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The regional economic effects of a reduction in carbon emissions*

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Concern about climate change has led to policy to reduce CO_2 emissions although 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, incorporating 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; we also consider a range of such policies. Using numerical simulation, we find that a 10 per cent reduction has relatively small but regionally differentiated economic effects. Standard fiscal policies are generally ineffective or counterproductive while labour market policies are more useful in offsetting the adverse effects.

Key words: carbon emission, numerical modelling, regional effects.

1. Introduction

While there is considerable controversy about the existence, the nature, the causes and the consequences of climate change, governments of many countries, bowing to increasing international pressure, are moving towards significant implementation of policy designed to limit the emission of greenhouse gases (GHG) which are widely held to be one of the main causes of global warming.

Two main alternative policies for achieving a reduction in the emissions of CO_2 (the main GHG) have been proposed – a carbon tax and a 'cap-and-trade' scheme. No matter which scheme is implemented, the result will be a significant realignment of relative prices, inducing a shift in consumption from high- to low-polluting production activity. The imposition of such a policy would be expected to have widespread repercussions on the economy.

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While the literature dealing with the general economic effects of pollution and pollution-reduction policies is extensive, this is not the case for the analysis of the economic impacts of pollution-abatement measures at the regional level.[1] Yet, the costs of the implementation of emission-mitigation policies can be expected to differ across industries and, since industry structure differs across regions, the cost of imposing the policies are likely to differ across regions, although economic adjustments over time might well spread the regional effects more evenly.

But this is not to say that, in the literature on the economic effects of pollution-control, the regional effects have been neglected altogether. For our purposes, it is convenient to group the literature into three categories; first, papers which focus on the economic effects of an exogenous change in pollution abatement; second, those which consider the question of the design of welfare-maximising abatement policy; and third, those which use large-scale numerical CGE models to analyse the detailed effects of the implementation of specific policies.

In the first group are papers such as those by Beladi and Frasca (1996) and Hosoe and Naito (2006). Both of these are theoretical models (even though Hosoe and Naito present some of their results in numerical form) which focus on the effects on regional variables such as output, unemployment and income of an exogenous reduction in the overall level of pollution.

In the second group are more recent papers in which the focus changes to the question of how the appropriate level of pollution should be determined and what is the best way of achieving this optimal level. Papers which do this in a variety of environments include Silva and Caplan (1997), Caplan and Silva (2005), Hadjiyiannis *et al.* (2009) and Boucekkine and Germain (2009).

In the third group are papers which arise from a desire to model details of actual or proposed policies in an economic and environmental-technical framework which much more closely mimics that of actual economies and actual policies. There are many examples of this type but some which have a regional dimension in their economic structure are Adams (2007) in which the regions within a single country (Australia) are analysed, Klepper and Peterson (2006) where the regions are the countries of the EU, and Nordhaus's RICE model, a global model in which individual countries may be considered the regions (see, e.g. Norhaus 2010 for a recent discussion). It is interesting that these CGE models all show substantial differences between the regional effects of centrally imposed policy. Adams, for example, considers an emissions-trading scheme which will reduce the level of emissions by about 21 per cent by 2030. While this has a relatively small effect on national output (a fall of about 1.2 per cent of GDP over the same time horizon), there is considerable regional variation with regional

[1] Note that while public policy discussion focusses on CO_2 reductions, at the level of generality of our model, we talk simply about pollution in general.

output reductions ranging from zero to about twice the national average, underlining the benefits of a regionally disaggregated analysis.

Our paper extends the existing literature in the first group by considering not only the regional effects of the imposition of emissions controls as such, but also the effectiveness of a range of supplementary, regionally differentiated policies designed to offset the expected adverse regional consequences of pollution reductions. We do not set out to address the problem of the optimal design of policy as papers in the second group do.[2] Moreover, while we solve our model numerically using a calibration based on Australian data, our analysis is not designed to produce 'realistic' numbers for Australia as is the case for the CGE literature.

Our model is a two-region one like much of the existing theoretical literature. We allow for internal migration and, like Hosoe and Naito (2006), we distinguish between short-run and long-run solutions on the basis of whether migration takes place or not. We explicitly model government expenditure and taxes at both national and regional levels in order to allow us to consider supplementary policies. Moreover, since the possible unemployment consequences of pollution-abatement policy are an important concern of government policy at both levels, we allow for equilibrium unemployment which is based on a union-bargaining model. 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.

Our model is small and incorporates many simplifications; nevertheless, it is complicated enough to be analytically intractable. We use it to analyse policy by linearising it, calibrating it and simulating the effects of a variety of shocks. While the model includes several broad features of the Australian economy (such as the two-tiered government system and some aspects of the tax and expenditure system) and we use Australian data to calibrate the model, it would be misleading to think of our analysis as an Australian application, with the results indicating the likely magnitudes of the policy effects. For that the model as it stands is too abstract and too highly aggregated. We focus mainly on the signs of effects and the relative magnitudes across the regions.

The structure of the rest of the paper is as follows. In the next section, we set out the model. In Section 3, we discuss the simulations to be undertaken. In Section 4, we report the results of these simulations, and in Section 5, we summarise our results and draw conclusions.

[2] 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 Burtraw and Evans (2009), Betz *et al.* (2010) and Pezzey *et al.* (2010) for an economic analysis of alternatives.

2. The model

Our modelling strategy is to build as simple a model as is consistent with our objective. This allows us to preserve, as much as possible, the transparency of the way in which the model drives the results and, besides, economises on data.

The model which we build is a closed-economy one which has two regions, each with households, firms and a regional government. In addition to regional governments, there is also a national government.

The firms in a region produce a single good which differs across regions. It is distributed to households (as wages, profits and capital rental) 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 and finances it by a payroll tax and its share of an income tax levied by the national government. The national government also provides the government good to households in both regions and finances this by its share of the income tax and revenue from the rental of emissions permits.

Output in each region is produced using four factors: land, labour, capital and the right to pollute (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. Inter-regional migration is allowed only in the long run. We assume migration to be costless and occur in response to inter-regional utility differentials.

Capital is owned by households and is mobile across regional boundaries. The national capital stock is assumed given, and each household owns an equal share of it.

The national government owns the stock of pollution permits which it rents to firms nationwide. The inter-regional allocation of permits and capital is determined so as to equalise the regional rental rates.

We allow for the possibility of equilibrium unemployment in each region, derived from a union-firm bargaining model.

2.1. Households

The representative household in each region has utility function:

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

where, for region i, V_i is utility, C_{ji} is real private consumption of region j's output, and G_i is the real government-provided consumption per household. β_i, γ_{ji} and δ_i are constants with $\beta_i > 0$, $0 < \gamma_{ji} < 1$, $0 < \delta_i < 1$, $\gamma_{1i} + \gamma_{2i} + \delta_i = 1$ for $i, j = 1, 2$.

We define a composite good which has a price index:

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

where P_j is the price of good j (j = 1, 2) and λ is the share of good 1 in total nominal output. Using this composite good, we write the household budget constraint as:

$$(1 - T_Y)J_i = (P_1C_{1i} + P_2C_{2i})/P_C = P^{1-\lambda}C_{1i} + P^{-\lambda}C_{2i}, \quad i = 1,2$$

where P has been used to denote the relative price P_1/P_2, T_Y denotes the income tax rate, and J_i denotes real household income in region i measured in terms of the composite good.

Constrained utility maximisation gives:

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

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

Households own a unit of labour each which they supply to firms in the region 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. 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 the sum of the wage, W_i, weighted by the employment rate, $1-U_i$, 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 region in which they originate so that household income measured in terms of the composite good is:

$$J_1 = P^{1-\lambda}(\Pi H_1 + (1 - U_1)W_1 + U_1UB_1 + R_{K1}K_1/N) + P^{-\lambda}R_{K2}K_2/N, \tag{3a}$$

$$J_2 = P^{-\lambda}(\Pi H_2 + (1 - U_2)W_2 + U_2UB_2 + R_{K2}K_2/N) + P^{1-\lambda}R_{K1}K_1/N, \tag{3b}$$

where ΠH_i is the real profit distribution per household, R_{Ki} is the capital rental rate, and K_i is the capital stock, all in region i. N is the total number of households (which is equal to the labour force, since each household supplies one unit of labour). We also assume for simplicity and without loss of generality that the household size is 1 so that N can also be used to denote the national population.

We assume that inter-regional migration is costless and continues until utilities are equal across regions:

$$V_1 = V_2. \tag{4}$$

We experiment with an alternative as part of our sensitivity analysis.

Capital is mobile across regions so that in equilibrium the rates of return are equalised:

$$R_{K1} = R_{K2} \tag{5}$$

2.2. Firms

We assume that there are a given number of firms in each region which, without loss of generality, we set equal to 1. It is assumed that firms in each region are completely specialised: firms in region i produce good i. 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. They emit pollution for which they must rent permits from the national government. Following Beladi and Frasca (1996), Rosendahl (2008) and Boucekkine and Germain (2009), we treat pollution permits as a factor of production.

Production technology is assumed to be Cobb-Douglas, with constant returns to scale:

$$Y_i = B_i(\mathrm{LAND}_i)^{(1-\alpha_{Li}-\alpha_{Ei}-\alpha_{Ki})}(L_i)^{\alpha_{Li}}(E_i)^{\alpha_{Ei}}(K_i)^{\alpha_{Ki}},$$

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

where B_i is the total factor productivity, K_i is capital, L_i is employment, and E_i is emission permits. We simplify by writing

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

so that

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

Firms maximise profits. Profits are

$$\Pi F_i = Y_i - (1 + T_{Wi})W_iL_i - R_{Ki}K_i - R_{Ei}E_i, \quad i = 1, 2, \tag{7}$$

where T_{Wi} is the payroll tax rate, and R_{Ei} is the emission permit rental rate. 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 and chooses employment, emissions and capital. The profit-maximising conditions are

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

$$\alpha_{Ki} Y_i = R_{Ki} K_i \quad i = 1, 2 \tag{8b}$$

$$\alpha_{Ei} Y_i = R_{Ei} E_i \quad i = 1, 2 \tag{8c}$$

Each household in each region is assumed to supply one unit of labour inelastically to the firms in its own region so that labour force and the number of households are equal. The wage is arrived at by a process of bargaining between firms and unions after which firms choose employment to satisfy Equation (8a). We assume that the resulting level of employment is always at most equal to the labour force so that generally there is (equilibrium) unemployment.

2.3. Wage bargaining

Following Layard *et al.* (1991), we assume that the bargained wage in region i solves

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

subject to (6), (7) and (8a) where A_i is the income which 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. We assume that in the bargaining process, 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.

We assume that A_i is a weighted average of the expected wage in the rest of the region (W_i^E) and unemployment benefits (UB_i):

$$A_i = (1 - U_i) W_i^E + U_i \mathrm{UB}_i$$

Assuming that in equilibrium, the expected wage elsewhere and the actual wage are the same, the first-order condition can be written as

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

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 uniform rate across the country, the revenue from which it shares with the regional governments. The national government also receives the income from firms for the rental of emissions permits. Revenue is converted 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 in amounts which are equal within regions but may differ across regions. The national government's budget constraint can be written as

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

where θ_i denotes the share of the income tax going to region i's government and GN_i, is the amount of the government consumption good *per capita* supplied by the national government in region i.

Regional governments tax payrolls in their own region and receive revenue in the form of output of the region. They also receive a share of the income tax raised in their region and use part of the revenue to pay unemployment benefits, converting the remainder into the government consumption good, denoted GR_i, in the same way that the national government does. The budget constraint for the regional governments can be written (in *per capita* terms) as:

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

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

2.5. Definitions and closure

The unemployment rate is defined as

$$U_i=1-L_i/N_i,\quad i=1,2 \tag{12}$$

The government-provided consumption good per household, G_i, is given by

$$G_i=GR_i+GN_i,\quad i=1,2 \tag{13}$$

There is a given national population, N

$$N_1+N_2=N, \tag{14}$$

a given national capital stock, K

$$K_1+K_2=K, \tag{15}$$

and a given stock of emission permits

$$E_1+E_2=E. \tag{16}$$

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

$$\Pi F_i = N_i \Pi H_i, \quad i = 1, 2 \tag{17}$$

Finally, there must be balanced trade between the regions:

$$N_1 C_{21} = N_2 P C_{12}. \tag{18}$$

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. We follow Hosoe and Naito (2006) and define the short run as the time before inter-regional migration begins to respond to utility changes; in terms of the model, Equations (4) and (14) are suspended and N_1 and N_2 become exogenous. In the long run, all migration adjustment is completed; it solves the model as set out above. We note that while the short-run/long-run distinction suggests that the model has dynamic properties, this is not so in our case. Dynamics could be introduced in various ways, but we leave such extensions for further research.

2.7. The linearised and calibrated version of the model

We linearised the model in proportional changes using log-differentiation and then calibrated it using data for the six Australian states for the period 2004–2008. Given that we have only two regions in our model, we choose one of the states as region 1 and the rest of the country as region 2. We focus on the case where Queensland (QLD) is region 1 since it turns out to be hardest-hit by the pollution reduction. We report the other possibilities as part of the sensitivity analysis.

Further details on the variables used, the linearised model, the details of the calibration and the data are provided in the Data S1 (Supporting information).

3. The simulations

The simulations we carry out are of two types: the 'base case' focusses on the economic effects of the reduction in permits on the regions, with QLD as region 1 and the rest of the country as region 2. Second, we examine the effectiveness of policies which might be undertaken by regional and national governments to offset the negative effects of the reduction in permits. Thus

1 A unit reduction in emissions permits ($e = -1$).[3]
2 A reduction in permits together with an increase in regional government expenditure (financed by payroll taxes). We compute two simulations, one where only region 1 responds and the other where both regions respond ($e = -1$, $gr_i = 1$).
3 A reduction in permits together with regional government unemployment-benefit reductions. Two cases are reported, one where only region 1 responds and the second where both regions react ($e = -1$, $ub_i = -1$).
4 A reduction in permits together with national government increases in expenditure. Two cases are reported – one where only expenditure in region 1 is increased and second where it is also increased in region 2 ($e = -1$, $gn_i = 1$).

These simulations are followed by a number of additional ones which constitute the sensitivity analysis to be reported at the end of Section 4.

4. The results

4.1. The base case

We begin with the base case: $e = -1$. We focus on QLD as region 1. The results for selected variables are reported in the first two columns in Table 1. Full simulations results are reported in the Data S1.

Consider the short-run effects first. The immediate effect of the reduction in permits is to push the emission rental rate up. In response, firms reduce the use of permits; the reduction in region 1 is greater than in region 2 since region 1 has a higher coefficient of E_i in the production function, reflecting a higher emissions-intensity in the data. This response is accompanied by a fall in output, larger in region 1 than in region 2 which results in a rise in the relative price, P. Thus far, the implications are similar to those of partial equilibrium analysis: national output falls and there is a reallocation of output from the high- to the low-pollution region and a rise in the relative price of the high-pollution output. Moreover, while not wanting to make too much of the magnitudes of the effects as such, we note that the effects of the policy on output are relatively small and that this is consistent with the results reported in papers based on CGE models such as Adams (2007) for Australia, Klepper and Peterson (2006) for EU countries, Norhaus (2010) and Zhang (2000) for China.

There are further repercussions when we take the rest of the economy into account. The fall in permits reduces the marginal products of both other

[3] Lower-case symbols represent proportional changes in their upper-case counterparts.

Table 1 Effects of a reduction in carbon emission and offsetting policies

Variable	Base case		Base case + an increase in regional government expenditure				Base case + a reduction in unemployment benefits				Base case + an increase in national expenditure			
	$e = -1$		$e = -1$ and $gr_1 = 1$		$e = -1$, $gr_1 = 1$, $gr_2 = 1$		$e = -1$, $ub_1 = -1$		$e = -1$, $ub_1 = -1$, $ub_2 = -1$		$e = -1$, $gn_1 = 1$		$e = -1$, $gn_1 = 1$, $gn_2 = 1$	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
v_1	−0.0398	−0.0226	−0.0157	−0.0225	−0.0432	−0.0276	−0.0227	−0.0185	−0.0193	−0.0020	0.0223	−0.0211	−0.0340	−0.0182
v_2	−0.0182	−0.0226	−0.0243	−0.0225	−0.0236	−0.0276	−0.0174	−0.0185	0.0024	−0.0020	−0.0322	−0.0211	−0.0141	−0.0182
l_1	−0.0016	−0.0890	−0.0091	0.0254	−0.0095	−0.0888	0.0298	0.0085	0.0296	−0.0580	−0.0003	0.2197	0.0051	−0.0753
l_2	−0.0005	0.0223	−0.0007	−0.0097	−0.0079	0.0128	−0.0005	0.0051	0.0306	0.0535	0.0008	−0.0566	0.0063	0.0273
k_1	−0.0297	−0.1081	−0.0349	−0.0039	−0.0299	−0.1011	−0.0073	−0.0265	−0.0297	−0.1083	−0.0297	0.1678	−0.0297	−0.1019
k_2	0.0077	0.0281	0.0091	0.0010	0.0078	0.0263	0.0019	0.0069	0.0077	0.0282	0.0077	−0.0436	0.0077	0.0265
e_1	−1.0227	−1.0828	−1.0267	−1.0030	−1.0229	−1.0774	−1.0056	−1.0203	−1.0227	−1.0830	−1.0227	−0.8714	−1.0227	−1.0781
e_2	−0.9854	−0.9466	−0.9828	−0.9981	−0.9852	−0.9501	−0.9964	−0.9869	−0.9854	−0.9465	−0.9853	−1.0829	−0.9853	−0.9497
r_{E1}	0.9702	0.9518	0.9678	0.9751	0.9651	0.9484	0.9797	0.9752	0.9908	0.9724	0.9710	1.0174	0.9747	0.9577
r_{E2}	0.9702	0.9518	0.9678	0.9751	0.9651	0.9484	0.9797	0.9752	0.9908	0.9724	0.9710	1.0174	0.9747	0.9577
y_1	−0.0526	−0.1310	−0.0589	−0.0279	−0.0578	−0.1290	−0.0259	−0.0450	−0.0319	−0.1106	−0.0517	0.1460	−0.0481	−0.1204
y_2	−0.0152	0.0052	−0.0149	−0.0230	−0.0201	−0.0017	−0.0167	−0.0117	0.0055	0.0259	−0.0143	−0.0655	−0.0107	0.0080
n_1	0.0000	−0.0884	0.0000	0.0349	0.0000	−0.0802	0.0000	−0.0216	0.0000	−0.0887	0.0000	0.2226	0.0000	−0.0814
n_2	0.0000	0.0231	0.0000	−0.0091	0.0000	0.0209	0.0000	0.0056	0.0000	0.0231	0.0000	−0.0581	0.0000	0.0212
y_1-n_1	−0.0526	−0.0426	−0.0589	−0.0628	−0.0578	−0.0488	−0.0259	−0.0234	−0.0319	−0.0219	−0.0517	−0.0766	−0.0481	−0.0390
y_2-n_2	−0.0152	−0.0179	−0.0149	−0.0139	−0.0201	−0.0226	−0.0167	−0.0173	0.0055	0.0028	−0.0143	−0.0074	−0.0107	−0.0132
u_1	0.0354	0.0133	0.1975	0.2063	0.2055	0.1854	−0.6461	−0.6515	−0.6425	−0.6647	0.0071	0.0628	−0.1113	−0.1317
u_2	0.0093	0.0142	0.0128	0.0109	0.1545	0.159	0.0101	0.0113	−0.5945	−0.5896	−0.0160	−0.0283	−0.1215	−0.1170
p	0.0376	0.1485	0.2524	0.2086	0.0511	0.1518	0.0094	0.0365	0.0374	0.1487	0.0370	−0.2425	0.0343	0.1364

Notes: The symbols in the first column are proportional changes of their upper-case counterparts. SR and LR denote 'short run' and 'long run'. $y_j - n_j$ is the proportional change in output *per capita*.

factors, and firms reduce demand for these factors. The reduced demand for labour decreases employment and increases unemployment; this weakens labour's bargaining position. The fall in profits strengthens firms' resolve to resist wage pressure. Both lead to a fall in the bargained wage.

The fall in the demand for capital reduces the return to capital sufficiently to clear the national market. Since the demand for capital falls by more in region 1 than it does in region 2, capital moves from region 1 to region 2.

Finally, the fall in wages, profits and capital income and the rise in unemployment serve to reduce household incomes and so the consumption of both goods. Welfare falls in both regions. The fall in welfare as well as output and employment and the rise in unemployment are all larger in region 1 than they are in region 2.

Thus, the signs of the effects of the abatement policy are 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 the 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 rises. As expected, the more heavily polluting region is worse affected.

In the long run, households migrate in response to welfare differences, in this case from region 1 to region 2. This puts further downward pressure on the wage in region 2 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 and the unemployment rate rises. The opposite happens in region 1 – 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). Finally, welfare improves in region 1 but worsens in region 2. 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).

4.2. Offsetting government policy: an increase in regional government expenditure

We now combine the emissions reduction with an increase in expenditure by the regional government, intended to offset the adverse effects on output and unemployment. The simulation results are reported in the second four columns in Table 1.

Consider first the case where only region 1 (QLD) responds. Compared to the base case, 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 seemingly counterproductive effect for region 1 is caused by the regional budget constraint which requires the payroll tax rate to be raised to finance the higher expenditure. This reduces both wages and employment considerably in region 1 and marginally in region 2. 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, the government of region 1 has been able to improve the lot of its citizens although at the cost of higher unemployment and at the expense of the welfare of those living in region 2.

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 output in region 1 but still leaves output *per capita* lower and the unemployment rate higher. The effect on region 2 is the opposite. Welfare falls in region 1 but rises in region 2.

Consider now what happens if the governments of both regions increase 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, is 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 counterproductive – output *per capita* is lower and the unemployment rate is higher than in the absence of the expenditure increase. This is driven by the need to raise taxes to finance the extra expenditure. 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. By and large therefore what might be considered a standard Keynesian fiscal response to unemployment is not effective.

4.3. Offsetting government policy: a cut in unemployment benefits

Consider now what might be called a classical response to unemployment – a reduction in unemployment benefits. The results for this simulation are reported in the third set of four columns of Table 1. When only region 1's government changes the level of unemployment benefits, the 'immediate' effect is on the bargaining process. For region 1, 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 rise in employment boosts output but not by enough to completely offset the effect of the fall in emissions permits. With the fall in unemployment benefits and the fall in payroll taxes (to balance the budget), the unemployment rate falls by enough to more than offset the effects of the pollution reduction. Finally, welfare still falls but by less than it would have had the regional government not responded.

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 the short run in all dimensions (*per capita* output, employment, unemployment and welfare). However, there is a cost to region 2. 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 short-run utility changes induce migration from region 1 to region 2 although the size of the migration flow is smaller than in the base case. This combined with a movement of capital to region 2 makes 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.

Suppose now that region 2's government also reduces unemployment benefits, financed by a payroll tax cut. We focus on the comparison with the case where only region 1 reacts. In the short run, employment now increases in both regions but a larger outflow of capital from region 1 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 acts 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, 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 wipes out the short-run employment gains in region 1. The employment changes do not completely offset the population movements so that unemployment falls further in region 1 but rises slightly in region 2. Output follows the same pattern as employment while output *per capita* follows the same pattern as unemployment. Moreover, welfare falls by considerably less than it would have in the absence of a regional reaction. Thus, there are distinct benefits to the pursuit of the classical solution to unemployment compared to the Keynesian fiscal response reported in the previous subsection.

4.4. Offsetting government policy: an increase in national government expenditure

The final pair of simulations analyse the case where the national government increases its expenditure (financed from income tax) at the same time that it imposes the cut in pollution permits. Results are reported in the last four columns of Table 1.

Consider first an increase in national government expenditure in region 1 only. The consequence is that output and output *per capita* still fall in both regions but by less than in the base case. Similarly, the falls 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 these favourable effects is that the national government maintains a balanced budget by increasing income tax which is shared with regional governments who use this to reduce payroll taxes which boost employment and wages. This effect operates in both regions. Profits still fall in both regions because of the increase in the costs of pollution so that after-tax income falls and consumption of both goods also 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, households migrate from region 2 to region 1, reinforcing the short-run output effects in region 1 but offsetting them in region 2. Unemployment rates move in the opposite direction since the magnitude of the employment changes are smaller than the migration flows. 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.

The final set of results in Table 1 shows the 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 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, more than offsetting the negative effects of the reduction in pollution. The main difference to the previous case is that the households in region 2 now also benefit from the direct utility effects of the increase in expenditure. Indeed, the income tax increase is so much greater now that region 1 actually suffers a welfare loss, although not as large as in the base case.

In the long run, there is migration from region 1 to region 2 which reinforces the employment and output increases in region 2 and reduces them in region 1, although *per capita* magnitudes move in the opposite direction. Compared to the short run, the unemployment rate rises and welfare falls in region 2 with the opposite effect occurring in region 1. However, compared to the base case, both regions are better-off in terms of both unemployment and welfare and from this perspective the policy has been worthwhile.

4.5. Sensitivity analysis

We also ran a number of extra simulations for the purposes of sensitivity analysis. In particular, we experimented with changing the region chosen as region 1, varying the proportion of output traded with the other region, changing the assumed return to capital and assuming that migration is motivated by expected wage differences.

The results are reported in the Data S1. The change in the choice of region 1 has little effect on the results apart from reversing the relative magnitudes across regions, as expected since in the base simulations we chose region 1 as the hardest-hit region and noted that all other states were less hard-hit than the national average. The remaining three sets of simulations show clearly that our qualitative conclusions are unaffected by these choices and, in many cases, there is also little change in the numerical values of the impacts of a pollution-reduction shock.

5. Conclusions

This paper has investigated some of the regional economic consequences of the imposition by the national government of a policy to reduce pollution. 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; so we also assessed the effects of a number of possible policies of this sort. 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 and regionally differentiated but small, a result consistent with CGE-based outcomes for a range of countries reported in the literature. Secondly, we show that some policies designed to reduce the negative regional economic impacts of the cut in emissions permits are ineffective, some are counterproductive and others are effective. Thus, in general, policies which involve increasing government expenditure in the regions (either by the regional governments or by the national government) have relatively small effects or are even counterproductive. On the other hand, a reduction in unemployment benefits financed by a payroll tax cut can offset 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.

Finally, we reiterate some points regarding our modelling approach and make suggestions for further research. Our model is a theoretical one chosen to be as simple as possible, consistent with our aims: analysing the effects of a pollution reduction as well as a variety of supplementary policies. We linearised the model and calibrated it using Australian data, a procedure we share with CGE models such as Adams (2007). But our model is far removed in terms of abstraction and aggregation from the CGE class. Like theoretical models, we focus on signs and relative magnitudes of the effects of shocks rather than the magnitudes of the effects themselves. Moreover, unlike CGE models, we did not seek to capture the details of a particular economy. Rather, our method is applicable to a range of economies which have broadly similar characteristics. As always, there are costs and benefits. On the cost side, our results depend on the calibration used, as is the case with the CGE approach. We addressed this issue by reporting a range of sensitivity tests which show our conclusions to be reasonably robust. Further, our results lack the precision of the large CGE model output. On the benefit side, our model is relatively transparent, and the relevance of our analysis is not confined to the economy from which we drew data for calibration; the results are likely to hold for any economy with a broadly similar structure. Besides, using the model (linearisation, calibration and solution) is orders of magnitude simpler than for a large CGE model.

We have made several simplifying restrictions which might usefully be relaxed and provide material for further research. Two simplifications which we have mentioned are the absence of international trade and the absence of dynamics. Both of these preclude the consideration of interesting issues in this area and could usefully be relaxed to allow the analysis to address additional questions.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1. Supplementary information.