The Regional Economic Effects of a Reduction in Carbon Emissions

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Abstract:

Climate change has lead to policy to reduce CO_2 emissions and it is likely that policy will have differential regional impacts. While regional impacts will be politically important, very little analysis of them has been carried out. This paper contributes to the analysis of this issue by building a small model involving two regions and we incorporate the right to emit CO_2 as a factor of production with the level of permitted emissions set by the national government. We argue that there is likely to be pressure on governments to use other policies to offset the possible adverse regional economic consequences of the pollution-reduction policy and also consider a range of such policies. Using numerical simulation we find that a 10% reduction has relatively small but regionally differentiated effects. Standard fiscal policies are generally ineffective or counter-productive while labour market policies are more useful in offsetting the adverse effects. (150 words)

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1. Introduction

There is considerable controversy about the existence, the nature, the causes and the consequences of climate change; in particular, the relationship between human activity, global warming and climate change is far from clear. Yet, governments of many countries are moving toward significant implementation of policy designed to limit the emission of greenhouse gases which are claimed to be one of the main causes of global warming. The assumptions underlying such policy may be characterised as: (i) climate change imposes significant costs which are likely to grow; (ii) climate change is driven largely by global warming; (iii) global warming, in turn, is caused by an increase in the concentration of greenhouse gases in the atmosphere; and (iv) such gases are the result of human activity.

Given this chain of reasoning, the policies being proposed are of the type that will limit the human activity which produces greenhouse gases of which carbon dioxide, CO_2, is the most commonly discussed. Two main alternative policies for achieving a reduction in CO_2 emission have been proposed – a carbon tax and a "cap and trade" scheme. The first of these is a common response to an external diseconomy associated with production or consumption activity, the emission of CO_2 in this case. It is to tax the externality so that its private and social costs are the same, making for a socially optimal outcome (in the absence of other externalities). The second policy involves a government decision on the maximum amount of CO_2 emission to be allowed (perhaps as part of an international agreement) and the issue of permits to pollute to this level. These permits are allocated to polluters in some systematic fashion and are then freely traded in a market.[1] No matter which scheme is

[1] For an interesting recent paper discussing the relative merits of different forms of regulation in a regional context see Rose *et al.* (2009). For a wider range of possible responses, although not in a regional context, see the seminal paper by Norhaus (1991). For a recent historical survey of the cap-and-trade approach see Tietenberg (2010).

implemented, the price of goods which are pollution-intensive would be expected to rise relative to other goods, thus shifting consumption from high- to low-polluting production activity. The imposition of such a policy would be expected to have widespread repercussions on the economy.

While popular discussion of climate change, global warming and the possible policy responses to these developments is a recent phenomenon, the economic analysis of the effects of pollution and the design of efficient policy has a long history in the academic literature, much of it pre-dating the recent popular upsurge in interest in the area. Initial analysis tended to be partial equilibrium in nature, concentrating on the market for the goods, the production of which is responsible for the emissions. When pollution controls are widespread, there are likely to be economy-wide effects of pollution abatement policies and general equilibrium analysis becomes more appropriate as a tool of analysis. While the literature dealing with the general economic effects of pollution and pollution-reduction policies is extensive, this is not the case, however, for the analysis of the regional economic impacts of pollution or pollution abatement measures. Yet, the costs of the implementation of emission-mitigation policies can reasonably be expected to affect different industries differently and, to the extent that industry structure differs across regions, the initial cost of imposing the policies are likely to differ across regions, although adjustments might well occur over time to spread the regional effects more evenly.

This is not to say that the regional effects have been neglected altogether, however. A number of papers has contributed to the theoretical analysis of some of the issues at stake. An early paper in the area by Beladi and Frasca (1996) builds on a previous one by Beladi and Rapp (1993) which was, in turn, based on the well-know Harris-Todaro model of the dual developing economy (see Harris and Todaro, 1970).

While it is, strictly-speaking, a two-country model, it can be interpreted in a regional context and analyses the regional employment, capital allocation and output effects of pollution controls which have an initial impact which is regionally differentiated. More recently, there has been a number of papers with models with regional disaggregation which focus on the welfare effects of pollution-abatement policy and address questions about the design of policy needed to re-establish a Pareto-optimal allocation of resources in the face of a pollution externality; examples are those by Silva and Caplan (1997), Caplan and Silva (2005) and Hadjiyiannis *et al.* (2009). The paper by Boucekkine and Germain (2009) adds endogenous growth to provide a dynamic analysis of the problem in a two-region model which in previous papers has been static. Finally, an interesting paper by Hosoe and Naito (2006) introduces the notion of agglomeration into the static two-region model and focuses on the effects of pollution (rather than pollution abatement policy) on urban structure including the inter-regional distribution of population.

The increasing complexity of these theoretical models, particularly when growth is introduced, makes clear analytical results increasingly difficult to derive. Indeed, Hosoe and Naito use numerical simulations to derive some of their conclusions. An extreme case of the use of numerical simulations is found in several papers which use large-scale computable general equilibrium (CGE) models – Klepper and Peterson (2006), Adams (2007) and Nordhaus (2010), all of which use numerical solution methods to analyse the general equilibrium effects of the imposition of pollution control policy, Klepper and Peterson for the European Union Adams for Australia and Nordhaus for the world.[2] These models all have structures

[2] There are also regionally-disaggregated models of specific components of the energy market, such as the HAIKU model of US electricity markets which divides continental US into 21 regions (see, e.g., Paul, Burtraw and Palmer, 2009). But the purpose of this model is the analysis of regional electricity markets as such rather than the general regional economic effects of pollution-reduction policies

which closely mimic the economic structure of the "economy" being analysed and are calibrated using data for those economies. While all are regionally disaggregated, only the Adams analysis is so in the sense used in this paper of a single country composed of different regions with the other two analysing policy in a multi-country environment where countries or groups of countries are denoted regions. They all show substantial differences between the regional effects of centrally imposed policy; Adams, for example, generates regional output reductions ranging from zero to 2.5% for a 21.1% reduction in emissions.

Our paper builds on the existing literature but differs from it in the following ways. First, we recognise that in the current policy environment the need to reduce pollution is increasingly likely to be derived from obligations under international agreements so that the immediate question and the focus of our paper is what the economic effects of such a reduction will be, rather than the design of welfare-maximising policy instruments which has been an important question in past papers.[3] Thus we take the reduction as exogenously imposed by the central government and we analyse the effects of the policy on a range of economic variables including output, per capita output, employment, unemployment, relative prices, consumption and welfare.[4]

Second, we assume that, while the national rather than the regional government has the obligation under international agreements to implement pollution-control policies, both the national and the regional governments will be concerned

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imposed by the central government which is our focus. Earlier multi-country analyses can be found in the FUND model by Tol (997) and the MERGE model by Manne *et al.* (1995).

[3] We assume nothing specific about the initial allocation of permits except that they are tradable and the market is in equilibrium when the reduction is imposed. This is consistent with various alternative initial allocation schemes; see Böhringer and Lange (2005), Mackenzie *et al.* (2008) and Betz *et al.* (2010) for an economic analysis of alternatives.

[4] For an interesting recent paper which assumes that the regional governments impose pollution limits with a central government effecting transfers to achieve optimality, see Silva and Yamaguchi (2010).

about the possible adverse regional consequences of such a policy. It is likely, therefore, that the imposition of pollution-abatement measures will be accompanied by further policies (such as regionally-differentiated expenditure boosts or labour-market policies) designed to offset the expected adverse regional consequences of the pollution-reduction measures. Our paper extends the existing literature by considering not only the regional effects of imposition of emissions controls as such, but also the effectiveness of a range such supplementary policies.

Third, given the questions we want to address, our model is distinct from existing ones. We use a simple two-region general equilibrium model which allows for inter-regional migration in the long run and inter-regional capital mobility. We incorporate pollution into the model by assuming that the right to pollute is a factor of production in the manner of “environmental capital” of Hosoe and Naito (2006). We assume that this factor is in fixed supply, its level being set by the national government, that firms must purchase it like other factors and that it can be substituted for other factors.

Fourth, the regional unemployment consequences of pollution-abatement policy is a serious policy concern in many countries and to enable us to consider this we incorporate equilibrium unemployment into the model using a union-firm bargaining structure to generate possible equilibrium deviations from full employment.

Finally, the model has an array of government policy instruments to allow us to address questions about the effectiveness of possible regional and national government policy responses to the imposition of limits to emissions.

While our model is small and incorporates many simplifications, it is complicated enough to be analytically intractable and we use it to analyse policy by linearising it, calibrating it and simulating the effects of a variety of shocks. Thus, strictly-speaking, it is a CGE model but one that is several orders of magnitude smaller than traditional CGE models and, we argue, one in which the effects of shocks are transparent. Moreover, while we use Australian data to calibrate the model, it would be misleading to think of our analysis as an Australian application. For that the model as it stands is too general and would require much greater detail about the actual structure of the Australian economy.

The structure of the rest of the paper is as follows. In the next section we set out the model. In section three we discuss the linearisation and calibration of the model and provide details of the simulations designed to assess the regional effects of a pollution-reduction policy as well as policies that might be undertaken in order to offset the adverse effects of the tightening of pollution controls. In section four we report the results of these simulations and in section five we summarise our results and draw conclusions.

2. The model

The model which we build has two regions, each with households, firms and a regional government. In addition to regional governments, there is also a national government. The households and firms are optimisers. Governments at both levels are treated as exogenous but subject to a budget constraint.

The firms in a region produce a single good which we assume to be different to that produced in the other region. It is supplied, in the region in which it is produced, to households and to the regional government as tax revenue. Households consume some, trade some with households in the other region and give some up to the national government as income tax. Governments costlessly transform the good they receive as tax revenue into a government good. The regional government supplies the transformed good in equal amounts to households in its region free of direct charge. It finances its expenditure by a payroll tax levied on firms located in its region as well as its share of an income tax levied by the national government. The national government provides output to households in both regions (possibly different amounts per capita) and finances this by its share of a tax levied at a uniform rate on household incomes in both regions as well as revenue from the rental of emissions permits to firms.

Output in each region is produced using four factors: land, labour, capital and the right to emit CO_2 (environmental capital). Land is region-specific and in fixed supply. We assume that one unit of labour is supplied inelastically by each household and that households are employed only by firms in the region in which they live, thus excluding the possibility of households' living in one region and commuting to work in the other. Regional population and labour force are therefore effectively the same. We do allow inter-regional migration in the long run, however, and this is one of several sources of inter-connectedness between the two regions. We follow the literature in the area of fiscal federalism (see, e.g., Boadway and Flatters,1982, Myers, 1990, Petchey, 1995, Petchey and Shapiro, 2000, Groenewold, Hagger and Madden, 2003, Groenewold and Hagger, 2007) and assume migration to be costless and to occur in response to inter-regional utility differentials.

Capital is owned by households and is mobile across regional boundaries in both short and long runs. There is no capital accumulation in the model so that the capital stock is given and we assume each household owns an equal share of the national capital stock.[5]

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[5] This assumption considerably simplifies the likely response of the firm to the imposition of controls such as the development of and substitution to more "pollution-efficient" capital. See Batabyal and Nijkamp (2008) for an analysis of this process in a partial-equilibrium framework.

The national government owns the stock of pollution permits which it rents to firms nation-wide (just as households do the capital stock). In the case of both the capital stock and the stock of permits, the inter-regional allocation is determined so as to equalise the regional rental rates.

We model the labour market to allow for the possibility of unemployment in each region. There are many ways in which this has been achieved in recent regional literature: a fixed wage as in the multi-regional model of tax-competition by Ogawa *et al*. (2006) as well as in the two-region model of Fuerst and Huber (2006); an efficiency-wage model as in Zenou (2006); job search as used by Epifani and Gancia (2005) in a model used to investigate spatial productivity differentials and by Moller and Aldashev (2006) in their investigation of participation rates in East and West Germany; or a union-based model used by Roemer (2006). We use a variant of the last; we assume that in each region firms bargain with a union which represents households. Bargaining is assumed to be restricted to wages and, once the wage has been agreed upon, firms choose employment to maximise profits. There is no reason why employment should equal the labour force in equilibrium so that, as required, the model allows for equilibrium unemployment.

There are therefore several sources of interconnectedness between the regions – inter-regional migration, inter-regional capital flows, inter-regional flows of pollution permits, inter-regional trade and the redistribution carried out by the national government. We abstract from other possible inter-regional connections. So, we assume that each regional government supplies the government good only to households living in its own region, thus abstracting from inter-regional spillover effects in the provision of government goods. Further, we assume that each firm is owned by households in the region in which it is located so that there are no inter-regional profit flows.

2.1 Households

Households derive utility from the consumption of the two privately-produced goods as well as from a good supplied by regional and national governments.[6] We assume a representative household in each region and that the utility function for this household is Cobb-Douglas and homogeneous of degree 1:[7]

(1) $V_i = \beta_i C_{1i}^{\gamma_{1i}} C_{2i}^{\gamma_{2i}} G_i^{\delta_i}$, $i = 1, 2$

where V_i = utility of the representative household, region i,

C_{ji} = real private consumption of region j's output per household in region i,

G_i = real government-provided consumption per household, region i.

β_i, γ_{ji} and δ_i are constants with:

$\beta_i > 0$, $i = 1, 2$

$0 < \gamma_{ji} < 1$, $j = 1, 2$, $i = 1, 2$,

$0 < \delta_i < 1$, $i = 1, 2$

$\gamma_{1i} + \gamma_{2i} + \delta_i = 1$ $i = 1, 2$.

The representative household maximizes utility subject to a budget constraint which requires combining quantities of the two goods. We compute real output by deflating by the price of a composite good which has a price index:

$P_C = (P_1)^{\lambda}(P_2)^{1-\lambda}$

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[6] Note that pollution does not have adverse consequences for utility. To allow for this would considerably complicate the model and, besides, it is likely that the direct welfare consequences of pollution are not an important consideration in the type of short-run questions we analyse in this paper.
[7] A list of the variables of the model is provided in Appendix 1.

where P_j is the price of good j (j = 1, 2) and λ is the share of good 1 in total nominal output.

The national government collects an income tax at a given rate T_Y which is the same in both regions so that the household budget constraint in region i may be written as:

$$(1\text{-}T_Y)J_i = (P_1 C_{1i} + P_2 C_{2i})/P_C = P^{1-\lambda}C_{1i} + P^{-\lambda} C_{2i}, \quad i = 1, 2$$

where P has been used to denote the relative price P_1/P_2 and J_i denotes real household income in region i measured in terms of the composite good. Utility maximisation subject to the household budget constraint gives the demand functions:

$$\text{(2a)} \qquad C_{1i} = \frac{\gamma_{1i}}{\gamma_{1i} + \gamma_{2i}} P^{\lambda-1}(1 - T_Y)J_i, \qquad i = 1, 2,$$

$$\text{(2b)} \qquad C_{2i} = \frac{\gamma_{2i}}{\gamma_{1i} + \gamma_{2i}} P^{\lambda}(1 - T_Y)J_i, \qquad i = 1, 2.$$

Households own a unit of labour each which they supply to firms in the regiona in which they live, they own the capital in the economy as a whole in equal shares and they own the firms in their region in equal shares.[8] They therefore receive wage income, capital income and profits. Some of the labour may be unemployed in which case the household is paid unemployment benefits by the regional government. The household makes decisions on the basis of expected labour income which is simply the sum of the wage, W_i, weighted by the employment rate, $1\text{-}U_i$, and unemployment benefits, UB_i, weighted by the unemployment rate, U_i. Wages, unemployment benefits, profits and capital income are all measured in terms of units of output of the

[8] We make the simplifying assumptions that only households in the region own the region's firms (and so receive profit distributions) and that households supply labour only to firms in the region in which they live. This helps to keep to a minimum the regional interrelationships and precludes commuting between regions for employment purposes; see Corcoran *et al.*(2011) for a recent model of inter-regional commuting. We do not make similar assumptions about capital ownership since we will assume inter-regional capital mobility which requires the ability of households to shift their capital freely from one region to the other. In an application of the model with regionally immobile capital, the results were not much affected by the introduction of capital mobility.

region in which they originate. Thus, the expression for the income of the representative household measured in terms of the composite good is:

(3a) $J_1 = P^{1-\lambda} (\Pi H_1 + (1-U_1)W_1 + U_1 UB_1 + R_{K1}K_1/N) + P^{-\lambda}R_{K2}K_2/N,$

(3b) $J_2 = P^{-\lambda} (\Pi H_2 + (1-U_2)W_2 + U_2 UB_2 + R_{K2}K_2/N) + P^{1-\lambda}R_{K1}K_1/N,$

where ΠH_i = real profit distribution per household, region i,

R_{Ki}= capital rental rate, region i, and

K_i = capital stock region i.

Inter-regional migration is possible and we make the simplifying assumption that migration is costless and continues until utilities are equal across regions:

(4) $V_1 = V_2$

We also assume that capital is mobile across regions and that in equilibrium the rates of return are equalised:

(5) $R_{K1} = R_{K2}.$

2.2 Firms

We assume that there is a given number of firms in each region which, without loss of generality, we set equal to 1. Two goods are produced in the economy and it is assumed that firms in each region are completely specialised so that firms in region 1 produce good 1 and in region 2 firms produce good 2. Thus we can use i to index both regions and goods. In each region, firms hire labour from households in their own region and capital from households across the country and combine them with the given supply of land to produce output.

In the process of production they emit pollution for which they must purchase permits from the national government. There are various ways in which emissions might be modelled. First, they might be included in the utility function to reflect the disutility of pollution. This would be particularly important for addressing the question of the optimal level of pollution which would balance the benefits to utility of lower pollution against the extra production costs.[9] However, we do not deal with this question, rather taking the level of permitted emissions as exogenous. Besides, for the sort of policy environment which we have in mind, the benefits to households of lower CO_2 emissions are likely to be much more diffused over both time and space that the extra costs. On the cost side, the literature has incorporated pollution in two main alternative ways. The first is to assume that pollution produced is linearly related to output – see, e.g., Hosoe and Naito (2006).[10] The alternative, more general approach which we also follow, is to treat pollution as a factor of production; see Beladi and Rapp (1993), Beladi and Frasca (1996), Rosendahl (2008), Hadjiyiannis *et al.* (2009) and Boucekkine and Germain (2009) for examples of this approach.

Production technology is assumed to be Cobb-Douglas, following Nordhaus (2010), with constant returns to scale so that the production function for the representative firm in region *i* can be written as:

$$Y_i = B_i(LAND_i)^{(1-\alpha_{Li}-\alpha_{Ei}-\alpha_{Ki})}\left(L_i\right)^{\alpha_{Li}}(E_i)^{\alpha_{Ei}}(K_i)^{\alpha_{Ki}},$$

$$0 < \alpha_{Li}, \alpha_{Ki}, \alpha_{Ei}, (1-\alpha_{Li}-\alpha_{Ki}-\alpha_{Ei}) < 1$$

where B_i = total factor productivity in region *i*,

K_i = the total capital in region *i*,

L_i = total employment in region *i*, and

E_i = pollution emission permits, region *i*.

We can simplify by writing:

$$D_i = B_i(LAND_i)^{(1-\alpha_{iL}-\alpha_{Ki}-\alpha_{Ei})}$$

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[9] See Silva and Caplan (1997), Caplan and Silva (2005) and Banzhaf and Chupp (2010), for example.

[10] An interesting recent variation is in Silva and Yamaguchi (2010) in which a separate energy good is introduced which produces pollution 1:1.

so that the production function becomes:

(6) $Y_i = D_i \left(L_i\right)^{\alpha_{iL}} (E_i)^{\alpha_{Ei}} (K_i)^{\alpha_{Ki}}, \quad 0 < \alpha_{Li}, \alpha_{Ki}, \alpha_{Ei}, (1-\alpha_{Li} - \alpha_{Ki} - \alpha_{Ei}) < 1, \quad i = 1, 2$

Consider now firms' behaviour. Profits (in terms of the firm's own output) are defined as:

(7) $\Pi F_i = Y_i - (1+T_{Wi})\, W_i L_i - R_{Ki} K_i - R_{Ei} E_i \qquad j = 1, 2$

where T_{Wi} is the payroll tax levied by the regional government on the wage bill in region i and R_{Ei} is the emission permit rental rate in region i. We allow for the possibility that the emission permit rental rate differs across regions but will generally assume it to be the same. Even though we have normalised the number of firms to be 1, we assume that each firm takes the wage, the payroll tax rate, the capital rental rate and the emission permit rental rate as given when it maximises profits. Hence the choice variables in each case are the level of employment, emissions and capital (which will also determine output via the production function).

he profit-maximising conditions are the usual marginal productivity conditions:

(8a) $\alpha_{Li} Y_i = (1+T_{Wi}) W_i L_i, \qquad i = 1, 2$

(8b) $\alpha_{Ki} Y_i = R_{Ki} K_i, \qquad i = 1, 2$

(8c) $\alpha_{Ei} Y_i = R_{Ei} E_i, \qquad i = 1, 2$

On the labour supply side, each household in each region is assumed to provide one unit of labour inelastically to the firms in its own region so that labour force and the number of households are equal.[11] The wage is arrived at by a process of bargaining between firms and unions after which firms choose employment to satisfy the marginal productivity condition, equation (8a). We assume that the

[11] We could, instead have proceeded along classical lines and assumed that households supply labour to maximise utility after including leisure in the utility function. This would have been more complicated and, more importantly, have been difficult to integrate with the union-bargaining model below which we use to allow for the possibility of unemployment in the model. Our assumption, implies, of course, that leisure consequent upon unemployment has no utility benefits but this is a common feature of wage-bargaining models.

resulting level of employment is always at most equal to the labour force and that generally there is (equilibrium) unemployment.

2.3 Wage Bargaining

We assume, then, that the wage in region *i* is determined by a process of negotiation between employers and trade unions. The union's bargaining aim is to push the wage bill as high as possible relative to the figure they believe workers could obtain elsewhere in the region if the bargaining process breaks down. In pursuing this aim, however, they are constrained by the bargaining aim of the employers which is to preserve profits. We formalise this set of assumptions, following Layard *et al.* (1991), by supposing that, for the representative firm in region *i*, the bargained wage is the outcome of the following optimisation problem:

$$\max_{\{W_i\}} \quad \Omega_i = (\Pi F_i)\ ((W_i - A_i)L_i)^{\omega_i}, \qquad 0< \omega_i <1$$

subject to (6), (7) and (8a) where A_i is the income workers expect to be able to obtain elsewhere in region *i* if an agreement is not reached and ω_i is a parameter representing union strength in the bargaining process in region *i*. We assume that in the bargaining process (and so in the solution to the maximisation problem), the firm and the union both ignore the general economic implications of their stance; in particular, the firm takes output and employment as given in assessing the effect of wage changes on its profit and the union takes the alternative wage, A_i, as given.

W assume that A_i depends on both the expected wage in the rest of the region (W^E_i) as well as unemployment benefits (UB_i):

$$A_i = (1-U_i)W^E_i + U_i UB_i$$

where $(1\text{-}U_i)$ is taken as the probability of employment elsewhere and U_i the probability of unemployment, should the bargaining process break down. In equilibrium the expected wage elsewhere and the actual wage are the same. Under these assumptions, the first-order condition for the bargaining problem can be written as:

(9) $$U_i\,(W_i\text{-}UB_i)\,(1+T_{Wi}) = \omega_i\,(\Pi F_i/L_i), \quad i = 1,2,$$

Thus, the higher is union power, as measured by ω_i, the lower is profit per employee and the higher is the excess of the wage over the level of unemployment benefits, *ceteris paribus.*

2.4 Governments

There are two levels of government, a national government and two regional governments. The national government levies a tax on household income at a constant rate across the country, the revenue from which it shares with the regional governments. We allow the tax shares to differ across regions although in most federal systems they would be the same. The national government also receives the income from firms for the rental of emissions permits. The national government's revenue is therefore:

$$T_Y[(1\text{-}\theta_1)J_1N_1 + (1\text{-}\theta_2)J_2N_2] + P^{1-\lambda}R_{E1}E_1 + P^{-\lambda}R_{E2}E_2$$

where we denote the share of income tax going to region i's government by θ_i and we have measured revenue in terms of the composite good (noting that income, J_i, is already in terms of the composite good).

On the expenditure side of its budget, the national government converts its revenue into a government consumption good at the rate of one unit of the consumption good per unit of the composite good. It provides this good to the residents of both regions on an equal per capita basis within each region although the per capita amount may differ across regions. Denoting the government consumption good per capita supplied by the national government in region *i* by GN_i, we can write the national government's budget constraint as:

(10) $T_Y[(1-\theta_1)J_1N_1 + (1-\theta_2)J_2N_2] + P^{1-\lambda}R_{E1}E_1 + P^{-\lambda}R_{E2}E_2 = N_1GN_1 + N_2GN_2.$

where we have assumed that the government good is private in the rival sense.

Each of the regional governments also has its own tax, *viz.*, a payroll tax which is levied on the region's wage bill. Regional governments receive payroll tax in the form of output produced in their region and use part of the revenue to pay unemployment benefits, converting the remainder into the government consumption good in the same way that the national government does. Regional governments also convert their share of the national income tax to the government consumption good. The budget constraint for the regional governments can be written as:

(11a) $P^{1-\lambda}[T_{W1}W_1(1-U_1) - U_1UB_1] + \theta_1T_YJ_1 = GR_1$, and

(11b) $P^{-\lambda}[T_{W2}W_2(1-U_2) - U_2UB_2] + \theta_2T_YJ_2 = GR_2$, .

where we use GR_i to denote the government good provided to residents of region *i* by their regional government and both sides of the constraint are in per capita terms.

2.5 Definitions and closure

There remains a number of definitions and market-clearing conditions which close the model. We first define the unemployment rate:

(12) $U_i = 1 - L_i/N_i$, $i = 1, 2$

Next, the relationship between G_i and its components is given by:

(13) $G_i = GR_i + GN_i$, $i = 1, 2$

There is a given national population, N:

(14) $N_1 + N_2 = N$,

a given national capital stock, K:

(15) $K_1 + K_2 = K$,

and a given stock of emission permits:

(16) $E_1 + E_2 = E$.

Firms are assumed to distribute all their profits to households in their own region in equal per capita amounts:[12]

(17) $\Pi F_i = N_i \Pi H_i$, $i = 1, 2$

Finally, regions must "balance their budgets", i.e. there must be balanced trade:

(18) $N_1 C_{21} = N_2 P C_{12}$.

To summarise, the model consists of the 35 equations, (1) to (18) in 49 variables: V_i, C_{ji}, G_i, GR_i, P, J_i, ΠH_i, W_i, R_{Ei}, D_i, Y_i, L_i, K_i, R_{Ki} N_i, ΠF_i, T_Y, T_{Wi}, GN_i, θ_i, N, K, U_i, UB_i, E_i, E, of which 13 are exogenous: D_i, θ_i, N, K, E, two of (GR_i, UB_i T_{Wi}) for each i=1,2 and two of (GN_1, T_Y, GN_2), so that there are 36 endogenous variables: V_i, C_{ji}, G_i, P, J_i, ΠH_i, W_i, R_{Ei}, Y_i, L_i, K_i, R_{Ki} N_i, ΠF_i, U_i, UB_i, E_i, one of (GR_i, UB_i T_{Wi}) for each i=1,2 and one of (GN_1, T_Y, GN_2). This leaves us one equation short which is made up by the condition that the emissions permit rental rate is equal across regions.

2.6 Short-run and long-run versions of the model

In the simulations to be reported below we distinguish between short-run and long-run versions of the model. The distinction is very simple: we define the short run as the stretch of time before inter-regional migration begins to respond to a gap between V_1 and V_2. In terms of the model, this simply involves suspending equations

[12] Note that firms do not pay a land rental so that profits include a return to land.

(4) and (14) and making N_1 and N_2 exogenous in the simulation. The long run is used to refer to the simulation results using the model as set out above.

3. Linearisation, calibration and simulation of the model

The model which we have set out in the previous section is non-linear and too complex to solve algebraically. We therefore solve it numerically and do so in linear form, converting each equation to proportional changes. The linearised model is given in Appendix 2.

The linearised model is solved numerically. To accomplish this there is a large number of parameters which need to be replaced with numerical values before the effects of a shock can be simulated. The parameters are of two kinds. The first are the parameters of the utility and production functions and the second are shares which arise during the lineariseation procedure. Using all the definitions and constraints in the model to ensure the numerical version of the model satisfies them, we are able to reduce the data required for calibration to the following: C_i, GR_i, GN_i, L_i, W_i, N_i, $R_{Ei}E_i$, $R_{Ki}K_i$, $UB_i(N_i-L_i)$ and transfers from the national government to the regional governments. The data used are for Australia for the period 2004-2008 and are reported in Appendix 3.[13] Australia has 6 states, data for which were used for the regions. We carry out preliminary simulations (choosing each state in turn as region 1 and the rest of the country as region 2) to identify the state which is most severely affected by the reduction in permits and call this region 1, the high-polluting region, and the remainder of the country region 2.

[13] To reiterate a point made earlier, we note that using Australian data to calibrate the model does not make this an Australian application. This is in contrast to large CGE models which have a more elaborate structure which is specifically designed to mimic the actual economy from which the data are derived.

Most of the data were straightforward national accounting data but there were some exceptions where strong assumptions needed to be made to enable us to compute the parameters. First, inter-regional trade data are not available for Australia so that C_i could not be split up into its components C_{ji}. On the basis of anecdotal evidence, we assumed that interstate trade is approximately 20% of output and used this assumption to split up C_1, then splitting up C_2 to ensure a balance of trade.

The payments to capital and for emissions permits were more problematical. There are no data on capital stock or capital income for the states so that a rough value for the capital stock was estimated by accumulating published data on gross fixed capital formation for the longest period available (from 1985(3)) and assuming a common real rate of return of 5%. Capital income was then calculated by multiplying the capital stock by a rate of return of 5%. While this is undoubtedly a very rough guess, it should be pointed out that these data are used only in shares so that it is the relativities between the regions rather than the absolute figures which are used in the model.

Payments for emissions permits were even more problematical since they do not exist at present and we could not, therefore, use actual data to calibrate the relevant production function parameters. We proceeded by using data in the *Garnaut Climate Change Review* (Garnaut, 2008) from which we gained information that current Australian emissions of CO_2 of 650MtCO_2-equivalent would cost $15,600m per annum at an estimated carbon price of $24 per tonne. These estimates were not disaggregated by state but in one of the background papers, *Economic Modelling Technical Paper No.7*, the likely effect of a 10% reduction in emissions on Gross State Product (GSP) was estimated and we used the ratios of these state-level effects to total to allocate the $15,600m across the states. The overall cost estimated by

Garnaut is very modest – 1.3% of annual GDP for 2008-09 and when we ran initial simulations, the effects of a 10% reduction in carbon emission permits resulted in output effects of a similar magnitude. These magnitudes are also comparable to those simulated by Adams (2007) who estimated a 1.3% reduction in real GDP by 2030 for a reduction in emissions 8% below 2007 levels. Moreover, our parameter values are similar to other estimates such as those in Keilbach (1995). We are reasonably confident, therefore, that we got the order of magnitude of the resulting production function parameters right.

Finally, in this section we set out the simulations which we chose to throw light on the two issues identified in the introductory section of the paper: "what are the general regional economic effects of a reduction in emissions permits?" and "will policies which regional governments and/or the national government might implement to offset possible adverse regional economic effects of the reduction in permits be effective?"

The simulations we carry out can be collected into two groups. First we simply look at the effects of the reduction in emissions permits on the regions with each of the states as region 1 in turn (and region 2 comprising the rest of the country), making for six simulations. We call this the "base case". We find widespread adverse effects of the reduction in permits on economic variables such as output, unemployment and welfare. Given political pressures in the face of unpopular anti-pollution policy, it is likely that either regional governments or the national government or both will undertake policy to attempt to offset its effects by changing standard policy instruments at their disposal. In the second group of simulations we examine the effectiveness of a number of such policies – increases in government expenditure (by both levels of government) and a reduction in unemployment benefits designed to reduce equilibrium unemployment. We report these simulations only for one state as region 1, choosing as region 1 the state which our base case simulations show to be the most severely affected by the original policy (which turns out to be Queensland, QLD).

In particular the simulations we have run are the following.

1. The effect of a unit reduction in emissions permits. The results for this simulation are reported for each state as region 1 in turn with the remainder of the country being region 2.
2. The effects of a unit reduction in emissions permits together with regional government increase in expenditure (balanced by an increase in regional payroll taxes). We compute two simulations, one where only region 1 (the more seriously affected region) responds by increasing expenditure and the other where the second region also increases expenditure (perhaps in "reaction to" region 1's response). The results in this case are reported only for QLD as region 1.
3. The effects of a unit reduction in emissions permits together with regional government unemployment-benefit reductions. In contrast to the policy in simulation 2 which might be termed a "Keynesian" response to unemployment, this is a classical response designed to increase the cost of unemployment and so reduce its incidence. The results are reported only with QLD as region 1 and, again, two cases are reported – the first where only region 1 responds and the second where region 2 also reacts, perhaps in response to region 1's policy action.
4. The effects of a unit reduction in emissions permits together with national government increases in expenditure. The results are reported only with QLD

as region 1 and, in this simulation too, two cases are reported – the first where only expenditure in region 1 is increased and second where the national government also raises expenditure in region 2.

4. The results

In this section we report the results of the simulations set out in the previous section, beginning with the effects simply of the imposition of a reduction in emissions limits (the "base case") and then going on to combine this with a number of policies which governments might be expected to implement to offset the adverse regional economic effects of the pollution limitations.

4.1 The base case

We begin with the base case in which we shock the national stock of emissions permits by -1%. The effects on the main variables for both regions in the short run and the long run are reported in Table 1 with each of the six states being taken as region 1 in turn.

[Table 1 about here]

Consider first the case where NSW is region 1, starting with the short-run effects. The immediate effect of the restriction on the availability of carbon permits is to push the emission rental rate up in each region and firms, in response, reduce the use of carbon permits in each region; the reduction in region 2 is greater than that in region 1 since region 2 has a higher emissions level in the data base which transforms into a higher coefficient of the right to pollute factor in the production function.[14] Since emissions permits are treated as a normal factor of production, the fall in the use

[14] Indeed, each state except QLD has a share in total emissions lower than its output share.

of permits is accompanied, other things held constant, by a fall in output in both regions, larger in region 2 than in region 1. The change in relative outputs also results in a fall in the price of output in region 1 relative to that in region 2, i.e., a fall in P. In this sense the effects are what would be anticipated on the basis of standard partial equilibrium analysis: within the fall in national output, there has been a re-allocation of output from the high- to the low-pollution region/industry and a rise in the relative price of the high-pollution output.

There are further repercussions when we take the rest of the economy into account. The fall in the use of permits reduces the marginal products of both other factors, labour and capital, both of which reduce the firms' demand for these factors. The fall in the demand for labour reduces employment and increases unemployment and weakens labour's position in the bargaining process and so leads to a fall in the bargained wage. This reduction in the wage is exacerbated by the fall in profits which strengthens the firms' resolve to resist wage pressure.

The fall in the demand for capital reduces the return to capital sufficiently to clear the national market for a given capital stock. Since the demand for capital falls by more in region 2 (being harder-hit by the reduction in pollution permits) than it does in region 1, inter-regional capital mobility results in capital moving from region 2 to region 1.

Finally, the fall in wages, profits and capital income and the rise in unemployment all serve to reduce household incomes and so the consumption of both goods. Not surprisingly, welfare is reduced in both regions.

Thus the signs of the effects of the abatement policy are therefore easily explained in terms of the model structure. The reduction in the availability of permits reduces aggregate output but also shifts output from the more heavily-polluting region to less-heavily polluting one. Moreover, regional governments are right to be concerned about the adverse consequences: output, output per capita, employment, wages and welfare all fall and the unemployment rate rise. As expected, the more heavily-polluting region is worse affected.

Nevertheless, the magnitudes of the repercussions are small, surprisingly so, perhaps. Thus a 10% reduction in emissions (which is a figure commonly cited in public debate in Australia and elsewhere) causes a fall in output of only around 0.2% in each region and an increase in the unemployment rate of about 0.01 percentage points; even for QLD which is hardest hit, the increase in the unemployment rate is only about twice this magnitude. Yet, as already mentioned in our discussion of calibration, these are magnitudes similar to those reported by Garnaut (2008) and Adams (2007).

In the long run, households move between regions in response to welfare differences. Since utility of the representative household in region 2 falls by more than it does in region 1 in the short run, people move from region 2 to region 1. This puts further downward pressure on the wage in region 1 and increases employment but not by enough to absorb all the new labour market entrants; the level of output rises but by less than the population so that, in the transition to the long run, output per capita falls. The opposite happens in region 2 – as people move out, output and employment fall but by less than population so that output per capita rises and the unemployment rate falls (relative to the short run). The relative price of region 2's output falls further. Finally, welfare improves in region 2 but worsens in region 1. Thus, in the long run internal migration results in some equalisation of the effects across the two regions – output per capita and unemployment effects are brought closer together and welfare effects are equalised (by assumption).

These results are more or less the same whichever state is chosen as region 1 with the exception of QLD. This state is the only one to be harder hit by the policy than average so that the relative regional effects are reversed when QLD is chosen as region 1. We presume, therefore, that the QLD government is most likely to use policy or advocate that the national government implement policy to offset the adverse regional consequences (even though these turn out to be small). Further simulations will focus on the case of QLD as region 1.

4.2 The effects of offsetting government policy: *an increase in regional government expenditure*

The next group of simulations are ones in which we combine the emissions reduction with policy intended to offset the adverse effects on output and unemployment. Naturally, such policies may be undertaken by governments independently of the imposition of pollution controls but, in practice, are likely to be combined with the latter since there is considerable political sensitivity to the possible adverse economic consequences of a reduction in emissions permits and therefore pressure on both national and regional governments to ensure that adverse effects on output, employment, unemployment, incomes and so on are minimised. Such policy may, therefore, be undertaken either by the regional government(s) or the national government since both will be under pressure to "do something". The first of these is reported in this sub-section and the results are given in Table 2 in which we investigate the case where the offsetting policy is an increase in expenditure by the regional government. The first set of results in Table 2 simply repeat the base case for QLD as region 1, taken from Table 1, with the second set of results adding an increase in GR in region 1 (the worse affected region) and the third set assuming that both regions attempt to offset the fall in output and increase in unemployment by an expenditure boosts.

When only region 1's government increases its expenditure the results are as follows. Compared to the base case (no policy reaction), the fall in output is now larger for region 1 and smaller for region 2 with a consequently greater increase in unemployment for region 1 and a marginally larger increase in region 2. This unemployment effect reflects a larger fall in employment in region 1 than when the regional government did nothing, the reason for which is the rise in the payroll tax needed to balance the regional government's budget – this reduces both wages and employment considerably in region 1 and marginally in region 2. Thus region 1's response to the reduction in emission permits seems to have been counter-productive – the fall in output (and output per capita) is greater and the rise in the unemployment rate is higher compared to the case where the government did nothing. Even region 2 seems to have been fared slightly worse as a result of the reaction of the other region's government. Despite this perverse effect, however, welfare in region 1 has been improved due to the direct effect of the expenditure boost on utility, while that in region 2 has worsened slightly. Thus, in the short run at least, the government of region 1 has been able to improve the lot of its citizens at the expense of that of those living in region 2.[15]

The reversal of the relative welfare effects causes households to migrate from region 2 to region 1 in the long run. This substantially offsets the short-run fall in

[15] It is, of course the case that the government of region 1 could have undertaken an increase in expenditure financed by a payroll tax in the absence of the national government's reducing emissions permits and could, thereby, have improved the welfare of its representative citizen. This simply reflects the fact that for the particular parameterisation we use, government expenditure is not optimal (in the welfare-maximising sense). However, we would argue that, in practice, it is difficult for governments to assess the optimality of their expenditure levels and, moreover, that the national government's imposing a pollution-control policy is an occasion for an expansionary fiscal policy whether it is optimal or not but simply in response to the need to "do something" to offset the (imagined) effects of the pollution policy.

output in region 1 but still leaves output per capita lower and the unemployment rate higher. The effect on region 2 is the opposite – output falls further but output per capita rises and the unemployment rate falls. Welfare falls in region 1 but rises in region 2. In the long run, the adverse welfare consequences of the reduction in emissions permits are effectively unchanged by the policy reaction of the government of region 1.

In summary, the results of region 1's government's expenditure boost are perverse for output, output per capita and the unemployment rate but "inadvertently" beneficial for welfare (with small costs for region 2) in the short run. In the long run, however, region 1's policy is completely counter-productive – output per capita falls by more and the unemployment rate rises by more than they would have done in the absence of the policy and welfare is largely unaffected.

Consider now what happens if the governments of both regions react to the emissions-permits cut by increasing expenditure by the same proportion, comparing the result to those when only region 1's government reacts. In the short run the fall in output and per capita output is smaller in region 1 but larger in region 2, while the rise in the unemployment rate is greater for both regions, considerably so for region 2. Thus, from the point of view of per capita output and unemployment, the decision by region 2 to increase its expenditure given that region 1 has "already" done this seems counterproductive. However, from a welfare point of view, the decision by region 2's government to join the fray has a small benefit although at considerable cost to region 1's citizens.

In the long run there is migration from region 1 to region 2, boosting output in region 2 but not by as much as population so that output per capita is lower, and the unemployment rate higher than it would otherwise have been. In the long run welfare is lower in both regions than it would have been had neither regional government reacted or had region 1 alone reacted.

In summary, if a regional government reacts to the loss of output and employment by increasing expenditure, the results are counter-productive – output per capita is lower and the unemployment rate is higher than in the absence of the expenditure increase. In the short run there is a welfare benefit to the citizens of the region in which the government acts but this disappears in the long run.

4.3 The effects of offsetting government policy: *a cut in unemployment benefits*

The next regional government policy reaction we consider is a cut in unemployment benefits which a government might do in the hope of reducing the unemployment consequences of the cut in emissions permits imposed by the national government. As explained in the previous section, we might consider this a "classical" rather than a "Keynesian" response to the emergence of unemployment. We again assume that the endogenous variable in the regional government's budget constraint is the payroll tax rate. The results for this simulation are reported in Table 3 where we have again repeated the effects of an emissions permits cut in the first two columns of results and then those for the case where only region 1's government reacts, followed by the case where region 2's government also reacts.

[Table 3 about here]

When only regions 1's government changes the level of unemployment benefits, the "immediate" short run effect is on the labour market and on the bargaining process in region 1 in particular. The wage rate still falls as a result of the emissions cut but by less than in the absence of offsetting policy and employment actually rises instead of falling. The fall in emissions permits and the rise in employment act in opposite directions on output and, given the relative shock sizes (and, of course, the model parameters) the overall effect in this simulation is to reduce output but by less than in the base case. Output per capita also falls by less. Under the dual effects of the fall in unemployment benefits and the fall in payroll taxes needed to balance the budget, the unemployment rate actually falls. Finally, welfare still falls but by less than it would have had the regional government not responded by cutting unemployment benefits. Thus, the decision of the regional government to cut unemployment benefits in response to the national government's reduction in emissions permits is beneficial in all dimensions (per capita output, employment, unemployment and welfare). It is not without cost to region 2, however. In particular, the boost to region 1's output partially reverses the relative price change generated by the emissions reduction policy with the result that region 2's output falls by more and unemployment rises by more. Despite this, region 2 is also made slightly less worse-off because the relative price effect allows residents of both regions to increase their consumption of region 1's output relative to the base case.

In the long run, the utility gap opened up in favour of region 2 induces migration from region 1 to region 2 although the size of the migration flow is smaller than it would have been in the absence of region 1's policy response. There is also a capital flow from region 1 to region 2 in response to changes in the relative rates of return but, again, smaller than in the base case. These combine to make for a boost in employment and output in region 2 relative to region 1 although the per capita output magnitudes move in the opposite direction. Finally, welfare in both regions falls by less than it did in the base case so that the policy response by region 1's government makes the residents of both regions better-off in the long run.

The final two columns in Table 3 show the effects when region 2's government also reacts by reducing its unemployment benefits (matched by a payroll tax cut). In the short run employment now increases in both regions (with the increase in region 1 being similar in magnitude to that which occurred when only region 1 reacted) but a larger outflow of capital from region 1 (due to enhanced marginal product of capital in region 2) leaves output in region 1 smaller (although not compared to the base case). In both regions the unemployment rate now falls. Finally, the welfare loss in region 1 is now smaller than it was when only region 1 acted while region 2 is actually better-off than in the initial equilibrium. Thus, in the short run, there are clear benefits to region 2 of its government also reacting to the imposition of a reduction in emissions permits and this benefit is at no appreciable cost to region 1.

In the long run the welfare gap in favour of region 2 attracts migrants from region 1 which further boosts employment in region 2 and more than offsets the short-run employment gains in region 1. The consequence is that unemployment falls further in region 2 but rises slightly in region 1 relative to the short run. Output follows the same pattern with that in region 1 falling and in region 2 expanding relative to the short run. Finally, despite these favourable developments, there is still a welfare loss in both regions relative to the initial equilibrium although this reduction is considerably smaller than when neither regional government or only one regional government reacts to the reduction in emissions permits. There are, therefore, distinct benefits to each of the regions of both regional governments responding to the national government's pollution reduction policy by reducing unemployment benefits. This is in contrast to the ineffectiveness of a traditional fiscal response of a tax-financed increase in government expenditure.

4.4 The effects of offsetting government policy: *an increase in national government expenditure*

The final case in this second group of simulations is where the national government increases its expenditure (financed from income tax) at the same time that it imposes the cut in pollution permits. It seems likely that there will be pressure from many quarters, including regional governments, for the national government to "do something about" the feared adverse consequences of it pollution-abatement policy. In Table 4 we explore two possible reactions: a rise in national government expenditure in region 1 and a rise in expenditure in both regions. In both cases we assume that the national government balances its budget by adjusting income taxes.

[Table 4 about here]

Consider first the case where the national government increases expenditure only in region1, the region expected to be hit hardest by the reduction in emissions permits. The consequence is that output and output per capita still fall in both regions but by less in each case than when the government does not engage in an offsetting expenditure increase. Similarly, the fall in employment and wages are less than in the base case so that unemployment rates are lower than they would have been in the absence of the national government's action. The reason for this favourable output effect is that the national government increases income tax to maintain a balanced budget and since this revenue is shared with the regional governments, the latter are able to reduce payroll taxes which boost employment and wages. This effect operates in both regions. Profits still fall in both regions because of the tightening of pollution controls and so the income change, though positive, is smaller than the increase in income tax so that consumption of both goods falls. Welfare therefore falls in region

2 but rises in region 1 because of the direct effect on utility of the national government's increase in expenditure.

In the long run the differential welfare effects cause households to migrate from region 2 to region 1, reinforcing the favourable short-run output effects in region 1 but offsetting them in region 2. The resulting output increase in region 1 is insufficient to absorb the extra labour so that the unemployment rate rises in the long run in region 1 while it falls for the opposite reason in region 2. In the long run the national government's policy has made little difference to welfare – it still falls in both regions although by slightly less than it did in the base case.

Although there will be pressure for the national government to act in the region most affected by the emissions reduction, it is likely that in the interests of fairness, the government will act in both regions and the second set of results in Table 4 shows the economic effects of the national government's increasing expenditure by the same proportion in both regions. The immediate result is, not surprisingly, a much larger increase in income tax needed to balance its budget (in our data base region 2 is about four times the size or region 1) and, consequently given the tax-sharing assumptions, a much larger cut in payroll tax is possible in both regions. This has the effect of increasing employment in both regions, thus offsetting the negative effects on output of the reduction in allowable pollution. The main difference to the previous case, where expenditure was increased only in region 1, is that the households in region 2 now also benefit from the direct utility effects of the increase in expenditure. Indeed, the incomes tax increase is so much greater now, that region 1 actually suffers a welfare loss, although not as large as in the base case.

The short-run welfare effects now mean that there is migration from region 1 to region 2 which reinforces the output increase in region 2 and reduces output in region 1, although per capita magnitudes move in the opposite direction. In the long run the unemployment rate falls and welfare falls in both regions but the latter by less than in the base case. Thus both from an unemployment and a welfare perspective, the policy is worthwhile in that it benefits both regions relative to the base case

5. Conclusions

This paper has investigated some of the regional economic consequences of the imposition by the national government of a policy to reduce carbon emissions. We did this in the context of a small two-region model in which we modelled pollution by assuming that firms have to rent permits to pollute from the national government and these permits are treated like a factor in the production function.

We argued that governments (both regional and national) would likely face pressure to undertake additional policy to offset the feared adverse effects of the reduction in pollution permits and so also assessed the effects of a number of possible policies which might be undertaken by either regional governments or the national government to curb the possible adverse impacts of the tightening of pollution controls on regional output, unemployment and welfare. The various questions were analysed using a series of numerical simulations of the model.

Broadly, the simulation results show that the economic effects of a substantial reduction in emissions are adverse but small. Secondly, we show that some policies designed to reduce the negative regional economic impacts of the cut in emissions permits are ineffective, some are counter-productive and others are effective. Thus, in general, policies which involve increasing government expenditure in the regions (either by the regional governments of by the national government) have relatively small effects or are even counter-productive. On the other hand, a reduction in unemployment benefits financed by a payroll tax cut can offsets the adverse welfare effects of the national government's pollution-abatement policy. This is especially so when the offsetting policy is implemented in both regions rather than being concentrated in the worse-affected region.

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Table 1 Base Case: Effects of a Reduction in Carbon Emission (e=-1)

Var	Region 1 = NSW		Region 1 = VIC		Region 1 = QLD		Region 1 = SA		Region 1 = WA		Region 1 = TAS	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
v_1	-0.0205	-0.0226	-0.0188	-0.0226	-0.0398	-0.0226	-0.0102	-0.0226	-0.0162	-0.0228	-0.0211	-0.0226
v_2	-0.0237	-0.0226	-0.0239	-0.0226	-0.0182	-0.0226	-0.0236	-0.0226	-0.0235	-0.0228	-0.0226	-0.0226
c_{11}	-0.0247	-0.0251	-0.0224	-0.0230	-0.0593	-0.0591	-0.0092	-0.0143	-0.0186	-0.0147	-0.0291	-0.0298
c_{21}	-0.0315	-0.0435	-0.0314	-0.0528	-0.0217	0.0894	-0.0307	-0.0914	-0.0305	-0.0883	-0.0291	-0.0367
c_{12}	-0.0247	-0.0129	-0.0224	-0.0015	-0.0593	-0.1705	-0.0092	0.0468	-0.0186	0.0426	-0.0291	-0.0223
c_{22}	-0.0315	-0.0313	-0.0314	-0.0312	-0.0217	-0.0220	-0.0307	-0.0303	-0.0305	-0.0310	-0.0291	-0.0291
j_1	-0.0230	-0.0310	-0.0230	-0.0390	-0.0230	0.0661	-0.0230	-0.0796	-0.0230	-0.0742	-0.0230	-0.0304
j_2	-0.0230	-0.0189	-0.0230	-0.0174	-0.0230	-0.0454	-0.0230	-0.0186	-0.0230	-0.0168	-0.0230	-0.0228
πh_1	-0.0184	-0.0196	-0.0160	-0.0183	-0.0526	-0.0427	-0.0019	-0.0121	-0.0123	-0.0139	-0.0210	-0.0222
πh_2	-0.0248	-0.0243	-0.0249	-0.0240	-0.0152	-0.0179	-0.0242	-0.0233	-0.0239	-0.0239	-0.0226	-0.0226
w_1	-0.0187	-0.0218	-0.0165	-0.0227	-0.0533	-0.0200	-0.0034	-0.0304	-0.0126	-0.0266	-0.0235	-0.0272
w_2	-0.0255	-0.0239	-0.0255	-0.0232	-0.0157	-0.0240	-0.0247	-0.0226	-0.0246	-0.0231	-0.0232	-0.0231
l_1	-0.0006	0.0075	-0.0005	0.0153	-0.0016	-0.0890	-0.0001	0.0552	-0.0003	0.0506	-0.0011	0.0061
l_2	-0.0008	-0.0048	-0.0008	-0.0062	-0.0005	0.0223	-0.0007	-0.0053	-0.0008	-0.0069	-0.0007	-0.0009
k_1	0.0044	0.0116	0.0068	0.0208	-0.0297	-0.1081	0.0208	0.0678	0.0098	0.0563	0.0016	0.0078
k_2	-0.0020	-0.0053	-0.0021	-0.0065	0.0077	0.0281	-0.0014	-0.0045	-0.0019	-0.0110	0.0000	-0.0001
r_{k1}	-0.0228	-0.0230	-0.0227	-0.0230	-0.0229	-0.0230	-0.0228	-0.0234	-0.0220	-0.0190	-0.0226	-0.0226
r_{k2}	-0.0228	-0.0230	-0.0227	-0.0230	-0.0229	-0.0230	-0.0228	-0.0234	-0.0220	-0.0190	-0.0226	-0.0226
e_1	-0.9955	-0.9881	-0.9929	-0.9780	-1.0227	-1.0828	-0.9782	-0.9291	-0.9892	-0.9380	-0.9984	-0.9922
e_2	-1.0019	-1.0050	-1.0017	-1.0054	-0.9854	-0.9466	-1.0004	-1.0014	-1.0009	-1.0053	-1.0000	-1.0002
r_{e1}	0.9771	0.9767	0.9769	0.9758	0.9702	0.9518	0.9763	0.9735	0.9770	0.9753	0.9774	0.9774
r_{e2}	0.9771	0.9767	0.9769	0.9758	0.9702	0.9518	0.9763	0.9735	0.9770	0.9753	0.9774	0.9774
y_1	-0.0184	-0.0114	-0.0160	-0.0022	-0.0526	-0.1310	-0.0019	0.0443	-0.0123	0.0373	-0.0210	-0.0148
y_2	-0.0248	-0.0283	-0.0249	-0.0296	-0.0152	0.0052	-0.0242	-0.0280	-0.0239	-0.0300	-0.0226	-0.0228
n_1	0.0000	0.0081	0.0000	0.0161	0.0000	-0.0884	0.0000	0.0564	0.0000	0.0512	0.0000	0.0074
n_2	0.0000	-0.0040	0.0000	-0.0055	0.0000	0.0231	0.0000	-0.0047	0.0000	-0.0061	0.0000	-0.0002
y_1-n_1	-0.0184	-0.0195	-0.016	-0.0183	-0.0526	-0.0426	-0.0019	-0.0121	-0.0123	-0.0139	-0.021	-0.0222
y_2-n_2	-0.0248	-0.0243	-0.0249	-0.0241	-0.0152	-0.0179	-0.0242	-0.0233	-0.0239	-0.0239	-0.0226	-0.0226
πf_1	-0.0184	-0.0114	-0.0160	-0.0022	-0.0526	-0.1310	-0.0019	0.0443	-0.0123	0.0373	-0.0210	-0.0148
πf_2	-0.0248	-0.0283	-0.0249	-0.0296	-0.0152	0.0052	-0.0242	-0.0280	-0.0239	-0.0300	-0.0226	-0.0228
p	-0.0068	-0.0184	-0.0090	-0.0297	0.0376	0.1485	-0.0215	-0.0771	-0.0119	-0.0736	0.0000	-0.0068
u_1	0.0104	0.0122	0.0101	0.0138	0.0354	0.0133	0.0025	0.0220	0.0070	0.0148	0.0175	0.0203
u_2	0.0161	0.0151	0.0154	0.0140	0.0093	0.0142	0.0147	0.0135	0.0150	0.0142	0.0140	0.0139
t_{w1}	0.0100	0.0327	0.0106	0.0536	0.0228	-0.2084	0.0119	0.1421	0.0070	0.1591	0.0199	0.0353
t_{w2}	0.0145	0.0039	0.0138	-0.0015	0.0105	0.0703	0.0131	0.0000	0.0139	0.0001	0.0128	0.0123
t_y	0.0322	0.0322	0.0322	0.0326	0.0322	0.0325	0.0322	0.0328	0.0322	0.0307	0.0322	0.0323
e	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000

Notes: The symbols in the first column are the proportional changes of their upper-case counterparts; thus, for example, v_1 is the proportional change in V_1. NWS, VIC, QLD, SA, WA and TAS are Australian states New South Wales, Victoria, Queensland, South Australia, Western Australia and Tasmania respectively. SR and LR are abbreviations of "short run" and "long run". Since y_j and n_j are log differences of output and population respectively, y_j-n_j is the log difference of output per capita.

Table 2 Effects of an Increase in Regional Government Expenditure

Variable	e = -1		e = -1 and gr_1 =1		e = -1 and gr_1=1, gr_2=1	
	SR	LR	SR	LR	SR	LR
v_1	-0.0398	-0.0226	-0.0157	-0.0225	-0.0432	-0.0276
v_2	-0.0182	-0.0226	-0.0243	-0.0225	-0.0236	-0.0276
c_{11}	-0.0593	-0.0591	-0.2715	-0.2716	-0.2669	-0.2668
c_{21}	-0.0217	0.0894	-0.0191	-0.0630	-0.2158	-0.1150
c_{12}	-0.0593	-0.1705	-0.2715	-0.2276	-0.2669	-0.3679
c_{22}	-0.0217	-0.0220	-0.0191	-0.0190	-0.2158	-0.2161
g_1	0.0000	0.0000	0.6716	0.6716	0.6716	0.6716
g_2	0.0000	0.0000	0.0000	0.0000	0.6565	0.6565
j_1	-0.0230	0.0661	-0.0593	-0.0945	-0.1882	-0.1073
j_2	-0.0230	-0.0454	-0.0593	-0.0505	-0.1882	-0.2085
πh_1	-0.0526	-0.0427	-0.0589	-0.0628	-0.0578	-0.0488
πh_2	-0.0152	-0.0179	-0.0149	-0.0139	-0.0201	-0.0226
w_1	-0.0533	-0.0200	-0.2976	-0.3108	-0.3096	-0.2794
w_2	-0.0157	-0.0240	-0.0216	-0.0183	-0.2613	-0.2688
l_1	-0.0016	-0.0890	-0.0091	0.0254	-0.0095	-0.0888
l_2	-0.0005	0.0223	-0.0007	-0.0097	-0.0079	0.0128
k_1	-0.0297	-0.1081	-0.0349	-0.0039	-0.0299	-0.1011
k_2	0.0077	0.0281	0.0091	0.0010	0.0078	0.0263
r_{k1}	-0.0229	-0.0230	-0.0240	-0.0240	-0.0279	-0.0280
r_{k2}	-0.0229	-0.0230	-0.0240	-0.0240	-0.0279	-0.0280
e_1	-1.0227	-1.0828	-1.0267	-1.0030	-1.0229	-1.0774
e_2	-0.9854	-0.9466	-0.9828	-0.9981	-0.9852	-0.9501
r_{e1}	0.9702	0.9518	0.9678	0.9751	0.9651	0.9484
r_{e2}	0.9702	0.9518	0.9678	0.9751	0.9651	0.9484
y_1	-0.0526	-0.1310	-0.0589	-0.0279	-0.0578	-0.1290
y_2	-0.0152	0.0052	-0.0149	-0.0230	-0.0201	-0.0017
n_1	0.0000	-0.0884	0.0000	0.0349	0.0000	-0.0802
n_2	0.0000	0.0231	0.0000	-0.0091	0.0000	0.0209
y_1-n_1	-0.0526	-0.0426	-0.0589	-0.0628	-0.0578	-0.0488
y_2-n_2	-0.0152	-0.0179	-0.0149	-0.0139	-0.0201	-0.0226
πf_1	-0.0526	-0.1310	-0.0589	-0.0279	-0.0578	-0.1290
πf_2	-0.0152	0.0052	-0.0149	-0.0230	-0.0201	-0.0017
p	0.0376	0.1485	0.2524	0.2086	0.0511	0.1518
u_1	0.0354	0.0133	0.1975	0.2063	0.2055	0.1854
u_2	0.0093	0.0142	0.0128	0.0109	0.1545	0.1590
t_{w1}	0.0228	-0.2084	2.3463	2.4376	2.4735	2.2636
t_{w2}	0.0105	0.0703	0.0757	0.0521	2.5737	2.6280
t_y	0.0322	0.0325	0.0525	0.0524	0.1984	0.1986
e	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000

Notes: The symbols in the first column is the proportional changes of their upper-case counterparts; thus, for example, v_1 is the proportional change in V_1. SR and LR are abbreviations of "short run" and "long run". Since y_j and n_j are log differences of output and population respectively, y_j-n_j is the log difference of output per capita.

Table 3 Effects of a Reduction in Unemployment Benefits

Variable	Base Case, e = -1		e = -1, ub_1=-1		e= =-1, ub_1=-1,ub2=-1	
	SR	LR	SR	LR	SR	LR
v_1	-0.0398	-0.0226	-0.0227	-0.0185	-0.0193	-0.0020
v_2	-0.0182	-0.0226	-0.0174	-0.0185	0.0024	-0.0020
c_{11}	-0.0593	-0.0591	-0.0314	-0.0313	-0.0325	-0.0324
c_{21}	-0.0217	0.0894	-0.0220	0.0052	0.0049	0.1163
c_{12}	-0.0593	-0.1705	-0.0314	-0.0585	-0.0325	-0.1442
c_{22}	-0.0217	-0.0220	-0.0220	-0.0221	0.0049	0.0045
j_1	-0.0230	0.0661	-0.0188	0.0029	-0.0020	0.0874
j_2	-0.0230	-0.0454	-0.0188	-0.0243	-0.0020	-0.0245
πh_1	-0.0526	-0.0427	-0.0259	-0.0235	-0.0319	-0.0220
πh_2	-0.0152	-0.0179	-0.0167	-0.0173	0.0055	0.0027
w_1	-0.0533	-0.0200	-0.0265	-0.0184	-0.0320	0.0014
w_2	-0.0157	-0.0240	-0.0171	-0.0191	0.0054	-0.0029
l_1	-0.0016	-0.0890	0.0298	0.0085	0.0296	-0.0580
l_2	-0.0005	0.0223	-0.0005	0.0051	0.0306	0.0535
k_1	-0.0297	-0.1081	-0.0073	-0.0265	-0.0297	-0.1083
k_2	0.0077	0.0281	0.0019	0.0069	0.0077	0.0282
r_{k1}	-0.0229	-0.0230	-0.0186	-0.0186	-0.0023	-0.0023
r_{k2}	-0.0229	-0.0230	-0.0186	-0.0186	-0.0023	-0.0023
e_1	-1.0227	-1.0828	-1.0056	-1.0203	-1.0227	-1.0830
e_2	-0.9854	-0.9466	-0.9964	-0.9869	-0.9854	-0.9465
r_{e1}	0.9702	0.9518	0.9797	0.9752	0.9908	0.9724
r_{e2}	0.9702	0.9518	0.9797	0.9752	0.9908	0.9724
y_1	-0.0526	-0.1310	-0.0259	-0.0450	-0.0319	-0.1106
y_2	-0.0152	0.0052	-0.0167	-0.0117	0.0055	0.0259
n_1	0.0000	-0.0884	0.0000	-0.0216	0.0000	-0.0887
n_2	0.0000	0.0231	0.0000	0.0056	0.0000	0.0231
y_1-n_1	-0.0526	-0.0426	-0.0259	-0.0234	-0.0319	-0.0219
y_2-n_2	-0.0152	-0.0179	-0.0167	-0.0173	0.0055	0.0028
πf_1	-0.0526	-0.1310	-0.0259	-0.0450	-0.0319	-0.1106
πf_2	-0.0152	0.0052	-0.0167	-0.0117	0.0055	0.0259
p	0.0376	0.1485	0.0094	0.0365	0.0374	0.1487
u_1	0.0354	0.0133	-0.6461	-0.6515	-0.6425	-0.6647
u_2	0.0093	0.0142	0.0101	0.0113	-0.5945	-0.5896
ub_1	0.0000	0.0000	-1.0000	-1.0000	-1.0000	-1.0000
ub_2	0.0000	0.0000	0.0000	0.0000	-1.0000	-1.0000
t_{w1}	0.0228	-0.2084	-0.2760	-0.3325	-0.2798	-0.5118
t_{w2}	0.0105	0.0703	0.0099	0.0246	-0.3153	-0.2553
t_y	0.0322	0.0325	0.0264	0.0264	0.0028	0.0031
e	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000

Notes: The symbols in the first column is the proportional changes of their upper-case counterparts; thus, for example, v_1 is the proportional change in V_1. SR and LR are abbreviations of "short run" and "long run". Since y_j and n_j are log differences of output and population respectively, y_j-n_j is the log difference of output per capita.

Table 4 Effects of a National Government Expenditure Increase

Variable	Base Case, e = -1		e = -1, gn_1=1		e = -1,gn_1=1,gn_2=1	
	LR	SR	SR	LR	SR	LR
v_1	-0.0398	-0.0226	0.0223	-0.0211	-0.0340	-0.0182
v_2	-0.0182	-0.0226	-0.0322	-0.0211	-0.0141	-0.0182
c_{11}	-0.0593	-0.0591	-0.0766	-0.0770	-0.1492	-0.1490
c_{21}	-0.0217	0.0894	-0.0396	-0.3195	-0.1149	-0.0126
c_{12}	-0.0593	-0.1705	-0.0766	0.2037	-0.1492	-0.2516
c_{22}	-0.0217	-0.0220	-0.0396	-0.0388	-0.1149	-0.1152
g_1	0.0000	0.0000	0.3284	0.3284	0.3284	0.3284
g_2	0.0000	0.0000	0.0000	0.0000	0.3436	0.3436
j_1	-0.0230	0.0661	0.0055	-0.2189	0.1245	0.2065
j_2	-0.0230	-0.0454	0.0055	0.0618	0.1245	0.1039
πh_1	-0.0526	-0.0427	-0.0517	-0.0767	-0.0481	-0.0390
πh_2	-0.0152	-0.0179	-0.0143	-0.0074	-0.0107	-0.0132
w_1	-0.0533	-0.0200	-0.0107	-0.0946	0.1677	0.1984
w_2	-0.0157	-0.0240	0.0270	0.0479	0.2055	0.1979
l_1	-0.0016	-0.0890	-0.0003	0.2197	0.0051	-0.0753
l_2	-0.0005	0.0223	0.0008	-0.0566	0.0063	0.0273
k_1	-0.0297	-0.1081	-0.0297	0.1678	-0.0297	-0.1019
k_2	0.0077	0.0281	0.0077	-0.0436	0.0077	0.0265
r_{k1}	-0.0229	-0.0230	-0.0220	-0.0219	-0.0184	-0.0185
r_{k2}	-0.0229	-0.0230	-0.0220	-0.0219	-0.0184	-0.0185
e_1	-1.0227	-1.0828	-1.0227	-0.8714	-1.0227	-1.0781
e_2	-0.9854	-0.9466	-0.9853	-1.0829	-0.9853	-0.9497
r_{e1}	0.9702	0.9518	0.9710	1.0174	0.9747	0.9577
r_{e2}	0.9702	0.9518	0.9710	1.0174	0.9747	0.9577
y_1	-0.0526	-0.1310	-0.0517	0.1460	-0.0481	-0.1204
y_2	-0.0152	0.0052	-0.0143	-0.0655	-0.0107	0.0080
n_1	0.0000	-0.0884	0.0000	0.2226	0.0000	-0.0814
n_2	0.0000	0.0231	0.0000	-0.0581	0.0000	0.0212
y_1-n_1	-0.0526	-0.0426	-0.0517	-0.0766	-0.0481	-0.039
y_2-n_2	-0.0152	-0.0179	-0.0143	-0.0074	-0.0107	-0.0132
πf_1	-0.0526	-0.1310	-0.0517	0.1460	-0.0481	-0.1204
πf_2	-0.0152	0.0052	-0.0143	-0.0655	-0.0107	0.0080
p	0.0376	0.1485	0.0370	-0.2425	0.0343	0.1364
u_1	0.0354	0.0133	0.0071	0.0628	-0.1113	-0.1317
u_2	0.0093	0.0142	-0.0160	-0.0283	-0.1215	-0.1170
t_{w1}	0.0228	-0.2084	-0.3853	0.1973	-2.0919	-2.3049
t_{w2}	0.0105	0.0703	-0.4351	-0.5859	-2.2983	-2.2432
t_y	0.0322	0.0325	0.2753	0.2747	1.2919	1.2921
e	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000

Notes: The symbols in the first column is the proportional changes of their upper-case counterparts; thus, for example, v_1 is the proportional change in V_1. SR and LR are abbreviations of "short run" and "long run". Since y_j and n_j are log differences of output and population respectively, y_j-n_j is the log difference of output per capita.

Appendix 1: A list of variables

V_i = utility of the representative household, region i,
C_{1i} = real private consumption of good 1 per household, region i,
C_{2i} = real private consumption of good 2 per household, region i,
G_i = real government-provided consumption per household, region i,
GR_i = amount of regional government provided per household, region i,
GN_i = amount of national government provided good per household, region i,
P = price of good 2 in terms of good 1,
J_i = real household income in region i,
ΠH_i = real profit distribution per household, region i,
W_i = real wage per worker, region i,
R_{Ei} = emission permit rental rate, region i,
D_i = productivity parameter, region i,
Y_i = output of the representative firm, region i,
L_i = employment, in region i,
K_i = capital, region i,
R_{Ki} =capital rental rate,
N_i =workforce (= population), region i,
ΠF_i = real profit per firm, region i,
T_Y = income tax,
T_{Wi}= payroll tax, region I,
θ_i = share of national income tax to region i
N = national population.
K = national capital
U_i = unemployment rate, region i,
UB_i= real unemployment benefits per unemployed person, region i,
E_i = pollution emission, region i
E = national pollution emission

Appendix 2: The linearised version of the model

The model is linearised in terms of proportional differences by taking logarithms and differentials of each equation. The linearised form of equations (1) to (18) are as follows, with the linearised form having the same number as the original equation but being distinguished by a prime.

The linearised utility function is:

(1') $v_i = \gamma_{1i} c_{1i} + \gamma_{2i} c_{2i} + \delta_i g_i$ $\qquad i = 1, 2$

where lower-case letters represent the proportional changes (log differential) of their upper-case counterparts.

The linearised consumption demand functions are:

(2a') $c_{1i} = (\lambda - 1)p - \sigma_{TY} t_Y + j_i$ $\qquad i = 1, 2$

(2b') $c_{2i} = \lambda p - \sigma_{TY} t_Y + j_i$ $\qquad i = 1, 2$

where $\sigma_{TY} = T_Y/(1\text{-}T_Y)$.

The linearised definitions of real household income are:

(3a') $$j_1 = \sigma_{J\Pi H1}[(1-\lambda)p + \sigma_{\Pi H\Pi H1}\pi h_1 + \sigma_{\Pi HW1}(w_1 - \sigma_{U1}u_1) + \sigma_{\Pi HUB1}(u_1 + ub_1) + \sigma_{\Pi HK1}(r_{K1} + k_1 - n)] + \sigma_{JK2}(-\lambda p + r_{K2} + k_2 - n)$$

where $\sigma_{J\Pi H1} = \dfrac{P^{1\text{-}\lambda}[\Pi H_1 + (1\text{-}U_1)W_1 + U_1 UB_1 + R_{K1}K_1/N]}{J_1}$,

$\sigma_{\Pi H\Pi H1} = \dfrac{\Pi H_1}{[\Pi H_1 + (1\text{-}U_1)W_1 + U_1 UB_1 + R_{K1}K_1/N]}$,

$\sigma_{\Pi HW1} = \dfrac{W_1(1\text{-}U_1)}{[\Pi H_1 + (1\text{-}U_1)W_1 + U_1 UB_1 + R_{K1}K_1/N]}$,

$\sigma_{\Pi HUB1} = \dfrac{U_1 UB_1}{[\Pi H_1 + (1\text{-}U_1)W_1 + U_1 UB_1 + R_{K1}K_1/N]}$,

$\sigma_{\Pi HK1} = \dfrac{R_{K1}K_1/N}{[\Pi H_1 + (1\text{-}U_1)W_1 + U_1 UB_1 + R_{K1}K_1/N]}$, $\sigma_{U1} = \dfrac{U_1}{1-U_1}$, $\sigma_{JK2} = \dfrac{P^{-\lambda}R_{K2}K_2/N}{J_1}$,

and

(3b') $$j_2 = \sigma_{J\Pi H2}[-\lambda p + \sigma_{\Pi H\Pi H2}\pi h_2 + \sigma_{\Pi HW2}(w_2 - \sigma_{U2}u_2) + \sigma_{\Pi HUB2}(u_2 + ub_2) + \sigma_{\Pi HK2}(r_{K2} + k_2 - n)] + \sigma_{JK1}((1-\lambda)p + r_{K1} + k_1 - n)$$

where $\sigma_{J\Pi H2} = \dfrac{P^{\text{-}\lambda}[\Pi H_2 + (1\text{-}U_2)W_2 + U_2 UB_2 + R_{K2}K_2/N]}{J_2}$,

$\sigma_{\Pi H\Pi H2} = \dfrac{\Pi H_2}{[\Pi H_2 + (1\text{-}U_2)W_2 + U_2 UB_2 + R_{K2}K_2/N]}$,

$\sigma_{\Pi HW2} = \dfrac{W_2(1\text{-}U_2)}{[\Pi H_2 + (1\text{-}U_2)W_2 + U_2 UB_2 + R_{K2}K_2/N]}$,

$\sigma_{\Pi HUB2} = \dfrac{U_2 UB_2}{[\Pi H_2 + (1\text{-}U_2)W_2 + U_2 UB_2 + R_{K2}K_2/N]}$,

$\sigma_{\Pi HK2} = \dfrac{R_{K2}K_2/N}{[\Pi H_2 + (1\text{-}U_2)W_2 + U_2 UB_2 + R_{K2}K_2/N]}$, $\sigma_{U2} = \dfrac{U_2}{1-U_2}$,

$\sigma_{JK1} = \dfrac{P^{1-\lambda}R_{K1}K_1/N}{J_2}$

The linearised migration equilibrium condition corresponding to equation (4) is:

(4') $v_1 = v_2$.

The capital allocation equilibrium condition is:

(5') $r_{K1} = r_{K2}$

The linearised production functions are:

(6') $y_i = d_i + \alpha_{Ei} e_i + \alpha_{Li} l_i + \alpha_{Ki} k_i$ $\quad i = 1, 2.$

The linearised profit definitions, rewritten as output equations, are given by:

(7') $y_i = \sigma_{Y\Pi Fi} \pi f_i + \sigma_{YWi}(\sigma_{TWi} t_{Wi} + w_i + l_i) + \sigma_{YKi}(r_{Ki} + k_i) + \sigma_{YEi}(r_{Ei} + e_i)$ $\quad i = 1, 2$

where $\sigma_{Y\Pi Fi} = \dfrac{\Pi F_i}{Y_i}$, $\sigma_{YWi} = \dfrac{(1+T_{Wi})W_i L_i}{Y_i}$, $\sigma_{TWi} = \dfrac{T_{Wi}}{1+T_{Wi}}$, $\sigma_{YKi} = \dfrac{R_{Ki}K_i}{Y_i}$, $\sigma_{YEi} = \dfrac{R_{Ei}E_i}{Y_i}$.

The profit-maximisation conditions in linear form are:

(8a') $y_i = \sigma_{TWi} t_{Wi} + w_i + l_i$, $\quad i = 1, 2$

(8b') $y_i = r_{Ki} + k_i$, $\quad i = 1, 2$

(8c') $y_i = r_{Ei} + e_i$, $\quad i = 1, 2$

The linear version of the wage-bargaining equilibrium condition is:

(9') $\sigma_{twi} t_{wi} + l_i + u_i + \sigma_{WBWi} w_i - \sigma_{WBUBi} ub_i = \omega_i * + \pi f_i$, $\quad i = 1, 2$

where $\sigma_{WBWi} = \dfrac{W_i}{W_i - UB_i}$, $\sigma_{WBUBi} = \dfrac{UB_i}{W_i - UB_i}$, and ω_i* is the proportional change in ω.

The national government's budget constraint is linearised as:

(10') $\sigma_{RVTY}[t_Y + \sigma_{JJ1}(-\sigma_{\theta 1}\theta_1 * + n_1 + j_1) + \sigma_{JJ2}(-\sigma_{\theta 2}\theta_2 * + n_2 + j_2)]$

$+\sigma_{RVE1}[(1-\lambda)p + r_{E1} + e_1] + \sigma_{RVE2}[-\lambda p + r_{E2} + e_2] = \sigma_{EXGF1}(n_1 + gn_1) + \sigma_{EXGF2}(n_2 + gn_2)$

where $\sigma_{RVTY} = \dfrac{T_Y[(1-\theta_1)N_1J_1 + (1-\theta_2)N_2J_2]}{T_Y[(1-\theta_1)N_1J_1 + (1-\theta_2)N_2J_2] + P^{1-\lambda}R_{E1}E_1 + P^{-\lambda}R_{E2}E_2}$

$\sigma_{JJ1} = \dfrac{(1-\theta_1)N_1J_1}{(1-\theta_1)N_1J_1 + (1-\theta_2)N_2J_2}$, $\sigma_{JJ2} = \dfrac{(1-\theta_2)N_2J_2}{(1-\theta_1)N_1J_1 + (1-\theta_2)N_2J_2}$,

$\sigma_{RVE1} = \dfrac{P^{1-\lambda}R_{E1}E_1}{T_Y[(1-\theta_1)N_1J_1 + (1-\theta_2)N_2J_2] + P^{1-\lambda}R_{E1}E_1 + P^{-\lambda}R_{E2}E_2}$

$\sigma_{RVE2} = \dfrac{P^{-\lambda}R_{E2}E_2}{T_Y[(1-\theta_1)N_1J_1 + (1-\theta_2)N_2J_2] + P^{1-\lambda}R_{E1}E_1 + P^{-\lambda}R_{E2}E_2}$

$\sigma_{EXGF1} = \dfrac{N_1GN_1}{N_1GN_1 + N_2GN_2}$, $\sigma_{EXGF2} = \dfrac{N_2GN_2}{N_1GN_1 + N_2GN_2}$, $\sigma_{\theta i} = \dfrac{\theta_i}{1-\theta_i}$, $\theta_i* = d\theta_i/\theta_i$.

Region 1's government budget constraint in linear form is given by:

(11a') $\sigma_{RVTW1}[(1-\lambda)p + \sigma_{TWTW1}(t_{W1} + w_1 - \sigma_{U1}u_1) - \sigma_{TWUB1}(u_1 + ub_1)]$

$+\sigma_{RV1TY}(\theta_1 * + t_Y + j_1) = gr_1$,

where $\sigma_{RVTW1} = \dfrac{P^{1-\lambda}[T_{W1}W_1(1-U_1) - U_1UB_1]}{P^{1-\lambda}[T_{W1}W_1(1-U_1) - U_1UB_1] + \theta_1 T_Y J_1}$, $\sigma_{TWTW1} = \dfrac{T_{W1}W_1(1-U_1)}{T_{W1}W_1(1-U_1) - U_1UB_1}$,

$\sigma_{TWUB1} = \dfrac{U_1UB_1}{T_{W1}W_1(1-U_1) - U_1UB_1}$, $\sigma_{RV1TY} = \dfrac{\theta_1 T_Y J_1}{P^{1-\lambda}[T_{W1}W_1(1-U_1) - U_1UB_1] + \theta_1 T_Y J_1}$.

Similarly, for region 2's government budget constraint we have:

(11b') $\sigma_{RVTW2}[-\lambda p + \sigma_{TWTW2}(t_{W2} + w_2 - \sigma_{U2}u_2) - \sigma_{TWUB2}(u_2 + ub_2)]$

$+\sigma_{RV2TY}(\theta_2 * + t_Y + j_2) = gr_2$, where $\sigma_{RVTW2} = \dfrac{P^{-\lambda}[T_{W2}W_2(1-U_2)-U_2UB_2]}{P^{-\lambda}[T_{W2}W_2(1-U_2)-U_2UB_2]+\theta_2 T_Y J_2}$,

$\sigma_{TWTW2} = \dfrac{T_{W2}W_2(1-U_2)}{T_{W2}W_2(1-U_2)-U_2UB_2}$,

$\sigma_{TWUB2} = \dfrac{U_2UB_2}{T_{W2}W_2(1-U_2)-U_2UB_2}$ $\sigma_{RV2TY} = \dfrac{\theta_2 T_Y J_2}{P^{-\lambda}[T_{W2}W_2(1-U_2)-U_2UB_2]+\theta_2 T_Y J_2}$.

The definition of the unemployment rate is linearised as:

(12’) $u_i = (1/\sigma_{Ui})(n_i - l_i)$, i = 1, 2

The definition of G_i is linearised as:

(13’) $g_i = \sigma_{GGRi} gr_i + \sigma_{GGFi} gn_i$ i = 1, 2

where $\sigma_{GGRi} = \dfrac{GR_i}{G_i}$, $\sigma_{GGFi} = \dfrac{GN_i}{G_i}$

The national employment constraint results in the following linearised condition:

(14’) $\sigma_{N1} n_1 + \sigma_{N2} n_2 = n$

where $\sigma_{N1} = N_1 / N, \sigma_{N2} = N_2 / N$.

The national capital constraint is linearised as:

(15’) $\sigma_{K1} k_1 + \sigma_{K2} k_2 = k$

where $\sigma_{K1} = K_1 / K, \sigma_{K2} = K_2 / K$

The linearised form of the national emissions permits constraint is:

(16’) $\sigma_{E1} e_1 + \sigma_{E2} e_2 = e$

where $\sigma_{E1} = E_1 / E, \sigma_{E2} = E_2 / E$

The profit distribution condition can be linearised to give:

(17’) $\pi f_i = n_i + \pi h_i$, i = 1, 2

The final equation of the model is the balance of trade condition which, in linear form, is:

(18’) $n_1 + c_{21} = n_2 + p + c_{12}$

Appendix 3: Data-Base

Region	C($m)	LW ($m)	GN($m)	GR($m)	L ('000)	N ('000)	R_kK($m)	R_EE($m)	UB(N-L) ($m)	TR($m)
Region 1 NSW	196376.0	149557.3	18545.4	35108.2	3286.5	3460.6	50031.8	4690.0	2836.7	23423.2
Region 2 ROC	361787.4	280734.7	36333.6	71171.0	6667.1	6993.7	110763.6	11232.0	5323.0	43980.8
Nation	558163.4	430292.0	54879.0	106279.2	9953.6	10454.3	160795.4	15922.0	8159.7	67404.0
Region 1 Vic	144591.6	109211.7	14830.2	26446.0	2542.8	2676.5	38373.6	3120.0	2178.9	17107.8
Region 2 ROC	413571.8	321080.3	40048.8	79833.2	7410.9	7777.9	122421.9	12802.0	5980.9	50296.3
Nation	558163.4	430292.0	54879.0	106279.2	9953.6	10454.3	160795.4	15922.0	8159.7	67404.0
Region 1 Qld	107950.4	84478.3	10591.8	21656.6	2068.0	2163.3	33185.9	6240.0	1553.7	13232.8
Region 2 ROC	450213.0	345813.7	44287.2	84622.6	7885.7	8291.0	127609.5	9682.0	6606.0	54171.2
Nation	558163.4	430292.0	54879.0	106279.2	9953.6	10454.3	160795.4	15922.0	8159.7	67404.0
Region 1 SA	41331.6	29415.9	4436.2	8612.2	757.3	798.5	10076.2	312.0	673.3	4607.7
Region 2 ROC	516831.8	400876.1	50442.8	97667.0	9196.4	9655.8	150719.3	15610.0	7486.4	62796.4
Nation	558163.4	430292.0	54879.0	106279.2	9953.6	10454.3	160795.4	15922.0	8159.7	67404.0
Region 1 WA	56082.8	49053.5	4949.0	11486.4	1074.6	1117.3	26359.6	1248.0	696.3	7689.1
Region 2 ROC	502080.6	381238.5	49930.0	94792.8	8879.0	9337.0	134435.9	14674.0	7463.4	59714.9
Nation	558163.4	430292.0	54879.0	106279.2	9953.6	10454.3	160795.4	15922.0	8159.7	67404.0
Region 1 Tas	11831.0	8575.2	1526.4	2969.8	224.5	238.1	2768.5	312.0	220.8	1343.5
Region 2 ROC	546332.4	421716.8	53352.6	103309.4	9729.1	10216.3	158027.0	15610.0	7939.0	66060.5
Nation	558163.4	430292.0	54879.0	106279.2	9953.6	10454.3	160795.4	15922.0	8159.7	67404.0

Notes: Data for C_i, L_i, LW_i N, NG, GR_i UB and TR are from ABS times series averaged over the period 2004 – 2008. Capital income R_kK is calculated by multiplying the capital stock by a rate of return of 5%. Payment for emissions permits are estimated from Garnaut (2008).