Comparison of alternative AGE model specifications for simulations of climate change policy instruments

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ABSTRACT

Besides benchmark data and parameter values, the model structure is key in explaining results of an applied general equilibrium model. This paper compares five alternative specifications of the computable general equilibrium model developed by Wissema and Dellink (2007a, 2007b), which simulates implementation of carbon taxation and an auctioned emission permits system in Ireland using different revenue recycling methods through endogenous taxes and transfers. These alternative specifications involve endogenous labour supply, the LES, the production structure concerning labour, capital and energy, an assumption that trading partners implement similar policies and the place of peat in the production function for electricity generation. We show the importance of modelling these features differently in a CGE model and evaluate the robustness of the model.

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1. INTRODUCTION

Wissema and Dellink (2007a) first used an AGE model for the analysis of the impact of revenue-neutral carbon energy taxation on the Irish economy. It emerged that a carbon tax in the range of EUR 10 to EUR 15 per tonne of CO_2 would achieve the target for reduction of CO_2 emissions from energy use and production of 25.8 percent, while reducing welfare by 0.5 percent. Wissema and Dellink (2007b) extended the AGE model of Wissema and Dellink (2007a) to compare the impact on welfare of climate change policy instruments (a revenue-neutral carbon tax and fully auctioned emission permits[1]) with different ways to recycle the revenue. The four simulations analysed are outlined in Table 1.

Table 1. The four revenue recycling schemes simulated

Simulation	Description of the recycling scheme
1. Lump sum	Increase the lump-sum transfer to the household
2. VAT	Reduce indirect tax rates
3. Labour tax	Reduce the labour tax rate
4. Output tax	Reduce output tax rates

Ideally, AGE models are validated by comparing the output with actual outcomes in reality. However, no country has implemented a carbon tax or a permit system the way it is modelled in these articles. Various exemptions are made to accommodate or protect certain sectors (see Böhringer & Rutherford, 1997, for an interesting CGE analysis of such exemptions). Even if the policy simulated was actually introduced in the country of interest, changes in emissions and welfare may be influenced by the policy introduced but also by other factors such as economic growth, other policy measures and foreign trade.

Together with the benchmark data and parameter values, the model structure determines the results of the model. Wissema and Dellink (2007a and 2007b) carried out a thorough sensitivity analysis to determine the influence of parameter values on model output. The elasticity values that determine the possibility to substitute energy for labour and capital, thus conserving energy, are found to be the most important.

This paper obtains some insight into the robustness of the model of Wissema and Dellink (2007b), henceforth referred to as the *Base Model*, by changing the structure of the model

[1] The results are presented in terms of the carbon tax. A fully auctioned permit system in which the permit price is fixed and equals the carbon tax level is equivalent, because both instruments provide the same price incentives and revenue recycling possibilities, assuming the permit market is perfectly competitive.

and comparing the new results with those resulting from the default model structure[2]. Sections 2 to 6 respectively investigate five alternative model specifications:

2 consumption preferences modelled as a Cobb-Douglas function instead of the LES;

3 a specification with fixed labour supply;

4 a different production (nesting) structure concerning labour, capital and energy;

5 a specification which assumes all trading partners implement a similar policy;

6 a different production structure for Electricity whereby Peat is entered in the production function the same way as it enters all other production functions, as opposed to enforcing a minimum percentage of peat input, as in the Base Model.

2. MODEL SPECIFICATION WITHOUT LINEAR EXPENDITURE SYSTEM

The model used in this section differs from the Base Model only in the sense that it applies a Cobb-Douglas utility function instead of the Linear Expenditure System (LES). Results are displayed in Table 2.1 where comparison with results from the Base Model is facilitated. The main difference is that in the Base Model the households are unable to substitute between commodities for the necessary share of consumption. Thus, for this part of consumption, the carbon tax cannot be avoided. Only in the luxury part of consumption is it possible to substitute away from commodities with relatively high prices.

Energy commodities are basic needs, except Oil, which is a luxury good.[3] This can be derived from Table 2.2, in which income elasticities and the related necessary consumption shares for each consumption commodity are sorted by magnitude.

The alternative model gives greater reductions in emissions because carbon-intensive Coal and Peat can be substituted for other commodities in a Cobb-Douglas function where the quantity purchased of each commodity falls (rises) as its price rises (drops) while expenditure shares remain constant. In contrast, the LES prevents the consumption of energy, where the energy commodity is a necessary good, from dropping below a minimum level.

[2] The equations of the model are given in Appendix A. For more details on the Base Model see Wissema (2007), chapter 5. Appendix B shows some useful benchmark data.
[3] The estimates are for 1987 at mean income and new estimates may well turn out to be very different due to changes in income levels and the extension of the gas network (Conniffe & Scott, 1990).

Table 2.1. Results from Alternative Model Specification (i.e. with a Cobb-Douglas utility function instead of the L.E.S.) compared with Results from Base Model (percent changes compared to the benchmark)

	Model	**Lump-sum**	**VAT**	**Labour tax**	**Output tax**
Emission reduction	Base Model	-24.71	-24.58	-24.65	-24.22
	Alternative	-28.62	-28.42	-28.55	-28.11
Welfare	Base Model	-0.35	-0.09	-0.65	-0.41
	Alternative	-0.36	-0.09	-0.46	-0.31
Leisure	Base Model	-0.15	-0.13	-0.63	-0.37
	Alternative	-0.07	-0.09	-0.42	-0.25
Luxury consumption	Base Model	-0.66	-0.04	-0.68	-0.47
Total household consumption	Base Model	-0.27	-0.02	-0.28	-0.20
Total household consumption	Alternative	-0.54	-0.09	-0.49	-0.35
Net wage rate	Base Model	-0.41	0.07	-0.04	-0.08
	Alternative	-0.59	0.00	-0.08	-0.13
Rental rate	Base Model	-0.33	0.03	-0.74	-0.35
	Alternative	-0.61	-0.06	-0.83	-0.44
Price basic consumption	Base Model	0.69	0.19	0.11	0.12
Price luxury consumption	Base Model	0.63	-0.11	0.06	0.13
Price of total consumption (*pc*)	Alternative	0.38	0.00	0.05	0.09

There are two mechanisms at work that change welfare in opposite directions: (1) The smaller chance to avoid the carbon tax suggests that the Base Model would have a stronger fall in welfare compared with the current alternative and (2) the carbon tax has a lower deadweight loss (DWL) in the Base Model, because the necessary part of consumption is fixed. With the more flexible Cobb-Douglas instead of the LES, the tax has a higher DWL due to more changes in the consumption pattern. This would imply that the alternative model should lead to a greater welfare loss than the Base Model.

In the lump-sum simulation, welfare falls more in the alternative model (-0.36) than in the Base Model (-0.35). This is explained by the fact that the latter effect (2) outweighs the former (1).

In simulations 3 and 4 of the alternative model, the carbon tax leads to a smaller net welfare cost than the Base Model, because enhanced possibilities to conserve energy and change the fuel mix (*cf.* mechanism 1) more than offset the welfare loss due to the exacerbated increase in distortion (*cf.* mechanism 2).

Table 2.2. Income Elasticity Values and Basic Necessity Shares for Each Commodity in the Base Model

Commodity	Income elasticity	Necessary share (%)
Oil	1.85	0
Trade	1.40	24
Construction	1.25	32
Other manufacturing	1.11	40
Metal products	1.10	41
Rubber plastic	1.00	46
Textiles	0.88	52
Chemicals	0.88	52
Lodging, catering	0.79	57
Commercial services	0.79	57
Electricity	0.76	59
Non-commercial services	0.76	59
Wood	0.64	65
Basic Metals	0.59	68
Agriculture	0.48	74
Food	0.44	76
Transport	0.39	79
Mining quarrying	0.38	80
Coal	0.38	80
Non-metal minerals	0.38	80
Gas	0.27	85
Peat	0.00	100

Source: Dellink (2005), except oil, coal, and gas from Conniffe & Scott (1990) and peat assumed zero due to an estimated income elasticity below zero, indicating inferiority.

The impact on consumption and price changes of replacing the LES with a Cobb-Douglas function is strongest in the first simulation, because in this lump-sum case commodity prices increase the most. Consumption demand drops more strongly in the alternative model than in the Base Model, because all consumption is free to decrease, instead of just the luxury part, pushing consumer prices back down. The net result is an increase in the price level, but much less than in the Base Model.

In other simulations, price increases due to the carbon tax are moderated by lower taxes or lower production costs. Especially in the VAT simulation, where consumer prices are directly affected by the revenue recycling scheme, price changes and other results differ the least between the two model specifications.

3 MODEL SPECIFICATION WITH FIXED LABOUR SUPPLY

In the Base Model, labour supply is endogenous. The elasticity of labour supply determines the flexibility with which leisure trades off with consumption. The elasticity is equal to 0.49 (Doris, 2001) implying a 'backward bending' labour supply curve where, in a partial equilibrium setting, supply increases when the wage rate falls. If the representative household gives up more leisure time in order to work more, household income will increase and more commodities can be consumed, assuming unemployment does not increase.

This mechanism is now 'switched off' by fixing labour supply. Labour and leisure are two separate commodities in this alternative specification, with the former valued at the net wage rate and the latter valued at the 'price' of leisure, *i.e.* the marginal utility of leisure, which can be interpreted as the value of time (which is equal to the net wage rate in the Base Model). The results are shown in Table 3.

Table 3. Results from Alternative Model Specification (Fixed Labour Supply) compared with Results from Base Model (percent changes compared to the benchmark)

	Model	**Lump-sum**	**VAT**	**Labour tax**	**Output tax**
Emission reduction	Base Model	-24.71	-24.58	-24.65	-24.22
	Alternative	-24.73	-24.59	-24.73	-24.20
Welfare	Base Model	-0.35	-0.09	-0.65	-0.41
	Alternative	-0.26	0.00	-0.26	-0.17
Leisure	Base Model	-0.15	-0.13	-0.63	-0.37
	Alternative	0.00	0.00	0.00	0.00
Luxury consumption	Base Model	-0.66	-0.04	-0.68	-0.47
	Alternative	-0.65	-0.01	-0.65	-0.43
Net wage rate	Base Model	-0.41	0.07	-0.04	-0.08
	Alternative	-0.17	0.30	1.32	0.63
Rental rate	Base Model	-0.33	0.03	-0.74	-0.35
	Alternative	-0.20	0.16	-0.20	0.00
Price basic consumption	Base Model	0.69	0.19	0.11	0.12
	Alternative	0.86	0.32	0.86	0.52
Price luxury consumption	Base Model	0.63	-0.11	0.06	0.13
	Alternative	0.81	0.01	0.81	0.53
Price of leisure	Base Model	-0.41	0.07	-0.04	-0.08
	Alternative	-0.52	0.00	-0.52	-0.34
Labour supply	Base Model	0.15	0.13	0.65	0.38
	Alternative	0.00	0.00	0.00	0.00

This alternative specification does not affect emission reductions as much as the specification without the LES, but again the carbon tax is more effective here than in the Base Model. With fixed labour supply, it is difficult for firms to maintain production at the initial level because capital is also fixed and labour and capital are the only substitutes for energy. Thus, they can only avoid the carbon tax by means of fuel switching. Output prices thus increase more than in the Base Model, reducing demand and forcing production levels down. Only in the simulation where the output tax rates are lowered, this is compensated by lowering output prices. Therefore emissions are reduced less in this simulation compared with the same simulation in the Base Model.

In all simulations, the alternative leads to lower welfare losses because the consumption level changes much the same as in the Base Model results while leisure does not fall. Consumption changes are similar in both model specifications because real income changes are much the same: even though in the alternative specification less labour is supplied and consumer prices increase more than with endogenous labour supply, the net wage rate is raised more (or reduced less) due to the fact that labour supply is fixed while producers would like to use labour as a substitute for the capital-energy composite.

As expected the third simulation, in which the revenue is recycled by lowering the labour tax, shows the biggest gap between the Base Model and the case with fixed labour supply. Both the strong shift from leisure to labour and the relatively great drop in income from capital, which constituted the main part of the explanation of Base Model results, do not occur when labour supply is fixed. Leisure is fixed because both time and labour supply are exogenous, preventing the sacrifice of leisure in favour of labour supply. And the substitution of labour (L) for the capital-energy composite (KE) is replaced by substitution between capital (K) and composite energy (E) while capital supply is fixed. The net result is that the rental rate falls less, preventing the relatively great fall in income from capital observed in Base Model results for the same simulation.

Notice that lowering the labour tax has essentially the same effect as recycling the revenue in a lump-sum to households when labour supply is fixed. Households receive income from labour, valued at the net wage rate and from capital, valued at the rental rate. The net wage rate increases as a direct result of the labour tax cut while producers still have to pay the same gross wage. Tax revenue from the labour tax as received by the government is reduced and household income is increased by the same amount. This comes down to a transfer from the government to households, just like in the lump-sum case. The only difference between the two sets of simulation results is that the net wage in the lump-sum case drops by 0.17 percent while it rises by 1.32 percent in the labour tax simulation.

The simulation with reductions in output tax rates is affected by the rigid labour specification more strongly than the first two simulations, because the less flexible labour market directly affects the production side of the economy, while recycling of the revenue by lowering output tax rates also primarily affects production by lowering production costs.

The VAT-reducing simulation, which showed a weak Double Dividend[4] with the Base Model, shows no significant fall in welfare at all in the case where labour supply is fixed. The alternative specification makes the Double Dividend stronger, mostly due to the reduced loss of utility from leisure.

It might be expected that the drop in welfare would be greater when the Representative Agent is more restricted in the labour-leisure choice. This effect, however, is not found in the results. This is perhaps surprising but it can be explained by the existence of another effect that is more powerful and tends toward smaller welfare losses. This other effect is concerned with the fact that the labour market is distorted and that a lower elasticity of substitution leads to a lower dead weight loss of the labour tax, the most important tax in the model. The reasoning is analogous to that in the sensitivity analysis in Wissema and Dellink (2007a), Section 5: "Increasing the value [of the elasticity of substitution between K and E] means that substitution away from energy is easier and this leads to […] but also to a greater deadweight loss and therefore to a larger decrease in welfare. A greater elasticity of substitution means that, *ceteris paribus*, the demand for energy is more price elastic. Tax theory shows that the dead weight loss of a tax is higher when demand for the taxed commodity is more price elastic." And a footnote notes that this is only a partial explanation, as the carbon tax is introduced in a second-best situation and interacts with pre-existing taxes.

Tax theory similarly shows that the dead weight loss of a tax is lower when supply of the taxed commodity is less price elastic. So applying this to the case of fixed labour supply, the price elasticity of labour supply is lower (compared with the Base Model) and thus the

[4] Here, the weak Double Dividend is defined as an outcome that has (1) at least the same environmental benefits and (2) a lower welfare loss than the case of lump-sum recycling, which does not reduce any pre-existing taxes.

dead weight loss of the labour tax is smaller. This leads to a smaller drop in welfare than in the case of the Base Model.

4 MODEL SPECIFICATION WITH DIFFERENT SUBSITUTION POSSIBILITIES FOR VALUE ADDED AND ENERGY

The nesting structure with regard to labour, capital and energy in the production function is very important. In the literature, there is considerable variety on this issue. The GREEN model (OECD, 1992), for instance, uses a composite of energy and capital, trading off against labour, whereas the MERGE model (Manne *et al.*, 1995) uses a composite of capital and labour, that trades off against energy. The choice of a particular nesting structure "is usually settled by *a priori* reasoning" (Kemfert & Welsch, 2000, p. 3). They note that the values of the elasticities of substitution between these three inputs are usually based on estimates found in the literature. Many of them are 'guestimates'. They point out that an elasticity should be estimated in the same functional form in which it is used in the model. In their paper they define three different nesting structures and estimate the corresponding elasticity values using German time series data. The model that best fits the data is determined statistically. All of the parameters found, and thus the elasticities of substitution, are statistically significant.

Unfortunately, elasticities of substitution between energy (E), labour (L) and capital (K) are not (yet) estimated in such a manner for Ireland. In the Base model, the decision of the nesting structure with regard to L, K and E is based on a German econometric study (Kemfert, 1998). Because Kemfert's sectoral disaggregation does not match the disaggregation used in this thesis, the German sectorally differentiated elasticities could not be plausibly adopted. Thus, assuming that Irish industry as a whole reacts equally flexible to price changes of these three inputs compared with the German case, the nesting structure that best fits the overall German economy and the elasticities that correspond to this structure are applied instead, thus matching the assumptions of the GREEN model. The resulting production function (abstracting from other intermediate inputs) in the Base Model is:

$$Y = f_1(L, f_2(K,E))$$

where the elasticity in f_1 is $s_{L\text{-}KE} = 0.846$ and that in f_2 is $s_{KE} = 0.653$ (Kemfert, 1998).

In the alternative specification the production function is changed to:

$$Y = f_1(E, f_2(K,L))$$

where the elasticity in f_1 is s_{KL-E} = 0.698 and that in f_2 is s_{KL} = 0.793 (Kemfert & Welsch, 2000).

The results of the two specifications are compared in Table 4.

Table 4. Results from Alternative Model Specification (LK-E Nesting) compared with Results from Base Model (percent changes compared to the benchmark)

	Model	**Lump-sum**	**VAT**	**Labour tax**	**Output tax**
Emission reduction	Base Model	-24.71	-24.58	-24.65	-24.22
	Alternative	-24.92	-24.79	-24.84	-24.43
Welfare	Base Model	-0.35	-0.09	-0.65	-0.41
	Alternative	-0.34	-0.09	-0.64	-0.40
Leisure	Base Model	-0.15	-0.13	-0.63	-0.37
	Alternative	-0.12	-0.10	-0.60	-0.35
Luxury consumption	Base Model	-0.66	-0.04	-0.68	-0.47
	Alternative	-0.67	-0.06	-0.69	-0.49
Net wage rate	Base Model	-0.41	0.07	-0.04	-0.08
	Alternative	-0.44	0.04	-0.08	-0.11
Rental rate	Base Model	-0.33	0.03	-0.74	-0.35
	Alternative	-0.21	0.14	-0.61	-0.24
Price basic consumption	Base Model	0.69	0.19	0.11	0.12
	Alternative	0.74	0.25	0.18	0.18
Price luxury consumption	Base Model	0.63	-0.11	0.06	0.13
	Alternative	0.69	-0.06	0.12	0.18

Interestingly, the results of the alternative model are much the same as those of the Base Model. Compared with the Base Model, emissions are reduced by more and welfare decreases by less in the specification with alternative nesting, but the differences are quite small compared to those observed in Sections 2 and 3. The explanation for the emissions results lies in the relative values of the elasticities that govern energy conservation. The elasticity between energy and composite value added, s_{KL-E}, in the alternative specification is greater then the elasticity between energy and capital, s_{KE}, in the Base Model. This makes energy conservation easier in the alternative model, which leads to greater emission reductions across all simulations.

The alternative has a slightly more favourable welfare result because its elasticity of substitution between labour and capital, s_{KL}, is lower than that between labour and composite capital and energy, s_{L-KE}, in the Base Model making changes in the use of the factor inputs more difficult and thus causing less distortion and a lower deadweight loss than in the Base Model.

The differences between simulations are so small because the nesting change is mostly concerned with energy conservation possibilities in production, which is most affected by the carbon tax and only very indirectly by the recycling scheme chosen.

The most noticeable differences are those in the price changes. These have the effect that, compared to the Base Model, the shift from consumption towards leisure in simulations 1, 3 and 4 is stronger, and in the second simulation the shift in the opposite direction is weaker, in the alternative specification. Compared with the Base model, there is a weaker downward (or in the case of simulation 2 a stronger upward) pressure on the rental rate of capital. This can be explained by the relative magnitude of the elasticity values and the fact that capital is not aggregated with composite energy (*E*) which causes the fall in the rental rate (*pk*) due to the substitution of *L* for *KE* observed in Base Model results.

In the Base Model, *K* substitutes for *E* and in the alternative, the *KL* composite substitutes for *E*. Substitution between *KL* and *E* in the alternative specification has a higher elasticity value than that between *K* and *E* in the Base Model ($s_{KL\text{-}E} < s_{KE}$). Therefore, the upward pressure on *pk* is greater in the alternative than in the Base Model.

Within the *KL* nest of the alternative structure, *L* needs to substitute for *K* as capital supply is fixed. In the Base Model, *L* is needed as a substitute for composite *KE*. Substitution between *K* and *L* in the alternative specification has a lower elasticity value than that between *L* and *KE* in the Base Model ($s_{KL} < s_{L\text{-}KE}$). Therefore, the downward pressure on *pk* is lower in the alternative than in the case of the Base Model. Both effects lead to a smaller reduction in *pk* in the alternative model specification and thus to less income loss.

5 MODEL SPECIFICATION WITH FOREIGN POLICY APPROXIMATION

In this section it is assumed that all foreign countries implement a carbon tax similar to the one proposed in Ireland. As information on the impacts of such an international policy on world market prices cannot be determined within the model, a more *ad hoc* assumption needs to be made. Specifically, the results of this situation can be approximated by assuming that it has the effect that commodity prices in the rest of the world undergo the same changes as Irish prices (*cf.* Dellink, 2005). When producers decide where to sell their products, they are interested in the relative price they would receive at home or abroad. As the assumption implies that this price ratio remains perfectly constant, there is no incentive to amend the export ratio of total production. In the model, the elasticity of transformation in the CET function is set to equal zero, creating a fixed proportions function to simulate this rigidity. Similarly, there is no incentive to change the import ratio and the Armington elasticity is reduced to zero as well. The results are presented in Table 5.

One might expect a fall in utility, as it is no longer possible to import carbon-intensive fuels tax-free (this is referred to as 'carbon leakage' because the emissions reduced domestically are increased abroad). However, the carbon tax is levied on domestic supply, which is made up of homogeneous 'Armington' commodities which in turn comprise domestically produced and imported commodities alike. Thus for this, say, *direct* form of 'carbon leakage' there is no incentive in the Base Model.

However, commodities produced using energy[5] do rise in price due to the introduction of the carbon tax, because producers partially pass on to consumers the increased cost of this energy. This induces higher domestic output price indices which induces import substitution for these commodities in the Base Model results. I shall use the term '*indirect carbon leakage*' for import substitution of carbon-intensive non-energy commodities, in order to distinguish this effect from '*direct carbon leakage*' which tends to occur when the carbon tax is only levied on domestically produced energy and untaxed imported energy can be used as a substitute for it.

The four commodities that are most affected by *indirect carbon leakage* in the Base Model, all of which are basic necessities according to Table 2.2, are:

- Electricity,
- Transport by road and water,
- Mining and quarrying products and
- products from the Basic metals industry.

[5] More precisely, commodities produced using a relatively high input of carbon-intensive fuels that are combusted in the production process. For instance, though Oil products are energy-intensive, the Crude oil used in Oil production is not combusted in the refining process and thus not subject to the carbon tax. Therefore, changes in imports of Oil products are not very different in the two models: -4.1 percent in the Base Model and -4.5 percent in the alternative.

Table 5. Results from Alternative Model Specification (foreign policy) compared with Results from Base Model (percent changes compared to the benchmark)

	Model	Lump-sum	VAT	Labour tax	Output tax
Emission reduction	Base Model	-24.71	-24.58	-24.65	-24.22
	Alternative	-22.59	-22.39	-22.53	-22.37
Welfare	Base Model	-0.35	-0.09	-0.65	-0.41
	Alternative	-0.33	-0.31	-0.62	-0.32
Leisure	Base Model	-0.15	-0.13	-0.63	-0.37
	Alternative	-0.14	-0.27	-0.60	-0.24
Luxury consumption	Base Model	-0.66	-0.04	-0.68	-0.47
	Alternative	-0.61	-0.38	-0.65	-0.44
Net wage rate	Base Model	-0.41	0.07	-0.04	-0.08
	Alternative	-0.38	-0.09	-0.04	-0.16
Rental rate	Base Model	-0.33	0.03	-0.74	-0.35
	Alternative	-0.66	-0.15	-0.97	-0.24
Price basic consumption	Base Model	0.69	0.19	0.11	0.12
	Alternative	0.80	0.56	0.29	0.39
Price luxury consumption	Base Model	0.63	-0.11	0.06	0.13
	Alternative	0.59	0.13	0.06	0.25
Exchange rate	Base Model	0.13	0.41	-0.41	-0.23
	Alternative	-1.17	-0.90	-1.74	-1.19
Electricity import	Base Model	39.0	38.7	38.8	38.3
	Alternative	-6.9	-6.8	-6.9	-6.6
Transport import	Base Model	11.5	11.1	11.5	10.8
	Alternative	-0.4	-0.4	-0.3	-0.3
Mine import	Base Model	1.2	1.8	1.4	-0.8
	Alternative	-0.4	-0.2	0.0	-0.3
Metal import	Base Model	1.0	1.5	1.5	1.2
	Alternative	-0.6	-0.4	-0.3	-0.5
Electricity export	Base Model	-38.5	-38.1	-38.3	-37.5
	Alternative	-6.9	-6.8	-6.9	-6.6
Transport export	Base Model	-14.3	-18.1	-14.0	-12.9
	Alternative	-0.4	-0.4	-0.3	-0.3
Mine export	Base Model	-3.7	-3.1	-3.2	-1.5
	Alternative	-0.4	-0.2	0.0	-0.3
Metal export	Base Model	-6.8	-6.1	-6.2	-5.4
	Alternative	-0.6	-0.4	-0.3	-0.5

Besides the usual results, Table 5 also shows changes in imports and exports of these commodities. In the Base Model, their import/domestic ratio increases and their export/domestic ratio decreases. In the alternative specification, however, these changes are not possible due to the Leontief Armington and transformation functions and the

‘Armington commodities’ have the same import share after implementation of the carbon tax as in the benchmark. This causes consumer prices to rise more than in the Base Model results, which negatively affects welfare. Logically, the counter-factual exchange rate is lower with the alternative model specification than with the Base Model.

Emissions are reduced by less than in the Base Model because the fixed trade coefficients obstruct the substitution effects, making *indirect carbon leakage* impossible. Clearly, if other countries implement a comparable carbon tax policy, the tax level needs to be higher in order to meet the emission target.

Differences between the two model specifications are biggest in the VAT simulation mainly because the lower consumer prices (compared with the numéraire) due to reduced indirect tax rates are the main drivers of the relatively favourable Base Model results of this simulation. Instead, in the alternative specification, domestic producer prices rise while import substitution is impossible. Therefore, Armington prices and domestic supply prices rise more than in the Base Model. Because the commodities most affected by this price increase, as listed above, are not luxuries, households cannot substitute away from them in their consumption bundle. This reduces real household income leading to both increased labour supply and thus a drop in leisure, and less consumption. Together these effects result in a relatively big gap between Base Model and alternative welfare results for the simulation with revenue recycling through lowering indirect tax rates.

This change in model specification leads to an important change in the overall conclusions. If other countries also implement a carbon tax, the weak Double Dividend is much more uncertain for Ireland as the difference between the welfare loss in the lump-sum simulation and the welfare loss in the VAT recycling scheme is reduced to just 2 percent-points compared to 26 percent-points in the Base Model results. Also, the chance of a strong Double Dividend, where the welfare change is positive, seems even more remote. The simulation where output taxes are reduced now leads to a smaller drop in welfare (-0.32) than the lump-sum simulation (-0.33) indicating a weak Double Dividend for this simulation as well as for the simulation with a revenue recycling scheme where indirect tax rates are lowered.

6 MODEL SPECIFICATION WITH PEAT AS A SUBSTITUTE FOR COAL IN ELECTRICITY GENERATION

As peat is no longer required to be used in Irish electricity generation by contract, as modelled in the Base Model, it is interesting to see how this would affect model results. The electricity production function is amended to resemble the other production functions where peat is concerned: Coal and Peat are substitutes in a nest for solid fuels with an elasticity of substitution equal to 4. The top of the tree is still different for electricity because of the renewables (see Figure 1 in Wissema and Dellink, 2007a), but the rest of the tree is the same for each industry in this section's alternative specification.

Table 6. Results from Alternative Model Specification (Peat in Electricity Generation) compared with Results from Base Model (percent changes compared to the benchmark)

	Model	Lump-sum	VAT	Labour tax	Output tax
Emission reduction	Base Model	-24.71	-24.58	-24.65	-24.22
	Alternative	-27.05	-26.92	-26.99	-26.58
Welfare	Base Model	-0.35	-0.09	-0.65	-0.41
	Alternative	-0.35	-0.11	-0.65	-0.42
Leisure	Base Model	-0.15	-0.13	-0.63	-0.37
	Alternative	-0.16	-0.14	-0.63	-0.38
Luxury consumption	Base Model	-0.66	-0.04	-0.68	-0.47
	Alternative	-0.66	-0.06	-0.68	-0.48
Total household consumption	Base Model	-0.27	-0.02	-0.28	-0.20
	Alternative	-0.28	-0.03	-0.28	-0.20
The use of Coal in electricity generation	Base Model	-37.95	-37.74	-37.94	-37.72
	Alternative	-51.07	-50.87	-51.14	-51.74
The use of Peat in electricity generation	Base Model	-7.59	-7.38	-7.52	-7.07
	Alternative	-13.92	-13.74	-13.73	-11.82
The use of Oil in electricity generation	Base Model	-64.64	-64.46	-64.63	-64.50
	Alternative	-64.86	-64.69	-64.85	-64.73
The use of Gas in electricity generation	Base Model	-12.27	-12.04	-12.23	-11.90
	Alternative	-12.83	-12.63	-12.80	-12.49
The use of Renewables in electricity generation	Base Model	114.36	116.69	114.79	123.21
	Alternative	149.88	152.29	150.27	158.31

The alternative welfare results differ relatively little from the Base Model results as can be seen in Table 6. However, Table 6 also shows that substituting Coal for Peat in electricity generation leads to a substantially stronger drop in emissions. The use of Peat in electricity generation is reduced much more, as expected, because the substitution for Peat of other inputs is more flexible. Interesting is the fact that Coal is also used a lot less than in the Base Model. This is due to the fact that Coal and Peat have the highest emission factors and the electricity producer has an incentive to substitute solid fuels (which are in a nest together in the production function) for other fuels as well as substituting Coal for Peat. Together, these changes induce a stronger emission reduction. The greater increase in the use of Renewables is due to a greater production level of Electricity. Electricity costs less to produce when possibilities to change the fuel mix are enhanced as in the alternative specification. This stimulates demand and thus supply of Electricity is raised to meet this demand.

7. CONCLUSIONS

Differences in welfare results between the Base Model and the alternative specifications are not so great that the qualitative conclusions are different. The conclusion that a weak Double Dividend is possible if the revenue is used to reduce indirect tax rates also remains unchanged with the alternative specifications.

However, in the specification where implementation of a similar carbon tax policy in all foreign countries is approximated, the recycling scheme where VAT rates are lowered has a far more negative welfare result and the Double Dividend is much less likely. The reason is that, in the Base Model, there is an incentive and a possibility to use imported commodities as a substitute for domestically produced carbon-intensive non-energy[6] commodities, the prices of which increase as an indirect result of the carbon tax. However, when price changes in other countries are the same, as simulated in the alternative specification in Section 5, there is no gain in this substitution, which can be called 'indirect carbon leakage', and domestic supply prices rise more as a result. Lowering the indirect tax rate reduces domestic consumer prices which leads to the weak DD with the Base Model. With the fixed-proportions foreign trade specification, the increase in domestic supply prices partially offsets the decrease in consumer prices due to the lower indirect tax rates of the VAT simulation. The welfare loss resulting from the VAT simulation with the alternative model is therefore much less different from the welfare loss from the lump-sum simulation compared with the difference between the results from these two simulations with the Base Model.

The LES leads to less emissions reduction compared with the specification with the Cobb-Douglas consumption function, due to the fact that substitution between energy commodities for necessary consumption is not possible in the LES. Fixing labour supply has a substantial effect on the results, because it effectively fixes leisure as well. The simulation with labour tax recycling is less unfavourable than in the case of the Base Model because with fixed labour supply this simulation essentially equals the lump-sum simulation. In both cases there is an equal transfer from the government to households. Therefore both simulations lead to the same fall in welfare. However, the conclusion that the preferred revenue recycling scheme is to reduce VAT followed by cuts in output tax rates, is not altered.

If the nesting of labour (*L*), capital (*K*) and composite energy (*E*) is changed so that *L* and *K* are in a nest trading off with *E*, the results are more favourable than in the Base Model, with emissions reduced by more (*e.g.* by 24.92 instead of 24.71 percent in the simulation with lump-sum recycling) and welfare falling by less (*e.g.* in the same simulation by 0.34 instead of 0.35 percent). However, the differences between these results and Base Model results are small compared to differences caused by other alternative model specifications.

If the policy change regarding the use of peat in electricity generation is implemented, in the sense that the input of peat is not subject to a minimum any longer and trades off with coal the same way as in other production processes, emissions drop a lot more (*e.g.* by 27.05 instead of 24.71 percent in simulation 1) and welfare is only relatively weakly negatively affected in simulations 1, 3 and 4 while welfare in the VAT simulation drops by 0.11 as opposed to 0.09 percent.

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APPENDIX A MODEL EQUATIONS

Indices

en	energy commodities	CRUD, COAL, PEAT, OILS, NGAS, ELEC, RNEW
f	agents	HOU, GOV, INV, RoW
i	commodities	1, …, 26 (see Appendix 3.A)
j	industries	1, …, 26 (see Appendix 3.A)

Alias *f*, *ff*

Variables

A_i	Armington supply of commodity *i*
BoPdef	Balance of international payments deficit
CBAS	Necessary share of aggregate household consumption
CD_i	Household demand (necessary+luxury) for commodity *i*
CLUX	Supernumerary share of aggregate household consumption
D_i	Domestic demand for commodity *i*
endtl	Endogenous labour tax multiplier
endty	Endogenous output tax multiplier
endSocSec	Endogenous social security contributions multiplier
endVAT	Endogenous value added tax multiplier
E	Aggregate exports
ED_i	Export demand for commodity *i*
G	Aggregate public good
GD_i	Government demand for commodity *i*
GovSur	Government budget surplus
HouSav	Household savings
I	Aggregate investment
$ID_{i,j}$	Intermediate demand for commodity *i* by industry *j*
IncTax	Income tax other than from labour
$INVD_i$	Investment demand for commodity *i*
K_j	Capital demand industry *j*
L_j	Labour demand industry *j*
LEIS	Leisure demand
LS	Labour supply
lsum	Lump sum tax rebatement multiplier
M_i	Imports of commodity *i*
pc_{BAS}	Weighted average price of basic necessity share of consumption
pc_{LUX}	Weighted average price of luxury share of consumption
pd_i	Price of domestically supplied commodity *i*
pfx	Foreign exchange rate
pk	Capital rental rate
pl	Net wage rate
px_i	Export price commodity *i*
py_i	Price of domestically produced commodity *i*
SD_i	Stock additions of commodity *i*
$te_{en,j}$	Carbon energy tax rate on energy commodity *en* used in industry *j*
$tef_{en,f}$	Carbon energy tax rate on energy commodity *en* consumed by agent *f*

$transfer_{f,ff}$	Lump sum transfers between agents
ur	Unemployment rate
$Welfare$	Total utility for measuring Hicksian equivalent variation
$Y_{j,i}$	Production of commodity *i* by industry *j*

Parameters

$BasShare_i$	Necessary minimum (basic) share of consumption of commodity *i*
$RepRate$	Replacement rate
ssc	Social security contribution rate
sy_j	Output subsidy industry *j*
$texcj_{i,j}$	Excise tax rate industry *j*
$texcf_{i,f}$	Excise tax rate agent *f*
$tfd_{i,f}$	Indirect tax rate on commodity *i* consumed by agent *f*
$tid_{i,j}$	Indirect tax rate on commodity *i* used in industry *j*
$TIME$	Time endowment
tl	Labour tax rate
ty_j	Output tax rate industry *j*
$ur0$	Unemployment rate in the benchmark

Equations

Production functions

$Y_{j,i} = CES(IO_{1,j},\ldots, IO_{26,j}, L_j, K_j) \quad \forall j$

Zero-profit in production

$0 = \Sigma_j \{(1\text{-}endty \cdot ty_j\text{-}sy_j) \cdot \Sigma_i (py_i \cdot Y_{j,i}) - \Sigma_i [(1+endVAT \cdot tid_{i,j}+te_{i,j} +texcj_{i,j}) \cdot pd_i \cdot ID_{i,j}] - (1+tl) \cdot pl \cdot L_j - pk \cdot K_j\} \quad \forall j$

Labour market

$TIME = LS + LEIS$

$\Sigma_j L_j = (1\text{-}ur) \cdot LS$

$ur \geq ur0$

$pl \geq RepRate$

Household

$CLUX = Cobb\text{-}Douglas([1\text{-}BasShare_1] \cdot CD_1,\ldots, [1\text{-}BasShare_{26}] \cdot CD_{26})$

$CBAS = Leontief(BasShare_1 \cdot CD_1,\ldots, BasShare_{26} \cdot CD_{26})$

$Welfare = CES(CLUX, LEIS; \sigma=0.49)$

$pc_{LUX} \cdot CLUX = \Sigma_i \{(1+ endVAT \cdot tfd_{i,HOU}+tef_{i,HOU}+texf_{i,HOU}) \cdot pd_i \cdot [1\text{-}BasShare_i] \cdot CD_i\}$

$pc_{BAS} \cdot CBAS = \Sigma_i \{(1+ endVAT \cdot tfd_{i,HOU}+tef_{i,HOU}+texf_{i,HOU}) \cdot pd_i \cdot BasShare_i \cdot CD_i\}$

$\Sigma_j \{(1\text{-}tl\text{-}ssc) \cdot pl \cdot L_j + pk \cdot K_j\} + lsum \cdot transfer_{GOV,HOU} + \Sigma_{f\,[f \neq GOV]} (transfer_{f,HOU})$
$\quad + (1\text{-}tl\text{-}ssc) \cdot pl \cdot LEIS = Welfare + pcBAS \cdot CBAS + IncTax + HouSav$

Government

$G = Leontief(GD_1,\ldots, GD_{26})$

$IncTax + \Sigma_j \{endty \cdot ty_j \cdot py_j \cdot Y_j + tl \cdot pl \cdot LD_j + \Sigma_{en} (te_{en,j} \cdot pd_i \cdot ID_{en,j})$
$\quad + \Sigma_i [(endVAT \cdot tid_{i,j}+texcj_{i,j}) \cdot pd_i \cdot ID_{i,j}]\}$
$\quad + \Sigma_{en} \{tef_{en,HOU} \cdot pd_{en} \cdot CD_{en}\} + \Sigma_i \{(endVAT \cdot tfd_{i,HOU}+texcf_{i,HOU}) \cdot pd_i \cdot CD_i$
$\quad + endVAT \cdot (tfd_{i,GOV} \cdot GD_i + tfd_{i,INV} \cdot INVD_i) \cdot pd_i$

$+ (endVAT \cdot tfd_{i,RoW} + texcf_{i,RoW}) \cdot px_i \cdot ED_i\} + \Sigma_f (transfer_{f,GOV})$
$= \Sigma_i \{(1 + endVAT \cdot tfd_{GOV}) \cdot pd_i \cdot GD\}_i + \Sigma_{j,i} \{sy_j \cdot py_i \cdot Y_{j,i}\} + \Sigma_f (transfer_{GOV,f}) +$
$GovSur$;
where $en \in i$

G is fixed; determines *lsum, endVAT, endtl* or *endty* when the others are fixed

Rest of the World
$E = Cobb\text{-}Douglas(ED_1, \ldots, ED_{26})$
$\Sigma_i \{pfx \cdot M_i - (1 + endVAT \cdot tfd_{i,RoW} + texcf_{i,RoW}) \cdot px_i \cdot ED_i\} + \Sigma_f \{transfer_{f,RoW}\}$
$= BoPdef$ (fixed); determines *pfx*

Investment
$I = Cobb\text{-}Douglas(INVD_1, \ldots, INVD_{26})$
$\Sigma_i \{(1 + endVAT \cdot tid_{i,j}) \cdot pd_i \cdot INVD_i + \Sigma_i SD_i\} = HouSav + GovSur + BoPdef$
$= \Sigma_f \{transfer_{f,INV}\}$

International trade
$A_i = CES(M_i, \Sigma_j \{Y_{j,i}\}; \sigma=4)$
$A_i = CET(D_i, ED_i; \sigma=4)$

Market clearing
$M_i + \Sigma_j \{Y_{j,i}\} = A_i = D_i + ED_i$
$D_i = \Sigma_j \{ID_{i,j}\} + CD_i + GD_i + INVD_i + SD_i$
$\Sigma_j L_j = (1\text{-}ur) \cdot LS$; determines *pl* and *ur*
$\Sigma_j K_j = KS$ (fixed); determines *pk*

APPENDIX B RELEVANT BENCHMARK DATA

Table B.1. Sectors sorted by emission-intensity and cost shares of VAT, labour and output tax

Sector[1]	Emission intensity[2]	Sector	VAT cost share	Sector	Labour cost share	Sector	Output tax cost share
TRNS	103.4	CHEM	0.013	SVCN	0.63	TRAD	0.021
ELEC	47.2	WOOD	0.010	TRAD	0.38	LDCT	0.019
METL	20.6	ELEC	0.010	LDCT	0.33	MINE	0.019
OMAN	7.8	NGAS	0.010	MINE	0.28	PEAT	0.019
NMIN	6.8	RNEW	0.010	PEAT	0.28	AIRT	0.016
TRAD	4.3	LDCT	0.010	SVCC	0.24	TRNS	0.014
MINE	4.2	FOOD	0.010	TRNS	0.24	TEXT	0.011
AGFF	3.4	TRAD	0.009	RBPL	0.22	NMIN	0.010
PEAT	2.0	RBPL	0.008	NMIN	0.22	ELEC	0.007
OILS	1.6	AIRT	0.008	AIRT	0.21	NGAS	0.007
NGAS	1.6	SVCC	0.007	CONS	0.19	RNEW	0.007
LDCT	1.6	SVCN	0.006	ELEC	0.17	FOOD	0.007
SVCN	1.6	CONS	0.006	RNEW	0.17	SVCC	0.006
SVCC	1.6	MINE	0.005	OILS	0.16	AGFF	0.005
CHEM	1.5	PEAT	0.005	OMAN	0.16	RBPL	0.004
RBPL	1.5	TRNS	0.005	TEXT	0.15	OMAN	0.003
FOOD	1.2	METL	0.004	NGAS	0.15	OILS	0.003
TEXT	0.9	MTPR	0.004	FOOD	0.10	METL	0.003
MTPR	0.1	NMIN	0.004	WOOD	0.09	SVCN	0.001
WOOD	0.1	OMAN	0.003	MTPR	0.09	WOOD	0.001
AIRT	0.0	OILS	0.003	AGFF	0.06	MTPR	0.001
CONS	0.0	TEXT	0.002	CHEM	0.04	CHEM	0.001
RNEW	0.0	AGFF	0.001	METL	0.04	CONS	0.000
Average	3.2	Average	0.007	Average	0.19	Average	0.004

1. Sectors CRUD, COAL and MARG are not listed as these do not have emissions or these production costs.

2. Unit: tonnes of CO_2 per EUR 100 million.