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Iain Fraser and Robert Waschik

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Iain Fraser
University of Kent

Robert Waschik
La Trobe University

Abstract

Employing a CGE model we examine the Double Dividend (DD) hypothesis for Australia and UK. Following Bento and Jacobsen (2007), we analyze specific factors in the production of energy goods and the impact on the DD. By incorporating endogenous labour supply we examine the labour market effect of targeted abatement policies. For Australia the DD is significantly larger with the specific factor characterisation of the economy when recycling revenue through reductions in consumption taxes, but there is no evidence of a DD when employing income tax. We find minimal evidence of a DD for UK for either recycling instrument.

Keywords: Environmental Taxes, Double Dividend, Specific Factors.

JEL Classification: Q52, Q48, C68

Address for Correspondence: Iain Fraser, School of Economics, University of Kent, Canterbury, Kent, CT2 7NP, UK, Phone: +44 (0)1227823513, Email: i.m.fraser@kent.ac.uk

1 Introduction

There continues to be significant interest in the potential form and use of environmental taxes (ie. Fullerton *et al.* 2008) so as to deal with negative environmental externalities, such as climate change. This can partly be attributed to the so called "Double Dividend" (DD) which may emerge when a tax is introduced to reduce a negative environmental externality (Pearce, 1991). The first dividend relates to the anticipated improvement in environmental quality, while the second dividend relates to the potential to use tax revenue raised by environmental taxes to offset or alleviate pre-existing welfare-reducing distortions in the economy. A Strong DD is said to exist if environmental taxes yield an improvement in environmental quality (a positive first dividend) along with an increase in efficiency solely due to the changes in the tax system implied by the imposition of environmental taxes and the concomitant reduction in pre-existing distortionary taxes (a positive second dividend).

To date much of the literature on the DD has focused on identification of situations or conditions under which the second dividend is positive, since this would yield unambiguous welfare gains regardless of the size of the first dividend. The size of the second dividend can be decomposed into the primary costs associated with environmental taxes, as well as two important indirect effects. Environmental taxes will increase the prices of the taxed environmental goods, creating a distortion between these prices and those of other taxed goods, resulting in a *tax interaction* effect. But the revenue raised by environmental taxes can be used to reduce other pre-existing distortionary taxes, resulting in a *revenue recycling* effect. While the primary costs of environmental taxes will result in an efficiency loss, the *revenue recycling* effect will improve efficiency due to the reduction of a pre-existing distortion. Since the *tax interaction* effect may either increase or decrease efficiency, it has become the focus of much of the research effort. A good overview of the theoretical literature on the double dividend is provided by Schoeb (2006).

There is now a considerable empirical literature that has attempted to assess the existence as well as the magnitude of the DD. Some papers offer support for the existence of a DD (Parry and Bento, 2000, Manresa and Sancho, 2005, Bento and Jacobsen, 2007, and Taheripour *et al.* 2008), others provide mixed support (Takeda, 2007) and others no support (Parry *et al.* 1998, Goulder *et al.* 1999, Williams, 2002, and Bovenberg *et al.* 2008). Three important reasons that have emerged to explain these contradictory results are: 1) the role of specific factors, 2) labour supply and the tax interaction effect, and 3) the choice of tax instrument used to recycle the environmental tax revenue.

First, the literature on the DD has paid little attention to the role played by the existence of specific factors of production in affecting the size of the DD. Perroni and Whalley (1998) have shown that the presence of specific factors results in an optimal tax system which is not uniform. When a share of value added in the production of some goods is accounted for by specific factors, it is optimal to charge a higher tax on production of these goods, since the specific factors will bear some incidence of tax. While Parry (2003) casts doubt on the importance of specific factors in relation to carbon taxes, Bento and Jacobsen (2007) demonstrated that the existence of specific factors in production of goods which are the subject of environmental taxes can lead to the existence of a DD which would not be present if account were not taken of the role of specific factors. Our results support those in Bento and Jacobsen, suggesting that the presence of specific factors in energy-producing industries strongly influences the potential for observing a DD.

Second, the importance attached to the tax interaction effect and its impact on the DD can in large part be linked to the change in labour supply which results from the tax policy change being modelled. Goodstein (2003) observes that many of the papers that find no evidence for the existence of the DD arrive at this result because the tax interaction effect dominates the revenue recycling effect. Several authors have argued that this result can in part be traced to the fact that these models assume that labour is the only primary input, and have shown how results are sensitive to specification of the labour supply elasticity.

Results in this paper suggest that the real return to labour increases in all counterfactuals, implying that with a positive labour supply elasticity, labour supply increases in equilibrium. This is in sharp contrast to those papers that highlight the negative impact of the tax interaction effect.It has also been argued by Jaeger (2002) that the contradictory results associated with the tax interaction effect obtain from a specific definition of environmental externalities.

Third, many of the existing papers on the DD have focused on the removal of labour taxes. For example, in Bento and Jacobsen (2007) there is only one pre-existing distortion in the market: a tax on labour. The model presented in this paper uses data derived from the GTAP model, which offers a much richer set of distortions in the initial equilibrium. This is in keeping with several other papers (eg, Babiker *et al.*, 2003, Takeda, 2007, Taheripur *et al.*, 2008). The inclusion of a richer set of distortions highlights how the choice of distortion through which environmental tax revenue is recycled can influence the existence of the DD. Like Babiker *et al.* (2003) and Takeda (2007) our results emphasize the crucial importance of the choice of tax instrument used to recycle revenue raised by environmental taxes in generating a DD.

In this paper we use a Computable General Equilibrium (CGE) model of the Australian and UK economies, with data drawn from version 7 of the GTAP model. We model the effects of carbon abatement policies by introducing taxes on the production of "energy goods" (coal, oil, gas, petroleum and electricity) which reduce production of these goods by up to 15%. Revenue raised by these carbon taxes is used to offset another pre-existing distortion in the CGE model by using an endogenous tax which adjusts to hold government revenue constant, to demonstrate whether such carbon taxes result in a DD. We suppose that natural resources and a share of capital used in the production of these "energy goods" is a specific factor, to show how the DD depends upon the presence of specific factors in production of energy goods. Australia and the UK are modelled as small open economies so that results will not be affected by any changes in terms-of-trade which may arise due to the imposition of environmental taxes. While many other CGE models of carbon taxes use dynamic models, we focus on a static model to get a clear idea of what is driving the DD results and to be able to clearly link our results to the existing theoretical literature on the DD.

This paper makes several important contributions to the literature. First, we find that when revenue is recycled through a reduction in consumption taxes, a strong DD results from environmental taxes which reduce production of "energy goods" by 12-13% in Australia, while virtually no DD exists for any level of abatement in the UK. Moreover, by employing a novel approach to modelling specific factors, our results demonstrate that there are significant differences in terms of the magnitude of the DD in the short-run versus the long-run. Specifically, evaluated at the optimal level of abatement in Australia, the DD is about twice as large in the short-run compared to the long-run. But when income taxes are reduced to recycle revenue, the DD disappears completely.

Second, by incorporating endogenous labour supply into the CGE model, we identify the role of flexibility of the labour market in affecting the size of the DD. We also observe how our specific factors characterisation of the economy impacts the return to labour. Our results in relation to labour supply provide empirical evidence for the important impact that the neo-classical ambiguity can have.

Third, we find that the choice of revenue recycling instrument does impact the existence of the DD. Specifically, we only find evidence for the DD when we employ a consumption tax. We find no evidence for either country when we employ income tax.

This result holds irrespective of the degree of specific factors we assume in our model. Our finding demonstrates that although specific factors can be important in relation to the existence and magnitude of a DD, their inclusion does not *a priori* imply that a DD will occur.

Finally, we argue that our focus on the role of specific factors in the production of energy goods which are subject to carbon taxes allows us to address the issue of compensation of energy industries which will be adversely affected by such abatement taxes. In particular, results from our CGE model include changes in returns to the natural resources and capital assets which are specific to production of energy goods. These changes in factor returns can be used by policymakers to inform debates over the extent to which energy producers should be compensated due to the imposition of policies designed to achieve given carbon abatement targets.

The paper is structured as follows. In Section 2 we provide an overview of the literatures relevant to the development of our CGE model of environmental taxes. In Section 3 we provide details of the data and model used to conduct our analysis. Results are presented in Section 4 and are composed of several counterfactuals to examine the key issues identified. Finally, in Section 5 we conclude.

2 Literature Review

2.1 The Double Dividend

A large literature has used two-good theoretical general equilibrium models to examine the DD hypothesis. An economy is assumed to produce a clean good $Y = Y(L_y)$ and a dirty good $X = X(L_x, Z)$, where L_i is labour which is perfectly mobile between production sectors, and Z is a factor specific to production of the dirty good X. Production technology is assumed to exhibit constant returns to scale, but with a fixed factor Z in production of the dirty good X, there are decreasing returns to scale in labour L_x used to produce X. These models frequently abstract from abatement technologies, and treat emissions E as being proportional to production of the dirty good X. A representative consumer owns an endowment of labour $\bar{L}$ and the fixed factor Z, and derives utility from consumption of X, Y, leisure $l = \bar{L} - L_x - L_y$, and disutility from emissions E according to a separable utility function:

$$U = U(X, Y, l) - \phi(E)$$

Initially governments tax labour at rate t_L, and provide a lump-sum transfer G to the representative consumer. The DD can arise when governments tax emissions at rate

t_E and simultaneously reduce the distortionary tax on labour t_L to hold constant the lump-sum government transfer to the representative consumer, because such a change will have a number of both positive and negative efficiency effects in general equilibrium.

Studies usually proceed by supposing that the representative consumer maximizes utility subject to the budget constraint:

$$p_x \cdot X + Y \quad = \quad (w - t_L) \cdot (L_x + L_y) + p_z \cdot Z + G$$

where p_x, w and p_z represent the prices of good X, leisure and the specific factor with respect to the numeraire price of good Y, yielding the indirect utility function (1):

$$V \quad = \quad V(p_x, w, p_z) - \phi(E), \tag{1}$$

In the simple case where there are no specific factors, $Z = 0$, the efficiency effects of a change in the environmental tax t_E are found by differentiating the indirect utility function (1) with respect to the environmental tax t_E:

$$\frac{1}{\lambda}\frac{dV}{dt_E} \quad = \quad \underbrace{\left(\frac{\phi'}{\lambda} - \frac{dp_X}{dt_E}\right)\left(-\frac{dX}{dt_E}\right)}_{W^P} + \underbrace{t_L\left(\frac{\partial L}{\partial p_X}\frac{dp_X}{dt_E}\right)}_{W^{TI}} + \underbrace{t_L\left(\frac{\partial L}{\partial t_L}\frac{dt_L}{dt_E}\right)}_{W^{RR}}, \tag{2}$$

where λ is the marginal utility of income and ϕ'/λ is the marginal external cost of pollution. This derivation of the efficiency effects of a change in the environmental tax t_E follows Bento and Jacobsen (2007:19–20).

Equation (2) breaks the efficiency effects of an environmental tax change dt_E into three separate effects:

- *Pigouvian welfare effect (W^P):* The efficiency gain associated with the decrease in consumption of the dirty good X multiplied by the difference between the marginal external cost of pollution and the change in the price of the dirty good dp_X
- *tax interaction effect (W^{TI}):* Environmental policies increase the price of polluting goods relative to leisure, creating (compounding) factor market distortions
- *revenue recycling effect (W^{RR}):* When revenue from environmental taxes is recycled through cuts in (other) marginal tax rates, this reduces the distortion caused by pre-existing taxes, improving welfare

Studies which use this approach to examine the issue of the DD (for example, Williams (2002) and Bovenberg *et al.* (2008)) typically find that the (negative) *tax interaction* effect dominates the (positive) *revenue recycling* effect, and as such there is no DD from environmental tax reform.

2.2 Specific Factors

Bento and Jacobsen (2007) challenge the impact and power of the *tax interaction* and the *revenue recycling* effects by including a sector-specific factor in their model. With $Z > 0$, two further effects complicate interpretation of equation (2):

- *Ricardian rent effect* ($Z \cdot \frac{dp_Z}{dt_E}$)*:* There is a loss in real income due to the reduction in Ricardian rents earned from ownership of the specific factor Z
- *surrogate tax effect* ($t_L \frac{\partial L}{\partial p_Z} \frac{dp_Z}{dt_E}$)*:* The environment tax reduces the representative consumer's income from the specific factor, which has a positive income effect on labour supply.

Bento and Jacobsen (2007) show that the presence of these additional effects due to the existence of a specific factor in the production of the dirty good weakens the *tax interaction* effect, and that the *Ricardian rent* and *surrogate tax* effects work in the same direction as the *revenue recycling* effect, increasing the optimal pollution tax. This is in keeping with results in Perroni and Whalley (1998), who observe that with no Ricardian rents the optimal tax structure is uniform. However, with fixed factors, taxes are partially borne by the specific factor and not fully passed on to consumers, resulting in higher optimal tax rates in sectors with more specific factors.

To illustrate this result Bento and Jacobsen (2007) calibrate their simple two-sector general equilibrium model where the dirty good represents 2.7% of GDP, consistent with the size of the US electricity sector. The share of the sector-specific factor in the value of supply of the dirty good is set at 25%, based on the value of fossil fuel use in US electricity generation. Their model is calibrated to uncompensated and compensated labour supply elasticities of 0.15 and 0.40, and a labour tax rate of $t_L = 0.40$. They then simulate the effects of an emissions tax which causes a reduction in production of the dirty good of 0-50%, with revenue raised by the emissions tax offset by reductions in the labour tax. They find that for their central parameter case, a strong DD exists for emissions reductions up to 12%. Repeating their experiment after reducing the share of the sector-specific factor to zero, they find that the DD disappears, confirming the importance of specific factors in affecting the relative size of the *tax interaction* and *revenue recycling* effects, and ultimately the existence of a DD.

We extend the analysis of Bento and Jacobsen (2007) by using specific factors to contrast the short-run and long-run comparative static results in our CGE model. Static CGE models normally compare short-run and long-run counterfactual responses by varying the Armington elasticity which measures the degree of substitutability between domestic and imported goods. However, we consider it more appropriate to contrast short-run and long-run behaviour by assuming that some share of primary factors of production is specific in the short-run, then allowing those specific factors to become perfectly mobile between sectors in the long-run. This approach to modelling differences between the short-run and the long-run using specific factors follows that adopted in Fraser and Waschik (2005), where a particular share of primary factors labour and capital is assumed to be specific in the short-run. This share is then reduced to zero to simulate a long-run response.

While the role of specific factors has been shown to be important in evaluating the effects of emissions taxes, there are other reasons to motivate careful attention to the modelling of specific factors. Edwards and Whalley (2007) observe that there are likely to be significant differences between the long-run and short-run behaviours in terms of the way in which wage inequality operates. In a world in which some factors are fixed (short-run) labour market responses need to be seen as being less than completely adjusted which is the situation that would be achieved in the long-run. They assume that some factors are not only immobile but that they incur adjustment costs from moving between sectors, due to search costs, transportation or removal costs, transaction costs, location preference and psychological costs. Edwards and Whalley (2007) show that the percentage of value added that is attributed to a fixed factor only needs to amount to 2-5% to be important in terms of changing key results.

2.3 Pre-existing Distortions and the DD

In papers on the DD such as Williams (2002), Bovenberg *et al.* (2008) and Bento and Jacobsen (2007), the only source of government revenue is a tax on labour. Of course, governments commonly have a number of tax instruments through which revenue generated by emissions taxes can be recycled. The existence and size of any DD has been shown to depend on which instrument is chosen to recycle emissions tax revenue. For example, Babiker *et al.* (2003) use a recursive dynamic multi-regional CGE model of the world economy to examine whether a DD arises from emissions taxes in a number of different European economies. They conclude that results for the double dividend differ between the countries examined: If a country has high pre-existing energy taxes, then the likelihood of a DD is reduced. Placing a tax on top of an already heavily taxed input and then redistributing the revenue to reduce other non-energy taxes only worsens the relative distortions between energy and other consumption goods.

Takeda (2007) uses a multisector dynamic CGE model of the Japanese economy to examine the DD when revenue can be recycled through reductions in any of a number of pre-existing distorting taxes. Takeda examines how revenue from a carbon tax can be used to reduce pre-existing distortionary taxes on labour, consumption and capital. Results show that the largest DD is generated when revenue is recycled through reductions in the capital tax.

These studies suggest that the way in which the revenue recycling experiment is conducted is important to the existence of a DD when a number of pre-existing distortions exist in an economy. Researchers need to be careful extrapolating from one country to another where different types and magnitudes of tax distortions may yield very different DD implications.

2.4 Labour Supply

As has already been noted, the labour supply response in the models presented in the literature is fundamental to the relative size of the tax interaction and revenue recycling effects. In a meta-analysis of the literature, Patuelli *et al.* (2005) observe that the structure of the labour market has a considerable impact on the results derived. Parry (2003) notes that there is considerable uncertainty over the size of the labour supply elasticity, arguing that it could lie between between 0.1 and 0.5. On the other hand, Goodstein (2003) argues that labour supply at the household may be backward bending.

There are a number of different ways in which labour supply has been modelled in the literature. The most common approach is to calibrate the CGE to a specific value of the labour supply elasticity or the elasticity of substitution between consumption and leisure. Bento and Jacobsen (2007) and Taheripour *et al.* (2008) follow Goulder *et al.* (1999) and employ an uncompensated labour supply elasticity equal to 0.15. Other papers employ different values. For example, Takeda (2007) employs a value of 0.19, noting that estimates in the literature are as low as 0.018. Babiker *et al.* (2003) calibrate their model to a labour supply elasticity of 0.25.

It is also common to conduct sensitivity analysis in relation to the labour supply elasticity. For example, Taheripour *et al.* conducted sensitivity analysis of this elasticity by reducing it by 25% (from 0.15 to 0.11). They observe that this change reduces the excess burden associated with the existing labour tax. Takeda (2007) conducted sensitivity analysis for values ranging from 0 to 0.4 and concluded that all results are robust. Babiker *et al.* (2003) consider a slightly wider range of values of 0.5 and 1. They observe a change in the results generated under the much higher elasticity but are at pains to point out that an elasticity of this magnitude is outside the range typically reported in the literature and as such these results can be dismissed as unrealistic. Manresa and Sancho (2005) examine two extreme forms of labour supply (ie, perfectly inelastic and perfectly elastic), and suggest that flexibility in labour supply is an important feature of an economy if it is to achieve a DD due to the introduction of environmental taxes.

Finally, while results in this literature are certainly sensitive to specification of the elasticity of supply of labour, the important role played by specific factors of production in the industries in which environmental taxes are being applied calls attention to the effect of environmental taxes on the real return to labour. In a general equilibrium model with specific factors of production, the *neoclassical ambiguity* implies that policies which change relative output prices will have an ambiguous effect on the real return to a mobile factor. Since labour is modelled as a mobile factor of production, we cannot be sure *a priori* whether environmental taxes will cause the real return to labour to rise or fall.

3 Data and Model

3.1 Data

To illustrate the role of specific factors and endogenous factor supply in affecting the DD arising from a carbon abatement policy, we adapt the GTAP-EG model model of Rutherford and Paltsev (2000) and the GTAP-E model described in Burnieaux and Truong (2002). The starting point for this model is an aggregated version of the GTAP7 dataset, described in Hertel (1997). The GTAP7 dataset depicts a global general equilibrium of production, consumption, and trade for 113 regions and 57 commodities produced using five primary factors of production and intermediate inputs for the year 2004. To keep the model as simple as possible and make results easier to interpret, we extract from the GTAP7 dataset an equilibrium for two countries which we model as small open economies facing fixed world prices for traded commodities. For both we aggregate the commodity side of the model from the 57 GTAP7 commodities to 20, maintaining as much disaggregation as possible for the five so-called "energy sectors" coal (coa), oil (oil), gas (gas), petroleum (p_c) and electricity (ely). A summary of aggregated data in shown in Table 1.

[Approximate Position of Table 1]

3.2 Representative Consumer

In the GTAP dataset, the primary factors of production are Land, Labour, Capital, and Natural Resources. We have also aggregated the primary inputs 'unskilled labour' and 'skilled labour' together into a single primary factor 'labour'.In any single region or country, a representative consumer is assumed to own a fixed endowment of all primary factors of production. All of the endowment of Land, Capital, and Natural Resources are supplied to the production sector, while labour is either supplied to the production sector or consumed as leisure, so the model is calibrated to a positive elasticity of supply of labour.

The consumer maximizes utility subject to an income constraint according to a two-stage budgeting process, illustrated in Figure 1. In the upper-most stage, the consumer substitutes between an aggregate consumption good and leisure, while in the lower stage, the aggregate consumption good is a Cobb-Douglas function of the 19 consumption goods. Note, as we are constructing a static model, we suppose that demand for the final good "investment" (cgd) is exogenous. The upper-level utility function is a CES aggregate of leisure and the aggregate consumption good, where the CES substitution elasticity σ_l is specified so as to calibrate the model to a leisure demand elasticity which is consistent with a labour supply elasticity of $\eta_{ls} = 0.15$ and a ratio of labour endowment to labour supply $\zeta = 1.75$. This is consistent with an initial equilibrium where the representative consumer works 40 hours out of a maximum 70 hour work week. See Ballard *et al.* (1985:127) on using the CES leisure demand elasticity σ_l and the endowment-to-labour-supply ratio ζ to calibrate a CGE model to an initial labour supply elasticity.

Since the labour supply elasticity will be important in affecting the size of the *tax interaction effect*, we later conduct sensitivity analysis around the central case value of the labour supply elasticity $\eta_{ls} = 0.15$, re-calibrating the model to a value $\eta_{ls}^{low} = 0.075$ and $\eta_{ls}^{high} = 0.30$.

[Approximate Position of Figure 1]

3.3 Production

The production side of the economy is modelled using a series of nested CES production functions so as to be consistent with the treatment of production in the GTAP-EG and GTAP-E models. All goods are produced using the 14 non-energy inputs and an aggregate energy good using fixed coefficients (Leontief) production technology, as shown in the upper-most nest of Figure 2.

[Approximate Position of Figure 2]

The aggregate energy input is "produced" as a CES aggregate of energy and value-added, as shown in the second-highest nest in Figure 2. As is common in such CGE models, value-added is modelled as a CES aggregate of primary factors of production, where the CES substitution elasticity between primary factors is taken from the GTAP7 dataset, shown in Table 2.

[Approximate Position of Table 2]

The nature of the counterfactual simulations in which we are interested necessitates a more complicated treatment of the use of energy inputs from that in a more common CGE model. Following Rutherford and Paltsev (2000), beginning in the bottom-most nest of Figure 2, we allow producers to substitute between liquid fuels (gas and petroleum) at a substitution elasticity $\sigma_{lqd} = 2$. This CES aggregate of liquid fuels can then be combined with coal in the next-higher nest at a substitution elasticity $\sigma_{nel} = 0.5$. Ultimately, an aggregate energy input is produced in the next-higher nest by combining the CES aggregate of coal and liquid fuels with electricity at a substitution elasticity $\sigma_e = 0.1$. This aggregate energy input is then combined with value-added at a substitution elasticity $\sigma_{vae} = 0.5$ to produce the energy which is ultimately combined with other non-energy inputs in the fixed-coefficients upper-level production function. This technology for usage of energy inputs is adopted for all production sectors except the three primary energy sectors coal, oil, and gas, for which all substitution elasticities in Figure 2 are equal to zero ($\sigma_{lqd} = \sigma_{nel} = \sigma_e = \sigma_{vae} = 0$). The CES substitution elasticities for all production sectors at all levels of input usage are summarized in Table 2. Note, virtually all of the primary energy input "oil" is used as an input into production of petroleum. Note that "oil" does not enter the production process through the energy nests in Figure 2, but rather is used in fixed coefficients in the top-most nest, reflecting the fact that it cannot be substituted in the production of petroleum.

3.4 Specific and Mobile Factors

The discussion in Section 2 has shown how the literature on the DD has identified the important role played by the existence of Ricardian rents earned by specific factors in energy industries. In the GTAP7 dataset, Land is a specific factor in the production of primary agricultural commodities (Crops and Animal Products), and Natural Resources are specific to production of Forestry-and-Fishing, Minerals, and the three primary energy industries: Coal, Oil and Gas. In contrast, we assume that Labour is always perfectly mobile between production sectors.

The importance of primary factors in the production of energy goods is evident from Table 3, which reports primary factor shares for the five energy sectors along with the average factor shares for the whole economy for Australia and the UK.

[**Approximate Position of Table 3**]

The aggregation and concordance to GTAP7 commodities is given in Table 1. For the three primary energy sectors Coal, Oil and Gas, the primary input Natural Resources makes up about one-third of value-added (one-half of value-added in the Coal sector in the UK) and one-quarter of the value of production.

In Australia the five energy goods represent 4.1% of the value of production in the whole economy, and use 4.4% of value added. In the UK, the five energy goods represent 2.3% of the value of production, and use 2.8% of value added. Bento and Jacobsen (2007:24) simulate electricity production in the US using a central case value of 2.7% for the value of the electricity sector as a share of the whole economy, and supposing that the specific factor in electricity generation accounts for 25% of the value of production.

The five energy sectors are also the most capital-intensive in the economy. While the average endowment of capital-to-labour is about 2/3 in both Australia and the UK, the usage of capital-to-labour is about three in the five energy sectors in Australia, and over 10 in the oil and gas sectors in the UK. Also from the lower part of Table 3 we observe that the share of usage of primary factors in the petroleum sector is very small. About 85% of the value of production in this sector is accounted for by the usage of oil and petroleum.

While it is most common to model all capital in such CGE models as being perfectly mobile, much of the capital used in production of these energy commodities may be specific to production of that particular energy commodity, particularly in the short-run. To reflect this fact, we alternately assume that 50%, 25% and 0% (hereafter referred to as Case A, Case B and Case C, respectively) of capital is a specific factor in production and is not mobile between production sectors.

Output supply elasticities for the three primary energy sectors Coal, Oil and Gas are reported in Table 4.[1]

[Approximate Position of Table 4]

In general the output supply elasticity more than doubles from the short-run Case A where 50% of capital is assumed to be specific to the long-run Case C where all capital is assumed to be perfectly mobile. This important role played by specific factors is evident from the output supply elasticities in the coal industry. In the long-run when all capital is perfectly mobile (Case C), the output supply elasticity in the coal industry is almost identical in Australia and the UK. But in the short-run when half of the capital used to produce coal is assumed to be a specific factor (Case A), the output supply elasticity in the UK is double that in Australia. As is evident from Table 3, capital accounts for a much larger share of the value of coal production in Australia than in the UK, so assuming that half of the capital used in coal production is specific has a much larger effect on the output supply elasticity in Australia.

3.5 Trade

Following Armington (1969), trade is incorporated into the model by treating domestic and imported varieties of the same good as differentiated products by domestic users of those goods: Firms using goods as intermediate inputs, the representative consumer, and the government. This is reflected by assuming that goods used in the domestic economy are CES aggregates of domestically produced goods and their imported counterparts, where the CES substitution elasticity σ_{arm} reflects the extent to which imported goods are substitutable for the domestic variety. As $\sigma_{arm} \to \infty$, goods become homogeneous or perfect substitutes. The elasticity of demand for imports is approximately equal to the substitution elasticity between domestic and imported varieties of the same good. These substitution elasticities are based upon those in the GTAP7 dataset and are reported in Table 4.[2] In equilibrium, trade must be balanced, and we assume that capital flows are fixed at their benchmark level so the current account balance is fixed.

4 Counterfactual Simulations and Results

To examine the potential for a DD arising from the introduction of environmental taxes in our CGE model, we suppose that emissions which arise from the production of the five energy goods in the GTAP7 dataset produce a negative externality, so that a decrease in emissions will produce a positive "first dividend". As is common in the literature on the DD hypothesis, we assume that emissions are proportional to production of energy goods, so a given reduction in emissions can be achieved by the same reduction in production of energy goods. To this end, we simulate the effects of emissions abatement of 0-15% by introducing into the CGE model an endogenous tax on production of energy goods which adjusts so as to reduce production of the five energy goods by 0-15%.

To ensure that our model captures the important *revenue recycling* effect of such environmental taxes, we suppose that the tax revenue raised by these endogenous production taxes is offset by a reduction in some other pre-existing tax instrument in the GTAP7 dataset, such that total government revenue remains unchanged.

There are a number of tax distortions in the GTAP7 dataset, and the size and sign of the *revenue recycling* effect will depend upon which pre-existing tax is adjusted to offset the revenue generated from the environmental taxes. In the simulations which follow, in Section 4.1 we suppose that the government holds its revenue constant by reducing domestic consumption taxes, and then in Section 4.2 we suppose that the government holds its revenue constant by reducing the domestic income tax.[3] In each case we highlight the role of specific factors by reporting results for different assumptions regarding the share of capital which is specific to production in each sector, changing the share of specific capital from 50% to 25% to 0%.

4.1 Revenue Recycling through Consumption Tax

In this section all the results reported are derived using central case values of all elasticities from Table 4 and a labour supply elasticity of 0.15. In addition, all welfare changes are Hicksian equivalent variations. The welfare effects due to the introduction of production taxes to achieve emissions abatement of 0-15% are reported in Figure 3 for different assumptions regarding the share of capital which is presumed to be specific.

[Approximate Position of Figure 3]

Welfare changes for abatement taxes in Australia (the upper panel of Figure 3 show that a strong DD exists for levels of abatement up to 12-13% relative to benchmark levels of production, with an "optimal" level of abatement of 5-6%. These results are comparable in magnitude to those reported by Bento and Jacobsen (2007). On the other hand, the lower panel of Figure 3 shows that there is virtually no strong DD at any level of abatement for the UK. Specifically, we find that the largest welfare gain in the UK is 0.000285% of benchmark welfare when 50% of capital is specific at a level of abatement of 0.3%.

As expected, Figure 3 indicates that the DD is stronger when the share of the specific factor (ie, capital) is larger, particularly in Australia. For example, in Australia, at a 5% level of abatement, the welfare gain increases from 0.055% to 0.076% to 0.100% of benchmark welfare as the share of specific capital rises from 0% to 25% to 50%. With a higher share of specific capital, the output supply elasticity is smaller, so a higher production tax is required to achieve a given level of abatement. The higher production tax raises more revenue, allowing a greater reduction in the consumption tax, implying a larger *revenue recycling* effect. When the share of specific capital is 0%, revenue recycling implies a reduction in the consumption tax by 25.8%. As the share of specific capital rises to 25% and 50%, this reduction in the consumption tax increases to 32.2% and 40.8%, respectively.

By comparison, the corresponding reductions in the consumption tax in the UK at a 5% level of abatement are 4.7%, 6.0% and 7.8%, respectively. Compared to Australia, the energy sectors in the UK represent a much smaller share of total production, so the taxes which reduce production of the energy goods raise comparatively less revenue. When all capital in the UK is perfectly mobile (Case C) or when 25% of capital is assumed to be specific (Case B), no strong DD exists in the UK. Existing studies (for example, Babiker *et al* (2003)) found that no DD exists for the UK. However, our results show that when the share of specific capital is sufficiently large a strong DD exists for the UK, albeit only up to a level of abatement of 0.9%.

To understand the source of the strong DD and why the *revenue recycling* effect is so much stronger in Australia than in the UK, we report the marginal excess burden (MEB) of the two taxes which are changing in the counterfactuals represented in Figure 3. Table 5 shows that the MEB of the private consumption tax in Australia is about 21%, much higher than that in the UK where it is about 1%. As a result, revenue earned from production taxes on energy goods allows for the reduction of a more distortionary tax in Australia, resulting in a larger *revenue recycling* effect and a stronger DD. It is also worth noting the MEB of taxes on the production of energy goods is negative.

[**Approximate Position of Table 5**]

As noted in Bento and Jacobsen (2007), a higher share of specific factors results in a greater share of the emissions tax being borne by specific factors, with less of the emissions tax being passed along to consumers. We have calculated this effect for both countries and some results are presented in Table 6.

[Approximate Position of Table 6]

Our results list the equilibrium production taxes required to achieve a 10% level of abatement and the ensuing change in domestic prices for the five energy goods. First, for the three primary energy goods (coal, oil and gas), the production tax needed to achieve a 10% level of abatement is about twice as high in Case A when 50% of capital is specific, compared to Case C when all capital is perfectly mobile.[4] But though the production taxes for the primary energy goods reach 30-40% when 50% of capital is specific, the domestic price never rises by more than 4%. Recall that we are treating Australia and the UK as small open economies facing fixed world prices, so the extent to which the domestic price of primary energy goods can adjust in equilibrium is very constrained.[5] The exception is the gas industry in Australia, which sees more of the production tax passed on to firms and consumers in the form of higher prices. Australia does not import any gas in the initial equilibrium, so the domestic price of gas can rise due to the imposition of emissions taxes.

This story is different for the two processed energy goods petroleum and electricity, where the increase in the domestic price is greater than the production tax needed to achieve a level of abatement of 10%. Capital never accounts for more than 5% of the value of production of petroleum, so the emissions tax and the domestic price are virtually independent of the share of specific capital. Likewise in the electricity sector, the emissions tax and the domestic price are only slightly higher in Case A than in Case C. But for both petroleum and electricity, the increase in the domestic price is larger than the production tax. Electricity is a non-traded good, so much more of this tax is passed along to consumers in the form of higher electricity prices. So to achieve a 10% level of abatement, electricity prices rise by 21-23% in Australia and 16-17% in the UK.

Endogenous Labour Supply

The role played by endogenous labour supply in the emissions tax simulations and the magnitude of the DD is illustrated in Figure 4.

[Approximate Position of Figure 4]

The upper panel shows that in Australia, the magnitude of the DD increases with the labour supply elasticity, since with a greater labour supply elasticity, the representative consumer can adjust more readily to changes in the relative price of labour. For example, at the optimal level of abatement, under Case A when 50% of capital is specific, welfare in Australia rises by 0.094%, 0.100% and 0.111% as the labour supply elasticity rises from 0.075 to 0.15 to 0.30, respectively.

In general, the effect of the abatement taxes on the real return to the mobile factors in the model may be positive or negative, an application of the *neoclassical ambiguity* in a general equilibrium model with specific factors (see Melvin and Waschik (2002) and the references therein). As noted in Bento and Jacobsen (2007:20), there will be a welfare gain (loss) arising from the labour market if the general equilibrium effect of the abatement policy is to increase (decrease) labour supply. While the neoclassical ambiguity suggests that the abatement policy will not necessarily result in an increase in the real return to a mobile factor like labour, we find that the real return to labour increases in all simulations, resulting in an increase in the supply of labour in equilibrium. This effect is more pronouced the higher is the labour supply elasticity, increasing the magnitude of the DD. For example, at a level of abatement of 10%, in the short-run under Case A when 50% of capital is specific, the equilibrium supply of labour increases by 0.40%, 0.47% and 0.60% when the labour supply elasticity is 0.075, 0.15 and 0.30, respectively.

Results for the UK are consistent with those for Australia, in that higher values of the labour supply elasticity yield welfare changes which are more positive or less negative. In particular, for the short-run Case A where 50% of capital is specific, as the labour supply elasticity rises from 0.075 to 0.15 to 0.3, welfare at the optimal level of abatement rises by 0.000028%, 0.000285% and 0.001641% respectively, and a strong DD exists for levels of abatement up to 0.2%, 0.8% and 2.0%, respectively.[6] And as was the case for Australia, the real return to labour and the supply of labour both increase as the level of abatement increases. For example, at a level of abatement of 10%, labour supply rises by 0.20%, 0.22% and 0.27% for values of the labour supply elasticity of 0.075, 0.15 and 0.30, respectively.

Returns to Specific Factors

Finally, we turn to the effect of the emissions taxes on the returns to specific factors. Table 7 shows the percentage change in the return to specific factors in the three primary energy industries where natural resources and capital are specific factors, and in the processed energy sectors petroleum and electricity where only capital is a specific factor. In Case C all capital is perfectly mobile, so natural resources in the coal, oil and gas industries are the only specific factors in the five energy industries.

[Approximate Position of Table 7]

As was shown in Table 6, in the three primary energy industries coal, oil and gas, a very large production tax is needed to achieve a given level of abatement, but only a small share of this tax is passed on to the consumer, implying a large decrease in the producer price of the primary energy goods. With specific factors, the *magnification effect*[7] implies that the decrease in the real return to specific factors will be greater than the decrease in the producer price, so we would expect to see large decreases in the real return to specific factors in the primary energy industries. The returns to specific factors in the primary energy industries coal, oil and gas fall dramatically, by 50-67% depending upon the share of capital which is specific to production. In Case C when capital is everywhere perfectly mobile, the return to specific factors falls by just over 50%. But in Case A, the larger share of specific factors requires a much larger emissions tax to achieve a given level of abatement, and more of this tax is borne by the specific factors, resulting in a decrease in the return to natural resources in the primary energy industries of about 67%. While a higher share of specific factors results in a larger DD, the cost of the abatement policy falls much more heavily on the specific factors in the energy industries.

The results presented in Table 7 can also be used to generate a crude estimate of the level of compensation which could be offered to owners of specific factors in primary and intermediate energy sectors. One example of the need for such results to guide policy-makers is evident from the recent attempt in Australia to pass an Emissions Trading Scheme (ETS). While legislation to pass the ETS was ultimately defeated in 2009, debate around the time that this legislation was being considered also included discussion of the degree of compensation to be awarded to energy industries. In November 2009, the Australian Federal government increased compensation offered to electricity generators under the proposed ETS by \$3.7 billion to \$6.8 billion, and doubled assistance offered to coal producers to \$1.4 billion.[8] Results in Table 7 suggest that in the long run when all capital is perfectly mobile, to achieve an abatement target of 10%, the real return to natural resources in the coal sector in Australia is expected to fall by just over 50%, representing almost \$1.5 billion of the initial \$2.883 billion used in production of coal in the 2004 equilibrium. Of course, this figure is dramatically larger in the short-run where 50% of capital is specific in coal production. In this case, the real return to the specific factors coal and natural resources falls by almost two-thirds, representing about \$3.2 billion of the initial \$4.8 billion which these specific factors represent in production of coal in the 2004 equilibrium. In the electricity generating industry, if 50% of the \$6.252 billion of capital used in the initial 2004 equilibrium is specific in the short-run, Table 7 suggests that a tax to reduce electricity output by 10% would result in a decrease in the real return to specific capital in the electricity industry of 10.2% or about \$0.319 billion. The differences in these estimates present us with an interesting question regarding calculation of compensation payments. Should we base our estimates at the point at which the tax change occurs or should we employ an estimate assuming a longer run perspective? Clearly the choice of counterfactual matters.

4.2 Revenue Recycling through Income Tax

We now repeat the emissions abatement experiments, this time using income tax as the revenue recycling instrument. In this case we now assume that any revenue raised through production taxes on energy goods will be offset by reductions in the income tax rate so that total government revenue remains constant.

Results of these simulations for Australia are presented in Figure 5. We also generated for the UK with revenue recycling through income taxes, but as we could find no DD we do not present these results.

[Approximate Position of Figure 5]

As is obvious from Figure 5, irrespective of the share of capital which is assumed to be specific to production, welfare falls for all levels of abatement. Therefore, there is no level of abatement for which a DD exists when revenue is recycled through the income tax.

As we have already demonstrated, when revenue was recycled through reductions in the consumption tax, the emissions taxes were accompanied by a reduction in a distortionary consumption tax. But when revenue is recycled through the income tax, emissions taxes are accompanied by a reduction in a tax instrument which is less distortionary. To raise a given amount of revenue, it is best for the government to tax income and not distort relative prices.[9] This is because when recycling revenue through the income tax, the government is replacing revenue raised through a less distortionary tax (the income tax) with revenue raised through a more distortionary tax (the emissions tax). This result shows that the existence and size of any DD depends crucially upon the way that the tax system is adjusted to accommodate increased revenue from any emissions taxes. These results support those previously reported in the literature by Babiker *et al.* (2003) and Takeda (2007).

On the other hand, the size of the production tax needed to achieve a given level of abatement is roughly the same when revenue is recycled through the income tax or the consumption tax. Since we are still using the same tax to reduce emissions, the production tax and the change in the domestic price of the five energy goods are virtually the same when revenue is recycled through a reduction in the income tax, compared to results reported in Table 6.[10]

4.3 Leakage

An important issue which has been ignored in this study is the potential for *leakage* to dilute the effectiveness of environmental taxes. For example, if the 10% decrease in production of energy goods is met by an increase in imports of energy goods from abroad, then the reduction in emissions due to the environmental taxes prescribed by our simulation will be less than 10%. Likewise a 10% decrease in production of energy goods can be accompanied by a large decrease in exports of energy goods, so that domestic usage of energy goods falls by less than 10%.

To make the scope of the role played by leakage more clear, we highlight the effects of environmental taxes on trade in gas and petroleum in Australia.[11] When production taxes are levied so as to reduce domestic production of all energy goods by 10%, Australian imports of petroleum increase by 12.9%, and exports of petroleum fall by 26.3%, with the result that domestic usage of petroleum only falls by 6.2%. While environmental taxes cause production of gas to fall by 10%, Australian gas exports fall by 17.5%, so that domestic usage of gas only falls by 3.6%.

At this point it is worth noting that the potential leakage that might occur as a result of a country independently imposing a carbon tax estimated within a CGE model (see Jacoby *et al.*, 1997 and Babiker, 2005) may be overstated. For example, Di Maria and van der Werf (2008) argue that many models do not capture the effects of induced technological innovation, leading to an over-estimation of carbon leakage. Alternatively, Barket *et al.* (2007) employ a large scale multisectoral integrated energy-environment model for 27 European countries and report estimates of leakage that are far smaller than many others reported in the literature. Indeed, they not only observe small amounts of leakage, but in some cases report negative leakage which has resulted from technological spillovers. The importance of technology spillover has also been identified by Gerlagh and Kuik (2007). Using a modified CGE model that includes endogenous energy-saving technology as well as international technology spillovers, they report small and at times negative carbon leakage.

However, if leakage is in fact a serious problem one way to address this leakage through trade is to apply *border tax adjustments* (BTA's) to hold the level of imports constant while simultaneously reducing domestic production of energy goods. For example, if we run the same simulation experiments to reduce domestic production of energy goods by 10% while at the same time increasing the Australian tariff on imports of petroleum to hold petroleum imports constant at their benchmark level, then carbon leakage through imports in the petroleum sector would be reduced.[12] This would necessitate an increase in the tariff on petroleum imports from 0% in the GTAP7 dataset to 11.7%.

Such BTA's to deal with carbon leakage have received considerable attention in the literature (eg, van Asselt and Brewer, 2010) and the media of late (for example, see the discussion of Border Measures and Relevant WTO Rules in IV-A-2 and IV-A-3 of Tamiotti *et al.* (2009:98-109)), and many have debated the legitimacy of using such BTA's to deal with changes in the relative competitiveness of domestic and foreign energy sectors when a subset of nations unilaterally apply environmental taxes to reduce emissions. In principle a CGE model such as the one used in this paper can be a very useful tool in illustrating the role and size of such BTA's to deal with carbon leakage. However, this analysis is beyond the scope of the current paper and as such is left for future work.

5 Summary

In this paper we have examined the potential for existence of a *Double Dividend* arising from pollution taxes imposed by a small open economy which unilaterally aims to achieve pollution abatement targets of 0-15% by charging taxes on the production of energy goods. Following the work of Perroni and Whalley (1998) and Bento and Jacobsen (2007), we confirm the important role played by the existence of specific (immobile) factors in the production of energy goods, particularly primary energy goods like coal, oil and gas. Using a CGE model of the Australian economy, we find that when revenue from emissions taxes is recycled through a reduction in consumption taxes, a strong DD exists up to levels of abatement of 12-13%. With more specific factors, a higher production tax is needed to achieve a given abatement target, but more of this tax is borne by factors specific to the production of energy goods. Thus, less of the production tax is passed along to consumers, resulting in a strong DD. A CGE model of the UK also yields evidence of a DD though it is much smaller than that for Australia and obtains for levels of abatement no larger than 2%. Although small, the emergence of this DD is in contrast with results previously reported in the literature, and it neatly illustrates the importance of specific factors identified by Bento and Jacobsen (2007).

In addition, and just as important as the role played by specific factors, the way in which revenue is recycled is shown to be fundamental to the existence of a DD. It must be the case that the imposition of emissions taxes raise revenue which is offset by the reduction of a more distortionary pre-existing tax. When we repeat our emissions reduction simulations by recycling revenue through a reduction in the income tax, the DD disappears completely for both Australia and the UK. Pollution abatement is achieved through the imposition of a production tax which is more distortionary than the income tax which is being reduced, resulting in an unambiguous reduction in welfare for all levels of abatement.

The CGE models in this paper have used taxes on the production of energy goods to achieve carbon abatement targets, presuming that a given reduction in the production of each energy good resulted in a corresponding reduction in carbon emissions. While this method of indirectly achieving carbon abatement targets by using production taxes has made our analysis more simple and directly comparable to that in the theoretical literature (as in Bento and Jacobsen (2007), for example), it should be noted that if different energy goods have different carbon intensities, our results will provide a lower bound on the welfare effects of achieving a given abatement target. For example, if a 10% reduction in coal production results in a larger reduction in the volume of carbon emissions than a 10% reduction in gas production, then it would be more efficient to achieve a 10% carbon abatement target by reducing coal production by more than 10% and reducing gas production by less than 10%. By modifying our CGE model to allow for direct taxation of carbon rather than indirect taxation through the use of production taxes, DD effects of a given abatement target should be stronger than those illustrated in this paper.

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Table 1: Sectors in Aggregated GTAP Dataset

Sector	GTAP 7 Sectors
Energy sectors	
Coal	coa
Oil	oil
Gas	gas
Petroleum, coal products	p_c
Electricity	ely
Non-energy sectors	
Crops	pdr, wht, gro, v_f, osd, c_b, pfb, ocr
Animal Products	ctl, oap, rmk, wol
Forestry, fishing	frs, fsh
Minerals	omn
Processed meat	cmt, omt
Processed food	vol, mil, pcr, sgr, ofd, b_t
Textiles, clothing, leather	tex, wap, lea
Wood, paper, publishing	lum, ppp
Chemical, rubber, plastic prod	crp
Minerals, metals	nmm, i_s, nfm, fmp
Manufactures	mvh, otn, ele, ome, omf
Gas manufacture, distribution	gdt
Transport	otp, wtp, atp
Services	wtr, cns, trd, cmn, ofi, isr, obs, ros, osg, dwe
Investment	cgd

Table 2: Central Case Substitution Elasticities in Aggregated GTAP Dataset

Sector	σ_{va}	σ_{vae}	σ_e	σ_{nel}	σ_{lqd}	σ_{arm}
Coal	0.20	0.00	0.00	0.00	0.00	3.05
Oil	0.20	0.00	0.00	0.00	0.00	10.40
Gas	0.20	0.00	0.00	0.00	0.00	17.20
Petroleum, coal products	1.26	0.00	0.10	0.50	2.00	2.10
Electricity	1.26	0.50	0.10	0.50	2.00	2.80
Crops	0.23	0.50	0.10	0.50	2.00	2.57
Animal Products	0.23	0.50	0.10	0.50	2.00	2.20
Forestry, fishing	0.20	0.50	0.10	0.50	2.00	1.89
Minerals	0.20	0.50	0.10	0.50	2.00	0.90
Processed meat	1.12	0.50	0.10	0.50	2.00	4.12
Processed food	1.12	0.50	0.10	0.50	2.00	2.14
Textiles, clothing, leather	1.26	0.50	0.10	0.50	2.00	3.77
Wood, paper, publishing	1.26	0.50	0.10	0.50	2.00	3.10
Chemical, rubber, plastic prod	1.26	0.50	0.10	0.50	2.00	3.30
Minerals, metals	1.26	0.50	0.10	0.50	2.00	3.41
Manufactures	1.26	0.50	0.10	0.50	2.00	3.82
Gas manufacture, distribution	1.26	0.50	0.10	0.50	2.00	2.80
Transport	1.68	0.50	0.10	0.50	2.00	1.90
Services	1.35	0.50	0.10	0.50	2.00	1.91

Table 3: Factor Shares in Energy Industries

Primary Factors as a Share of Value Added	Land	Labour	Capital	Nat'l Res.
Australia (Aus)				
Coal	0.00	0.15	0.49	0.37
Oil	0.00	0.16	0.46	0.37
Gas	0.00	0.15	0.50	0.36
Petroleum, coal products	0.00	0.21	0.79	0.00
Electricity	0.00	0.27	0.73	0.00
Economy Average	0.01	0.60	0.38	0.01
United Kingdom (UK)				
Coal	0.00	0.29	0.16	0.55
Oil	0.00	0.04	0.63	0.33
Gas	0.00	0.05	0.63	0.32
Petroleum, coal products	0.00	0.70	0.30	0.00
Electricity	0.00	0.32	0.68	0.00
Economy Average	0.00	0.60	0.39	0.01
Primary Factors as a Share of Output Supply	Land	Labour	Capital	Nat'l Res.
Australia (Aus)				
Coal	0.00	0.10	0.32	0.24
Oil	0.00	0.10	0.30	0.24
Gas	0.00	0.10	0.34	0.25
Petroleum, coal products	0.00	0.01	0.04	0.00
Electricity	0.00	0.13	0.36	0.00
Economy Average	0.00	0.29	0.18	0.01
United Kingdom (UK)				
Coal	0.00	0.10	0.05	0.19
Oil	0.00	0.03	0.46	0.24
Gas	0.00	0.04	0.49	0.25
Petroleum, coal products	0.00	0.02	0.01	0.00
Electricity	0.00	0.16	0.34	0.00
Economy Average	0.00	0.23	0.15	0.00

Table 4: Output Supply Elasticities in Primary Energy Industries

	Share of specific capital					
	0.50		0.25		0.00	
	Case *A*		Case *B*		Case *C*	
Sector	Aus	UK	Aus	UK	Aus	UK
Coal	0.198	0.400	0.319	0.461	0.521	0.529
Oil	0.260	0.193	0.385	0.322	0.588	0.574
Gas	0.212	0.150	0.330	0.272	0.531	0.515

Table 5: Marginal Excess Burden of Taxes in GTAP7 Dataset

Share of Specific Capital		Labour Supply Elasticity		
		0.30	0.15	0.075
		Tax on Private Consumption		
Case A: 0.50	Aus	0.2074	0.2058	0.2050
	UK	0.0101	0.0098	0.0100
Case B: 0.25	Aus	0.2148	0.2129	0.2118
	UK	0.0104	0.0101	0.0099
Case C: 0.00	Aus	0.2216	0.2193	0.2181
	UK	0.0107	0.0103	0.0091
		Tax on Production of Energy Goods		
Case A: 0.50	Aus	-0.0202	-0.0078	-0.0012
	UK	-0.0732	-0.0538	-0.0436
Case B: 0.25	Aus	-0.0191	-0.0066	-0.0000
	UK	-0.0660	-0.0466	-0.0364
Case C: 0.00	Aus	-0.0178	-0.0051	0.0015
	UK	-0.0555	-0.0359	-0.0257

Table 6: Production Tax and Consumer Price to Achieve 10% Level of Abatement

	Sector									
	Coal		Oil		Gas		Petrol		Elect	
	Aus	UK	Aus	UK	Aus	UK	Aus	UK	Aus	UK
Production Tax (%)										
Benchmark	1.0	-3.4	1.1	6.6	1.1	4.4	0.8	0.0	1.0	2.2
Case *A*	30.0	11.2	29.5	41.6	34.3	41.6	9.1	4.9	18.4	17.0
Case *B*	22.0	9.8	22.0	29.8	26.2	29.3	9.1	4.9	16.9	15.9
Case *C*	15.5	8.5	15.9	20.7	19.7	19.7	9.2	4.8	15.8	15.1
Domestic Price (%Δ)										
Case *A*	3.8	1.3	3.3	1.2	12.0	1.9	13.1	7.6	23.3	16.5
Case *B*	3.2	1.2	2.8	1.0	11.4	1.7	12.7	7.4	22.3	16.3
Case *C*	2.7	1.0	2.4	0.8	11.0	1.5	12.5	7.2	21.3	16.2

Table 7: Return to Specific Factor with 10% Abatement (% change)

	Sector									
	Coal		Oil		Gas		Petrol		Elect	
	Aus	UK	Aus	UK	Aus	UK	Aus	UK	Aus	UK
Case *A*	-65.7	-65.1	-65.5	-67.7	-65.4	-67.0	-12.6	-9.1	-10.2	-10.9
Case *B*	-58.7	-62.9	-58.8	-58.5	-58.3	-58.0	-9.6	-8.6	-8.2	-9.0
Case *C*	-53.0	-60.8	-53.3	-51.5	-52.6	-51.1				

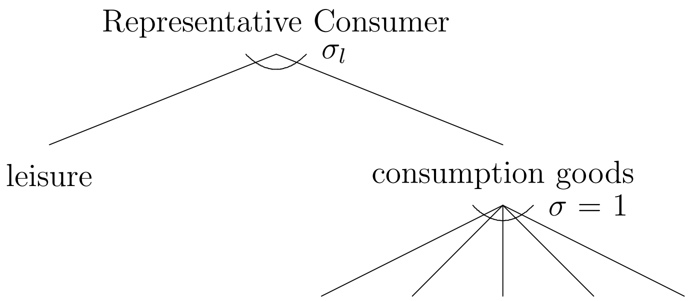


Figure 1: Structure of Consumption for Representative Consumer

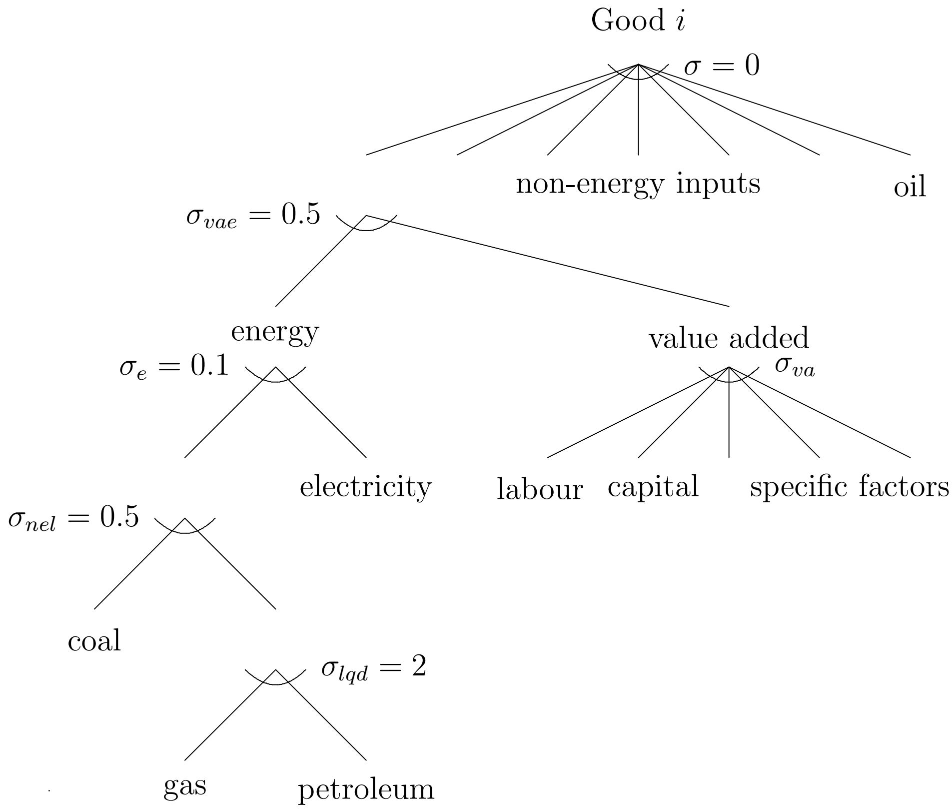


Figure 2: Substitutability between Inputs in Production

Figure 3: Welfare Effects of Carbon Abatement with Different Shares of Specific Capital

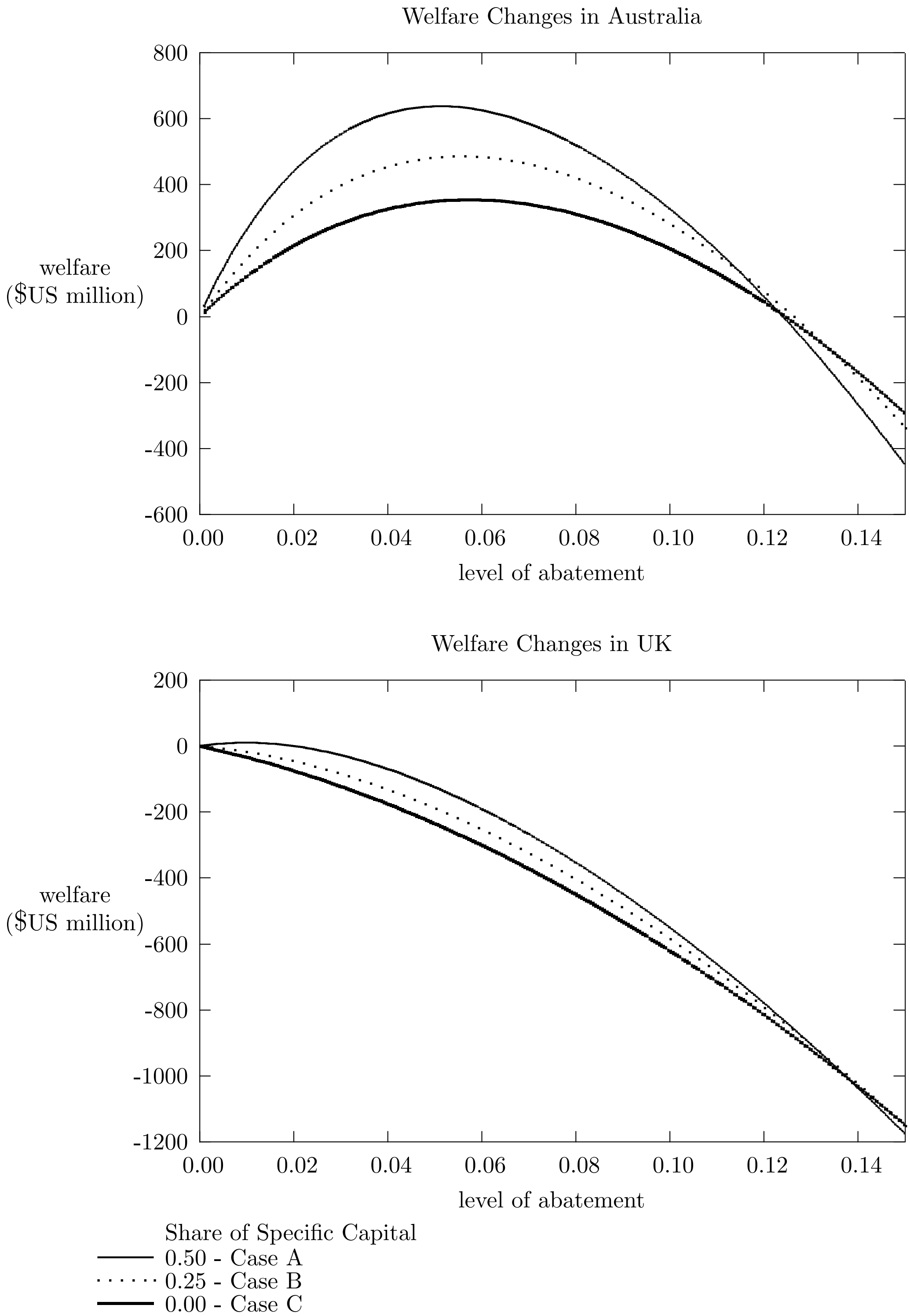


Figure 4: Welfare Effects of Carbon Abatement with Different Labour Supply Elasticity

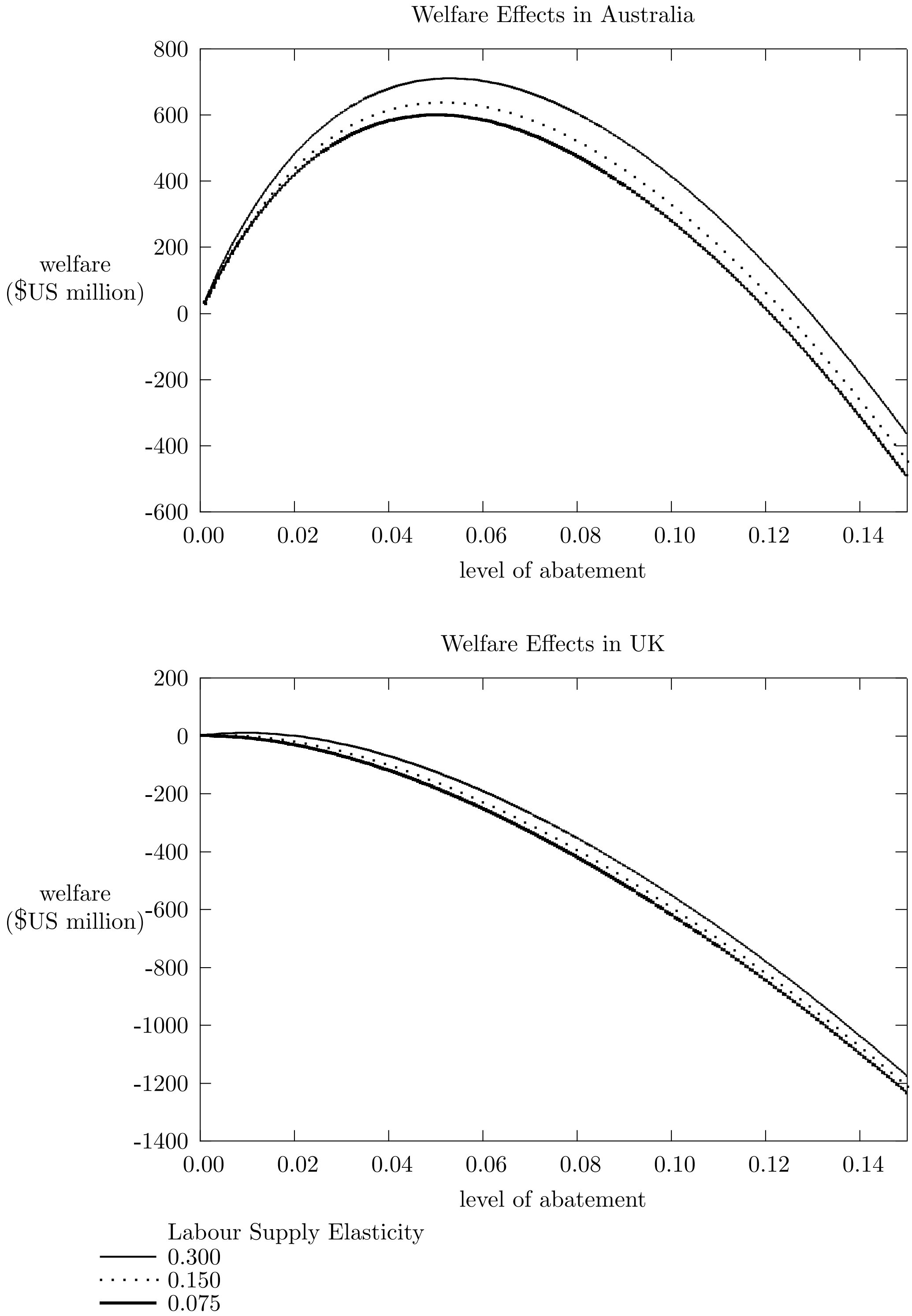
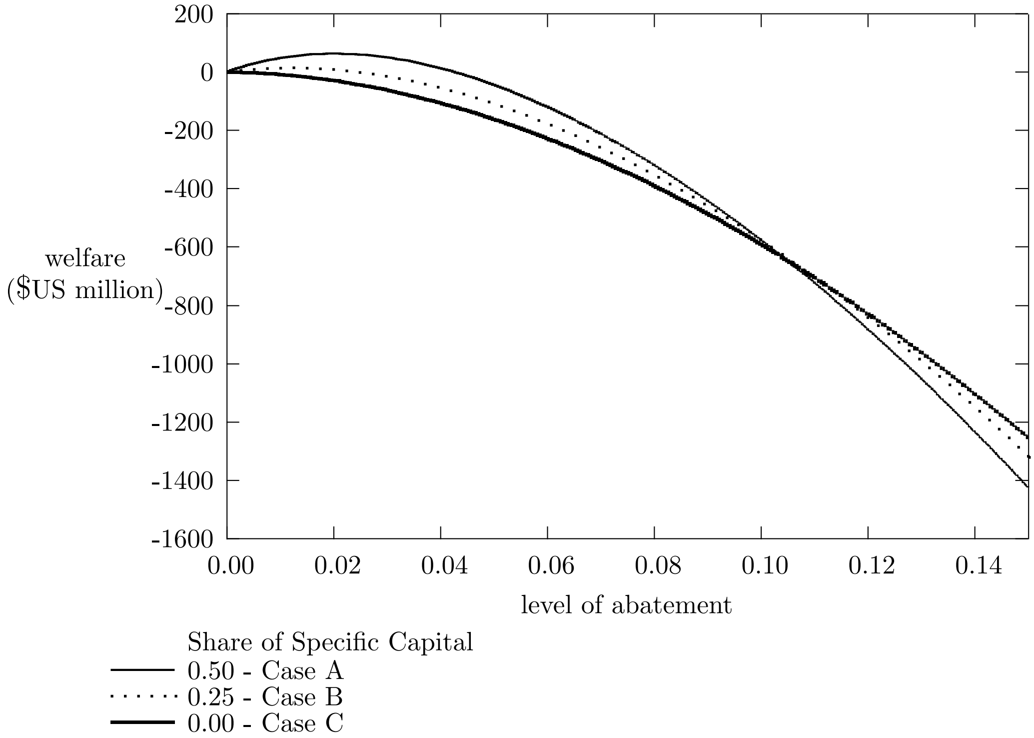


Figure 5: Welfare Effects of Carbon Abatement with Income Tax Recycling

$\sigma_{vae} = 0.5$, $\sigma_e = 0.1$, $\sigma_{nel} = 0.5$, $\sigma_{lqd} = 2$



Notes

[1]The output supply elasticities in Table 4 are derived following the method described in Appendix C of Rutherford *et al.* (1993:A9–10).

[2]The GTAP7 substitution elasticity between domestic and imported varieties of the good "oil" is 5.2, which we regard as too low, so we adopt a central case Armington elasticity for "oil" of 10.4.

[3]Specifically, consumption taxes are given by the difference between household purchases at market prices and agents' prices (GTAP7 vectors $vdpm(\cdot) + vipm(\cdot)$ and $vdpa(\cdot) + vipa(\cdot)$, as a proportion of $vdpm(\cdot) + vipm(\cdot)$). Given all other taxes in the GTAP7 dataset, using the GTAP7 data on income taxes (vector $ty(\cdot)$) would imply calibrating the model to a budget surplus for Australia of almost 9.3% of GDP in the benchmark dataset. We regard this figure as being too high, and instead use a value for the income tax which calibrates the model to a budget surplus for Australia of 1.1% of GDP, consistent with the General Government Underlying Balance reported in Annex Table 29 of OECD (2009).

[4]The exception is the coal sector in the UK, where capital represents only 5% of the value of production. Allowing more or less of this capital to be mobile or specific has only a small effect on the production tax needed to achieve a given level of abatement.

[5]While the Armington assumption implies that Australia and the UK will have some market power in all sectors, the Armington elasticities for coal, oil and gas are 3.05 and 10.4 and 17.2, respectively.

[6]Under Case B and Case C welfare changes are negative for all levels of abatement for all values of the labour supply elasticity.

[7]See Jones (1971) for a description and derivation of the magnification effect in models with specific factors.

[8]See the Australia Herald Sun Newspaper, 24 November 2009, `http://www.heraldsun.com.au/news/australia-on-verge-of- signing-emissions-trading-scheme-plan-after-last-m concessions-to-coalition/story-e6frf7jo-1225802571908`. These figures have been converted from Australian to US dollars using an exchange rate of \$US/\$AUD = 0.9214, to more readily compare them to figures in this paper which are all reported in US dollars.

[9]In Bento and Jacobsen (2007) the income tax distorts the price of labour relative to other goods. This is not the case in our CGE model since the income tax is collected on income earned regardless of source.

[10]Complete results on abatement taxes and changes in the prices of energy goods are available from the authors on request.

[11]Australian imports of coal and gas are zero, and electricity is not traded.

[12]These results are reported for central case values of all elasticities, assuming that

50% of capital and skilled labour is specific in production.

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