.736	-0.725	0.148	-4.918
SAP	-0.613	0.147	-4.169	-0.686	0.157	-4.363
AND	-0.503	0.140	-3.604	-0.468	0.149	-3.148
TND	-0.523	0.156	-3.362	-0.593	0.156	-3.801
UED	-0.594	0.147	-4.036	-0.379	0.159	-2.386
_cons	-9.320	3.153	-2.956	-14.961	3.341	-4.478
rho	0.769			0.763		
R^2	0.991			0.992		
Pseudo Adj R^2	0.979			0.982		
# Parameters	22			37		
N	1098			1098		

Table 3.2.2 Estimation Results – SFA Models (2006-2023)

	SFACD			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.266	0.074	3.576	0.350	0.097	3.608
ln(CircLen)	0.114	0.042	2.683	0.095	0.062	1.540
ln(RMDemand)	0.531	0.082	6.436	0.383	0.094	4.061
ln(Energy)	0.020	0.047	0.429	0.109	0.067	1.623
ln(CMOS)	0.030	0.007	3.978	0.021	0.009	2.300
x1*x1/2				1.036	0.493	2.100
x1*x2				-0.253	0.126	-2.009
x1*x3				-1.581	0.472	-3.353
x1*x4				0.730	0.242	3.021
x1*x5				-0.039	0.048	-0.805
x2*x2/2				0.090	0.062	1.450
x2*x3				0.549	0.136	4.025
x2*x4				-0.337	0.092	-3.651
x2*x5				0.022	0.013	1.692
x3*x3/2				1.945	0.513	3.790
x3*x4				-1.035	0.247	-4.193
x3*x5				-0.014	0.060	-0.226
x4*x4/2				0.662	0.210	3.160
x4*x5				0.027	0.049	0.539
x5*x5/2				0.008	0.010	0.878
ln(ShareUGC)	-0.134	0.031	-4.299	-0.143	0.044	-3.237
Year	0.010	0.001	10.270	0.011	0.001	8.567
New Zealand	0.013	0.090	0.146	0.001	0.076	0.008
Ontario	0.074	0.075	0.990	-0.008	0.095	-0.089
_cons	-10.115	1.952	-5.181	-12.602	2.661	-4.737
lnsigma2	-2.284	0.573	-3.989	-1.285	0.956	-1.344
lgtgamma	1.670	0.681	2.452	2.878	1.017	2.830
mu	0.053	0.244	0.218	-0.323	0.791	-0.408
sigma2	0.102	0.058		0.277	0.265	
gamma	0.842	0.091		0.947	0.051	
sigma_u2	0.086	0.058		0.262	0.265	
sigma_v2	0.016	0.001		0.015	0.001	
LLH	602.34			634.97		
Iterations #	9			12		
Pseudo Adj R2	0.991			0.992		
BIC	-1113.66			-1073.91		
# Parameters	13			28		
N	1098			1098		

Table 3.2.3 Estimation Results – LSE Models (2012-2023)

	LSECD			LSETLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.461	0.075	6.138	0.178	0.082	2.165
ln(CircLen)	0.234	0.033	7.167	0.213	0.034	6.204
ln(RMDemand)	-0.083	0.096	-0.861	0.110	0.093	1.185
ln(Energy)	0.328	0.076	4.306	0.412	0.084	4.879
ln(CMOS)	0.019	0.005	3.851	0.019	0.007	2.826
x1*x1/2				-0.153	0.556	-0.275
x1*x2				0.136	0.130	1.041
x1*x3				-1.270	0.696	-1.825
x1*x4				1.063	0.506	2.101
x1*x5				-0.039	0.038	-1.023
x2*x2/2				0.008	0.043	0.194
x2*x3				0.053	0.188	0.282
x2*x4				-0.171	0.131	-1.300
x2*x5				0.015	0.010	1.522
x3*x3/2				0.366	1.290	0.283
x3*x4				0.883	1.035	0.853
x3*x5				0.039	0.060	0.655
x4*x4/2				-1.615	0.943	-1.713
x4*x5				-0.018	0.047	-0.375
x5*x5/2				0.004	0.008	0.503
ln(ShareUGC)	-0.081	0.026	-3.063	-0.092	0.026	-3.581
Year	0.004	0.002	2.001	0.008	0.002	3.703
New Zealand	-0.479	0.145	-3.311	-0.547	0.124	-4.398
Ontario	-0.277	0.144	-1.931	-0.477	0.127	-3.767
AGD	-0.204	0.190	-1.071	-0.029	0.170	-0.168
CIT	-0.390	0.150	-2.602	-0.436	0.131	-3.336
END	-0.341	0.161	-2.117	-0.335	0.140	-2.388
ENX	-0.316	0.151	-2.090	-0.170	0.141	-1.208
ERG	-0.219	0.175	-1.248	-0.437	0.180	-2.436
ESS	-0.320	0.180	-1.775	-0.397	0.192	-2.063
JEN	-0.326	0.158	-2.058	-0.178	0.149	-1.196
PCR	-0.702	0.155	-4.518	-0.637	0.148	-4.298
SAP	-0.537	0.161	-3.334	-0.391	0.166	-2.352
AND	-0.464	0.155	-2.984	-0.209	0.156	-1.340
TND	-0.538	0.179	-3.007	-0.594	0.156	-3.805
UED	-0.589	0.164	-3.601	-0.274	0.154	-1.782
_cons	1.964	4.304	0.456	-5.076	4.244	-1.196
rho	0.727			0.674		
R^2	0.995			0.995		
Pseudo Adj R^2	0.982			0.985		
# Parameters	22			37		
N	732			732		

Table 3.2.4 Estimation Results – SFA Models (2012-2023)

	SFACD			*SFATLG*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.074	0.102	0.722	-0.013	0.122	-0.103
ln(CircLen)	0.268	0.062	4.320	0.245	0.067	3.677
ln(RMDemand)	0.026	0.110	0.234	0.120	0.125	0.963
ln(Energy)	0.542	0.093	5.833	0.570	0.096	5.908
ln(CMOS)	0.028	0.008	3.705	0.032	0.009	3.372
x1*x1/2				0.173	0.618	0.280
x1*x2				0.109	0.180	0.608
x1*x3				-3.455	0.720	-4.801
x1*x4				2.927	0.525	5.579
x1*x5				0.007	0.048	0.150
x2*x2/2				0.023	0.085	0.266
x2*x3				0.479	0.188	2.545
x2*x4				-0.593	0.145	-4.082
x2*x5				0.031	0.013	2.407
x3*x3/2				2.563	1.241	2.066
x3*x4				0.359	0.933	0.384
x3*x5				-0.011	0.076	-0.148
x4*x4/2				-2.509	0.818	-3.066
x4*x5				-0.014	0.065	-0.222
x5*x5/2				-0.009	0.010	-0.849
ln(ShareUGC)	0.001	0.042	0.026	0.002	0.064	0.033
Year	0.004	0.001	2.933	0.007	0.002	4.291
New Zealand	-0.204	0.085	-2.399	-0.250	0.083	-3.032
Ontario	-0.063	0.091	-0.689	-0.227	0.097	-2.336
_cons	1.661	2.898	0.573	-4.648	3.524	-1.319
lnsigma2	-3.021	0.288	-10.474	-2.892	0.325	-8.898
lgtgamma	1.117	0.388	2.883	1.548	0.411	3.771
mu	0.237	0.076	3.106	0.326	0.105	3.103
sigma2	0.049	0.014		0.055	0.018	
gamma	0.753	0.072		0.825	0.059	
sigma_u2	0.037	0.014		0.046	0.018	
sigma_v2	0.012	0.001		0.010	0.001	
LLH	481.50			542.55		
Iterations #	6			9		
Pseudo Adj R2	0.993			0.995		
BIC	-877.26			-900.41		
# Parameters	13			28		
N	732			732		

3.2.1 Consistency with economic theory or industry knowledge

In these models, the role of CMOS differs from that in the productivity index analysis. In the index analysis, CMOS is a negative output, because the costs to customers of outages represents the negative value of this output. In these econometric models, the coefficient on CMOS reflects the partial effect of customers interruption on opex, which will be associated with the cost of dealing with outages. It is expected to be positive because more outages will require more work in rectifying the supply failures.

As shown in tables 3.2.1 and 3.2.2, in the long period, all four models yield positive coefficients for the five output variables, although not all are statistically significant at the 5 per cent level. In the LSECD and SFACD models, Energy Delivered is not significant, while in the LSETLG model, CMOS lacks significance. The SFATLG model shows two insignificant outputs: Circuit Length and Energy Delivered.

In the long period LSE models, the coefficient on the underground share is negative and statistically significant; the sign aligning with expectations. In the SFA long-period models this variable is not statistically significant.

In the short period, results are more mixed, as presented in tables 3.2.3 and 3.2.4. In the LSECD model, RMD is negative and not significant, whereas the remaining outputs are positive and significant. The underground share remains negative and statistically significant. In the LSETLG model, CMOS is again not significant, but the other four outputs are both positive and significant, with the underground share also negative and significant. The SFACD model shows Customer Numbers and RMD as not significant, while the other outputs are positive and significant; notably, the underground share here is positive but not statistically significant. Similarly, in the SFATLG model, Customer Numbers are negative and not significant, and RMD is positive but not significant. The other three outputs are positive and significant, while the underground share remains positive and not statistically significant.

Tables 3.2.5 and 3.2.6 provide a comparative view of the output elasticities estimated under four model specifications for both the long and short periods. While total output elasticities are broadly similar across models, close to 1, the distribution of elasticities across the five outputs varies considerably. The LSECD model consistently assigns a relatively higher share of total elasticity to customer numbers. In contrast, the SFACD model places greater emphasis on Energy and RMD. This distinction between the Cobb-Douglas models is consistent across the long and short periods. Also notable is the small output elasticity for CMOS, which is between 0.02 and 0.03 in the CD models.

In the Translog models, elasticities vary across observations, and Table 3.2.6 shows considerable variation in average elasticities across jurisdictions, particularly in the short period. The TLG models also tend to produce more dispersed estimates across outputs, with some cases of negative or near-zero elasticities. The SFATLG model, in particular, shows greater variability across jurisdictions and between periods.

Table 3.2.5 Output elasticities Long Period

Sample	*Cust.*	*CL*	*RMD*	*Energy*	*CMOS*	*Total*
LSECD						
Full Sample	0.503	0.206	0.154	0.080	0.018	0.961
SFACD						
Full Sample	0.266	0.114	0.531	0.020	0.030	0.961
LSETLG						
Australia	0.098	0.328	0.320	0.197	0.001	0.944
NZ	0.657	0.216	0.121	-0.059	0.014	0.949
Ontario	0.155	0.190	0.370	0.222	0.013	0.950
Full sample	0.299	0.227	0.282	0.129	0.011	0.948
SFATLG						
Australia	0.142	0.246	0.237	0.103	0.027	0.755
NZ	0.451	0.060	0.630	-0.061	0.036	1.116
Ontario	0.378	0.051	0.286	0.222	0.009	0.946
Full sample	0.350	0.095	0.383	0.109	0.021	0.958

Table 3.2.6 Output elasticities Short Period

Sample	*Cust.*	*CL*	*RMD*	*Energy*	*CMOS*	*Total*
LSECD						
Full Sample	0.461	0.234	-0.083	0.328	0.019	0.959
SFACD						
Full Sample	0.074	0.268	0.026	0.542	0.028	0.938
LSETLG						
Australia	-0.365	0.320	-0.013	0.921	0.023	0.886
NZ	0.544	0.216	-0.116	0.257	0.025	0.926
Ontario	0.181	0.163	0.312	0.284	0.012	0.952
Full sample	0.178	0.213	0.110	0.412	0.019	0.932
SFATLG						
Australia	-0.705	0.411	-0.300	1.322	0.052	0.780
NZ	0.508	0.235	-0.102	0.333	0.057	1.031
Ontario	-0.043	0.177	0.454	0.388	0.006	0.982
Full sample	-0.013	0.245	0.120	0.570	0.032	0.954

Tables 3.2.7 and 3.2.8 report the frequency of monotonicity violations across output variables for the Translog models, separately for the long and short periods. Overall, including the two additional outputs generally worsens model performance in terms of monotonicity violations when compared to the standard specification. In the long period the total violation rate for the Australian DNSPs is 72.2 per cent under LSETLG and 77.8 per cent under SFATLG. For the full sample, the corresponding totals are 48.3 per cent for LSETLG and 71.2 per cent for SFATLG. In the short period monotonicity violations become even more prevalent. The total violation rate for Australian DNSPs reaches 98.7 per cent under both LSETLG and SFATLG models. For the full sample, violations rise to 70.0 per cent for LSETLG and 89.8 per cent for SFATLG. Again, SFATLG records a consistently higher rate of violations.

Table 3.2.7 Frequency of Monotonicity Violations - Long Period

Sample	*LSETLG*						*SFATLG*					
	Cust.	*CL*	*RMD*	*Energy*	*CMOS*	*Total*	*Cust.*	*CL*	*RMD*	*Energy*	*CMOS*	*Total*
By DNSP												
EVO	5.6	0.0	0.0	0.0	88.9	88.9	0.0	0.0	0.0	5.6	33.3	33.3
AGD	100.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0
CIT	100.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	100.0	0.0	100.0	100.0
END	100.0	0.0	0.0	0.0	38.9	100.0	33.3	0.0	0.0	0.0	0.0	33.3
ENX	100.0	0.0	0.0	0.0	94.4	100.0	0.0	0.0	66.7	0.0	0.0	66.7
ERG	0.00	0.0	0.0	100.0	0.0	100.0	100.0	0.0	0.0	100.0	0.0	100.0
ESS	0.00	0.0	0.0	100.0	0.0	100.0	100.0	0.0	0.0	100.0	0.0	100.0
JEN	88.9	0.0	0.0	0.0	100.0	100.0	0.0	11.1	100.0	0.0	66.7	100.0
PCR	0.00	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	72.2	0.0	72.2
SAP	0.00	0.0	0.0	16.7	0.0	16.7	100.0	0.0	0.0	100.0	0.0	100
AND	0.00	0.0	0.0	0.0	33.3	33.3	0.0	0.0	5.6	0.0	0.0	5.6
TND	0.00	0.0	0.0	0.0	0.0	0.0	83.3	0.0	0.00	100.0	0.0	100.0
UED	100.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	100.0	0.0	44.4	100.0
By jurisdiction												
Australia	45.7	0.0	0.0	16.7	50.4	72.2	32.9	0.9	36.3	36.8	18.8	77.8
NZ	4.1	0.0	17.3	71.1	6.1	79.5	5.6	34.5	3.2	56.1	2.9	80.1
Ontario	14.4	0.0	0.0	2.9	1.0	17.1	6.5	31.6	16.7	5.8	21.6	62.5
Full sample	17.9	0.0	5.4	27.1	13.1	48.3	11.8	26.0	16.7	28.1	15.0	71.2

Table 3.2.8 Frequency of Monotonicity Violations – Short Period

Sample	*LSETLG*						*SFATLG*					
	Cust.	*CL*	*RMD*	*Energy*	*CMOS*	*Total*	*Cust.*	*CL*	*RMD*	*Energy*	*CMOS*	*Total*
By DNSP												
EVO	83.3	0.0	83.3	0.0	0.0	83.3	100.0	0.0	91.7	0.0	0.0	100.0
AGD	100.0	0.0	8.3	0.0	0.0	100.0	100.0	0.0	100.0	0.0	0.0	100.0
CIT	100.0	0.0	33.3	0.0	16.7	100.0	100.0	0.0	100.0	0.0	0.0	100.0
END	100.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	33.3	0.0	0.0	100.0
ENX	100.0	0.0	8.3	0.0	0.0	100.0	100.0	0.0	100.0	0.0	0.0	100.0
ERG	100.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	100.0	0.0	100.0
ESS	100.0	0.0	0.0	0.0	0.0	100.0	83.3	0.0	0.0	0.0	0.0	83.3
JEN	100.0	0.0	100.0	0.0	75.0	100.0	100.0	0.0	100.0	0.0	0.0	100.0
PCR	100.0	0.0	66.7	0.0	0.0	100.0	100.0	0.0	100.0	0.0	0.0	100.0
SAP	100.0	0.0	83.3	0.0	0.0	100.0	100.0	0.0	58.3	0.0	0.0	100.0
AND	100.0	0.0	100.0	0.0	0.0	100.0	100.0	0.0	100.0	0.0	0.0	100.0
TND	100.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0	0.0	100.0
UED	100.0	0.0	100.0	0.0	0.0	100.0	100.0	0.0	100.0	0.0	0.0	100.0
By jurisdiction												
Australia	98.7	0.0	44.9	0.0	7.1	98.7	98.7	0.0	68.0	7.7	0.0	98.7
NZ	10.5	0.0	72.8	27.6	0.0	98.3	15.78	0.0	67.5	31.6	0.0	92.5
Ontario	19.8	0.0	8.3	8.9	2.9	38.5	51.4	2.6	14.7	19.8	32.2	83.9
Full sample	33.7	0.0	36.2	12.8	2.9	70.0	50.4	1.2	42.5	20.9	15.3	89.8

3.2.2 Specification Tests

Tables 3.2.1 and 3.2.4 show the LLH value, the number of iterations, BIC and the pseudo-adjusted R^2. Additional diagnostic statistics are presented in Table 3.2.9. Normality tests reject the assumption of normally distributed residuals. Multicollinearity is moderate in the Cobb–Douglas models but elevated in the Translog models. Functional form tests support the use of the Translog specification, as the joint tests confirm that the higher-order output terms are jointly significant in both the long and short periods.

Table 3.2.9 Diagnostic Statistics

	Long Period		*Short Period*	
	Stat.	*p-value**	*Stat.*	*p-value**
LSECD				
Normality of residuals				
IQR (% severe outliers)(1)	0.09		0.00	
Shapiro–Wilk W test(2)	0.978	0.000	0.991	0.000
Multicollinearity				
Average VIF(3)	25.30		32.89	
Condition number(3)	1339.43		1917.75	
LSETLG				
Normality of residuals				
IQR (% severe outliers)	0.09		0.00	
Shapiro–Wilk W test	0.985	0.000	0.991	0.000
Multicollinearity				
Average VIF	2242.25		8614.69	
Condition number	960.40		1989.46	
Joint parameter tests				
Higher-order output terms	56.35	0.000	100.16	0.000
SFACD				
Normality of residuals				
IQR (% severe outliers)(1)	0.18		0.14	
Shapiro–Wilk W test(2)	0.985	0.000	0.979	0.000
Multicollinearity				
Average VIF(3)	44.07		58.49	
Condition number(3)	1269.50		1830.46	
SFATLG				
Normality of residuals				
IQR (% severe outliers)	0.09		0.14	
Shapiro–Wilk W test	0.987	0.000	0.983	0.000
Multicollinearity				
Average VIF	2005.59		7439.44	
Condition number	2670.54		3595.43	
Joint parameter tests				
Higher-order output terms	25.74	0.000	73.01	0.000

Note: * Null hypothesis is rejected in these tests, if the p-value is less than 0.05. Equivalently, the reported statistic exceeds the critical value for that statistic; (1) Severe outliers comprise about .0002% of the normal population; (2) The null hypothesis is that residuals are normally distributed; (3) Collinearity is potentially a problem if VIF>10 or the Condition number > 30.

3.2.3 Efficiency Scores

Tables 3.2.10 and 3.2.11 present the efficiency scores and rankings of Australian DNSPs under four model specifications for both the long and short periods.

Table 3.2.10 Efficiency Scores: Long Period

	LSE				*SFA*			
Sample	*CD*	*Rank*	*TLG*	*Rank*	*CD*	*Rank*	*TLG*	*Rank*
EVO	0.514	13	0.484	13	0.525	13	0.547	10
AGD	0.592	11	0.505	12	0.618	10	0.377	13
CIT	0.794	6	0.723	6	0.917	4	0.860	4
END	0.689	9	0.658	8	0.728	8	0.545	11
ENX	0.702	8	0.623	9	0.713	9	0.498	12
ERG	0.573	12	0.620	10	0.587	12	0.730	8
ESS	0.676	10	0.739	5	0.605	11	0.712	9
JEN	0.736	7	0.592	11	0.742	7	0.805	6
PCR	1.000	1	1.000	1	0.969	2	0.965	2
SAP	0.950	2	0.961	2	0.926	3	0.930	3
AND	0.851	5	0.773	4	0.766	6	0.749	7
TND	0.868	4	0.876	3	0.908	5	0.974	1
UED	0.932	3	0.708	7	0.971	1	0.854	5
Australia	0.760		0.712		0.767		0.734	

Table 3.2.11 Efficiency Scores: Short Period

	LSE				*SFA*			
Sample	*CD*	*Rank*	*TLG*	*Rank*	*CD*	*Rank*	*TLG*	*Rank*
EVO	0.496	13	0.529	13	0.579	13	0.552	11
AGD	0.608	12	0.544	12	0.655	12	0.441	13
CIT	0.732	6	0.818	4	0.845	5	0.811	3
END	0.697	7	0.739	7	0.794	6	0.687	7
ENX	0.680	10	0.627	11	0.741	7	0.551	12
ERG	0.617	11	0.819	3	0.684	11	0.807	4
ESS	0.683	9	0.787	5	0.690	9	0.770	5
JEN	0.687	8	0.632	10	0.686	10	0.603	8
PCR	1.000	1	1.000	1	0.963	1	0.921	2
SAP	0.848	4	0.782	6	0.881	3	0.750	6
AND	0.788	5	0.652	9	0.724	8	0.582	9
TND	0.849	3	0.959	2	0.920	2	0.972	1
UED	0.893	2	0.696	8	0.868	4	0.559	10
Australia	0.737		0.737		0.772		0.693	

In general, the Cobb-Douglas models yield higher and more stable average efficiency scores across periods. In contrast, the Translog models, particularly SFATLG, tend to produce lower average scores. A similar pattern is observed in the efficiency rankings. Rankings from the Cobb-Douglas models are relatively consistent, particularly for DNSPs at the top (e.g. PCR, SAP, TND) and bottom (e.g. EVO, AGD) of the rank. In contrast, the Translog models, especially SFATLG, exhibit greater volatility in rankings across both periods.

When comparing rankings between models, there is generally greater agreement within each functional form (ie. between LSECD and SFACD, or between LSETLG and SFATLG), rather than across functional forms. For example, DNSPs that rank highly under LSECD tend to also perform well under SFACD, with only minor differences in position. However, rankings can differ substantially when comparing a Cobb-Douglas model to a Translog model.

Figures 3.2.1 to 3.2.4 compare these efficiency scores with those from ABR24, as well as with the Opex MPFP. The inclusion of the Opex MPFP is important because, unlike the econometric models used in ABR24, it incorporates CMOS and Energy Delivered as output measures in its calculation.

Broadly speaking, the Cobb-Douglas models, in both periods show strong alignment with their ABR24. The same is observed for the LSETLG in the long period. In contrast, the other Translog specifications, specially the SFATLG, exhibit greater variability

Figure 3.2.1 Efficiency Scores- LSE models - Long Period

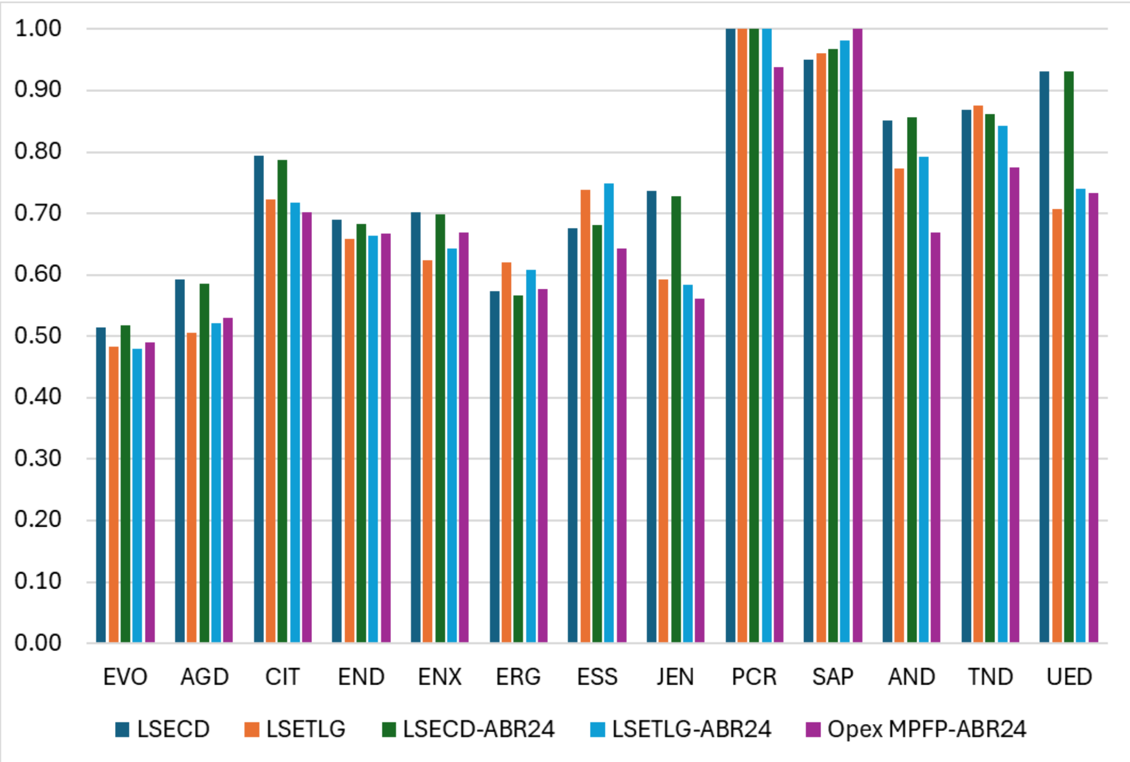


Figure 3.2.2 Efficiency Scores- SFA models - Long Period

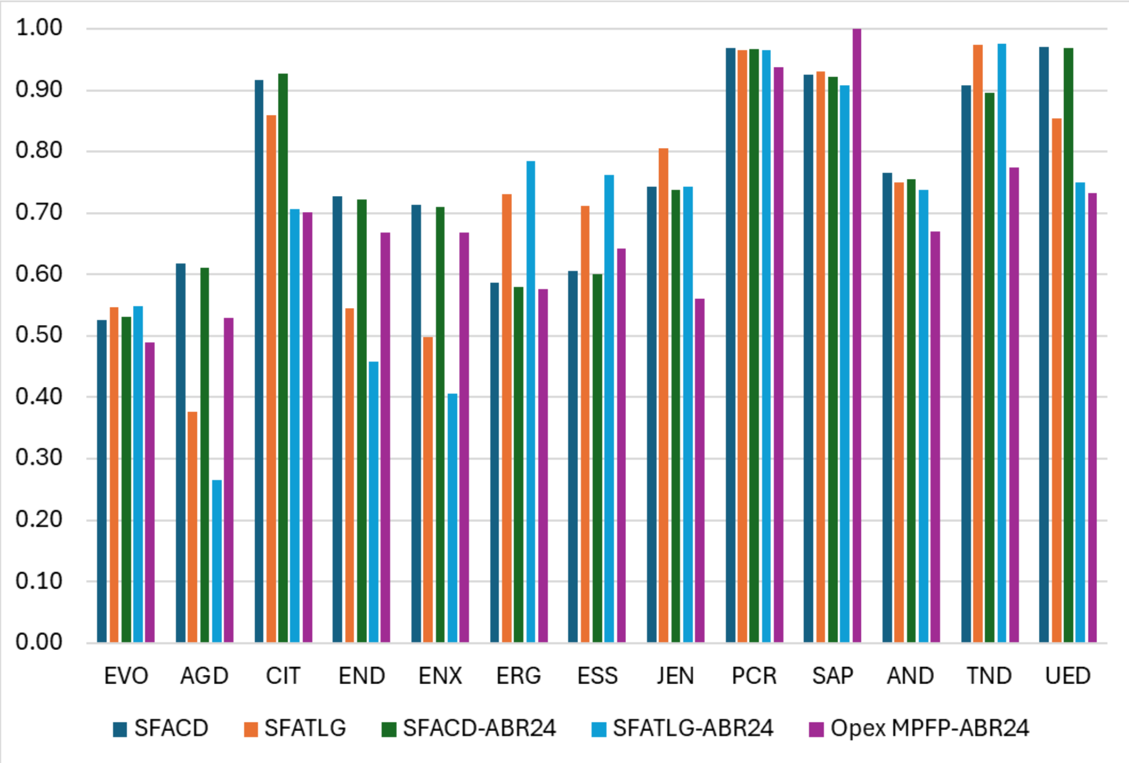


Figure 3.2.3 Efficiency Scores- LSE models – Short Period

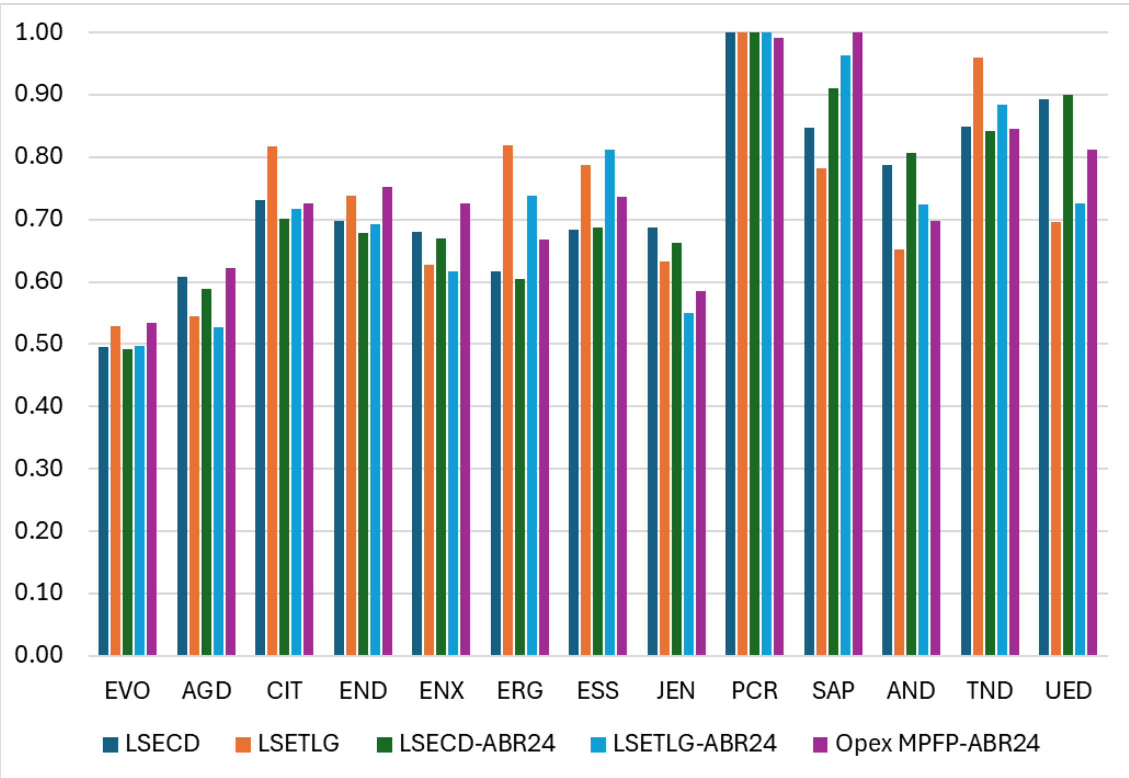
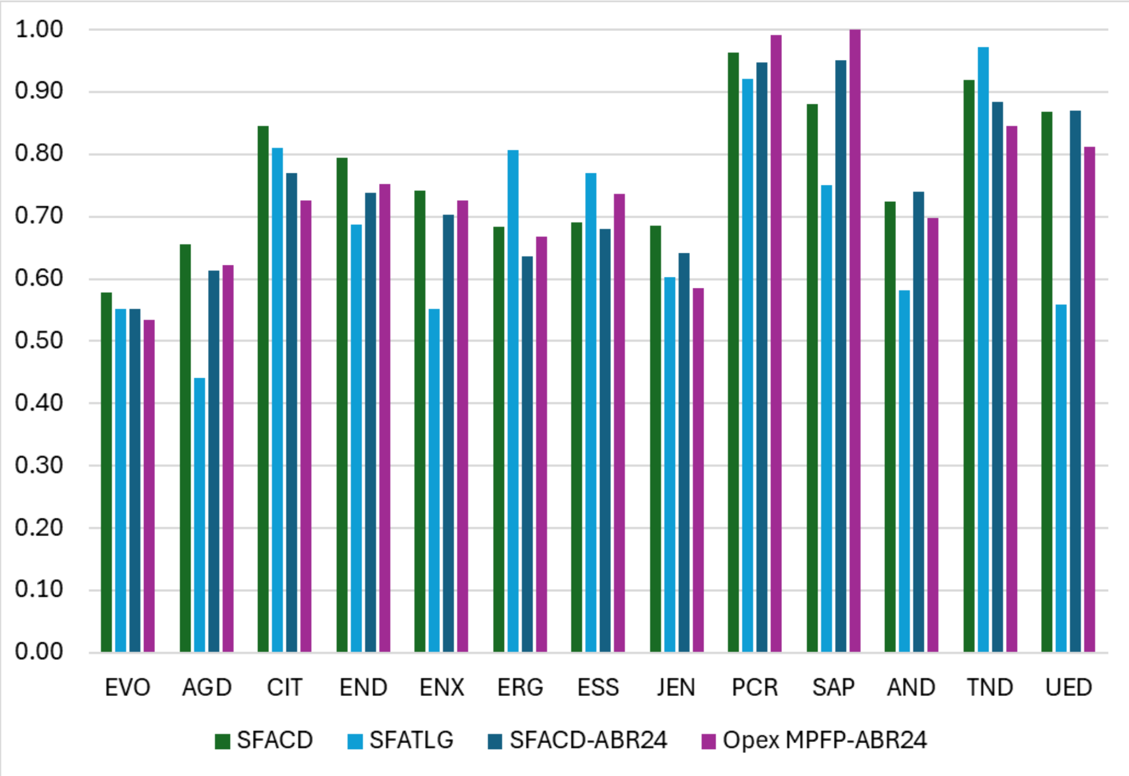


Figure 3.2.4 Efficiency Scores- SFA models – Short Period



3.2.4 Conclusion

This model specification produced weaker results compared to the standard ABR24 models. This is primarily due to the lack of statistical significance in some output coefficients and a substantial increase in monotonicity violations across all TLG models. The only apparent advantage is that the SFATLG model converged in the short-period estimation. However, this gain is limited, as the resulting estimates are not considered reliable.

3.3 Estimation Results with Four Outputs: Including Energy Delivered

Four output variables were included in the four models, Customer Number, Circuit Length, RMD and Energy Delivered. Tables 3.3.1 to 3.3.4 present the estimation results for each model, for both the long and short periods. Again, unlike in the standard models SFATLG in the short period, this extended specification achieves convergence.

Table 3.3.1 Estimation Results – LSE Models (2006-2023)

	LSECD			*LSETLG*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.520	0.079	6.553	0.312	0.085	3.672
ln(CircLen)	0.218	0.036	6.043	0.237	0.036	6.568
ln(RMDemand)	0.138	0.073	1.882	0.264	0.077	3.430
ln(Energy)	0.087	0.044	1.964	0.134	0.052	2.566
x1*x1/2				-0.361	0.552	-0.654
x1*x2				0.319	0.131	2.432
x1*x3				-0.333	0.476	-0.700
x1*x4				0.243	0.235	1.034
x2*x2/2				-0.045	0.047	-0.954
x2*x3				-0.039	0.128	-0.304
x2*x4				-0.198	0.082	-2.406
x3*x3/2				0.751	0.480	1.567
x3*x4				-0.365	0.230	-1.591
x4*x4/2				0.410	0.177	2.310
ln(ShareUGC)	-0.093	0.026	-3.510	-0.109	0.029	-3.732
Year	0.010	0.002	6.312	0.013	0.002	7.701
New Zealand	-0.400	0.134	-2.988	-0.473	0.132	-3.587
Ontario	-0.184	0.132	-1.392	-0.326	0.131	-2.499
AGD	-0.129	0.194	-0.664	-0.049	0.196	-0.249
CIT	-0.431	0.148	-2.911	-0.384	0.147	-2.620
END	-0.280	0.156	-1.800	-0.311	0.154	-2.020
ENX	-0.300	0.143	-2.101	-0.262	0.151	-1.740
ERG	-0.090	0.169	-0.531	-0.248	0.190	-1.304
ESS	-0.267	0.176	-1.514	-0.454	0.198	-2.292
JEN	-0.349	0.162	-2.162	-0.194	0.168	-1.152
PCR	-0.654	0.151	-4.319	-0.746	0.156	-4.786
SAP	-0.600	0.158	-3.788	-0.700	0.166	-4.216
AND	-0.491	0.150	-3.267	-0.492	0.157	-3.131
TND	-0.506	0.169	-2.991	-0.595	0.167	-3.563
UED	-0.584	0.159	-3.669	-0.370	0.169	-2.188
_cons	-10.212	3.273	-3.120	-16.033	3.443	-4.657
rho	0.791			0.782		
R^2	0.991			0.992		
Pseudo Adj R^2	0.979			0.981		
# Parameters	21			31		
N	1098			1098		

Table 3.3.2 Estimation Results – SFA Models (2006-2023)

	SFACD			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.274	0.075	3.637	0.333	0.098	3.402
ln(CircLen)=x2	0.131	0.044	2.998	0.115	0.064	1.789
ln(RMDemand)=x3	0.524	0.083	6.298	0.371	0.096	3.877
ln(Energy)	0.032	0.047	0.664	0.141	0.066	2.116
x1*x1/2				0.965	0.495	1.951
x1*x2				-0.232	0.125	-1.858
x1*x3				-1.494	0.471	-3.171
x1*x4				0.641	0.235	2.727
x2*x2/2				0.100	0.064	1.578
x2*x3				0.519	0.133	3.894
x2*x4				-0.301	0.086	-3.488
x3*x3/2				1.853	0.506	3.663
x3*x4				-1.036	0.244	-4.249
x4*x4/2				0.745	0.204	3.649
ln(ShareUGC)	-0.135	0.032	-4.241	-0.140	0.046	-3.060
Year	0.010	0.001	10.892	0.012	0.001	9.153
New Zealand	0.003	0.091	0.038	0.002	0.078	0.030
Ontario	0.077	0.074	1.042	-0.009	0.099	-0.089
_cons	-11.266	1.946	-5.789	-14.222	2.674	-5.319
lnsigma2	-2.367	0.514	-4.606	-1.009	1.063	-0.949
lgtgamma	1.557	0.623	2.498	3.160	1.114	2.836
mu	0.111	0.195	0.571	-0.491	1.096	-0.448
sigma2	0.094	0.048	0.034			
gamma	0.826	0.090	0.583			
sigma_u2	0.077	0.048	-0.017			
sigma_v2	0.016	0.001	0.015			
LLH	594.46			627.08		
Iterations #	9			13		
Pseudo Adj R2	0.991			0.992		
BIC	-1104.90			-1100.13		
# Parameters	12			22		
N	1098			1098		

Table 3.3.3 Estimation Results – LSE Models (2012-2023)

	LSECD			*LSETLG*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.494	0.078	6.363	0.198	0.086	2.300
ln(CircLen)	0.240	0.034	7.122	0.234	0.035	6.632
ln(RMDemand)	-0.110	0.098	-1.129	0.097	0.093	1.045
ln(Energy)	0.338	0.077	4.368	0.406	0.084	4.812
x1*x1/2				-0.300	0.578	-0.518
x1*x2				0.182	0.136	1.343
x1*x3				-1.225	0.701	-1.748
x1*x4				1.085	0.507	2.142
x2*x2/2				0.012	0.045	0.274
x2*x3				0.060	0.189	0.318
x2*x4				-0.207	0.132	-1.573
x3*x3/2				0.414	1.289	0.321
x3*x4				0.798	1.038	0.768
x4*x4/2				-1.514	0.946	-1.600
ln(ShareUGC)	-0.088	0.027	-3.285	-0.098	0.027	-3.627
Year	0.005	0.002	2.323	0.009	0.002	4.159
New Zealand	-0.467	0.148	-3.157	-0.548	0.134	-4.079
Ontario	-0.252	0.147	-1.714	-0.461	0.136	-3.384
AGD	-0.199	0.195	-1.022	-0.036	0.182	-0.200
CIT	-0.394	0.154	-2.560	-0.407	0.141	-2.880
END	-0.334	0.165	-2.022	-0.349	0.151	-2.306
ENX	-0.315	0.155	-2.034	-0.195	0.152	-1.285
ERG	-0.213	0.180	-1.184	-0.469	0.192	-2.444
ESS	-0.326	0.185	-1.763	-0.469	0.203	-2.308
JEN	-0.331	0.162	-2.040	-0.159	0.159	-0.999
PCR	-0.709	0.159	-4.458	-0.695	0.158	-4.403
SAP	-0.532	0.165	-3.218	-0.443	0.176	-2.520
AND	-0.463	0.159	-2.908	-0.249	0.166	-1.495
TND	-0.530	0.184	-2.877	-0.612	0.170	-3.594
UED	-0.593	0.168	-3.530	-0.259	0.165	-1.567
_cons	0.423	4.361	0.097	-7.405	4.336	-1.708
rho	0.736			0.704		
R^2	0.995			0.995		
Pseudo Adj R^2	0.982			0.985		
# Parameters	21			31		
N	732			732		

Table 3.3.4 Estimation Results – SFA Models (2012-2023)

	SFACD			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.088	0.106	0.833	-0.058	0.129	-0.445
ln(CircLen)=x2	0.289	0.060	4.809	0.288	0.073	3.928
ln(RMDemand)=x3	-0.007	0.111	-0.065	0.157	0.129	1.218
ln(Energy)	0.567	0.094	6.039	0.579	0.097	5.944
x1*x1/2				-0.102	0.637	-0.160
x1*x2				0.268	0.184	1.461
x1*x3				-3.281	0.730	-4.493
x1*x4				2.851	0.519	5.495
x2*x2/2				0.011	0.088	0.131
x2*x3				0.380	0.188	2.017
x2*x4				-0.599	0.139	-4.309
x3*x3/2				2.122	1.224	1.734
x3*x4				0.701	0.905	0.775
x4*x4/2				-2.776	0.782	-3.548
ln(ShareUGC)	0.003	0.042	0.071	0.004	0.069	0.053
Year	0.005	0.001	3.399	0.009	0.002	5.219
New Zealand	-0.206	0.087	-2.361	-0.239	0.086	-2.778
Ontario	-0.048	0.094	-0.509	-0.216	0.109	-1.979
_cons	0.364	2.876	0.126	-8.130	3.579	-2.272
lnsigma2	-3.034	0.261	-11.607	-2.751	0.371	-7.425
lgtgamma	1.077	0.356	3.025	1.691	0.460	3.673
mu	0.256	0.068	3.743	0.355	0.109	3.247
sigma2	0.048	0.013		0.064	0.024	
gamma	0.746	0.067		0.844	0.061	
sigma_u2	0.036	0.013		0.054	0.024	
sigma_v2	0.012	0.001		0.010	0.001	
LLH	474.69			530.23		
Iterations #	9			8		
Pseudo Adj R2	0.993			0.995		
BIC	-870.23			-915.35		
# Parameters	12			22		
N	732			732		

3.3.1 Consistency with economic theory or industry knowledge

As shown in tables 3.3.1 and 3.3.2, in the long period, all four models generally produce positive coefficients for the four output variables, but not all are statistically significant. In the LSECD model, RMD is not statistically significant at the 5 per cent level, while the remaining outputs are significant. The LSETLG model performs slightly better, with all outputs being both positive and statistically significant. In the SFACD model, Energy Delivered lacks statistical significance, whereas in the SFATLG model, Circuit Length is not significant. In all four models, the coefficient on the underground share is negative and statistically significant, consistent with expectations.

In the short period, as shown tables 3.3.3 and 3.3.4, the LSECD model shows RMD as negative and not statistically significant, while the other three outputs are positive and significant. In the LSETLG model, all outputs are positive, but RMD is again not significant. For the SFACD model, Customer Numbers is not statistically significant, and RMD is negative and also not significant. The SFATLG model similarly produces a negative and insignificant coefficient for Customer Numbers, with RMD being positive but not significant. In both Translog models during the short period, the underground share is positive and not statistically significant.

Table 3.3.5 presents the output elasticities for four models estimated over the long and short periods. While the total output elasticities are relatively stable across models and close to 1, the distribution of elasticities across individual outputs varies considerably.

Table 3.3.5 Output elasticities

	Long Period					*Short Period*				
Sample	*Cust.*	*CL*	*RMD*	*Energy*	*Total*	*Cust.*	*CL*	*RMD*	*Energy*	*Total*
LSECD										
Full Sample	0.520	0.218	0.138	0.087	0.962	0.494	0.240	-0.110	0.338	0.961
SFACD										
Full Sample	0.274	0.131	0.524	0.032	0.960	0.088	0.289	-0.007	0.567	0.937
LSETLG										
Australia	0.117	0.341	0.274	0.215	0.948	-0.349	0.365	-0.042	0.925	0.899
New Zealand	0.684	0.228	0.110	-0.072	0.950	0.596	0.236	-0.115	0.218	0.935
Ontario	0.156	0.196	0.360	0.233	0.945	0.182	0.174	0.299	0.297	0.952
Full sample	0.312	0.237	0.264	0.134	0.947	0.198	0.234	0.097	0.406	0.935
SFATLG										
Australia	0.104	0.296	0.188	0.133	0.721	-0.767	0.496	-0.337	1.363	0.755
New Zealand	0.464	0.074	0.633	-0.024	1.147	0.578	0.276	-0.092	0.305	1.068
Ontario	0.350	0.061	0.281	0.252	0.943	-0.156	0.202	0.541	0.408	0.996
Full sample	0.333	0.115	0.371	0.141	0.959	-0.058	0.288	0.157	0.579	0.967

The LSECD model consistently attributes a larger share of total elasticity to customer numbers, particularly in the long period. In contrast, the SFACD model gives considerably more weight to RMD in the long period, and to Energy in the short period.

The Translog models (LSETLG and SFATLG) display greater variation between sample periods and considerable differences between jurisdictions. Elasticities under LSETLG are more evenly distributed. The SFATLG model shows the highest variability, especially in the short period. It produces negative elasticities for customer numbers and RMD in Australia and New Zealand, while attributing a disproportionate share to energy delivered in some cases (e.g., Australia in the short period).

Tables 3.3.6 and 3.3.7 present the frequency of monotonicity violations for the Translog models, for the long and short periods respectively.

Table 3.3.6 Frequency of Monotonicity violations - Long Period

Sample	LSETLG					SFATLG				
	Cust.	CL	RMD	Energy	Total	Cust.	CL	RMD	Energy	Total
By DNSP										
EVO	5.6	0.0	0.0	0.0	5.6	5.6	0.0	5.6	5.6	11.1
AGD	100.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	100.0
CIT	100.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	100.0
END	83.3	0.0	0.0	0.0	83.3	72.2	0.0	5.6	0.0	77.8
ENX	94.4	0.0	0.0	0.0	94.4	0.0	0.0	100.0	0.0	100.0
ERG	0.0	0.0	0.0	100.0	100.0	100.0	0.0	0.0	100.0	100.0
ESS	0.0	0.0	0.0	94.4	94.4	100.0	0.0	0.0	100.0	100.0
JEN	94.4	0.0	0.0	0.0	94.4	0.0	0.0	100.0	0.0	100.0
PCR	0.0	0.0	0.0	0.0	0.0	22.2	0.0	0.0	27.8	27.8
SAP	0.0	0.0	0.0	5.6	5.6	100.0	0.0	0.0	100.0	100.0
AND	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	5.6
TND	0.0	0.0	0.0	0.0	0.0	83.3	0.0	0.0	100.0	100.0
UED	100.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	100.0
By jurisdiction										
Australia	44.4	0.0	0.0	15.4	59.8	37.2	0.0	39.7	33.3	78.6
NZ	1.8	0.0	17.3	71.9	74.0	2.4	32.8	3.5	45.3	71.9
Ontario	15.5	0.0	0.0	3.3	18.4	12.5	34.5	16.7	5.0	59.2
Full sample	17.4	0.0	5.4	27.2	44.5	14.6	26.6	17.9	23.5	67.3

Table 3.3.7 Frequency of Monotonicity violations Short Period

Sample	LSETLG					SFATLG				
	Cust.	CL	RMD	Energy	Total	Cust.	CL	RMD	Energy	Total
By DNSP										
EVO	100.0	0.0	66.7	0.0	100.0	100.0	0.0	91.7	0.0	100.0
AGD	100.0	0.0	33.3	0.0	100.0	100.0	0.0	100.0	0.0	100.0
CIT	100.0	0.0	25.0	0.0	100.0	100.0	0.0	100.0	0.0	100.0
END	100.0	0.0	0.0	0.0	100.0	100.0	0.0	41.7	0.0	100.0
ENX	100.0	0.0	41.7	0.0	100.0	100.0	0.0	100.0	0.0	100.0
ERG	100.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	91.7	100.0
ESS	83.3	0.0	33.3	0.0	83.3	83.3	0.0	58.3	0.0	100.0
JEN	100.0	0.0	100.0	0.0	100.0	100.0	0.0	100.0	0.0	100.0
PCR	100.0	0.0	91.7	0.0	100.0	100.0	0.0	100.0	0.0	100.0
SAP	100.0	0.0	100.0	0.0	100.0	100.0	0.0	100.0	0.0	100.0
AND	100.0	0.0	100.0	0.0	100.0	100.0	0.0	100.0	0.0	100.0
TND	100.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0	100.0
UED	100.0	0.0	100.0	0.0	100.0	100.0	0.0	100.0	0.0	100.0
By jurisdiction										
Australia	98.7	0.0	53.2	0.0	98.7	98.7	0.0	76.3	7.1	100.0
New Zealand	10.5	0.0	73.7	29.4	96.9	13.6	0.0	65.8	32.0	91.2
Ontario	20.4	0.0	7.5	8.6	36.5	61.8	2.6	7.8	20.1	82.5
Full sample	34.0	0.0	37.8	13.3	68.6	54.6	1.2	40.4	21.0	88.9

In the long period, the total violation rate among Australian DNSPs is 59.8 per cent for LSETLG and increases to 78.6 per cent for SFATLG. For the full sample, the rate is 44.5 per cent for LSETLG and 67.3 per cent for SFATLG. In the short period, monotonicity violations become even more pronounced. For Australian DNSPs, the total violation rate reaches 98.7 per cent under LSETLG and 100 per cent under SFATLG. For the full sample, violations rise from 68.6 per cent under LSETLG to 88.9 per cent under SFATLG.

Overall, the inclusion of the energy delivered output led to a considerable increase in monotonicity violations compared to the standard models.

3.3.2 Specification Tests

Tables 3.3.1 and 3.3.4 show BIC and the pseudo-adjusted R^2. Other diagnostic statistics are presented in Table 3.3.8. Normality tests reject the assumption of normally distributed residuals. Multicollinearity is moderate in the Cobb–Douglas models but elevated in the Translog models. Functional form tests support the use of the Translog specification, as the joint tests confirm that the higher-order output terms are jointly significant in both the long and short periods.

Table 3.3.8 Diagnostic Statistics

	Long Period		*Short Period*	
	Stat.	*p-value**	*Stat.*	*p-value**
LSECD				
Normality of residuals				
IQR (% severe outliers)[(1)]	0.00		0.00	
Shapiro–Wilk W test[(2)]	0.978	0.000	0.992	0.000
Multicollinearity				
Average VIF[(3)]	24.88		32.68	
Condition number[(3)]	1210.52		1754.78	
LSETLG				
Normality of residuals				
IQR (% severe outliers)	0.09		0.00	
Shapiro–Wilk W test	0.984	0.000	0.993	0.002
Multicollinearity				
Average VIF	1717.24		7412.15	
Condition number	2311.26		3187.14	
Joint parameter tests				
Higher-order output terms	52.40	0.000	89.93	0.000
SFACD				
Normality of residuals				
IQR (% severe outliers)	0.18		0.27	
Shapiro–Wilk W test	0.984	0.000	0.976	0.000
Multicollinearity				
Average VIF	46.47		62.47	
Condition number	1160.65		1691.25	

Table 3.3.8 (comt.)

	Long Period		Short Period	
	Stat.	*p-value**	*Stat.*	*p-value**
SFATLG				
Normality of residuals				
IQR (% severe outliers)	0.09		0.14	
Shapiro–Wilk W test	0.988	0.000	0.980	0.000
Multicollinearity				
Average VIF	2305.43		8394.16	
Condition number	2198.00		2999.64	
Joint parameter tests				
Higher-order output terms	28.79	0.000	85.37	0.000

Note: * Null hypothesis is rejected in these tests, if the p-value is less than 0.05. Equivalently, the reported statistic exceeds the critical value for that statistic; (1) Severe outliers comprise about .0002% of the normal population; (2) The null hypothesis is that residuals are normally distributed; (3) Collinearity is potentially a problem if VIF>10 or the Condition number > 30.

3.3.3 Efficiency Scores

Tables 3.3.9 and 3.3.10, along with Figures 3.3.1 and 3.3.2, present the efficiency scores and rankings of Australian DNSPs under four model specifications for both the long and short periods. Across both periods, the Cobb-Douglas models (LSECD and SFACD) tend to yield higher and more stable average efficiency scores, while the Translog models, particularly SFATLG, often report lower average scores. For instance, in the short period, the average score under SFATLG drops to 0.673, compared to 0.763 under SFACD.

Table 3.3.9 Efficiency Scores - Long Period

	LSE				*SFA*			
Sample	*CD*	*Rank*	*TLG*	*Rank*	*CD*	*Rank*	*TLG*	*Rank*
EVO	0.520	13	0.474	13	0.533	13	0.548	10
AGD	0.591	11	0.498	12	0.611	10	0.342	13
CIT	0.800	6	0.696	6	0.928	3	0.816	4
END	0.688	9	0.647	8	0.723	8	0.520	11
ENX	0.702	8	0.616	9	0.710	9	0.468	12
ERG	0.569	12	0.608	10	0.581	12	0.723	8
ESS	0.679	10	0.747	5	0.603	11	0.721	9
JEN	0.737	7	0.576	11	0.739	7	0.780	6
PCR	1.000	1	1.000	1	0.967	2	0.966	2
SAP	0.947	2	0.955	2	0.919	4	0.921	3
AND	0.849	5	0.776	4	0.754	6	0.736	7
TND	0.862	4	0.860	3	0.897	5	0.973	1
UED	0.932	3	0.686	7	0.968	1	0.808	5
Australia	0.760		0.703		0.764		0.717	

Table 3.3.10 Efficiency Scores Short Period

	LSE				SFA			
Sample	*CD*	*Rank*	*TLG*	*Rank*	*CD*	*Rank*	*TLG*	*Rank*
EVO	0.492	13	0.499	13	0.581	13	0.549	10
AGD	0.601	12	0.518	12	0.642	12	0.397	13
CIT	0.730	6	0.750	6	0.844	5	0.760	5
END	0.687	7	0.708	7	0.782	6	0.660	7
ENX	0.675	10	0.607	10	0.734	7	0.522	11
ERG	0.609	11	0.798	3	0.676	11	0.787	3
ESS	0.682	9	0.798	4	0.687	9	0.786	4
JEN	0.686	8	0.585	11	0.680	10	0.555	9
PCR	1.000	1	1.000	1	0.959	1	0.936	2
SAP	0.837	3	0.778	5	0.871	3	0.746	6
AND	0.782	5	0.640	9	0.710	8	0.566	8
TND	0.836	4	0.920	2	0.904	2	0.970	1
UED	0.891	2	0.647	8	0.855	4	0.508	12
Australia	0.731		0.711		0.763		0.673	

A similar dynamic is observed in the efficiency rankings. DNSPs ranked near the top (such as PCR, SAP, and TND) and bottom (e.g. EVO and AGD) remain relatively consistent under the Cobb-Douglas specifications. In contrast, rankings under the Translog models—especially SFATLG—tend to fluctuate more between the long and short periods. When comparing rankings across models, there is typically greater alignment within each functional form than across them. DNSPs that perform well under one Cobb-Douglas model usually maintain their position under the other, whereas shifts can be substantial when moving from a Cobb-Douglas to a Translog model.

Figure 3.3.1 Efficiency Scores - Long Period

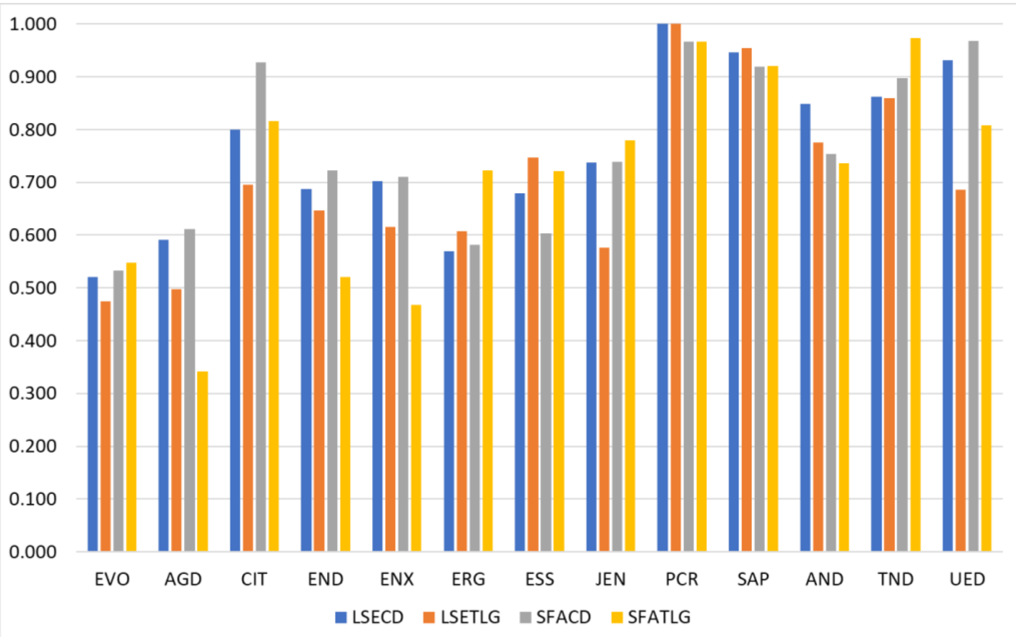
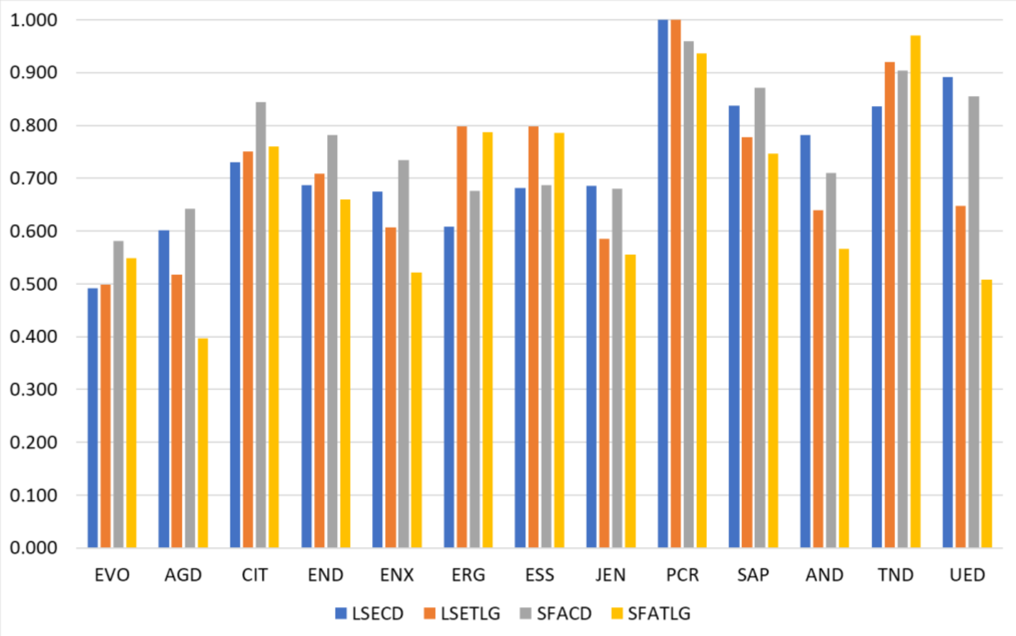


Figure 3.3.2 Efficiency Scores Short Period



3.3.4 Conclusion

Again, compared to the standard ABR24 models, this specification performs worse overall. The weaker results stem from two key issues: several output coefficients are not statistically significant, and all Translog models exhibit an increase in monotonicity violations. While the SFATLG model did achieve convergence in the short-period estimation, this is not a meaningful strength, as the resulting estimates are not robust or reliable.

3.4 Estimation Results with Four Outputs: Including CMOS

In this specification, four output variables were included in the four models, Customer Numbers, Circuit Length, RMD and CMOS. Tables 3.4.1 to 3.4.2 present the estimation results for each model, for both the long and short periods. Similar to the standard models, this extended specification does not achieve convergence in the SFATLG short period model.

3.4.1 Consistency with economic theory or industry knowledge

As shown tables 5.22 to 5.25, in both the long and short periods, all four models—LSECD, LSETLG, SFACD, and SFATLG—produce positive and statistically significant coefficients for all four output variables and the coefficient for the underground share is negative and statistically significant, aligning with expectations.

Table 3.4.1 Estimation Results – LSE Models (2006-2023)

	LSECD			LSETLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.521	0.074	7.023	0.348	0.079	4.411
ln(CircLen)	0.213	0.034	6.318	0.221	0.034	6.463
ln(RMDemand)	0.211	0.063	3.323	0.372	0.067	5.574
ln(CMOS)	0.018	0.004	4.192	0.013	0.006	2.202
x1*x1/2				-0.238	0.531	-0.448
x1*x2				0.247	0.125	1.974
x1*x3				-0.097	0.421	-0.231
x1*x4				-0.028	0.036	-0.776
x2*x2/2				-0.030	0.044	-0.679
x2*x3				-0.189	0.103	-1.833
x2*x4				0.004	0.009	0.425
x3*x3/2				0.371	0.335	1.107
x3*x4				0.014	0.027	0.521
x4*x4/2				0.007	0.006	1.278
ln(ShareUGC)	-0.093	0.025	-3.715	-0.105	0.028	-3.761
Year	0.009	0.002	6.075	0.011	0.002	7.083
New Zealand	-0.415	0.123	-3.383	-0.445	0.121	-3.672
Ontario	-0.195	0.121	-1.610	-0.283	0.120	-2.366
AGD	-0.137	0.178	-0.766	-0.087	0.184	-0.475
CIT	-0.425	0.135	-3.147	-0.429	0.136	-3.152
END	-0.290	0.143	-2.034	-0.324	0.143	-2.266
ENX	-0.312	0.131	-2.385	-0.287	0.138	-2.086
ERG	-0.113	0.154	-0.731	-0.229	0.174	-1.311
ESS	-0.285	0.161	-1.764	-0.406	0.182	-2.235
JEN	-0.354	0.148	-2.391	-0.213	0.156	-1.365
PCR	-0.673	0.138	-4.858	-0.716	0.143	-4.991
SAP	-0.637	0.144	-4.422	-0.694	0.150	-4.623
AND	-0.517	0.137	-3.770	-0.483	0.143	-3.374
TND	-0.531	0.153	-3.467	-0.566	0.151	-3.737
UED	-0.601	0.146	-4.129	-0.454	0.157	-2.889
_cons	-8.117	3.059	-2.654	-11.539	3.107	-3.714
rho	0.764			0.753		
R^2	0.991			0.992		
Pseudo Adj R^2	0.979			0.982		
# Parameters	21			31		
N	1098			1098		

Table 3.4.2 Estimation Results – SFA Models (2006-2023)

	SFACD			SFATLG		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.272	0.073	3.711	0.336	0.086	3.926
ln(CircLen)=x2	0.114	0.042	2.711	0.137	0.054	2.516
ln(RMDemand)=x3	0.546	0.075	7.292	0.431	0.080	5.361
ln(CMOS)	0.030	0.007	4.010	0.025	0.009	2.711
x1*x1/2				1.180	0.478	2.467
x1*x2				-0.308	0.117	-2.618
x1*x3				-0.987	0.397	-2.488
x1*x4				-0.029	0.048	-0.605
x2*x2/2				0.065	0.056	1.161
x2*x3				0.340	0.112	3.033
x2*x4				0.017	0.013	1.332
x3*x3/2				0.517	0.341	1.519
x3*x4				0.008	0.037	0.217
x4*x4/2				0.008	0.009	0.854
ln(ShareUGC)	-0.135	0.031	-4.359	-0.123	0.044	-2.795
Year	0.010	0.001	10.781	0.009	0.001	8.473
New Zealand	0.018	0.089	0.199	-0.016	0.074	-0.218
Ontario	0.082	0.073	1.121	0.024	0.085	0.282
_cons	-9.838	1.840	-5.346	-8.508	2.214	-3.843
lnsigma2	-2.274	0.573	-3.969	0.810	3.868	0.209
lgtgamma	1.682	0.680	2.474	5.009	3.897	1.285
mu	0.050	0.246	0.203	-6.358	26.987	-0.236
sigma2	0.103	0.059		2.248	8.694	
gamma	0.843	0.090		0.993	0.026	
sigma_u2	0.087	0.059		2.233	8.694	
sigma_v2	0.016	0.001		0.015	0.001	
LLH	602.25			624.27		
Iterations #	11			18		
Pseudo Adj R^2	0.991			0.992		
BIC	-1120.48			-1094.51		
# Parameters	12			22		
N	1098			1098		

Table 3.4.3 Estimation Results – LSE Models (2012-2023)

	LSECD			*LSETLG*		
Variable	*Coefficient*	*SE*	*t–ratio*	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)	0.503	0.076	6.584	0.269	0.082	3.289
ln(CircLen)	0.257	0.033	7.799	0.257	0.031	8.171
ln(RMDemand)	0.184	0.069	2.649	0.399	0.070	5.678
ln(CMOS)	0.021	0.005	4.071	0.021	0.007	3.041
x1*x1/2				-0.366	0.564	-0.650
x1*x2				0.198	0.130	1.528
x1*x3				-0.014	0.434	-0.032
x1*x4				-0.033	0.039	-0.854
x2*x2/2				0.023	0.042	0.546
x2*x3				-0.206	0.106	-1.942
x2*x4				0.015	0.010	1.423
x3*x3/2				0.378	0.336	1.123
x3*x4				0.019	0.030	0.623
x4*x4/2				0.003	0.007	0.461
ln(ShareUGC)	-0.081	0.026	-3.087	-0.081	0.026	-3.175
Year	0.003	0.002	1.313	0.005	0.002	2.268
New Zealand	-0.442	0.145	-3.047	-0.483	0.131	-3.676
Ontario	-0.193	0.143	-1.347	-0.293	0.130	-2.252
AGD	-0.186	0.193	-0.962	-0.035	0.183	-0.193
CIT	-0.352	0.152	-2.311	-0.392	0.140	-2.792
END	-0.331	0.162	-2.047	-0.307	0.147	-2.090
ENX	-0.310	0.151	-2.047	-0.173	0.146	-1.183
ERG	-0.221	0.174	-1.269	-0.356	0.179	-1.992
ESS	-0.340	0.180	-1.891	-0.414	0.189	-2.187
JEN	-0.294	0.159	-1.847	-0.103	0.157	-0.658
PCR	-0.710	0.155	-4.565	-0.636	0.152	-4.196
SAP	-0.622	0.160	-3.896	-0.604	0.154	-3.917
AND	-0.501	0.155	-3.233	-0.326	0.154	-2.119
TND	-0.553	0.178	-3.115	-0.566	0.160	-3.538
UED	-0.602	0.165	-3.639	-0.375	0.163	-2.297
_cons	4.854	4.321	1.123	0.982	4.212	0.233
rho	0.722			0.671		
R^2	0.995			0.995		
Pseudo Adj R^2	0.981			0.984		
# Parameters	21			31		
N	732			732		

Table 3.4.4 Estimation Results – SFACD Model (2012-2023)

	SFACD		
Variable	*Coefficient*	*SE*	*t–ratio*
ln(Custnum)=x1	0.248	0.111	2.232
ln(CircLen)=x2	0.272	0.068	3.982
ln(RMDemand)=x3	0.400	0.094	4.268
ln(CMOS)	0.031	0.008	4.032
ln(ShareUGC)	-0.018	0.048	-0.366
Year	0.002	0.001	1.072
New Zealand	-0.097	0.086	-1.125
Ontario	0.118	0.088	1.348
_cons	6.868	2.932	2.342
lnsigma2	-2.966	0.301	-9.861
lgtgamma	1.133	0.399	2.836
mu	0.248	0.096	2.585
sigma2	0.052	0.015	
gamma	0.756	0.074	
sigma_u2	0.039	0.015	
sigma_v2	0.013	0.001	
LLH	435.07		
Iterations #	7		
Pseudo Adj R2	0.993		
BIC	-850.99		
# Parameters	12		
N	732		

Table 3.4.5 presents the estimated output elasticities under four model specifications for both the long and short periods. Across models, the total output elasticities remain close to 1, indicating approximate constant returns to scale.

The distribution of elasticities across outputs varies significantly between models. The LSECD model consistently places the greatest weight on customer numbers, both in the long (0.521) and short (0.503) periods. In contrast, the SFACD model attributes a larger share to RMD, with elasticities of 0.546 and 0.400 in the long and short periods, respectively. The Translog models, LSETLG and SFATLG, exhibit more variation across jurisdictions and periods. The SFATLG model, reported only for the long period, demonstrates even greater volatility.

Tables 3.4.6 and 3.4.7 present the frequency of monotonicity violations for the LSETLG and SFATLG models across the long and short periods. In the long period, the total violation rate among Australian DNSPs is 34.6 per cent for LSETLG and rises to 71.4 per cent under SFATLG. Across the full sample, the violation rates are 23.5 per cent for LSETLG and 42.0 per cent for SFATLG. In the short period, monotonicity issues become more pronounced for LSETLG, with the violation rate for Australian DNSPs increasing to 65.4 per cent. For the full sample, violations reach 38.4 per cent, a notable increase from the long period.

In summary, the frequency of monotonicity violations is slightly worsened in the LSETLG model for the long period, slightly improved in the SFATLG long period, and worsened considerably in the LSETLG for the short period.

Table 3.4.5 Output elasticities

	Long Period					Short Period				
Sample	*Cust.*	*CL*	*RMD*	*CMOS*	*Total*	*Cust.*	*CL*	*CMOS*	*Energy*	*Total*
LSECD										
Full Sample	0.521	0.213	0.211	0.018	0.962	0.503	0.257	0.184	0.021	0.964
SFACD										
Full Sample	0.272	0.114	0.546	0.030	0.961	0.248	0.272	0.400	0.031	0.952
LSETLG										
Australia	0.200	0.294	0.472	0.006	0.972	-0.079	0.336	0.636	0.027	0.919
New Zealand	0.637	0.225	0.069	0.016	0.947	0.556	0.308	0.043	0.027	0.935
Ontario	0.226	0.185	0.525	0.014	0.950	0.238	0.188	0.527	0.014	0.966
Full sample	0.348	0.221	0.372	0.013	0.954	0.269	0.257	0.399	0.021	0.946
SFATLG										
Australia	0.134	0.316	0.214	0.032	0.695					
New Zealand	0.416	0.037	0.652	0.036	1.142					
Ontario	0.373	0.122	0.384	0.014	0.893					
Full sample	0.336	0.137	0.431	0.025	0.929					

Table 3.4.6 Monotonicity violations: Long Period (%)

Sample	LSETLG					SFATLG				
	Cust.	*CL*	*RMD*	*CMOS*	*Total*	*Cust.*	*CL*	*RMD*	*CMOS*	*Total*
By DNSP										
EVO	0.0	0.0	0.0	38.9	38.9	0.0	0.0	0.0	0.0	0.0
AGD	100.0	0.0	0.0	38.9	100.0	0.0	0.0	100.0	0.0	100.0
CIT	100.0	0.0	0.0	100.0	100.0	0.0	0.0	100.0	77.8	100.0
END	0.0	0.0	0.0	0.0	0.0	72.2	0.0	0.0	0.0	72.2
ENX	0.0	0.0	0.0	16.7	16.7	0.0	0.0	33.3	0.0	33.3
ERG	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
ESS	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
JEN	0.0	0.0	0.0	94.4	94.4	0.0	0.0	100.0	0.0	100.0
PCR	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	50.0
SAP	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
AND	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TND	0.0	0.0	0.0	0.0	0.0	72.2	0.0	0.0	0.0	72.2
UED	77.8	0.0	0.0	94.4	100.0	0.0	0.0	100.0	0.0	100.0
By jurisdiction										
Australia	21.4	0.0	0.0	29.5	34.6	38.0	0.0	33.3	6.0	71.4
New Zealand	0.0	0.0	35.4	2.9	38.0	8.2	34.2	0.0	0.0	42.4
Ontario	8.8	0.0	0.0	0.2	9.0	10.3	17.0	0.2	4.4	28.5
Full sample	8.7	0.0	11.0	7.3	23.5	15.6	18.8	7.2	3.4	42.0

Table 3.4.7 Monotonicity violations: Short Period (%)

Sample	LSETLG				
	Cust.	*CL*	*RMD*	*Energy*	*Total*
By DNSP					
EVO	0.0	0.0	0.0	0.0	0.0
AGD	100.0	0.0	0.0	0.0	100.0
CIT	100.0	0.0	0.0	0.0	100.0
END	100.0	0.0	0.0	0.0	100.0
ENX	100.0	0.0	0.0	0.0	100.0
ERG	0.0	0.0	0.0	0.0	0.0
ESS	0.0	0.0	0.0	0.0	0.0
JEN	100.0	0.0	0.0	0.0	100.0
PCR	66.7	0.0	0.0	0.0	66.7
SAP	83.3	0.0	0.0	0.0	83.3
AND	100.0	0.0	0.0	0.0	100.0
TND	0.0	0.0	0.0	0.0	0.0
UED	100.0	0.0	0.0	0.0	100.0
By jurisdiction					
Australia	65.4	0.0	0.0	0.0	65.4
New Zealand	5.3	0.0	51.3	0.0	56.6
Ontario	14.1	0.0	0.0	0.3	14.4
Full sample	22.3	0.0	16.0	0.1	38.4

3.4.2 Specification Tests

Tables 3.4.1 and 3.4.4 show the LLH value, the number of iterations, BIC and the pseudo-adjusted R^2. Additional diagnostic statistics are presented in Table 3.4.8.

Table 3.4.8 Diagnostic Statistics

	Long Period		Short Period	
	Stat.	*p-value**	*Stat.*	*p-value**
LSECD				
Normality of residuals				
IQR (% severe outliers)(1)	0.09		0.00	
Shapiro–Wilk W test(2)	0.977	0.000	0.985	0.000
Multicollinearity				
Average VIF(3)	15.55		15.88	
Condition number(3)	1167.74		1724.03	
LSETLG				
Normality of residuals				
IQR (% severe outliers)	0.09		0.00	
Shapiro–Wilk W test	0.982	0.000	0.990	0.000
Multicollinearity				
Average VIF	565.39		572.15	
Condition number	2104.66		3108.62	
Joint parameter tests				
Higher-order output terms	41.77	0.000	75.84	0.000

Table 3.4.8 (cont.)

	Long Period		Short Period	
	Stat.	*p-value**	*Stat.*	*p-value**
SFACD				
Normality of residuals				
IQR (% severe outliers)(1)	0.18		0.00	
Shapiro–Wilk W test(2)	0.985	0.000	0.979	0.000
Multicollinearity				
Average VIF(3)	24.35		25.08	
Condition number(3)	1119.92		1661.83	
SFATLG				
Normality of residuals				
IQR (% severe outliers)	0.09			
Shapiro–Wilk W test	0.987	0.000		
Multicollinearity				
Average VIF	605.63			
Condition number	2018.51			
Joint parameter tests				
Higher-order output terms	27.65	0.000		

Note: * Null hypothesis is rejected in these tests, if the p-value is less than 0.05. Equivalently, the reported statistic exceeds the critical value for that statistic; (1) Severe outliers comprise about .0002% of the normal population; (2) The null hypothesis is that residuals are normally distributed; (3) Collinearity is potentially a problem if VIF>10 or the Condition number > 30.

Normality tests reject the assumption of normally distributed residuals. Multicollinearity is moderate in the Cobb–Douglas models but elevated in the Translog models. Functional form tests support the use of the Translog specification, as the joint tests confirm that the higher-order output terms are jointly significant in both the long and short periods.

3.4.3 Efficiency Scores

Tables 3.4.9 and 3.4.10, together with Figures 3.4.1 and 3.4.2, summarise the efficiency scores and rankings of Australian DNSPs under four model specifications for both long and short periods.

The rankings broadly mirror the patterns observed in the efficiency scores. DNSPs with consistently strong performance (such as PCR, SAP and TND) retain top rankings under both Cobb-Douglas models and across periods. Conversely, DNSPs like EVO and AGD remain at the bottom of the distribution. The Translog models, particularly SFATLG, introduce more volatility in both scores and rankings. Comparisons between models suggest greater alignment within each functional form (e.g. between LSECD and SFACD) than across forms.

That is, DNSPs ranked highly under one Cobb-Douglas model tend to perform similarly under the other, while their relative position often changes when evaluated under a Translog specification.

Table 3.4.9 Efficiency Scores: Long Period

	LSE				SFA			
Sample	*CD*	*Rank*	*TLG*	*Rank*	*CD*	*Rank*	*TLG*	*Rank*
EVO	0.510	13	0.489	13	0.523	13	0.554	10
AGD	0.585	11	0.533	12	0.617	10	0.309	13
CIT	0.781	6	0.750	6	0.913	4	0.763	7
END	0.682	9	0.676	8	0.726	8	0.494	11
ENX	0.697	8	0.651	9	0.712	9	0.446	12
ERG	0.571	12	0.614	10	0.586	12	0.777	6
ESS	0.678	10	0.734	7	0.605	11	0.740	9
JEN	0.727	7	0.605	11	0.740	7	0.782	5
PCR	1.000	1	1.000	1	0.969	2	0.966	2
SAP	0.965	2	0.978	2	0.929	3	0.915	3
AND	0.856	5	0.792	4	0.767	6	0.759	8
TND	0.868	4	0.860	3	0.908	5	0.977	1
UED	0.931	3	0.769	5	0.972	1	0.818	4
Australia	0.758		0.727		0.767		0.715	

Figure 3.4.1 Efficiency Scores: Long Period

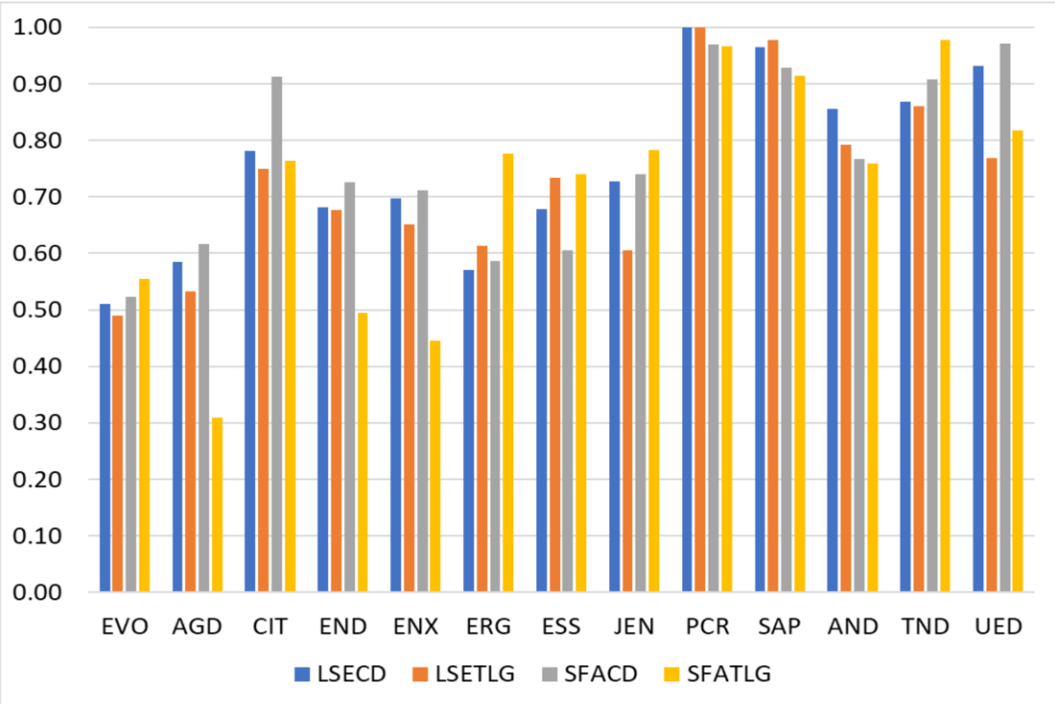
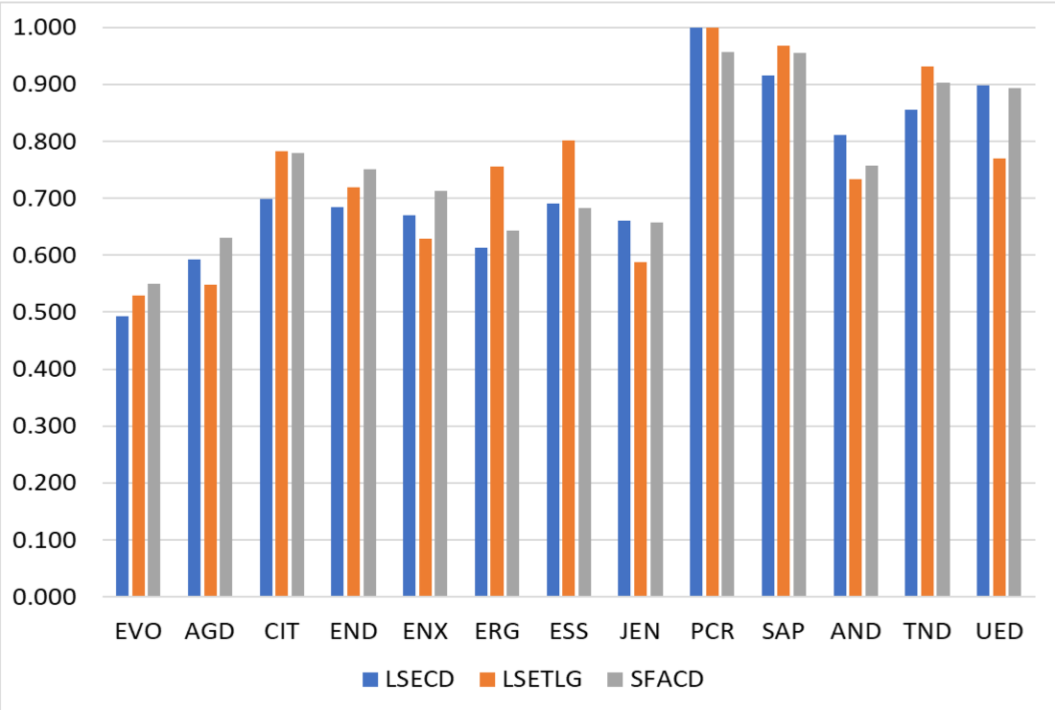


Table 3.4.10 Efficiency Scores: Short Period

	LSE				*SFACD*	
Sample	*CD*	*Rank*	*TLG*	*Rank*	*Eff*	*Rank*
EVO	0.492	13	0.529	13	0.549	13
AGD	0.592	12	0.548	12	0.631	12
CIT	0.699	6	0.783	5	0.779	5
END	0.685	8	0.720	9	0.751	7
ENX	0.670	9	0.629	10	0.713	8
ERG	0.613	11	0.755	7	0.643	11
ESS	0.691	7	0.801	4	0.683	9
JEN	0.660	10	0.587	11	0.657	10
PCR	1.000	1	1.000	1	0.956	1
SAP	0.916	2	0.968	2	0.955	2
AND	0.811	5	0.733	8	0.758	6
TND	0.855	4	0.932	3	0.903	3
UED	0.898	3	0.770	6	0.894	4
Australia	0.737		0.750		0.759	

Figure 3.4.2 Efficiency Scores: Short Period



3.4.4 Conclusion

Unlike the previous two specifications, this model includes four output coefficients that are all positive and statistically significant. Like the standard model, the SFATLG model for the short period fails to converge. The frequency of monotonicity violations is slightly worsened in the LSETLG model for the long period, slightly improved in the SFATLG long period, and worsened considerably in the LSETLG for the short period.

3.5 Final Conclusion

The models including the additional two outputs, Energy Delivered and CMOS, underperform when compared to the standard ABR24 specifications. The models with 5 outputs, and the models with 4 outputs including energy, suffered from either statistically insignificant output coefficients, increased monotonicity violations, or both. While the inclusion of CMOS alone led to statistically significant coefficients for all outputs, it had a mixed poorer monotonicity performance which did not improve on the standard models, and like to standard model, it failed to converge in the short-period SFATLG model. Hence, while CMOS could potentially be added to the model, it is a minor variable with very little overall effect on the model. There is also a concern about endogeneity, since opex includes the cost of preventative maintenance, and higher levels of preventative maintenance may reduce CMOS.

4 Input Substitution

This analysis explores the impact of including input price variables in the econometric opex cost models used in the AER's annual electricity distributor benchmarking. Specifically, the log ratio of the prices of capital and non-capital inputs. The ratio of input prices is used to ensure that the demand for opex inputs is homogeneous of degree zero in input prices.[1]

The purpose is to identify the effect of substitution between inputs on the quantity of opex inputs. Including the ratio of the prices of capital and non-capital inputs in the opex cost function model serves to identify substitutability between inputs in response to movements in relative input prices. The opex price index is already calculated and used to deflate nominal opex to obtain the dependent variable of the opex cost function. Hence, it is only necessary to derive a price index for capital services input.

Specifically, we estimate the capex price index for all the DNSPs in the sample using the method outlined in Section 4.1 and estimate opex cost function models that incorporate an input substitution variable and compare these with the results from the standard models used in ABR24 (Section 4.2).

4.1 Overseas Capital Input Prices Calculation

In the established methodology for index analysis, the nominal cost of capital inputs is estimated by the Annual User Cost (AUC) of capital, which is calculated for each DNSP and year, by asset type. For a specific DNSP, the formulas for calculating AUC for asset type i in period t are:

$$AUC_{it} = WACC_t . RAB_{it}^B + Reg.Depreciation_{it} + Benchmark\ Tax\ Liability \qquad (4.1)$$

where RAB_{it}^B refers to the regulatory asset base (RAB) at the beginning of period t for asset type i. $WACC$ refers to the weight average cost of capital, and '$Reg.Depreciation$' refers to regulatory deprecation. RAB and Regulatory Depreciation are defined as follows:

$$Reg.Depreciation_{it} = SL\ Depreciation_{it} - Inflation\ Addition_{it} \qquad (4.2)$$

$$RAB_{it}^B = RAB_{i,t-1}^B + Capex_{i,t-1} - Disposals_{i,t-1} - Reg.Depreciation_{i,t-1} \qquad (4.3)$$

where '$SL\ Depreciation$' refers to straight-line depreciation. Equations (4.1) and (4.3) can be simplified by defining the following variables:

[1] Note that in 2023, the AER completed a consultation on how differences in capitalisation practices should be accounted for in economic benchmarking. 'Capitalisation practices' was broadly defined to include both accounting policies for treating types of expenditure (especially overheads) as recurrent or capital items, and choices relating to the mix of capital and non-capital inputs used in production (ie, substitution between capital and non-capital inputs, or "opex/capital trade-offs").

- Average straight-line depreciation rate of asset type i in period t (for a given DNSP) is $\delta_{it} \equiv SL\ Depreciation_{it}/RAB^B_{it}$, and
- The rate of asset price inflation is denoted as $\dot{p}$. The Inflation Addition equals $\dot{p} \cdot RAB^B_{it}$.
- The benchmark tax ratio is: $\tau_{it} \equiv Benchmark\ Tax\ Liability_{it}/RAB^B_{it}$.

Hence, the equations for AUC and RAB can be written as:

$$AUC_{it} = RAB^B_{it}(WACC_t + \delta_{it} - \dot{p}_{it} + \tau_{it}) \tag{4.4}$$

$$RAB^B_{it} = RAB^B_{i,t-1}\left(1 - \delta_{i,t-1} + \dot{p}_{it}\right) + Capex_{i,t-1} - Disposals_{i,t-1} \tag{4.5}$$

It is commonplace to assume that the quantity of capital input in period t is proportionate to the real value of the capital stock at that time:

$$K_{it} = RAB^B_{it}/p_{it} \tag{4.6}$$

Since price is the ratio of cost to quantity, the price index of capital inputs can be expressed as:

$$\begin{aligned} w^K_{it} &= AUC_{it}/K_{it} \\ &= p_{it}(WACC_t + \delta_{it} - \dot{p}_{it} + \tau_{it}) \end{aligned} \tag{4.7}$$

WACC is defined as:

$$WACC_t = G_t(NRFR_t + DM_t) + (1 - G_t)(NRFR_t + \beta_t \cdot MRP_t) \tag{4.8}$$

where G_t is the proportion of enterprise value funded from debt in period t, and $1 - G_t$ is the proportion funded from equity. $NRFR_t$ is the nominal risk-free rate (ie, nominal 10-year government bond rate); DM_t is the debt margin, which is the Cost of Debt (ie, the cost of corporate BBB+ debt) minus the $NRFR_t$; $\beta_t$is the equity beta for DNSPs; and MRP_t is the market risk premium.

Based on equations (4.7) and (4.8) it is possible, with some assumptions relating to parameter values, to calculate the capital input price for each jurisdiction. Next, we discuss the variables and parameters used for calculating the WACC and the calculation of the remaining variables in equation (4.7).

4.1.1 WACC Parameter Assumptions

Equation (3.8) can be rewritten to show that the WACC is equal to the nominal risk-free rate (NRFR) plus a risk margin:

$$WACC_t = NRFR_t + \{G_tDM_t + (1 - G_t)\beta_tMRP_t\} \tag{4.9}$$

The Nominal Risk-Free Rate ($NRFR$) is the average yield on 10-year government bonds in each of jurisdiction. Here, we discuss the parameters that determine the risk margin.

We have elected to adopt uniform parameters for the risk margin across all three jurisdictions, because the different values chosen by regulators in these jurisdictions may not systematically reflect different risk margins for DNSPs in those jurisdictions. They may also arise due to different regulatory perspectives and decision-making.

Leverage (G)

The proportion of debt funding (G) is set as 0.6 for all jurisdictions. It reasonable to a single value to all DNSPs because G is an estimated optimal value which should be similar for assets with similar risk characteristics.

Debt funding at 0.6 is the AER's and Ontario Energy Board's assumption.[2] However, the NZ Commerce Commission has used lower rates, such as 0.44 from 2012 to 2017, 0.42 from 2018 to 2024 and 0.41 from 2025.[3]

Market Risk Premium (MRP)

The MRP is equal to the long-term average return to equities minus the average return on long-term government bonds (ie, the risk-free return) over the same period. The MRP can differ between jurisdictions.

For calculating the AUC of Australian DNSPs, the AER uses an MRP of 6.5 per cent from the financial year (FY) ending June 2006 to FY 2019. Thereafter it uses 6.1 per cent.[4] The MRP used by the Commerce Commission for New Zealand DNSPs was 7.0 per cent in 2011, and same value was used from 2016 to 2023.[5] However, this is described as a *tax-adjusted* MRP (TAMRP). Unlike the standard MRP, the TAMRP accounts for differential personal taxation of interest, dividends and capital gains. These parameters is not available for Ontario DNSPs.[6]

In this study, we use the weighted average of the MRP values, from Australia and New Zealand as the common MRP value for all observations.[7]

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[2] Ontario Energy Board (2009, p. 53)

[3] WACC parameters for New Zealand DNSPs are sourced from the Commerce Commission (2011; 2012; 2015; 2016; 2017; 2018; 2019; 2020; 2021; 2022; 2023; 2024).

[4] This change reflects the AER's Rate of Return Instrument (AER 2018, p.3).

[5] . Note: For most of this period the Commerce Commission determined the allowed return as the 75th percentile estimate of vanilla WACC. However, here we are only interested in the midpoint estimates of WACC parameters.

[6] In 2009, the Ontario Energy Board released guidance to update the cost of capital for Ontario's regulated utilities, which is still in use (Ontario Energy Board , 2009: 53). However, it does not specify the market risk premium or several other WACC parameters.

[7] The weighted average is based on the number of observations from Australia (13 DNSPs over 18 years, totalling 234 observations) and New Zealand (19 DNSPs over 18 years, totalling 342 observations) in the sample. Specifically, the weighted average is 6.76 per cent.

Equity Beta (β)

For Australian DNSPs, the Equity Beta is 0.70 from 2006 to 2019 and 0.60 from 2020 to 2023. For New Zealand DNSPs, in accordance with the cost of capital determination from Commerce Commission, the Equity Beta is 0.61 from 2011 to 2017 and 0.60 from 2018 to 2023. Since we were unable to find the values for the period previous 2011, it is assumed to be 0.61. The Equity Beta for Ontario is not provided in the Ontario Energy Board's guidance on updating the cost of capital.

Again, the weighted average of the Equity Beta values from Australia and New Zealand is used as the common input for all observations.[8]

Debt Margin (DM)

Debt Margin values for Australian DNSPs are provided within the DNSPs AUC dataset. The NZ Electricity Information Disclosure Data contains information on the Cost of Debt (CD_t). Based on this, the Debt Margin for New Zealand DNSPs is calculated as the Cost of Debt minus Nominal Risk-Free Rate ($NRFR_t$).[9] For Ontario DNSPs the Debt Margin is not available.[10]

The definition of the Debt Margin (DM_t) can vary depending on whether the regulator includes debt issuance costs in the Cost of Debt, or as a separate expense item in opex. The latter is the AER's practice which we follow here. Again, the weighted average of the Debt Margin values from Australia and New Zealand is used as the common input for all observations in Equation (2.8).[11]

4.1.2 Depreciation and Tax Liability Assumptions

Asset price index (p)

The deflator used here is the Consumer Price Index (CPI) series for each jurisdiction, since RAB values are typically inflated by regulators using CPI.

Straight Line Depreciation/RAB ($\boldsymbol{\delta_{it}}$)

It is possible to calculate the Straight-Line Depreciation-to-RAB ratio for Australian DNSPs using data from the DNSPs AUC dataset.

For New Zealand, Regulatory Depreciation, RAB and its components are obtained from the NZ disclosure dat To calculate the Straight-Line Depreciation, the regulatory depreciation is

[8] Specifically, 0.64.

[9] For 2006 and 2007, the New Zealand Debt Margin is assumed to be equal to the calculated value for 2008, as the Cost of Debt data required to estimate the Debt Margin is only available from 2008 onwards.

[10] It would be possible to derive the debt margin for Ontario using the average yield of BBB-rated corporate bonds based on Bloomberg dat However, Bloomberg is a paid data source, and access would require a subscription.

[11] Specifically, 1.89 per cent.

adjusted by adding Inflation Addition ($\dot{p} \cdot RAB_{it}^{B}$) as shown in Equation (4.2). The component Total Revaluations is available for NZ and seems to be analogous to Inflation Addition.

Comparable data is not available for Ontario DNSPs.

As before, the weighted average of the Straight-Line Depreciation rate values from Australia and New Zealand is used as a common input for all observations in Equation (4.8).[12]

Benchmarking Tax Liability/RAB (τ_{it})

For Australia, the tax ratios are sourced from DNSPs AUC dataset and for New Zealand, from the disclosure workbooks. The data is not available for Ontario DNSPs.

However, there is a significant difference between the average of τ_{it} for Australia compared to New Zealand, raising concerns about the reliability of the latter. Therefore, it was decided to calculate τ_{it} for all DNSPs including Australia, New Zealand and Ontario, using the following equation:

$$\tau = (1 - G)(NRFR_t + \beta_t \cdot MRP_t)\left(\frac{T(1-\gamma)}{1-(1-\gamma)T}\right) \tag{4.10}$$

where T is the Statutory Corporate Tax rate and γ is the rate of utilisation of dividend imputation (franking) credits. For New Zealand and Ontario, $\gamma = 0$, because a dividend imputation tax scheme does not apply to electricity distribution businesses in those jurisdictions.

The Statutory Corporate Tax values were sourced from the OECD. The OECD data are aligned with Statutory Corporate Tax used for AER and reasonably well aligned with the New Zealand disclosure dat The potential weakness of this approach is the assumption that the statutory corporate tax rate for Ontario is the same as that for Canad

4.1.3 Index base

The chosen index base for the capital price index and the opex price index is 2012 (financial year, i.e., 2011–12). In the opex cost function programs, the opex price (Propex) is adjusted for Purchasing Power Parities (PPPs). However, such adjustments are not necessary in this context, as both the capital price index and the opex price index are influenced by the PPP exchange rate. Consequently, the ratio between these indices remains unaffected by variations in the PPP exchange rate.

4.2 Estimation results

Tables 4.1 to 4.4 present the modelling results for both long and short periods, incorporating the log of the ratio of the input prices of opex and capital services. Similar to the standard

[12] Specifically, 6.0 per cent.

model, the Input Prices Ratio SFATLG model in the short period did not converge Variable *lratioprice* represents the log of the ratio of opex price to capital price. For convenience, models that include the log of the input price ratio are referred to in this section as Input Substitution (IS) models.

Table 4.1 Input Substitution LSECD Model

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.551	0.075	7.32	0.539	0.078	6.89
ly2	0.223	0.035	6.46	0.264	0.034	7.72
ly3	0.191	0.065	2.95	0.163	0.071	2.30
lz1	-0.096	0.025	-3.78	-0.085	0.026	-3.21
lratioprice	-0.074	0.025	-2.96	-0.062	0.028	-2.21
yr	0.013	0.002	7.08	0.006	0.003	2.45
jur2	-0.407	0.124	-3.28	-0.419	0.145	-2.88
jur3	-0.160	0.122	-1.31	-0.154	0.143	-1.07
d2	-0.128	0.180	-0.71	-0.180	0.193	-0.93
d3	-0.429	0.136	-3.14	-0.360	0.152	-2.37
d4	-0.280	0.145	-1.94	-0.321	0.161	-1.99
d5	-0.306	0.132	-2.31	-0.307	0.152	-2.02
d6	-0.100	0.156	-0.64	-0.205	0.175	-1.17
d7	-0.285	0.163	-1.75	-0.335	0.180	-1.86
d8	-0.356	0.149	-2.39	-0.302	0.159	-1.90
d9	-0.678	0.140	-4.84	-0.714	0.155	-4.59
d10	-0.632	0.147	-4.30	-0.614	0.162	-3.80
d11	-0.517	0.139	-3.72	-0.499	0.156	-3.20
d12	-0.518	0.156	-3.32	-0.537	0.179	-3.00
d13	-0.605	0.149	-4.06	-0.609	0.167	-3.65
_cons	-14.949	3.582	-4.17	-1.738	5.015	-0.35
rho	0.771			0.726		
N	1,098			732		
R^2	0.9914			0.9947		
PseudoR^2	0.9788			0.9806		

Table 4.2 Input Substitution LSETLG Model

	Long Period (2006-2023)			*Short Period (2012-2023)*		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.373	0.081	4.61	0.305	0.086	3.56
ly2	0.231	0.034	6.71	0.278	0.033	8.47
ly3	0.352	0.068	5.16	0.372	0.073	5.12
ly11	-0.208	0.534	-0.39	-0.344	0.587	-0.59
ly12	0.249	0.125	1.99	0.217	0.132	1.64
ly13	-0.148	0.426	-0.35	-0.070	0.456	-0.15
ly22	-0.027	0.044	-0.60	0.027	0.043	0.63
ly23	-0.188	0.103	-1.83	-0.207	0.108	-1.91

Table 4.2 (cont.)

	Long Period (2006-2023)			Short Period (2012-2023)		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly33	0.426	0.340	1.25	0.439	0.355	1.24
lz1	-0.105	0.028	-3.74	-0.083	0.027	-3.10
lratioprice	-0.070	0.025	-2.83	-0.060	0.028	-2.18
yr	0.014	0.002	7.92	0.008	0.002	3.41
jur2	-0.450	0.124	-3.62	-0.472	0.139	-3.40
jur3	-0.264	0.122	-2.16	-0.259	0.136	-1.90
d2	-0.097	0.188	-0.52	-0.066	0.192	-0.34
d3	-0.419	0.138	-3.04	-0.372	0.147	-2.53
d4	-0.331	0.147	-2.25	-0.333	0.155	-2.15
d5	-0.303	0.141	-2.15	-0.221	0.154	-1.43
d6	-0.240	0.178	-1.34	-0.388	0.188	-2.06
d7	-0.444	0.185	-2.40	-0.486	0.198	-2.46
d8	-0.221	0.159	-1.39	-0.108	0.164	-0.66
d9	-0.749	0.146	-5.13	-0.706	0.158	-4.46
d10	-0.717	0.154	-4.66	-0.661	0.163	-4.05
d11	-0.518	0.147	-3.53	-0.386	0.162	-2.37
d12	-0.569	0.156	-3.64	-0.574	0.171	-3.37
d13	-0.464	0.162	-2.86	-0.391	0.173	-2.26
_cons	-18.251	3.619	-5.04	-6.197	4.909	-1.26
rho	0.764			0.697		
N	1,098			732		
R^2	0.9918			0.9951		
PseudoR^2	0.9815			0.9842	0.	

Table 4.3 Input Substitution SFACD Model

	Long Period (2006-2023)			Short Period (2012-2023)		
	Coeff	*std. err.*	*t-ratio*	*Coeff*	*std. err.*	*t-ratio*
ly1	0.307	0.075	4.10	0.243	0.116	2.09
ly2	0.130	0.044	2.98	0.311	0.065	4.82
ly3	0.524	0.075	6.99	0.398	0.095	4.18
lz1	-0.138	0.032	-4.35	-0.005	0.050	-0.10
lratioprice2	-0.144	0.033	-4.37	-0.072	0.033	-2.20
yr	0.016	0.001	10.48	0.006	0.002	2.62
jur2	0.009	0.091	0.10	-0.105	0.092	-1.14
jur3	0.112	0.074	1.53	0.150	0.090	1.67
_cons	-21.374	2.956	-7.23	-1.156	4.272	-0.27
/mu	0.116	0.191	0.61	0.279	0.083	3.36
/lnsigma2	-2.384	0.508	-4.69	-2.991	0.249	-12.00
/lgtgamma	1.547	0.617	2.51	1.065	0.338	3.15
sigma2	0.092	0.047		0.050	0.013	
gamma	0.825	0.089		0.744	0.065	
sigma_u2	0.076	0.047		0.037	0.012	
sigma_v2	0.016	0.001		0.013	0.001	
N	1098			732		
LLH	599.477			454.952		
BIC	-1114.94			-830.755		
PseudoR^2	0.991			0.993		

Table 4.4 Input Substitution SFATLG Model

	Long Period (2006-2023)		
	Coeff	*std. err.*	*t-ratio*
ly1	0.357	0.084	4.26
ly2	0.151	0.051	2.94
ly3	0.416	0.080	5.21
ly11	1.483	0.480	3.09
ly12	-0.307	0.114	-2.70
ly13	-1.318	0.397	-3.32
ly22	0.070	0.055	1.28
ly23	0.364	0.107	3.41
ly33	0.794	0.341	2.33
lz1	-0.127	0.044	-2.92
lratioprice	-0.148	0.032	-4.60
yr	0.015	0.002	9.78
jur2	-0.033	0.074	-0.45
jur3	0.033	0.085	0.39
_cons	-20.981	3.166	-6.63
/mu	-31.737	294.481	-0.11
/lnsigma2	2.400	9.081	0.26
/lgtgamma	6.611	9.094	0.73
sigma2	11.029	100.148	
gamma	0.999	0.012	
sigma_u2	11.014	100.148	
sigma_v2	0.015	0.001	
N	1,098		
LLH	623.854		
BIC	-1121.686		
PseudoR^2	0.9919		

4.3 Consistency with economic theory or industry knowledge

Since the dependent variable, real opex, is the quantity of opex inputs, the coefficient on *lratioprice* is equal to the elasticity of opex input demand with respect to the opex input price. Tables 4.1 to 4.4 show that the coefficient for *lratioprice* is negative and statistically significant at the 5 per cent level across all models. The negative sign of the coefficients is consistent with economic theory, since the own-price elasticity of demand for opex input is negative and the cross-price elasticity of demand with respect to the capital input price is positive, indicating that the two inputs are substitutes.

The results for the LSE models indicate that a 1 per cent increase in the price of opex relative to capital price leads to a slight decrease in real opex, by 0.07 per cent in the long period models and by 0.06 per cent in the short period. In the SFA models, a stronger substitution effect is observed in the long period, with a decrease of 0.15 per cent in real opex for a 1 per cent increase in price of opex relative to capital price. In the short period SFACD model, a 1 per cent increase in the input price ratio decreases opex inputs by 0.07 per cent. The smaller coefficients in the SFACD short period models imply that DNSPs do not change their input mix by as much over a shorter time frame.

Other comments from Tables 4.1 to 4.4 are:

- For all models, across both the long and short periods, the coefficients of the output variables have the expected signs and are statistically significant.
- The coefficients on the variables *yr*, which captures the time trend for all the sample, are positive and statistically significant in all models for both periods.
- The Pseudo R^2 is above 0.97 for all models, indicating a high goodness of fit.

Table 4.5 shows the elasticities of opex with respect to the individual and the total outputs. Similar to previously established results, the cost-output elasticities are close to 1, which suggests near-constant returns to scale.

Table 4.5 IS Models: Output Cost Elasticities

	Long Period (2006-2023)				*Short Period (2012-2023)*			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
LSECD	0.551	0.223	0.191	0.965	0.539	0.264	0.163	0.967
LSETLG								
- AUS	0.241	0.309	0.431	0.981	-0.010	0.377	0.579	0.946
- NZ	0.677	0.236	0.039	0.952	0.618	0.323	0.005	0.946
- Ontario	0.234	0.193	0.521	0.948	0.241	0.203	0.519	0.963
- Average	0.373	0.231	0.352	0.956	0.305	0.278	0.372	0.954
SFACD	0.307	0.130	0.524	0.961	0.243	0.311	0.398	0.952
SFATLG								
- AUS	0.188	0.353	0.103	0.644				
- NZ	0.525	0.039	0.610	1.174				
- Ontario	0.322	0.134	0.429	0.886				
- Average	0.357	0.151	0.416	0.924				

In the IS LSE-CD models, for both the long and short period samples, the customer numbers output received the highest weight, followed by circuit length and RMD. This pattern is consistent with the standard LSE-CD models in ABR24. In the IS LSE-TLG models, the weights were more evenly distributed between customer numbers and RMD, with CL receiving the lowest weight—again, in line with the standard LSE-TLG models.

The IS SFA-CD model, however, shows a markedly different distribution of output weights between the long and short samples. In the long-period sample, RMD received the highest weight, followed by customer numbers and CL. In contrast, the short-period sample showed a more balanced allocation, with RMD still weighted most heavily, followed by CL and then customer numbers. The IS SFATLG model displayed a similar weighting pattern to the IS SFA-CD in the long period. In ABR24's long-period estimates, both the SFA-CD and SFATLG models also allocated a higher share of output elasticity to RMD.

Tables 4.6 and.7 present the frequency of monotonicity violations (*MVs*) for the IS Translog models in both the long and short periods. In the long-period LSETLG model, the frequency of monotonicity violations in the Australian DNSPs sample declined from 22.2 per cent in the standard version reported in ABR24 to 15.4 per cent in the IS version, and from 21.9 per cent to 19.4 per cent for the total sample. In the long-period SFATLG model, MVs fell from 79.5 per cent in the standard version to 77.8 per cent in the IS version for Australian DNSPs but increased from 45.5 per cent to 47.4 per cent for the total sample.

In the long-period LSETLG model, the IS version excluded two DNSPs (AGD and CIT) due to excessive MVs, while the standard version excluded three (AGD, CIT, and UED). In the long-period SFATLG model, the IS version excluded all DNSPs due to excessive MVs (11 DNSPs), consistent with the standard version.

Table 4.6 Frequency of Monotonicity Violations (2006-2023, %)

	LSETLG				SFATLG			
	Cust.	*CL*	*RMD*	*Total*	*Cust.*	*CL*	*RMD*	*Total*
Aust	15.4	0.0	0.0	15.4	32.5	0.0	45.3	77.8
NZ	0.0	0.0	41.2	41.2	9.7	36.0	3.5	49.1
Ontario	6.9	0.0	0.0	6.9	13.8	17.6	1.3	32.6
Total	6.6	0.0	12.8	19.4	16.5	19.6	11.4	47.4
Aust:								
- EVO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- AGD	100.0	0.0	0.0	100.0	0.0	0.0	100.0	100.0
- CIT	100.0	0.0	0.0	100.0	0.0	0.0	100.0	100.0
- END	0.0	0.0	0.0	0.0	72.2	0.0	16.7	88.9
- ENX	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
- ERG	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0
- ESS	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100.0
- JEN	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
- PCR	0.0	0.0	0.0	0.0	11.1	0.0	0.0	11.1
- SAP	0.0	0.0	0.0	0.0	88.9	0.0	0.0	88.9
- AND	0.0	0.0	0.0	0.0	0.0	0.0	72.2	72.2
- TND	0.0	0.0	0.0	0.0	50.0	0.0	0.0	50.0
- UED	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0

In the short-period LSETLG model, MVs dropped from 48.7 per cent in the standard version to 46.2 per cent in the IS version for Australian DNSPs, and from 36.6 per cent to 36.1 per cent for the total sample. In the short-period LSE-TLG model, the IS version excluded six DNSPs (AGD, CIT, END, ENX, JEN, and UED) for excessive MVs, the same as in the standard version.

While the IS models offered a very modest improvement in the frequency of MVs relative to the Translog models in ABR24, this suggests that the inclusion of the input price ratio does not solve the problem of monotonicity violations in the models.

Table 4.7 Frequency of Monotonicity Violations (2012-2023, %)

	LSETLG			
	Cust.	*CL*	*RMD*	*Total*
Aust	46.2	0.0	0.0	46.2
NZ	5.3	0.0	57.9	63.2
Ontario	13.8	0.0	0.0	13.8
Total	18.0	0.0	18.0	36.1
Aust:				
- EVO	0.0	0.0	0.0	0.0
- AGD	100.0	0.0	0.0	100.0
- CIT	100.0	0.0	0.0	100.0
- END	100.0	0.0	0.0	100.0
- ENX	100.0	0.0	0.0	100.0
- ERG	0.0	0.0	0.0	0.0
- ESS	0.0	0.0	0.0	0.0
- JEN	100.0	0.0	0.0	100.0
- 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	100.0	0.0	0.0	100.0

4.4 Specification Tests

Tables 4.1 and 4.4 show the BIC and Pseudo Adjusted R^2 goodness-of-fit statistic for each model. Table 4.8 compares the Pseudo-adjusted-R^2 statistics for the IS models and the corresponding standard models. Other diagnostic statistics are shown in Table 4.9 and 4.10.

Table 4.8 Pseudo-adjusted-R^2

	Input Prices Ratio		*ABR24 Models*	
	Long Period	*Short Period*	*Long Period*	*Short Period*
LSECD	0.9788	0.9806	0.9787	0.9805
LSETLG	0.9815	0.9842	0.9813	0.9842
SFACD	0.9912	0.9930	0.9910	0.9930
SFATLG	0.9919	NA	0.9917	NA
Average	0.9859	0.9889*	0.9857	0.9859*

Incorporating the Input Substitution variable marginally enhances the goodness of fit across all models in the long period compared to the standard models. However, in the short period, there is no observable difference in the average Pseudo-adjusted R^2 between the IS models and the standard models. In short, the addition of the log ratio of input prices has little or no effect on the model fit. Residual diagnostic tests indicate that severe outliers are low. The Shapiro–Wilk test rejects the null hypothesis of normality in both models and periods ($p = 0.000$). Multicollinearity is moderate in the CD models. In contrast, the TLG models present severe multicollinearity, largely due to the inclusion of interaction and squared terms. Functional form tests support the TLG specification, as the joint tests confirm that the higher-order output terms are jointly significant in both periods

Table 4.9 Diagnostic Statistics: LSE Models

	Long Period		*Short Period*	
	Stat.	*p-value**	*Stat.*	*p-value**
LSECD				
Normality of residuals				
IQR (% severe outliers)(1)	0.09		0.00	
Shapiro–Wilk W test(2)	0.975	0.000	0.984	0.000
Multicollinearity				
Average VIF(3)	14.61		14.91	
Condition number(3)	2277.53		2964.19	
LSETLG				
Normality of residuals				
IQR (% severe outliers)	0.09		0.00	
Shapiro–Wilk W test	0.982	0.000	0.991	0.000
Multicollinearity				
Average VIF	573.47		580.49	
Condition number	3198.44		4162.57	
Joint parameter tests				
Higher-order output terms	39.78	0.000		

Table 4.10 Diagnostic Statistics: SFA Models

	Long Period		*Short Period*	
	Stat.	*p-value**	*Stat.*	*p-value**
SFACD				
Normality of residuals				
IQR (% severe outliers)(1)	0.18		0.27	
Shapiro–Wilk W test(2)	0.984	0.000	0.977	0.000
Multicollinearity				
Average VIF(3)	22.74		23.29	
Condition number(3)	2234.89		2911.81	
SFATLG				
Normality of residuals				
IQR (% severe outliers)	0.09			
Shapiro–Wilk W test	0.987	0.000		
Multicollinearity				
Average VIF	664.39			
Condition number	3093.11			
Joint parameter tests				
Higher-order output terms	48.51	0.000		

Note: * Null hypothesis is rejected in these tests, if the p-value is less than 0.05. Equivalently, the reported statistic exceeds the critical value for that statistic; (1) Severe outliers comprise about .0002% of the normal population; (2) The null hypothesis is that residuals are normally distributed; (3) Collinearity is potentially a problem if VIF>10 or the Condition number > 30;

4.5 Efficiency Scores

Tables 4.11 and 4.12 and Figures 4.1 and 4.2 present the efficiency scores for the four models in the long and short periods.

Table 4.11 IS Models: Efficiency Scores -Long Period (2006-2023)

	LSECD		*LSETLG*		*SFACD*		*SFATLG*		*AVERAGE*	
	Eff	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*	*Eff*	*Rank*
EVO	0.508	13	0.473	13	0.527	13	0.560	10	0.517	12
AGD	0.577	11	0.521	12	0.606	10	0.272	13	0.494	13
CIT	0.779	6	0.719	7	0.916	4	0.730	9	0.786	6
END	0.672	10	0.658	8	0.714	8	0.458	11	0.626	9
ENX	0.690	8	0.640	9	0.705	9	0.410	12	0.611	11
ERG	0.561	12	0.601	10	0.575	12	0.745	7	0.621	10
ESS	0.675	9	0.737	6	0.602	11	0.735	8	0.687	8
JEN	0.725	7	0.590	11	0.737	7	0.789	5	0.710	7
PCR	1.000	1	1.000	1	0.968	2	0.966	2	0.983	1
SAP	0.955	2	0.968	2	0.919	3	0.890	3	0.933	2
AND	0.852	5	0.794	4	0.758	6	0.764	6	0.792	5
TND	0.852	4	0.835	3	0.891	5	0.976	1	0.889	3
UED	0.930	3	0.752	5	0.969	1	0.796	4	0.862	4
AVG	0.752		0.714		0.761		0.699		0.732	

Figure 4.1 Input Substitution Efficiency Scores -Long Period (2006-2023)

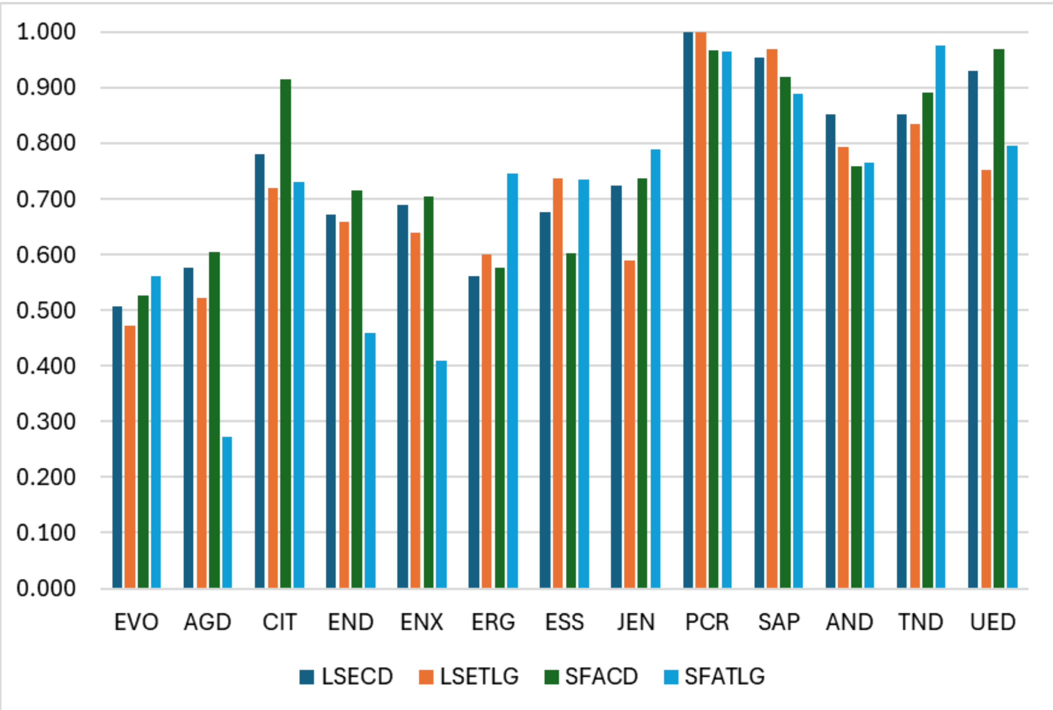
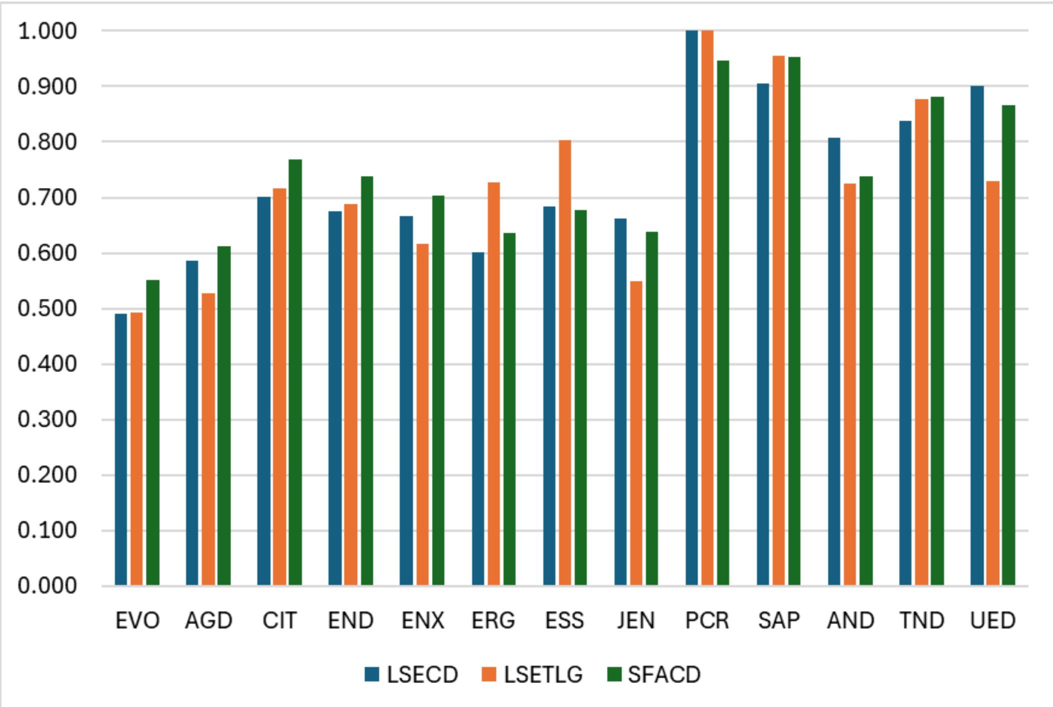


Table 4.12 IS Models: Efficiency Scores -Short Period (2012-2023)

	LSECD		LSETLG		SFACD		AVERAGE	
	Eff	Rank	Eff	Rank	Eff	Rank	Eff	Rank
EVO	0.490	13	0.494	13	0.551	13	0.512	13
AGD	0.586	12	0.527	12	0.612	12	0.575	12
CIT	0.702	6	0.716	8	0.768	5	0.729	6
END	0.675	8	0.689	9	0.738	7	0.701	8
ENX	0.666	9	0.616	10	0.703	8	0.662	9
ERG	0.601	11	0.728	6	0.636	11	0.655	10
ESS	0.685	7	0.803	4	0.678	9	0.722	7
JEN	0.662	10	0.550	11	0.639	10	0.617	11
PCR	1.000	1	1.000	1	0.945	2	0.982	1
SAP	0.905	2	0.956	2	0.952	1	0.938	2
AND	0.807	5	0.726	7	0.738	6	0.757	5
TND	0.838	4	0.876	3	0.882	3	0.866	3
UED	0.900	3	0.730	5	0.865	4	0.832	4
AVG	0.732		0.724		0.747		0.734	

Figure 4.2 Input Substitution Efficiency Scores -Short Period (2012-2023)



The comparison of efficiency scores across the four models in the long period shows varying degrees of consistency for each DNSP. For EVO, AGD, and ENX, the scores are generally consistent across models, with only modest differences. In contrast, CIT and ERG show more variation, particularly in the SFACD and SFATLG models. PCR, SAP, TND, and UED exhibit high efficiency and close alignment across all models. Meanwhile, END, ESS, and JEN show moderate differences, though the results remain broadly comparable.

The rankings of average efficiency scores for the long period IS models show only minor differences compared to the ABR24 results. In the LSECD model, END drops from 9th to 10th, while ESS improves from 10th to 9th, with all other DNSPs retaining their positions. In the LSETLG model, ESS falls slightly from 5th to 6th, while UED improves from 6th to 5th, with the rest of the rankings unchanged. The SFACD model shows a small shift as CIT moves from 3rd to 4th and SAP rises from 4th to 3rd, with all other positions remaining the same. Finally, in the SFATLG model, ESS drops from 5th to 7th, JEN moves up from 7th to 5th, and UED improves from 6th to 4th, while the remaining DNSPs maintain their previous rankings.

The comparison of efficiency scores across the three short-period models reveals a generally consistent pattern for most DNSPs, with some exceptions. CIT, END, ENX, PCR, SAP, TND, and UED display similar scores across the LSECD, LSETLG, and SFACD models, indicating robustness to model specification. However, differences are more evident for ESS and JEN, where the LSETLG model shows notably higher and lower scores, respectively. EVO, AGD, and ERG also show moderate variation between models, particularly between the SFA and LSE specifications.

The rankings of average efficiency scores for the short period IS models show minimal to no change compared to the ABR24 results. For both the LSE-CD and SFA-CD models, the rankings are identical, with all DNSPs retaining their original positions. In the LSE-TLG model, only a minor shift is observed: the DNSP ranked 5th in ABR24 drops to 6th, while the DNSP previously ranked 6th moves up to 5th. All other rankings remain unchanged.

4.6 Conclusion

The estimation of a price index for capital services, consistent between jurisdictions, enables measurement of the ratio of opex price and capital input price. Including this input price ratio in the opex cost function model allows the extent of input substitution to be estimated. The modelling finds that the variable defined as the log ratio of opex price to capital price is significant across all models, both in the short and long periods. The sign of the coefficient is consistent with economic theory in all models, since the own-price elasticity of demand for opex input is negative and the cross-price elasticity of demand with respect to the capital input price is positive, indicating that the two inputs are substitutes.

This finding suggests that the input price ratio is potentially an omitted variable. That said, the inclusion of the input substitution variable did not result in any notable improvements over the standard models in terms of goodness-of-fit or convergence of the SFATLG model in the short period. We plan to test this model using the half normal distribution of inefficiencies to remedy the convergence issue.

The additional variable also led to only a marginal reduction in the frequency of monotonicity violations. The efficiency scores remain closely aligned with those from the standard specifications, suggesting that the impact of incorporating this variable is small. The main implication of these findings is that including the log ratio of input prices into the model may yield some marginal improvements.

4.7 Directions for further research

As outlined in Section 4.1, the parameters required to estimate the risk premium in the cost of capital are not consistently available across all jurisdictions. Consequently, we made some assumptions to construct these parameters, which raises concerns about the reliability of the variable's values.

Three methodological issues needing further consideration and potential improvement:

- The method of imputing missing values of the risk premium parameters in jurisdictions and years where they are unavailable
- Whether there should be any averaging of parameters across jurisdictions; and
- Whether all of these parameters can be treated as constants or whether some should vary over time.

One parameter that should perhaps vary over time is the debt margin. This parameter may vary over the business cycle. For example, the debt margin used by the AER increased rapidly between 2008 and 2011, probably reflecting the impact of the global financial crisis. However, in constructing the input substitution variable, we assumed a constant debt margin of 1.89 per cent for all observations. This simplification overlooks the temporary spike associated with the 2008 crisis. It remains a question of whether a variable debt margin is relevant and if so, can be adequately estimated.

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