Infometrics Working Paper

The Effects of a Carbon Charge on Electricity Generation – Comparing Two Models

Evans at al (2011)[1] develop a model of an electricity market that incorporates forward–looking expectations, uncertain lake inflows and storage options. The model is calibrated to New Zealand's electricity market, making it suitable for studying issues such as the effects of climate change and the effects of a carbon price on the electricity generation. The latter is of interest here as the results may be compared with those produced by the ESSAM general equilibrium model, and potentially provide data to improve the ESSAM model.

Modelling

The modelling results are expressed relative to a Business as Usual (BAU) scenario to 2020. The BAU is certainly not a forecast of the economy in that year. It is simply intended to be a plausible projection of the economy (without a carbon price or any emissions obligation), that can constitute a frame of reference against which the carbon price scenarios may be compared. Further detail on the BAU is given in Stroombergen (2010).[2] The following macroeconomic closure rules apply.

1. Labour market closure: Total employment is held constant at the BAU level, with wage rates being the endogenous equilibrating mechanism.
2. Capital market closure: We assume that post-tax rates of return on capital held constant at BAU levels, with capital formation being endogenous.
3. External closure: The balance of payments is a fixed proportion of nominal GDP, with the real exchange rate being endogenous.
4. Fiscal closure: The fiscal position is held constant at the BAU level, with personal income tax rates being endogenous.

For the carbon price scenarios is it assumed that New Zealand has a responsibility obligation for emissions in 2020 that are above 85% of 1990 emissions. This means that any emissions reduction not undertaken domestically has to be covered by purchasing emission units from offshore.

Table 1 shows the results from the ESSAM model with a carbon charge of $25/tonne. Scenario 1 has the standard ESSAM generation elasticities of substitution while Scenario 2 calibrates the elasticities so that the results approximate those produced by Evans et al. We say "approximate" as the model by Evans et al does not separately identify coal fired generation, implicitly absorbing it into the gas component of the model. Similarly, other types of renewables generation are implicitly part of the hydro component.

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[1] Evans, L., G. Guthrie & A. Lu (2011): The Effect of Climate Change on Electricity Markets with Hydroelectric Generation. Victoria University of Wellington.

[2] Stroombergen, A. (2010): *General Equilibrium Analysis of CO_2 Mitigation Options.* Report to Motu.

Under a \$25/tonne price on carbon the model by Evans et al produces a 10.3% fall in gas generation and no change in hydro generation. At \$50/tonne the reduction gas generation is 18.6%, again with no change in hydro generation.[3] Clearly gas generation is on the margin.

Table 1: Summary of Results

	Scenario 1	Scenario 2	
		Evans et al	MED
		% change on BAU	
Private Consumption	-0.6	-0.6	
Exports	-1.1	-1.1	
Imports	-0.6	-0.6	
GDP	-0.6	-0.6	
RGNDI	-0.5	-0.5	
Terms of trade	0.9	0.9	
CO_2e emissions	-4.5	--5.3	
Electricity generation			
Coal	-4.6	-20.4	-46.3
Gas	-2.2	-5.1	0.0
Renewable	-3.3	0.1	5.0
Total	-3.2	-2.7	-0.1

The macroeconomic effects show no difference at one decimal place – more decimal places are considered spurious.

With regard to electricity generation the results are more interesting. In the original ESSAM scenario (Scenario 1) the model reduces generation from all sources by varying amounts. Although the cost of coal generation increases the most proportionately, even with a carbon price of \$25/tonne it is only just more expensive than gas generation – its higher CO_2 content and lower conversion efficiency being offset by a much lower raw material price. Also some hydro is more expensive than gas baseload, so the model also elects to reduce generation from renewable sources as well – relative to no carbon price. In reality this means that some new capacity is not built, rather than plant being idle for more time than is usually required to meet demand peaks.

In Scenario 2 the change in thermal generation (gas and coal combined) is the same as that in Evans et al. As the ESSAM model has no mechanisms to simulate the effect of a shadow price on stored water (a key feature of the Evans et al model), the generation substitution elasticities are over-ridden to achieve the desired result.

The implied elasticity of substitution between hydro and gas (coal) in the Evans et al model is 0.40±0.05. There is no implied gas-coal elasticity of substitution as the two fuels are effectively infinitely substitutable at the margin. Indeed Huntly can run on gas or coal and change from one to the other very quickly. In terms

[3] These results relate to the competitive market option in Evans et al.

of new capacity of course the elasticity of substitution is affected by other factors such as resource consent issues and location of fuel sources in relation to the pattern of regional demand. In practice we find that the *ex post* elasticity that produces the above result is about 0.85±0.05.

In practice the difficulty with this result is that the elasticity all depends on whether Huntly is in operation and to what extent. If, as MED assumes in the *Energy Outlook* Huntly is gradually decommissioned regardless of a carbon price,[4] it may be better not to attempt to use elasticities to simulate changes in the generation mix in response to a carbon charge.

The MED projections shown in Table 1 are based on a different model again, with changes in the amount of generation from coal being largely by assumption – as noted above. Generation from renewables takes the slack as the supply of gas is constrained. A major difference, however, is that there is virtually no change in total demand for electricity in response to the carbon price. This is despite a 9.4% increase in the wholesale price of electricity. A reduction in demand similar to that in Scenarios 1 and 2 would remove the increase in renewables generation.

In this connection Evans et al estimate a demand reduction of 4.1% for a $25/tonne carbon price, rising to 7.4% for a price of $50/tonne. The ESSAM model suggests a reduction of around 3% at $25/tonne. The difference is plausible as the 4.1% emerges from a partial equilibrium model that permits greater profits by hydro generators under a carbon price, than in the ESSAM general equilibrium model where super-normal profits are not possible. Again this is could be a largely short run versus long run distinction.

Conclusion

It would seem useful to replace the ESSAM model's existing electricity generation substitution elasticities with those implied by the results from the Evans et al model. However, substitution between coal and gas needs to be treated cautiously. The distinction is not explicit in the model by Evans et al, so the implied substitution elasticity may be misleading. Furthermore, in reality coal-gas substitution may be more about the economics of one old and inefficient power station (Huntly) than about the choice of new thermal generation capacity. Allowing for geothermal generation might also change the effective storage of the 'hydro' component and thus the implicit substitution elasticities.

Another useful aspect of Evans et al (2011) is that it contains estimates of how the generation mix might respond to climate change – manifested by lower mean lake inflows, greater volatility of lake inflows, and/or slow mean reversion of inflows. These results could be input into the ESSAM model in order to examine the wider economic effects of climate change through energy sector impacts.[5]

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[4] Two Huntly coal units are switched to dry year reserve plant in 2012 and 2015 respectively with the remaining two units decommissioned in 2019 and 2023. Source: *Energy Outlook.*

[5] For earlier research on this topic see Stroombergen A., A. Tait, K. Patterson and J. Renwick (2006): *The Relationship between New Zealand's Climate, Energy and the Economy to 2025*, New Zealand Journal of Social Sciences.