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Regional effects of an emissions-reduction policy in China: Taxes, subsidies and the method of financing

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Regional Effects of an Emissions-Reduction Policy in China: Taxes, Subsidies and the
Method of Financing

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Abstract

The issue of the possible adverse effects of a reduction in pollution on the economy is a very real one for China, given its public commitment to substantial cuts in CO₂ emissions by 2020. An important part of this issue is the regional dimension – the pollution reduction is likely to have significantly different effects across the regions and so possibly exacerbate the already large and persistent inter-regional disparities in China. Policy choices will therefore be complicated and will need to be carried out with a clear understanding of the impact of alternative policies at national and regional levels. One important policy choice which has received little, if any, attention in the regional context is the one between a tax on pollution and a subsidy on abatement activity. We help elucidate this policy choice by exploring the tax-subsidy issue in a small theoretical model which captures some of the salient features of the Chinese regions and the tax/expenditure system. We also use the model to address closely related questions regarding the importance of alternative methods of financing the tax or subsidy. We solve the model numerically based on Chinese data. We find that if revenue-recycling via lump-sum taxes and subsidies is possible, a centrally imposed emissions tax has the same effects on all relevant variables (except for the distribution of income between wages and profits) as an equivalent abatement subsidy. The move from recycling to more realistic financing methods results in differences between the effects of an emissions tax and an abatement subsidy -- more for economic variables such as wages, profits, incomes and output than for welfare. Generally, welfare falls in both regions for both instruments under all financing assumptions. But the regional welfare disparity narrows in all cases except where recycling is assumed. The disparities in other variables generally widen for all central government policies without recycling but are reduced for regional government subsidies financed by output taxes or infrastructure. In the last two case, however, the narrowing of the gaps is achieved by a greater reduction in the variable in the coast than in the interior, an outcome which may please no one. (360 words)

Key Words: carbon emissions, tax v subsidy, regional effects, China

JEL classifications: Q52, Q58, R12, R13

1. Introduction

China's high growth rate in the past 30-plus years has brought great benefits to the country on the one hand, but on the other it has also resulted in serious problems such as environmental deterioration and widening regional disparities. The rapid growth of carbon emissions is claimed to be one important factor which has contributed to national environmental degradation and which has also spilled over to the global environment. China's carbon dioxide (CO₂) emissions have jumped from 1422 million tonnes (Mt) in 1978 to 8979 Mt in 2011, representing an average annual growth rate of 5.8 per cent during this period.¹ Given the size and growth of the Chinese economy, it is not surprising that China has become the largest emitter of carbon in the world, accounting 26.4 per cent of the total world emissions in 2011.

Partly because of the realisation of the problems which high emissions impose on sustainable economic development and but also because of international pressure to reduce emissions, the Chinese central government announced its carbon emission mitigation target in 1999. It promised to reduce CO₂ emissions per unit of GDP by 40-50 per cent below 2005 levels by 2020. To implement this commitment, China has set a national target of reducing CO₂ intensity (CO₂ emission per unit of GDP) by 17 per cent over the 12th Five-Year Plan (2011-2015). A new development concept called "Beautiful China" has been advocated at the 18th National Congress of the Communist Party of China in November 2012, reflecting the greater environmental concerns in China.

These environmental concerns have simulated a number of potential policy responses, including a proposal to cap CO₂ emission for each province, establishing industrial energy efficiency audits, setting targets for the deployment of renewable electricity generation, introducing a carbon tax, developing markets for trading carbon emissions permits, providing

¹ The data on emissions come from BP (2012).

financial subsidies for carbon reduction and so on. Among these policies, a carbon tax has received much attention, and is believed to be one of the most likely mitigation instruments in the near future (Liang and Wei, 2012).

The main rationale for a carbon tax is to internalise the externalities associated with emissions. It is expected that a carbon tax will lead to an increase in the price of goods which are pollution-intensive relative to other goods and a shift in the economic structure from high-emission-intensity to low-emission-intensity production. Thus, the imposition of such a policy can be expected to result in widespread reallocations within the economy.

Given the growing concern about the adverse global effects of carbon emissions, it is not surprising that the effects of policies designed to reduce such emissions have been extensively analysed. Analysis has been undertaken both within small theoretical models as well as in large Computable General Equilibrium (CGE) models. The first category includes papers such as Hoel (2006) which derives the optimal carbon taxes for cooperating countries, Fischer (2008) which considers the socially optimal level of R&D in abatement technology when optimal carbon taxing or carbon pricing is not possible and Galinato and Yoder (2010) which solves for sector-specific pollution taxes to maximise utility of the representative household.

In the CGE class, there are models for many countries; e.g., Bohringer and Hutherford (1997) for Germany, Gilbert and Netcalf (2009) for the U.S., Meng, Siriwardana and McNeill (2013) for Australia, Callan *et al.* (2009) for Ireland, Bye and Jacobsen (2011) for Norway and Devarajan *et al.* (2011) for South Africa.

There are relatively few papers which develop models to explore the effects of carbon taxes on emission reduction in China. Garbaccio, Ho and Jorgenson (1999) builds a CGE model of Chinese economy which includes carbon emissions besides many other elements of the economy. They find the potential for a “double dividend” in China, i.e., a decrease in

emissions of CO₂ and a long-run increase in GDP and consumption if the carbon tax revenue is spent on investment. In a new generation of the Garbaccio, Ho and Jorgenson model, Fisher-Vanden and Ho (2007) finds that the effects of carbon taxes on the economy are affected by the reform of the capital market in China.

Lu, Tong and Liu (2012) constructs a dynamic recursive CGE model and estimates the effects of carbon taxes and complementary policies on the Chinese economy. They find that carbon taxes can reduce emissions substantially with little negative impact on economic growth. In addition, the use of carbon-tax revenue to replace indirect taxes on firms and to provide lump-sum subsidies to consumers has large effects on production and consumption.

Liang, Fan and Wei (2007) develops a CGE model with 16 sectors and simulates the effects of a carbon tax policy in China. They find that the negative macroeconomic impact of a carbon tax on the economy can be alleviated by properly relieving or subsidising production sectors. Using a similar model, Liang and Wei (2012) explores the impact of a carbon tax on household disposable income. They find that a carbon tax will not only widen the urban–rural gap, but also reduce the living standards of households in both urban and rural areas.

All the papers on China above focus their analysis on the effects of a tax on carbon emissions on the macro economy. None of them evaluates the regional economic effects of the emissions control. We argue that this is a serious shortcoming since there exists significant heterogeneity across regions in China. In general, the coastal region has a higher per-capita GDP as well as higher carbon emissions but a lower emission intensity compared with the interior region (Li and He, 2010). Since emissions-control policy will almost certainly have regionally-differentiated effects, it is possible that it will exacerbate existing inter-regional differences at a time when policy-makers at all levels agree they are a serious problem which need to be addressed in their own right.²

² For recent discussion of regional disparities, see Chen (2010), Chen and Groenewold (2012) and Lin, Lin and Ho (2013).

This is not to say that the regional effects of carbon taxes have been completely ignored; several papers have extended the CGE analysis to include regions.³ Li and He (2010) builds a regional CGE model for China with 30 regions and 23 sectors and analyses the effects of a uniform carbon tax on the regions. They find that the welfare losses of the provinces in the central and western regions are bigger than those in the coastal region. The carbon tax will enlarge the regional income gap if other support measures are not implemented.

Zhang *et al.* (2012) builds a regional CGE model for China with 30 provinces, three regions in the world and 26 commodity groups and assesses the impact of alternative approaches to achieving the emissions reduction target in the 12th Five-Year Plan with an endogenous tax on CO₂ embodied in energy used. They find that a regionally-differentiated target and a single national uniform target have differing effects on the economy across provinces.

Finally, Pu and Hayashiyama (2012) builds a multi-regional CGE model for China with 8 regions and 30 sectors to evaluate the effects of an energy resource tax on China's regional economy. They find that such a tax can reduce emissions with minor adverse effects on macroeconomic variables although the effects differ across regions.

Thus, there are relatively few papers using models which permit an analysis of the regional dimension of the effects of a tax to reduce carbon emissions in China. Moreover, there appears to be considerable disagreement on the nature and extent of regional effects.

Our paper contributes to and builds on the existing literature as follows. Like Li and He (2010), Zhang *et al.* (2010), Pu and Hayashiyama (2012), we investigate the regional economic effects of a carbon tax in China. But, while they use CGE models, we use a small two-region theoretical model. Our regions are based on the common distinction in China

³ The regional economic effects of other carbon control policies, such as an emissions cap have received attention in recent work, e.g., Aunan *et al.* (2007), Vennemo *et al.* (2009), Chen and Groenewold (2013).

between the coastal and interior regions. We specify our model to include various aspects of the Chinese economy, including the household registration or *hukou* system and elements of its tax and expenditure system. Our model has only two goods, one produced in each region, identical households in each region and identical firms in each region. It abstracts from open-economy considerations. It is, therefore, several orders of magnitude smaller and considerably simpler than a normal CGE model, and we argue that it is, by comparison, quite transparent so that we can more easily trace the effects of the carbon tax through the model structure. In addition, our model requires far less disaggregated data, an attractive feature given the paucity of China's data which creates difficulties in calibrating the parameters of large numerical models (Pu and Hayashiyama, 2012).

Moreover, we explore the effects not only of carbon taxes but also of subsidies. The subsidies we model are not simply lump-sum recycling of pollution-tax revenues as in Garbaccio, Ho and Jorgenson (1999), Liang and Wei (2012) and Lu, Tong and Liu (2012). Rather, they are emissions-reduction instruments in their own right. In addition, many studies assume the existence of lump-sum taxes and subsidies which can be used to finance emissions-abatement subsidies or distribute emissions-tax revenue. While this is a convenient theoretical device and it is one which we use as a starting point for our analysis, it is not available in practice and, following Bye and Jacobsen (2011), we argue that subsidies need to be financed and tax revenue needs to be distributed through channels captured by the relevant government budget constraint and which will themselves have distortionary effects on the economy. This leads us to explore and compare various alternative methods of financing subsidies and distributing tax revenue.

We find that if we assume the availability of lump-sum taxes and subsidies for balancing the government's budget constraint (the revenue/tax-recycling case), a centrally imposed emissions tax has the same effects on all relevant variables (except for the

distribution of income between wages and profits) as an abatement subsidy that reduces overall emissions by the same amount. The move from recycling to more realistic financing methods results in differences between the effects of an emissions tax and an abatement subsidy although the differences are more apparent for economic variables such as wages, profits, incomes and per capita outputs than for welfare. With one minor exception, welfare fall in both regions for both instruments under all financing assumptions. But the disparity in welfare between the coast and the interior narrows in all cases except where recycling is assumed in which case it widens. The disparities in other variables (wages, incomes and per capita outputs) generally widen for all central government policies without recycling but are reduced when the regional government increases subsidies financed by output taxes increases or reductions in infrastructure expenditure. In the last two case, however, the narrowing of the gaps is achieved by a greater reduction in the relevant variable in the coast than in the interior, an outcome which may please no one.

We conclude that it is important for governments first to decide on their target variable(s): welfare or more readily measurable economic variables such as wages, income or per capita output and: levels of the variables or inter-regional disparities. Having decided this question, they need to give careful attention to alternative financing methods. Finally, since inter-regional gaps generally narrow in the long run, governments must decide on the time horizon of their policy objectives to avoid over-reaction to short-run movements.

The structure of the paper is as follows. In section 2 we develop the model, we set out the simulations in section 3 and report the results of these simulations in section 4.

Conclusions are presented in section 5.

2. The model

We use a simple two-region model with some features reflecting Chinese economic characteristics. The simplest regional division of China is into coastal and inland (or interior) regions. These two regions have been the basis for the discussion of regional policy until the mid-1980s. It has also been the scheme used in much empirical work on regional issues in China.⁴ We use this two-region division in our model and denote the coastal and interior regions C and I respectively.⁵

Each region has households, firms and regional governments. There is also a central government. Households supply labour to firms which produce output. Households receive income from wages and profits and they use this income to purchase some of each region's output for consumption; in addition, they receive a government-provided consumption good which is private in the rival sense.

Firms within a region produce a homogeneous output which differs across regions. We therefore talk of a single industry consisting of identical firms within each region. Firms use three conventional factors – labour, capital and land, as well as a government-provided public good which we call infrastructure. National supplies of labour, capital and land are fixed and neither capital nor land is inter-regionally mobile, making regional supplies also fixed. We assume that labour is inter-regionally mobile in the long run so that long-run regional labour supplies are endogenous.⁶

We model emissions in keeping with much of the recent literature in the area by assuming that pollution is proportional to output; see, e.g., Fischer (2008), Galinato and

⁴ Recent papers using this classification include Whalley and Zhang (2007), He *et al.* (2008), Fleisher *et al.* (2010) and Su and Jefferson (2012).

⁵ The coastal region consists of Beijing, Tianjin, Hebei, Guangdong, Hainan, Shandong, Fujian, Zhejiang, Jiangsu, Shanghai, Liaoning and Guangxi with the remaining provinces being allocated to the interior region. The interior therefore consist of: Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Sichuan, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Tibet, Xinjiang.

⁶ We have also experimented with an expanded model in which there is capital-mobility between regions. The model is considerably more complicated, making the results less transparent without greatly changing our conclusions. We report the results for this model as part of our robustness analysis in Appendix 6.

Yoder (2010) and Bye and Jacobsen (2011).⁷ The emissions-intensity of output is allowed to vary across the regions. Firms can reduce actual emissions at each level of output by incurring abatement costs. We ignore the disutility of pollution since we are not interested in deriving the optimal level of pollution for which this would be necessary. While we analyse the welfare effects of various model shocks, we do not include the direct effects on utility of reductions in pollution and in this we follow Bye and Jacobsen (2011). Like them, we focus on emissions which cause global warming which is related to world-wide pollution levels. Since global pollution is not greatly affected at the margin by current regional emissions levels, even for a country as large as China, we ignore the direct adverse effects of regional emissions on welfare. We assume that firms must pay a pollution tax to the central government. They may also receive government subsidies to encourage abatement.

We distinguish between central and regional governments, with the latter including all sub-national government levels although we recognise that, in practice, the latter level includes several layers (provincial, prefecture, county and township). In our model, both levels of government provide households with a consumption good. In addition to this, the regional governments also provide infrastructure which is a public factor of production. Moreover, both levels of government may pay firms a subsidy to encourage pollution-abatement activity.

On the taxation side, in addition to the pollution tax we assume three taxes in the model in a way which broadly reflects the stylised facts of the Chinese taxation system. The first is a national VAT, the rate for which is set by the central government at the same level for both regions and the proceeds from which are shared between the central government and the regions. The other two taxes are levied by each regional government on the output produced in its own region.

⁷ An alternative to our treatment of emissions is to assume that production uses “environmental capital” (Hosoe and Naito, 2006) so that permits to pollute are treated as a factor of production; see, e.g., Beladi and Rapp (1993), Beladi and Frasca (1996), Rosendahl (2008), Hadjiyiannis et al. (2009) and Boucekine and Germain (2009).

We assume that households supply labour inelastically to firms in their own region (each household supplying one unit) and choose consumption to maximise utility. Firms choose factor inputs, output and abatement activity to maximise profits, taking the factor prices, tax rates and the abatement subsidy level as parameters. We assume that governments are exogenous but each must satisfy a budget constraint.

We consider the behaviour of households, firms and governments in more detail in turn.⁸

2.1 Households

Households derive utility from the consumption of the two privately-produced goods (one produced by the firms in each region) as well as from a good supplied by governments. We assume a representative household in each region i ($i = I, C$) and that the utility function for this household is of the constant-elasticity-of-substitution (CES) form:

$$(1) \quad V_i = \beta_i (\gamma_{II} C_{II}^{-\rho} + \gamma_{CI} C_{CI}^{-\rho} + \delta_i GH_i^{-\rho})^{\frac{-1}{\rho}}, \quad i = I, C$$

where V_i = utility, C_{ji} = real private consumption of good j ($j = I, C$), GH_i = real government-provided consumption, in region i and β_i , γ_{ji} , δ_i and ρ , are parameters with $\beta_i > 0$, $0 < \gamma_{ji} < 1$, $0 < \delta_i < 1$, $\gamma_{II} + \gamma_{CI} + \delta_i = 1$, and $\rho > -1$.

Households receive income from wages and profits paid by firms in the region in which they live.⁹ Household income in each region is measured in terms of its own output. Thus in the interior region the household budget constraint is:

$$C_{II} + P^I C_{CI} = J_I,$$

and in the coast it is:

$$PC_{IC} + C_{CC} = J_C,$$

⁸ A list of variables is given in Appendix 1.

⁹ We therefore abstract from inter-regional commuting and from inter-regional firm ownership. Each assumption simplifies the extent of inter-regional links without sacrificing any essential relationships.

where J_i ($i = I, C$) is income in region i in terms of its own output, P denotes the relative price P_I/P_C and income is measured net of the VAT which we account for when we define income below.¹⁰

Utility maximisation subject to the household budget constraint gives the consumption demand functions:

$$(2a) \quad C_{II} = \frac{J_I}{P^{-1} \left[P \frac{\gamma_{CI}}{\gamma_{II}} \right]^{\frac{1}{\rho+1}} + 1},$$

$$(2b) \quad C_{IC} = \frac{J_C}{\left[P \frac{\gamma_{CC}}{\gamma_{IC}} \right]^{\frac{1}{\rho+1}} + P},$$

$$(2c) \quad C_{CI} = \frac{J_I}{\left[P \frac{\gamma_{CI}}{\gamma_{II}} \right]^{\frac{-1}{\rho+1}} + P^{-1}},$$

$$(2d) \quad C_{CC} = \frac{J_C}{P \left[P \frac{\gamma_{CC}}{\gamma_{IC}} \right]^{\frac{-1}{\rho+1}} + 1}.$$

Household income is derived from wages and profits. Households each own a unit of labour which they supply to firms in their own region and they own the firms in equal shares in their region. Wages and profits are both measured in terms of output of the region in which they originate. Recalling that household income is also measured in terms of units of output of their own region, we have:

$$(3a) \quad (1+T_V)J_I = \Pi H_I + W_I,$$

$$(3b) \quad (1+T_V)J_C = \Pi H_C + W_C,$$

¹⁰ The simple structure of the model implies that the VAT is equivalent to a tax on consumption and, given that households spend all their income, it is also equivalent to an income tax.

where T_V = the VAT rate, W_j = the real wage in industry j , and ΠH_i = real profit distribution per household in region i .

Inter-regional migration has been an important spatial equilibrating mechanism in regional models. In our model we allow for migration from one region to another although, given the slow reaction of migration to economic incentives, we allow for it only in the long run. Since the household registration system (*hukou*) is a prominent feature of Chinese internal migration, we include it in our model by assuming that it increases the costs of migration where the cost of migrating from the interior to the coast increases with the population density of the coast relative to the interior, reflecting a greater resistance to further migrants from coastal residents, the more crowded the coastal cities become.¹¹ To simplify the analysis, we assume that if *hukou* costs were removed, migration would occur from the poor to the rich region.¹²

In the models with free migration it is customary to assume that migration occurs until utility is equalised across regions. But under the *hukou* system, people will be worse-off in the (poorer) interior since they will have to incur costs to obtain *hukou* for the coastal region. We therefore model the migration equilibrium condition as:

$$(4) \quad V_C = \left[\frac{L_C / A_C}{L_I / A_I} \right]^\mu V_I, \quad \mu > 0$$

where L_i is the population and A_i the area of region i so that L_i/A_i is the population density in region i ; μ can be thought of as the *hukou* parameter – the larger is μ the greater will be the difference in utilities across the two regions (since the coastal population density exceeds that in the interior so that the term in brackets exceeds one).

¹¹ See Liu (2005) for a general description and history of the *hukou* system.

¹² This avoids the discontinuities which result from two-way costly migration; see Mansoorian and Myers (1993) for an analysis of a model with such discontinuities and Woodland and Yashida (2006) for an approach similar to ours but applied to international immigration. Other authors such as Groenewold and Hagger (2007) have avoided the discontinuity by assuming migration to be costless but this is not consistent with the presence of *hukou* restrictions.

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. We call the two goods interior and coastal goods according to the region in which they are produced. In each region, firms use their fixed endowments of land and capital, hire labour from households in their own region and combine them with infrastructure provided by the regional government to produce output. Production technology is assumed to be Cobb-Douglas with constant returns to scale:

$$Y_j = \varphi_j (LAND_j)^{(1-\alpha_{Lj}-\alpha_{Kj}-\alpha_{Gj})} (CAPITAL_j)^{\alpha_{Kj}} (L_j)^{\alpha_{Lj}} (GRF_j)^{\alpha_{Gj}},$$

where L_j = employment and GRF_j = infrastructure provided by the regional government, both for industry j . We can simplify by writing:

$$D_j = \varphi_j (LAND_j)^{(1-\alpha_{Lj}-\alpha_{Kj}-\alpha_{Gj})} (CAPITAL_j)^{\alpha_{Kj}},$$

so that:

$$(5) \quad Y_j = D_j (L_j)^{\alpha_{Lj}} (GRF_j)^{\alpha_{Gj}}, \quad 0 < \alpha_{Lj}, \alpha_{Gj}, (1-\alpha_{Lj}-\alpha_{Gj}) < 1, \quad j = I, C$$

Firms produce emissions in proportion to their output and reduce it by abatement activity:

$$(6) \quad E_j = \varepsilon_j Y_j - B_j, \quad j = I, C$$

where E_j represents emissions, ε_j is the emissions intensity of output (at zero abatement levels) and B_j denotes abatement. Abatement activity is costly and we follow Fischer (2008) in specifying a simple quadratic cost-of-abatement function. In particular, we assume that abatement costs are given by:

$$COST_j(B_j) = \omega_j B_j^2 - S_j B_j$$

where ω_j is a constant and S_j denotes a subsidy per unit of abatement. The firm pays a wage rate W_j and an output tax at the rate T_j as well as an emissions tax of T_{Ej} per unit of emissions. Hence, profits for the representative firm in region j are:

$$(7) \quad \Pi F_j = (1-T_j)Y_j - W_j L_j - T_{Ej}(\varepsilon_j Y_j - B_j) - (\omega_j B_j^2 - S_j B_j), \quad j = I, C.$$

Profits are maximised by choosing employment, output and abatement activity with the wage, the output tax rate, the emission tax rate, the abatement subsidy and the supply of government infrastructure taken as given. Profit-maximisation therefore implies the usual marginal conditions:

$$(8a) \quad \alpha_{Lj} Y_j (1 - T_j - T_{Ej} \varepsilon_j) = W_j L_j, \quad j = I, C,$$

$$(8b) \quad B_j = (T_{Ej} + S_j) / 2\omega_j, \quad j = I, C.$$

The labour market clears. On the labour supply side, each household is assumed to provide one unit of labour to the firms in its own region. We assume that wages adjust to ensure the demand for labour derived from (8a) equals the supply. Hence labour force, labour supply, employment, the number of households and population are all equal.

2.3 Governments

The central government derives revenue from the emissions tax and the VAT, the latter of which is shared with the regional governments. In addition to its VAT share, each regional government levies a tax on output in its own region. All tax revenue is assumed to be measured in terms of the output of the region in which the tax is paid. Thus the central government receives VAT revenue as well as pollution-tax revenue in terms of output I and C , depending on the origin of the tax. In addition, it pays abatement subsidies. Thus the net amount of region i 's output it receives is $\theta T_V L_i J_i + T_{Ei} E_i - S C_i B_i$, where θ is the central government's share of the VAT revenue and $S C_i$ is the central government's subsidy to abatement activities by firms in region i . Each of the net revenues are costlessly converted

into a government good with units of the goods chosen so that one unit of region I 's good converts to one unit of the government good and one unit of region C 's good converts to η units of the government good. Thus the central government's budget constraint may be written as:

$$(9) \quad L_I GC_I + L_C GC_C = [\theta T_V L_I J_I + T_{EI} E_I - SC_I B_I] + \eta [\theta T_V L_C J_C + T_{EC} E_C - SC_C B_C]$$

where GC_i is the amount of the government consumption good provided by the central government per household in region i .

Regional governments receive a share $(1-\theta)$ of VAT revenue collected from households in their region and levy an output tax on firms in their region both measured in terms of their own region's output. They use some of the revenue for subsidising the abatement activities of firms in their own region and convert the remainder to a government good with the same "technology" as the central government's. Each regional government provides some of the government good to households as a consumption good (in equal per capita amounts) within its own region as well as providing some to firms as infrastructure, a public good. The regional governments' budget constraints have the form:

$$(10a) \quad L_I GRH_I + GRF_I = T_I Y_I + (1-\theta) T_V L_I J_I - SR_I B_I$$

$$(10b) \quad L_C GRH_C + GRF_C = \eta [T_C Y_C + (1-\theta) T_V L_C J_C - SR_C B_C],$$

where GRH_i is the provision of the government consumption good per household by the regional government in region i and SR_i is the regional government's subsidy to abatement activities by firms in region i .

2.4 Definitions and Closure

The relationship between GH_i and its components is given by:

$$(11) \quad GH_i = GRH_i + GC_i, \quad i = I, C,$$

and the relationship between S_i and its components is given by:

$$(12) \quad S_i = SC_i + SR_i, \quad i = I, C.$$

Goods markets clear in each region:

$$(13) \quad Y_i = L_I C_{iI} + L_C C_{iC} + T_i Y_i + T_V L_i J_i + T_{Ei} E_i, \quad i = I, C$$

Firms distribute profits to households in their own region in equal per capita amounts:

$$(14) \quad \Pi F_i = L_i \Pi H_i, \quad i = I, C$$

The trade between regions must balance:

$$(15) \quad L_C PC_{IC} = L_I C_{CI}$$

There is a given national labour force (= population), L :

$$(16) \quad L_I + L_C = L.$$

The national level of emissions is given by:

$$(17) \quad E_I + E_C = E.$$

To summarise, the model consists of the 33 equations, (1) to (17) in 47 variables:

$V_i, C_{ji}, GH_i, P, J_i, \Pi H_i, T_{Ej}, E_j, B_j, S_j, D_j, Y_j, L_j, \Pi F_j, T_V, T_j, W_j, SC_i, SR_i, GRH_i, GRF_j, GC_i, \theta, L, K$, and E , of which 16 are exogenous: $D_j, T_{Ei}, SC_i, SR_i, T_j$, one of (GRH_I, GRF_I) , one of (GRH_C, GRF_C) , one of (GC_I, GC_C) , θ, T_V, L , so that there are 31 endogenous variables: $V_i, C_{ji}, GH_i, P, J_i, \Pi H_i, Y_j, L_j, \Pi F_j, E, E_j, B_i, S_i, W_j$, one of (GRH_I, GRF_I) , one of (GRH_C, GRF_C) , and one of (GC_I, GC_C) .

Two equations, however, are redundant since (3), (5), (14), (15) and the household budget constraint can be used to derive (13) so that the balance between the number of equations and the number of endogenous variables is restored.

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

We distinguish between short-run and long-run versions of the model based, as in Krugman (1991), on differences in closure assumptions. We define the short run as the length of time before inter-regional migration begins to respond to the changes in V_I and V_C .

In terms of the model, this simply involves suspending equations (4) and (16) and making L_I and L_C exogenous in the short-run simulations. The long run is used to refer to the simulation results using the model as set out above.

2.6 The linearised, numerical version of the model

The model as it stands is too complicated to solve analytically so that we linearise it in terms of proportional changes and calibrate the parameters using data for China's regions reported in Appendix 2. The linearised version is given in Appendix 3. Calibration is discussed in Appendix 4.

3. The simulations

We ran a number of simulations differentiated by the pollution control instrument, by whether the tax revenue or subsidy cost was recycled to profits as well as by the method used to finance the subsidy or dispose of the tax revenue. We report the results of nine such simulations in the next section.

There are three possible instruments (a central government imposed emissions tax, a subsidy for abatement paid by the central government and a subsidy paid by the regional governments) and a variety of financing methods. Many combinations are possible of which we report the results of the following nine in some detail:

Simulation 1. An increase in the abatement subsidy paid by the central government with recycling of the cost of the subsidy to profits via a lump-sum profits tax.¹³ The endogenous variable for the central government budget constraint is GC_i with the assumption that $g_{CI} = g_{CC}$; the endogenous variable in the regional government budget constraint is GRH .¹⁴

¹³ Note that the lump-sum profits tax and subsidy are not explicitly included in the model as set out above but in simulations 1 and 2 a transfer variable is entered symmetrically in the firm's profit definition and the central government's budget constraint.

¹⁴ The lower-case symbols denote the proportional change in their upper-case counterparts; thus, e.g., g_{CI} is the proportional

Simulation 2. An increase in the emissions tax with recycling of revenue to firms via a lump-sum subsidy to profits. Government budget constraints are satisfied in the same way as in simulation 1.

Simulation 3. An increase in the central government abatement subsidy financed by a reduction in central government consumption expenditure so that GC_i varies to satisfy the central government's budget constraint.. Government budget constraints are satisfied in the same way as in simulation 1.

Simulation 4. An increase in the central government abatement subsidy financed by an increase in the VAT rate so that the VAT rate, T_v is now the endogenous variable in the central government budget constraint. Since the VAT is shared with the regional governments, a change in the VAT rate also affects their budgets. To avoid this complication, we assume that the share which the regions receive is adjusted so that their revenue is not affected by the central government's changes in the VAT rate. The endogenous variable in the regional government budget constraint is GRH .

Simulation 5. An increase in the emissions tax rate with the revenue used to increase central government consumption expenditure. Government budget constraints are satisfied in the same way as in simulation 1.

Simulation 6. An increase in the emissions tax, with the revenue used to reduce the VAT rate. The same adjustment is made to quarantine regional government VAT receipts from changes in the VAT rate. The endogenous variable in the regional government budget constraint is GRH .

Simulation 7. An increase in the regional government abatement subsidy financed by a reduction in regional government consumption expenditure. The central government's budget is satisfied by varying GC with $g_{CI} = g_{CC}$.

Simulation 8. An increase in the regional government abatement subsidy financed by a reduction in regional government infrastructure expenditure. The central government's budget is satisfied in the same way as in simulation 7.

Simulation 9. An increase in the regional government abatement subsidy financed by an increase in the regional government output tax rate. The central government's budget is satisfied in the same way as in simulation 7.

To discuss the results of these simulations we group them into four groups:

1. Simulations 1 and 2 are considered together to throw light on the tax *v.* subsidy question.
2. Simulations 3 and 4 are considered together to permit an analysis of the effect of financing of a central government's subsidy.
3. Simulations 5 and 6 are combined to allow us to analyse the effects of the method of financing an emissions tax through the central government's budget.
4. Simulations 7, 8 and 9 are considered together to analyse the effects of a regional government subsidy under alternative financing assumptions.

In addition to these nine simulations, we also ran a number of others to assess the robustness of the results. In particular, we ran two extra sets of simulations. The first repeats simulations 1 to 9 above using a model with inter-regionally mobile capital to assess the sensitivity of the results to the simplifying assumption of fixed regional capital stocks. The second was for shocks which were regionally differentiated on the basis of discussions in Chinese policy circles that the interior, being poorer and having a higher emissions intensity, ought to be subject to less serious intervention than the coast. Details are reported in Appendices 6 and 7.

4. The results

4.1 Tax v. subsidy with revenue recycling

In this pair of simulations we introduce a lump-sum profits tax/subsidy which is levied on/paid to firms by the central government. The relevant term, therefore, appears in both the firms' profits definition and the central government's budget constraint. This device allows us to assume that the revenue collected from the emissions tax or the cost of the abatement subsidy, as the case may be, are offset by a lump-sum profits subsidy or tax. In this way we can focus on the emissions tax and subsidy *per se* without dealing with the confounding effects through the government budget and through firms' profit distributions.

We begin with the simpler of the two shocks, the subsidy. The level of the subsidy is chosen to ensure a unit reduction in emissions, $e = -1$, and it is assumed that the proportional increase in subsidies is the same in each of the two regions, $sc_I = sc_C$.¹⁵ The results for selected variables are reported as simulation 1 in Table 1.¹⁶

[Table 1 about here]

Consider the short run effects first. The “initial” effect is on firms. There are no direct effects on the production of output. The only immediate reaction of the firms is that they change their abatement activity since the change in the subsidies changes the incentives to abate emissions. In both regions abatement increases as expected. The increase in abatement is greater in the interior than in the coast because central government subsidies are relatively more important for the interior. Despite the proportionately larger increase in abatement in the interior, there is a smaller fall in total emissions in that region than in the coast since abatement is much larger in the coast in the initial equilibrium.

¹⁵ We assume equal changes in subsidies (and later, equal changes in tax rates) across regions for ease of exposition rather than descriptive reality. In Appendix 7 we report the results of simulations based on an alternative assumption, viz. that the central government implements policies which seek to achieve different emissions reduction in each of the regions, reflecting Chinese government policy discussion in which it has been proposed that the interior region be less heavily taxed than the coast since it is poorer as well as having a higher emissions intensity so that a uniform tax would be expected to impose a proportionately greater burden on the interior provinces.

¹⁶ The full simulation results are reported in Appendix 5.

The short-run effect on income depends on profits and wages. It is surprising that profits fall in both regions: the subsidy increases profits but we assume that there is complete ‘recycling’ in the sense that a lump-sum profits tax is increased to absorb the extra revenue from the subsidy. Despite this, profits fall because the firms incur extra abatement costs which reduce profits and this is not included in the recycling process. The increase in costs is greater in the coast since marginal abatement costs are increasing and in the initial equilibrium the coastal region has a higher abatement level and therefore a higher marginal cost. The profit falls flow through to incomes. The other component of income, *viz.* wages, does not change in this simulation so that the effect of the policy shock on incomes depends only on profits and this affects the coast more than it does the interior.

Finally, consider utility which depends on private consumption and provision of the government consumption good. Private consumption depends on incomes and relative prices. Given that there is no change in output in the short run, the relative price effect depends on demands when the residents of the two regions trade: the balance-of-trade condition requires prices to change to reconcile the interior’s demand for the coastal good with the coast’s demand for the interior good. These demands, in turn, depend only on incomes (at given prices). We have already seen that income in the coast falls by more than it does in the interior so that the coast’s demand for interior output falls by more than the interior’s demand for the coastal output. Hence, the relative price moves in favour of coastal output: $P (=P_I/P_C)$ falls. This benefits coastal residents in consumption and offsets the adverse effects of the greater fall in their income. The outcome is that the consumption by residents of the interior falls more for each good than is the case for coastal residents despite their smaller income reduction.

The second influence on utility is government consumption; both central and regional government provision of the consumption good fall. Central government revenue falls

despite the recouping of the abatement subsidy through the lump-sum profits tax because of a fall in VAT revenue (based on lower income caused by higher abatement costs). The reduction in VAT revenue hits both levels of government. There is an additional effect on regional government revenue since the increased abatement activity induced by the central government subsidy requires the regional governments to pay higher subsidies to firms in their region which reduces further revenue and hence the provision of the regional government consumption good. Both of the effects on regional government revenue hit the coast harder because, on the one hand, income and therefore VAT revenue reductions are greater for the coast and, on the other hand, abatement is higher in the coast so that a given proportional increase in abatement requires more additional subsidies to be paid by the coast's government. Hence, total government consumption, GH , falls by more in the coast than in the interior.

Finally, consider the effect on utility: since all private consumption falls and government provision of the consumption goods also falls, utility falls in both regions. Comparing utility effects across regions: the coast suffers a greater fall in government consumption but smaller falls in private consumption than the interior. The numbers are such that the latter dominates but only by little – the fall in coastal welfare is (slightly) less than that in the interior.

We now turn briefly to the long-run effects. Given the short-run utility effects, labour migrates from the interior to the coast but there are only small effects since there is only a small short-run utility difference. The movement in labour results in small effects on output (which increases in the coast and falls in the interior), but the opposite effects on per capita outputs because of the decreasing marginal product of labour. Migration depresses wages in the coast and increases them in the interior, amplifying the short-run income effects. But the

price fall is smaller in the long run because of supply effects which do not operate in the short run. Overall, the effects are only slightly different in the long run compared to the short run.

Finally, we briefly draw out the implications of the policy for regional disparities. Disparities have been measured in various ways and we consider four different measures: wages, per capita output, income and utility. The results are summarised in the “Simulation 1” columns in Table 2.

[Table 2 near here]

The numbers in the table are the difference between the proportional change in the relevant variable in the coast and the proportional change in the interior. The gap in all variables in the initial situation favours the coast so that a positive value of the difference results in a widening of the disparity. In the short run, there are no wage effects of the policy shock so that the wage gap is unchanged, the income disparity narrows, there is no change in the per capita output gap and the disparity in welfare increases. In the long run the wage gap is reduced, as is the income gap, both relative to the initial equilibrium and the short run, the disparity in per capita output decreases and the gap in welfare narrows relative to the short run but still increases relative to the initial equilibrium. Thus, particularly in the long run the disparities as conventionally measured (wage, income and per capita output) all narrow but the welfare gap moves in the opposite direction.

We turn now to the effects of an emissions tax with the revenue recycled to firm profits through a lump-sum subsidy. The results are reported as simulation 2 in Table 1. The tax increase is chosen to be equal across regions and such as to ensure $e = -1$ to ensure comparability to the previous case. In contrast to the abatement subsidy, firms react to the tax not only by changing their abatement levels but also by changing their output supply decisions, seeking to supply less of each good. They do this by reducing their demand for labour, the only variable factor of production. However, labour supply is fixed in the short

run and the labour market clears so that the only effect of the reduction in labour demand is the fall in wages necessary to ensure all labour is employed. Thus, despite firms' supply decisions, output does not change in either region and emissions are therefore reduced solely by changes in abatement, producing emissions reductions similar to those generated by a subsidy.¹⁷

The short run fall in wages results in an increase in profits by enough to more than offset the extra abatement costs which lead to a reduction of profits. The wage reduction and the profit boost both flow into income and, not surprisingly, the net effect is as for a subsidy since the positive wage effect on profits exactly offsets the wage loss in the income calculation. Thus, overall, income falls and for reasons discussed above, it does so by more in the coast than in the interior. As a consequence, the income effects are identical to those in the subsidy case and, therefore, so is the relative price change and the changes in consumption. The effects on government expenditure are as they were in the previous simulation – the effect of the emissions tax on the central government's budget is exactly offset by the lump-sum subsidy just as the effect of the subsidy was offset by a lump-sum tax in the previous simulation. The budget effects via VAT revenue (driven by income changes which are the same as in the previous simulation) and regional government subsidy costs (which are driven by abatement changes of the same magnitudes as in the previous simulation) are as in the subsidy case. Hence, utility changes are as they were for the previous simulation.

Thus, to sum up, as long as the direct effects on government revenue and firm profits are neutralised by lump-sum taxes and subsidies, the switch from an emissions tax to an abatement subsidy affects only the distribution of income between profits and wages but not income as a whole nor private consumption, public consumption or welfare and, in this sense, the two instruments are equivalent. In terms of disparities, however, there is an effect on

¹⁷ Note that the figure in Table 1 indicate that regional abatement increases and emissions reduction are identical in the short run in response to a subsidy and a tax. This is not necessarily the case and appears so only because of rounding.

wage disparities which are increased under the emissions tax (interior wages fall by more than coastal wages since interior firms are more sensitive to the emissions tax) but unaffected by the abatement subsidy. It is noteworthy that in our model the distribution of factor payments between wages and profits does not affect the income of the representative household and therefore does not affect consumption and utility. However, in a model in which wages and profits flow to different types of households, as is likely in practice, this difference might have important distributional consequences and may, through that channel, also have aggregate effects and so undermine the neutrality result.

Since the short-run utility effects are as they were for the subsidy, the inter-regional migration which takes place in the long run in response to short-run utility differences is identical and so the long-run effects of the tax are as for the subsidy except, again, for the distribution of income between wages and profits.

The implications of an emissions tax for inter-regional disparities are reported as simulation 2 in Table 2. The results there confirm the discussion above: only the wage disparity behaves differently under a tax to the way it does following a subsidy increase: it widens in the short and then narrows slightly in the long run but not by enough to offset the adverse short-run effect.

4.2 A central government abatement subsidy: financing effects

We now consider two alternative subsidy shocks in which the cost of the subsidy is not met by a lump-sum profits tax but from other budgetary sources. While a lump-sum tax/subsidy assumed in the simulations of the previous sub-section is a convenient theoretical device, it is not available in practice which makes it interesting and of practical importance to analyse alternatives. Hence we revisit the effects of a central government subsidy to abatement activity but assume that it must be financed either by reducing government

expenditure or by increasing the VAT rate. In both cases the subsidy shock is assumed to be equal across regions with the magnitude chosen so as to produce a unit fall in national emissions levels. In this way the results are comparable to those of simulation 1 described in the previous sub-section.

The effects of an increased subsidy financed by reduced central government expenditure are reported as simulation 3 in Table 1. The main difference to the results of simulation 1 is in profits and the central government's budget position. In the present case profits increase because firms retain the subsidy. While profits are still reduced because of the increase in abatement costs, overall profits rise.¹⁸ As in the subsidy with recycling, wages and output are not affected by the policy shock. With no change in wages, income changes only because of the increase in profits which is greater in the coast because more of the subsidy flows to the coast than to the interior (initial abatement is much greater and subsidies are higher in the coast so that an equi-proportionate increase in subsidies benefits the coast by more). Hence relative prices now change in favour of the interior which offsets the effect on consumption of higher coastal incomes. In fact, interior residents are able to increase their consumption of each good by more than the coastal consumers are – the relative price effect more than offsets the income effect.

As to government consumption, now that the central government has to pay for the subsidies by reducing consumption expenditure, central government expenditure falls, in equal proportion in the two regions (by assumption). Regional government consumption expenditure also falls. While VAT revenue increases (since incomes increase), the cost of subsidy payments for extra abatement in the region reduces revenue by more than is provided by the additional VAT proceeds. The fall in regional government expenditure is much larger in the coast because initial levels of subsidies and abatement are much higher there. Hence,

¹⁸ It will be noted that profits increase by exactly the amount they fell in simulation 1. This is not coincidental but implied by the algebra of the model.

overall, government consumption expenditure falls and does so more in the coast than the interior.

The effect on utility is theoretically ambiguous since private consumption increases but government consumption falls. The numerical magnitudes are such that the latter outweighs the former so that utility falls in both regions, by considerably more in the coast than in the interior since private consumption increases by less and government consumption falls by more in the coast than in the interior.

In the long run there are greater changes than in simulation 1 since there is a greater short-run utility gap. With the coast now relatively worse-off, labour moves from the coast to the interior. This increases output in the interior and reduces it in the coast but output per capita moves in the opposite direction because of decreasing marginal product of labour. This is also reflected in income, with coastal income increasing and interior income falling relative to the short run (although they are both still higher than in the initial equilibrium). The relative price increase is considerably reduced so that the advantage to the interior residents from this source is much smaller than in the short run. Given that incomes favour the coast, private consumption now also favours the coast. The reduction in government consumption is also tilted towards the coast compared to the short run so that, all in all, while welfare changes still favour the interior, they do so by less than in the short run.

The effects of this shock on inter-regional disparities are reported in Table 2 and may be summarised as follows. In the short run there is no change in the wage and output gaps, as was the case in simulation 1. There are effects on the income and utility gaps and these are of opposite sign to the corresponding changes when the subsidy is financed by a lump-sum profits tax. In the long run the gaps for wages, per capita output and income all increase relative to the initial equilibrium but the utility gap is reduced, although not relative to the

short run position. In this case the signs of the changes are also all the opposite to what they were in simulation 1.

Thus, there are interesting and important consequences of relaxing the assumption of lump-sum taxes and we now further explore this by assuming that the subsidies are financed by an increase in the VAT rate. Recall that the VAT revenue is shared between the central and regional governments. To ensure that the VAT changes affect only the central government (which receives the emissions tax revenue), we assume that the share which the regions receive is adjusted to keep the regions' VAT receipts constant. The results of a VAT-financed subsidy are reported as simulation 4 in Table 1.

We consider the short run first and start with the effect on firms again which are as for the expenditure-financed subsidy: there is no change in wages and an increase in profits equal to that for simulation 3. The effect on income differs from simulation 3, however, because of the change in the VAT rate. Since income is measured after VAT, the rise in the VAT rate lowers income and this reduction is large enough to more than offset the increase in profits derived from the subsidy so that, overall, income falls in both regions. But the fall is greater in the interior: the VAT rate increase is the same in both regions (by assumption) but the profits boost is smaller in the interior because coastal firms receive larger subsidies in the base solution so that an equi-proportionate increase in subsidies benefits the coastal firms more, as was the case in simulation 3. The changes in income mean that there will be relative excess demand for the interior good in inter-regional trade so that the relative price rises which benefits interior residents – while consumption of both goods by both regions falls, consumption of each good by interior residents falls by less than it does for the coastal residents.

There is no change in central government consumption by assumption (its budget is balanced by VAT changes) so that only regional governments change their expenditure in

response to the shock and, for the same reasons as in the expenditure-financed subsidy case, the fall in total government consumption is larger for coast than the interior.

Since both private and government consumption fall in both regions utility also falls in both regions. The fall in both consumption components is larger in the coast so that, not surprisingly, utility also falls by more in the coast.

In the long run the population migrates in response to the short-run utility gap, in this case from the coast to the interior. This increases output in the interior and reduces it in the coast although per capita output moves in the opposite direction under the force of falling marginal productivity of labour. Wages fall in the interior with the influx of labour which reinforces the short-run income differences with the income gap widening further in the long run although this effect is cushioned by a change in profits in the opposite direction (reflecting the wage falls). The gap between changes in government consumption is also reduced and both these effects serve to reduce the utility gap in the long run compared to the short run, although not by enough to reverse the short-run effect – the coast is still worse-off as a result of the shock than the interior is.

The effect on disparities is reported in Table 2 and may be summarised as follows. In the short run there is no change in the wage and per capita output gaps, the income disparity increases but the welfare disparity falls. These signs are the same as for simulation 3 and thus the opposite of those for the lump-sum-tax financed case. In the long run the wage and per capita output gaps increase, as does the income gap (both relative to the initial equilibrium and to the short-run solution). The welfare gap narrows but not by as much as in the short run. Thus the signs of the changes in disparities are not affected by whether expenditure or the VAT rate is adjusted to balance the budget but both differ markedly from the case where a lump-sum tax is assumed to be available to finance the abatement subsidy. Moreover, while the signs of the disparity effects do not depend on the method of financing,

the underlying numbers and mechanisms do. Thus in the expenditure-financed case, there is a significant cut in government expenditure but a large increase in income which, in turn, boosts private consumption, largely offsetting the effect of the government consumption cut on welfare.

4.3 An emissions tax: financing effects

We now turn to the consideration of the importance of the way in which an emissions tax increase is “financed” (i.e., the way in which the tax revenue is used). As in the previous sub-section, we consider two alternative variables for balancing the central government’s budget – government consumption expenditure and the VAT rate. The results are reported as simulations 5 and 6 in Table 1.

As in the case of simulation 2 (an emissions tax increase with the revenue recycled to profits), there is a production effect as the emissions tax hike leads firms to try to change their output which they do by reducing their demand for labour. With labour supply fixed in each region and fully employed, the reduced labour demand serves only to reduce wages, more in the interior than the coast since interior labour demand is more sensitive to the emissions tax. In contrast to the recycling case (simulation 2), profits fall. There are two forces reducing profits (the emissions tax and additional abatement costs) and one increasing profits (reduced wages); the former prevail so that, overall, profits fall, by more for the interior than for the coast. The difference across the regions is because wages fall more and so increase profits more in the interior than in the coast; the common tax increase results in a greater proportional reduction in interior profits (since emissions taxes are a greater proportion of profits for interior firms) and the increase in abatement costs incurred by coastal firms is greater than that of interior firms. The parameter values are such that the direct tax effect

dominates the other two so that the eventual reduction in profits in the interior is greater than that in the coast.

The effect of the shock on incomes is unambiguous: both profits and wages fall and they do so more in the interior than in the coast so that interior income falls by more.

As for government expenditure, central government expenditure rises in equal proportions in the two regions due to the extra tax revenue while regional government expenditure falls for reasons already discussed in previous cases: VAT revenue falls due to the fall in income and subsidy costs increase due to the higher abatement induced by the rise in the emissions tax. The VAT revenue reduction hits the interior harder because the fall in income there is larger while the increased subsidy costs hit the coast harder due to the higher levels of subsidies and the greater initial abatement levels. The effect on regional government expenditure is dominated by the latter so that it falls more in the coast but because regional government expenditure is a smaller part of total government consumption expenditure for the coast, its overall level of government expenditure goes up by more than the interior's.

Not surprisingly, given the large falls in income reflecting the re-allocation of output from the private to the public sector, there is a fall in private consumption of both goods by both regions, with the fall being larger for coast in each case (the relative price change favours the interior). Thus from a welfare point of the view, the two components of utility move in opposite directions with private consumption falling and public consumption rising (thus there is a substitution of public for private consumption). A priori, the sign of the effect on utility will be ambiguous. The numerical magnitudes, however, favour a reduction in utility with the reduction being larger for the coast than the interior, despite the coast's benefitting considerably more for extra central government expenditure.

In the long run people will move from the coast to the interior since the coast suffered a larger reduction in welfare in the short run. This increases output but reduces output per

capita in the interior and *vice versa* in the coast. Similarly, wages fall by slightly more in the interior and slightly less in the coast. Utility changes are brought closer together but the welfare losses are still greater in the coast than the interior.

The effects on inter-regional disparities are reported in Table 2 and may be summarised as follows. In the short run there is no change in the per capita income gap, the disparities in wages and incomes rise and that in utility falls. In the long run the disparities in income and wages rise further, there is a widening of the per capita output gap and the disparity in utility increases relative to the short run but is still lower than in the initial equilibrium.

Consider now the alternative “financing” method, a fall in the VAT rate. The results of this policy are reported as simulation 6 in Table 1. Recall that the VAT revenue is shared between the central and regional governments. To ensure that the VAT changes affect only the central government (which receives the emissions tax revenue), we assume that the share which the regions receive is adjusted to keep their VAT receipts constant.

We begin with the short-run effects. As for both previous simulations of an increase in emissions tax (simulations 2 and 5), there are no output effects and the wage effects are the same since the method of financing does not affect the firms’ behaviour, although it does affect profits. In the present simulation the change in profits is the same as for the expenditure-financed case (simulation 5) since the forces are the same – wages fall which increases profits but the emissions tax reduces profits by more so that, on balance, profits fall by the same amount as in simulation 5. The fall in wages and profits are both larger for the interior and these differences feed into incomes which fall by more in the interior. Compared to simulation 5, however, there is an additional effect on income – the emissions tax increase allows a reduction in the VAT rate which increases incomes (measured after tax) although the lower VAT effect does not completely offset the effect of lower wages and profits (which

also reflect the resource cost of increasing abatement) so that, on balance, incomes still fall, although by considerably less than in simulation 5. The relative magnitudes of the income reduction do not change from simulation 5: the interior still loses more income than the coast. Indeed, the difference between the income falls, $j_C - j_I$ is the same in both simulations (see Table 2), reflecting the fact that the VAT reduction is uniform across the two regions. This has the effect that the change in the relative price (which depends on the change in relative excess demand) is the same as in the expenditure-financed case – it changes in favour of the interior. The resulting change in private consumption favours the interior with this region's consumption of the coastal good actually increasing despite the fall in income.

Turning to government consumption, central government consumption does not change by assumption. Its regional counterpart changes as it does in simulation 5 but by less. Recall there were two sources of reduction in regional government revenue in simulation 5: an increase in subsidy costs for higher abatement and a reduction in VAT revenue because of a fall in income. In the present case the first of these operates as before and, while income before VAT still falls by the same amount in each region, the regional governments are protected from the effect on their VAT revenue by the assumption that the regions' VAT share is adjusted to keep their revenue constant. Hence the reduction in regional government revenue is smaller than in the previous case and therefore their expenditure reduction is also smaller.

Turning, finally, to the effect on utility, even though income and government consumption fall in both regions, the change in the relative price means that the interior can considerably increase its consumption of the coastal good and this is sufficient to more than offset the effects on utility of the reduction in its consumption of its own good and the government good so that utility for interior households actually rises – the only case for

which this happens in any of the simulations. Utility of the coast, however, falls as in the previous simulations.

In the long run the relative deterioration of the coast's short-run welfare position drives labour from the coast to the interior. The result is an increase in interior output and a fall in coastal output with per capita outputs changing in the opposite direction under the influence of falling marginal product of labour. Wages also fall in the interior and rise in the coast relative to the short-run equilibrium but only by a small amount. Profits move in the opposite direction to wages relative to the short run. Incomes still fall relative to the initial equilibrium although this is less than in the short run for the coast and more than in the short run for the interior so that the income gap widens relative to the short run. Despite this the change in the relative price is smaller, owing to the changes on the supply side – interior output rises and coastal output falls. The consumption position of the interior therefore deteriorates compared to the short run and the coast's consumption improves. This is also the case with respect to government consumption so that, on balance, utility in both regions now falls relative to the initial equilibrium but does so by more for the interior and by less for the coast so that relative utility changes are closer than in the short run.

The effects on disparities are reported in Table 2 and may be summarised as follows. In the short run there is no effect on the gap in per capita output, the wage and income disparities increase and the utility disparity falls. In the long run the wage and income gaps widen further and the gap in output per capita also increases. The welfare gap widens relative to the short run but is still narrower than it was in the initial solution.

Finally, we sum up the results reported in this sub-section and compare them to the effects of an emissions tax increase with revenue recycling. In all three simulations of an increase in the emissions tax, wages and income fall in both regions in the short run and the long run. This is also generally true of utility with one minor exception – the utility of the

representative interior household actually increases by a small amount in the short run when the tax increase is VAT-financed. Profits also fall in two of the simulations; the exception is simulation 2 where the emissions tax revenue is returned to the firms as a lump-sum profit subsidy. Thus generally there are adverse effects of an increase in emissions taxes in both short and long runs irrespective of the method of “financing”. The method of financing does, however, have an impact on disparities. The wage gap is widened in both short and long runs in all three simulations but the disparities in income, output per capita and utility generally move in opposite directions when the tax revenue is returned as a lump-sum subsidy compared to the more realistic alternatives of expenditure or VAT adjustment. Moreover, the welfare gap usually changes in the opposite direction to the income and per capita output gaps so that the latter are poor proxies for the former.

We began by arguing that, while lump-sum taxes and subsidies are a convenient theoretical device, they are typically not available to governments in practice so that the effects of using more realistic financing options ought to be explored. We are able to conclude that more plausible financing assumptions have an important influence on the effects of an emissions tax – both on the direction of changes in disparities and on the magnitudes of the underlying numbers. On the other hand, whether the emissions tax is expenditure- or VAT-financed does not affect the sign of changes in disparities but the underlying effects do differ; in particular, the financing method matters for the distribution of output between private and government consumption and, to this extent, the method of financing matters.

4.4 Regional government subsidies: financing effects

We now turn to our last set of simulations, of which we discuss two in some detail. They all involve changes in subsidies by regional governments. In our model only the central

government can levy a pollution tax but both central and regional governments pay subsidies. It is interesting to consider the effects of a regional government subsidy because the regional governments have instruments to balance their budget which have different effects to those available to the central government. In particular, the central government has only expenditure on the government consumption good and the VAT which can be adjusted to balance its budget in response to an emissions tax or subsidy change while the regional governments have not only consumption expenditure but also expenditure on infrastructure as well as the regional output tax.

We deal very briefly, first, with the case where the regional governments balance their budgets by changing their provision of the consumption good to households since this, not surprisingly, is very similar to the case where the central government pays a uniform subsidy and balances its budget by expenditure on the government consumption good (simulation 3). The results are reported as simulation 7 in Table 3. We also reproduce the results for simulation 3 from Table 1 to facilitate comparison.

[Table 3 about here]

To further facilitate comparison to the equivalent case of a central government subsidy, we assume the changes in the regional government subsidies are such that they produce the same reductions in emissions in each region in the short run. A comparison of simulations 3 and 7 in Table 3 shows that the effects are almost identical, with the difference driven by small differences in the regional distribution of the government consumption good.

We, therefore, now proceed to the remaining two cases, starting with the case where the regional governments increase their subsidies and finance this by a reduction in infrastructure expenditure, the results of which are reported as simulation 8 in Table 3.

The main difference from simulation 7 is that the regional government's budget is balanced by a reduction in infrastructure expenditure which has direct effects on output,

reducing output in each region. The output reduction is considerably greater for the coast even though the proportional increase in the subsidy is greater in the interior. This reflects the fact that the initial level of subsidies are much higher in the coast than the interior so that a given proportional increase represents a greater absolute increase which has a greater impact on the budget and therefore requires a larger reduction in infrastructure expenditure. The result is much greater falls in output and wages in the coast than the interior. Note that the reduction in output further reduces emissions so that in this case, the eventual reduction in emissions is greater than in all other simulations.

Despite the reduction in infrastructure expenditure having an adverse effect on output, profits increase, partly because of the increase in subsidies and partly because of the reduction in wages. While the reduction in wages is higher in the coast, the increase in subsidies is greater so that the effect on profits is approximately the same in the two regions. The result is that income falls by substantially more in the coast because of the greater fall in wages.

Regional government consumption expenditure is constant by assumption so that only central government consumption expenditure changes and it falls in each region. The central government has to pay extra subsidies on the additional abatement induced by the regional government's policy and it also loses revenue due to the reduction in income which depresses VAT receipts. The reduction in central government expenditure is the same in each region (by assumption) but this has a greater impact on the coast since it is more reliant on central government expenditure than the interior is. The coast therefore suffers greater income loss and greater reductions in government consumption expenditure but the change in the relative price means that consumption in the coast falls by less than in the interior despite the larger income fall. The effect on utility is that it falls in both regions, at more or less the same rate.

In the long run there is not much change given the small short-run utility difference – there is a small migration from the coast to the interior, making for a slightly smaller output loss in the interior and a slightly larger one in the coast. Output per capita again moves in the opposite direction. Income changes move a little closer together in the long run but relative the price change moves in the opposite direction because of supply changes so that consumption changes move further apart. The upshot is that utility changes become almost identical in the long run

The effect on disparities is reported in Table 4 and may be summarised as follows.

[Table 4 about here]

In the short run all disparities are reduced. They all increase in the long run but remain lower than they were in the initial equilibrium

Finally, we consider simulation 9 in which we assume an increase in regional government abatement subsidies financed by an increase in output tax. The results are reported in Table 3.

In this case there is no output effect but the tax change does affect firms' decisions so that they attempt to reduce employment so as to reduce output but since factor supplies are fixed and fully employed the only effect is to reduce wages. Since the output tax is more important for the coastal firms than for the interior ones, coastal wages fall by more than they do in the interior. Profits are boosted by the subsidy (greater for the coast) and wage reductions (greater for the coast) and depressed by the extra costs of the abatement (also greater for the coast). On balance, profits rise, more for the coast than the interior.

The profit rise offsets the effect of the wage fall on incomes but only partially (because of the extra abatement costs) so that incomes fall on the whole, with the fall greater for the coast than the interior. There is therefore a fall in the relative price which cushions the effect of income falls on consumption of the coast which reduces its consumption of each

good by less than the interior does. Regional government expenditure is held fixed by assumption so that changes in central government consumption expenditure are the only sources of changes in government consumption. The central government reduces its expenditure in response to an increase in subsidy costs caused by an increase in abatement (at unchanged central government subsidy levels), with the reduction being equi-proportionate across the two regions. Since central government expenditure is more important for the coast than it is for the interior, total government expenditure falls by more in the coast.

From the point of view of utility, both private and public consumption fall in both regions so that utility falls unambiguously. The fall is greater in the coast than the interior indicating that the relative regional government consumption effects are stronger than the private consumption effects.

In the long run migration takes place from the coast to the interior which increases output but reduces per capita output in the interior and *vice versa* in the coast. The wage gap and the incomes gap are both reduced relative to the SR and there is little change in government consumption so that utility levels are brought closer together although the fall in utility is still slightly larger in the coast.

The effects of the tax-financed subsidy increase on inter-regional disparities are reported in Table 4 and we summarise them as follows. There is no change in the gap in output per capita in the short run but all the remaining disparities (wage, income and utility) are reduced as a result of the regional government policy. In the long run the output per capita gap increases as do the other three in comparison to the short run although they are still lower than in the initial equilibrium.

In comparing the three simulations reported in this sub-section, the following points can be made. First, utility falls in all three cases by a similar amount and the utility gap is reduced in all three cases, in contrast to the simulation of an abatement subsidy in which we

assume the availability of a lump-sum tax which can be used to recoup the subsidy cost (simulation 1). Secondly, wage effects are adverse and similar in magnitude for the tax- and infrastructure-financed cases but when the subsidy is financed by a reduction in government consumption, there is no short-run wage effect and long-run effects are small. The wage gap between the two regions is reduced in the first two of these cases and increased in the last. It should be noted, though, that where a reduction in the wage gap is achieved, this is done by a reduction in the levels of wages in both regions, something that may not be welcomed either by governments or households. Thirdly, the subsidy boosts profits in all three simulations although by more when consumption-financing is used – not surprisingly, since here the offset through the government budget constraints is on households rather than on firms. Fourthly, the effects on incomes reflect both wage and profit effects; they increase only in the case where a reduction in government consumption is used to finance the subsidy. In the other two cases wage falls are enough to more than offset profit increases. As in the case of wages, the income gap is enlarged when the tax is consumption-financed but reduced when changes in infrastructure or output taxes are used for financing the abatement subsidy although, again, this occurs because the income fall in the coast is larger than that in the interior which may not be widely welcomed. Finally, there are dramatic falls in output when the subsidy is financed by a reduction in infrastructure expenditure since it directly impinges on productivity of remaining factors. Moreover, this is the only one of the three cases in which the per capita output gap improves. It is also the only case (of all nine) in which all four gaps narrow relative to the initial position.

5. Conclusions

This paper has set out and derived a number of numerical solutions to a small two-region model designed to have some features of the Chinese economy. The model has been

used to simulate the economic effects of a number of shocks specified to capture possible ways in which policy might be implemented to reduce CO₂ emissions in China. We have simulated pollution taxes as well as subsidies to abatement activities, we have varied the way in which the government implementing the policy might finance the change and we have considered policy both at the central and the regional levels.

The first substantive question we addressed was that of the effects of a pollution tax v. an abatement subsidy as a method of reducing emissions. We did this in an environment in which the emissions-tax revenue or abatement-subsidy cost was recycled to profits via a lump-sum profits subsidy/tax. We found that under this assumption the switch from an emissions tax to an abatement subsidy affects only the distribution of income between profits and wages but not income as a whole, private consumption, public consumption or welfare and, in this sense, the two instruments are equivalent.

We then moved to relax this lump-sum assumption on the argument that, while a lump-sum tax or subsidy is a convenient theoretical device, they are not available in practice so that pollution-control instruments need to be financed through changes in more conventional taxes or expenditure changes. We explore various of these at both central and regional government levels. We found that in the seven variations, the effects of an emissions tax and an abatement subsidy had remarkably similar effects on the levels of welfare as well as on the inter-regional welfare gap. Moreover, the changes in welfare were of a similar magnitude to those reported for the recycling case but the change in the welfare gap was strikingly different – it increased (widened) in both the recycling cases but fell in all the cases with more plausible financing assumptions.

While welfare effects were broadly similar across different simulations, the same was not true of other variables. In the case of a central government subsidy to abatement activity, we found that the signs of the changes in disparities are not affected by whether expenditure

or the VAT rate is adjusted to balance the budget although both differ markedly from the case where a lump-sum tax is assumed to be available to finance the abatement subsidy.

Moreover, while the signs of the disparity effects do not depend on the method of financing, the underlying numbers and mechanisms do. Thus in the expenditure-financed case, there is a significant cut in government expenditure but a large increase in income which, in turn, boosts private consumption, largely offsetting the effect of the government consumption cut on welfare while in the VAT-financed case there are large reductions in income and consumption but a smaller fall in government consumption which more or less balance each other in their effects on utility.

In the case of alternative central government financing methods, we are able to conclude that moving from a lump-sum subsidy assumption to more plausible financing methods has an important influence on the effects of an emissions tax – both on the direction of changes in disparities and on the magnitudes of the underlying numbers. On the other hand, whether the emissions tax is expenditure- or VAT-financed does not affect the sign of changes in disparities but the underlying effects do differ; in particular, the financing method matters for the distribution of output between private and government consumption and, to this extent, the method of financing matters.

Finally we considered a regional government subsidy under three alternative financing assumptions – a reduction in government consumption, a reduction in infrastructure expenditure and an increase in output tax. Here there were differences in the effects both on disparities and the levels of the variables. With the exception of welfare, disparities were widened by the first financing method but narrowed by the other two. In terms of the levels of the variables, a cut in infrastructure had the largest adverse effects on output, profits, wages and incomes so that the narrowing of wage, income and output gaps under this policy

were actually achieved by large adverse effects on these variables in both regions but which were even bigger in the coast than the interior.

To summarise, relaxing the lump-sum profits tax/subsidy assumption is important and which alternative assumption is made is also important for the effects of policy to reduce emissions, both the effect on disparities and on the levels of individual variables.

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Table 1: The effects of an emissions tax and an abatement subsidy by the central government

Variable	Simulation 1		Simulation 2		Simulation 3		Simulation 4		Simulation 5		Simulation 6	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
v_I	-0.1090	-0.1052	-0.1090	-0.1052	-0.0307	-0.0593	-0.0628	-0.0750	-0.0751	-0.0811	0.0035	-0.0424
v_C	-0.0965	-0.0998	-0.0965	-0.0998	-0.1261	-0.1010	-0.1037	-0.0930	-0.0951	-0.0899	-0.1500	-0.1097
gh_I	-0.1034	-0.1027	-0.1034	-0.1027	-0.5322	-0.5377	-0.0613	-0.0644	1.0738	1.0726	-0.0787	-0.0903
gh_C	-0.1857	-0.1866	-0.1857	-0.1866	-0.8053	-0.7990	-0.1057	-0.1040	1.6187	1.6201	-0.0937	-0.0875
j_I	-0.0690	-0.0677	-0.0690	-0.0677	0.0690	0.0588	-0.1048	-0.1090	-0.5997	-0.6018	-0.1743	-0.1898
j_C	-0.0999	-0.1015	-0.0999	-0.1015	0.0999	0.1130	-0.0739	-0.0680	-0.4505	-0.4477	-0.0251	-0.0031
y_I	0.0000	-0.0010	0.0000	-0.0010	0.0000	0.0080	0.0000	0.0035	0.0000	0.0017	0.0000	0.0129
y_C	0.0000	0.0014	0.0000	0.0014	0.0000	-0.0106	0.0000	-0.0046	0.0000	-0.0022	0.0000	-0.0171
l_I	0.0000	-0.0024	0.0000	-0.0024	0.0000	0.0182	0.0000	0.0078	0.0000	0.0038	0.0000	0.0293
l_C	0.0000	0.0031	0.0000	0.0031	0.0000	-0.0236	0.0000	-0.0101	0.0000	-0.0050	0.0000	-0.0380
πf_I	-0.1230	-0.1241	0.4032	0.4021	0.1230	0.1309	0.1230	0.1264	-0.5428	-0.5412	-0.5428	-0.5301
πf_C	-0.1803	-0.1788	0.2665	0.2680	0.1803	0.1698	0.1803	0.1758	-0.3662	-0.3683	-0.3662	-0.3830
w_I	0.0000	0.0013	-0.6724	-0.6710	0.0000	-0.0101	0.0000	-0.0044	-0.6724	-0.6745	-0.6724	-0.6887
w_C	0.0000	-0.0017	-0.5552	-0.5569	0.0000	0.0130	0.0000	0.0056	-0.5552	-0.5525	-0.5552	-0.5343
p	-0.0732	-0.0672	-0.0732	-0.0672	0.0732	0.0294	0.0732	0.0544	0.3531	0.3439	0.3531	0.2826
grh_I	-0.0837	-0.0821	-0.0837	-0.0821	-0.0283	-0.0400	-0.0981	-0.1030	-0.2968	-0.2993	-0.1260	-0.1445
grf_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
grh_C	-0.2438	-0.2449	-0.2438	-0.2449	-0.1377	-0.1296	-0.2300	-0.2264	-0.4302	-0.4285	-0.2041	-0.1905
grf_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gc_I	-0.1364	-0.1371	-0.1364	-0.1371	-1.3725	-1.3677	0.0000	0.0000	3.3593	3.3603	0.0000	0.0000
gc_C	-0.1364	-0.1371	-0.1364	-0.1371	-1.3725	-1.3677	0.0000	0.0000	3.3593	3.3603	0.0000	0.0000

Notes: The symbols in the first column are the proportional changes of their upper-case counterparts; thus, for example, v_I is the proportional change in V_I . SR and LR are abbreviations of “short run” and “long run”. Simulation 1: central government abatement subsidy with recycling. Simulation 2: emissions tax with recycling. Simulation 3: central government abatement subsidy, no recycling, GC endogenous in the central government budget constraint (CGBC). Simulation 4: central government abatement subsidy, no recycling, T_v endogenous in CGBC. Simulation 5: emissions tax, no recycling, GC endogenous in CGBC. Simulation 6: emissions tax, no recycling, T_v endogenous in CGBC.

Table 2: The effects on inter-regional disparities of an emissions tax and an abatement subsidy by the central government

Variable	Simulation 1		Simulation 2		Simulation 3		Simulation 4		Simulation 5		Simulation 6	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
wage gap	0.0000	-0.0030	0.1171	0.1141	0.0000	0.0231	0.0000	0.0099	0.1171	0.1220	0.1171	0.1544
income gap	-0.0309	-0.0338	-0.0309	-0.0338	0.0309	0.0542	0.0309	0.0409	0.1492	0.1541	0.1492	0.1867
output per capita	0.0000	-0.0030	0.0000	-0.0030	0.0000	0.0231	0.0000	0.0099	0.0000	0.0049	0.0000	0.0373
utility gap	0.0125	0.0054	0.0125	0.0054	-0.0955	-0.0417	-0.0410	-0.0179	-0.0201	-0.0088	-0.1535	-0.0673

Notes: wage gap equals the difference between w_C and w_I , i.e., $w_C - w_I$. Similarly, income gap equals $j_C - j_I$, output per capita gap equals $(y_C - l_C) - (y_I - l_I)$ and utility gap equals $u_C - u_I$. SR and LR are abbreviations of “short run” and “long run”. Simulation 1: central government abatement subsidy with recycling. Simulation 2: emissions tax with recycling. Simulation 3: central government abatement subsidy, no recycling, GC endogenous in the central government budget constraint (CGBC). Simulation 4: central government abatement subsidy, no recycling, T_v endogenous in CGBC. Simulation 5: emissions tax, no recycling, GC endogenous in CGBC. Simulation 6: emissions tax, no recycling, T_v endogenous in CGBC.

Table 3: The effects of abatement subsidies by regional governments

Variable	Simulation 3		Simulation 7		Simulation 8		Simulation 9	
	SR	LR	SR	LR	SR	LR	SR	LR
v_I	-0.0307	-0.0593	-0.0318	-0.0598	-0.0970	-0.0993	-0.0782	-0.0824
v_C	-0.1261	-0.1010	-0.1254	-0.1008	-0.1051	-0.1030	-0.0929	-0.0892
gh_I	-0.5322	-0.5377	-0.5372	-0.5427	-0.2906	-0.2904	-0.2658	-0.2655
gh_C	-0.8053	-0.7990	-0.8019	-0.7957	-0.4191	-0.4189	-0.3833	-0.3829
j_I	0.0690	0.0588	0.0690	0.0590	-0.0129	-0.0140	-0.0081	-0.0101
j_C	0.0999	0.1130	0.0999	0.1127	-0.0349	-0.0336	-0.0209	-0.0187
y_I	0.0000	0.0080	0.0000	0.0079	-0.0823	-0.0818	0.0000	0.0013
y_C	0.0000	-0.0106	0.0000	-0.0104	-0.1360	-0.1368	0.0000	-0.0017
l_I	0.0000	0.0182	0.0000	0.0178	0.0000	0.0016	0.0000	0.0030
l_C	0.0000	-0.0236	0.0000	-0.0231	0.0000	-0.0021	0.0000	-0.0038
πf_I	0.1230	0.1309	0.1230	0.1307	0.0414	0.0420	0.0462	0.0472
πf_C	0.1803	0.1698	0.1803	0.1700	0.0465	0.0456	0.0603	0.0587
w_I	0.0000	-0.0101	0.0000	-0.0099	-0.0823	-0.0834	-0.0775	-0.0795
w_C	0.0000	0.0130	0.0000	0.0127	-0.1360	-0.1347	-0.1219	-0.1196
p	0.0732	0.0294	0.0732	0.0303	-0.0520	-0.0553	-0.0303	-0.0364
grh_I	-0.0283	-0.0400	-0.5306	-0.5422	0.0000	0.0000	0.0000	0.0000
grf_I	0.0000	0.0000	0.0000	0.0000	-0.6355	-0.6367	0.0000	0.0000
grh_C	-0.1377	-0.1296	-1.1006	-1.0927	0.0000	0.0000	0.0000	0.0000
grf_C	0.0000	0.0000	0.0000	0.0000	-1.4031	-1.4022	0.0000	0.0000
gc_I	-1.3725	-1.3677	-0.5481	-0.5435	-0.7751	-0.7747	-0.7089	-0.7082
gc_C	-1.3725	-1.3677	-0.5481	-0.5435	-0.7751	-0.7747	-0.7089	-0.7082

Notes: The symbols in the first column are the proportional changes of their upper-case counterparts; thus, for example, v_I is the proportional change in V_I . SR and LR are abbreviations of “short run” and “long run”. Simulation 3: central government abatement subsidy, no recycling, GC endogenous in CGBC. Simulation 7: regional government abatement subsidy, no recycling, GRH endogenous in the regional government’s budget constraint (RGBC). Simulation 8: regional government abatement subsidy, no recycling, GRF endogenous in RGBC. Simulation 9: regional government abatement subsidy, no recycling, Tj endogenous in RGBC.

Table 4: The effects on regional disparities of abatement subsidies by regional governments

Variable	Simulation 3		Simulation 7		Simulation 8		Simulation 9	
	SR	LR	SR	LR	SR	LR	SR	LR
wage gap	0.0000	0.0231	0.0000	0.0227	-0.0536	-0.0513	-0.0444	-0.0402
income gap	0.0309	0.0542	0.0309	0.0537	-0.0220	-0.0196	-0.0128	-0.0086
output per capita gap	0.0000	0.0231	0.0000	0.0227	-0.0536	-0.0513	0.0000	0.0038
utility gap	-0.0955	-0.0417	-0.0936	-0.0409	-0.0081	-0.0037	-0.0147	-0.0068

Notes: wage gap equals the difference between w_C and w_I , i.e., $w_C - w_I$. Similarly, income gap equals $j_C - j_I$, output per capita gap equals $(y_C - l_C) - (y_I - l_I)$ and utility gap equals $u_C - u_I$. SR and LR are abbreviations of “short run” and “long run”. Simulation 3: central government abatement subsidy, no recycling, GC endogenous in CGBC. Simulation 7: regional government abatement subsidy, no recycling, GRH endogenous in the regional government’s budget constraint (RGBC). Simulation 8: regional government abatement subsidy, no recycling, GRF endogenous in RGBC. Simulation 9: regional government abatement subsidy, no recycling, Tj endogenous in RGBC.

Appendix 1 Variable definitions

V_i = utility of the representative household, region i
 C_{Ii} = real private consumption of interior output per household, region i
 C_{Ci} = real private consumption of coastal output per household, region i
 GH_i = real government-provided consumption per household, region i .
 P = price of interior output in terms of coastal output
 J_i = real household income (net of VAT), region i
 W_j = real wage, industry j
 ΠH_i = real profit distribution per household, region i
 T_{Ej} = emissions tax, industry j
 E_j = emissions, industry j
 E = national emissions
 B_j = abatement, industry j
 S_j = subsidy per unit of abatement, industry j
 SC_j = subsidy per unit of abatement paid by the central government, industry j
 SR_j = subsidy per unit of abatement paid by the regional government, industry j
 D_j = productivity parameter, industry j
 Y_j = real output, industry j
 L_j = employment, industry j
 L = national population
 ΠF_j = firm profit, industry j
 T_v = value added tax rate
 T_j = output tax rate, industry j
 GRH_i = real regional government-provided consumption good per household, region i
 GRF_j = real regional government-provided infrastructure good, industry j
 GC_i = real central government-provided consumption good per household in region i
 θ = central government share of valued tax
 μ = *hukou* parameter

Appendix 2: Data base

Variables	Units of Measurement	Coastal	Interior
C_C	100 million yuan	34079.60	22719.73
C_I	100 million yuan	22719.73	17206.99
$W*L$	100 million yuan	32491.98	22487.58
L	10,000	29737.89	38628.87
GRH	100 million yuan	7558.78	7032.19
GRF	100 million yuan	6998.46	6599.20
GC	100 million yuan	8897.81	4217.09
$E*T_E$	100 million yuan	2615.63	2447.82
T_E	yuan per ton	83.00	83.00
SC	yuan per ton	64.00	64.00
SR	yuan per ton	36.00	36.00
B	100 million ton	6.99	3.39

Sources: *Comprehensive Statistical Data and Materials on 60 Years of New China* (SSB, 2010), *China Energy Statistical Year Book* (SSB, various issues), *China Statistics Year Book* (SSB, various issues), *Contract Management and Financial Subsidy on Energy Consumption* (NDRC, 2010), and *State and Trends of the Carbon Market* (World Bank, various issues).

Appendix 3 Linearised 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 (17) (excluding equations (13) which are redundant) of the model 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:

$$(1') \quad v_i = \sigma_{cliv} c_{li} + \sigma_{cCiv} c_{Ci} + \sigma_{ghiv} gh_i, \quad i=I, C$$

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

$$\sigma_{cliv} = \frac{\gamma_{li} C_{li}^{-\rho}}{\gamma_{li} C_{li}^{-\rho} + \gamma_{Ci} C_{Ci}^{-\rho} + \delta_i GH_i^{-\rho}},$$

$$\sigma_{cCiv} = \frac{\gamma_{Ci} C_{Ci}^{-\rho}}{\gamma_{li} C_{li}^{-\rho} + \gamma_{Ci} C_{Ci}^{-\rho} + \delta_i GH_i^{-\rho}},$$

$$\sigma_{ghiv} = \frac{\delta_i GH_i^{-\rho}}{\gamma_{li} C_{li}^{-\rho} + \gamma_{Ci} C_{Ci}^{-\rho} + \delta_i GH_i^{-\rho}}.$$

The linearised consumption demand functions are:

$$(2a') \quad c_{II} = j_I - \sigma_{clI} p - \sigma_{elas} p + p,$$

$$\text{where } \sigma_{clI} = \frac{\frac{\rho}{\rho+1}}{1 + P^{\frac{\rho}{\rho+1}} \left(\frac{\gamma_{Cl}}{\gamma_{II}} \right)^{\frac{1}{\rho+1}}}, \quad \sigma_{elas} = \frac{1}{\rho+1}, \text{ and}$$

$$(2b') \quad c_{IC} = j_C - \sigma_{clC} p - \sigma_{elas} p,$$

$$\text{where } \sigma_{clC} = \frac{\frac{\rho}{\rho+1}}{1 + P^{\frac{\rho}{\rho+1}} \left(\frac{\gamma_{CC}}{\gamma_{IC}} \right)^{\frac{1}{\rho+1}}}$$

$$(2c') \quad c_{CI} = j_I - \sigma_{clI} p + p$$

$$(2d') \quad c_{CC} = j_C - \sigma_{clC} p$$

The linearised definitions of real household income are:

$$(3a') \quad \sigma_{iv} t_v + j_I = \sigma_{j\pi h\pi h1} \pi h_1 + \sigma_{j\pi hwl} w_I$$

$$\text{where } \sigma_{iv} = \frac{T_v}{1+T_v}, \quad \sigma_{j\pi h\pi h1} = \frac{\Pi H_1}{(1+T_v)J_1}, \quad \sigma_{j\pi hwl} = \frac{W_I}{(1+T_v)J_1}$$

$$(3b') \quad \sigma_{iv} t_v + j_C = \sigma_{j\pi h\pi hC} \pi h_C + \sigma_{j\pi hwc} w_C$$

$$\text{where, } \sigma_{j\pi h\pi hC} = \frac{\Pi H_C}{(1+T_v)J_C}, \quad \sigma_{j\pi hwc} = \frac{W_C}{(1+T_v)J_C}$$

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

$$(4') \quad v_C = v_I + \mu^* \mu \log\left(\frac{L_C/A_C}{L_I/A_I}\right) + \mu(l_C - l_I)$$

where $\mu^* = d\mu/\mu$ and we have made the obvious assumption that area is constant.

The linearised production functions are:

$$(5') \quad y_j = d_j + \alpha_{Lj} l_j + \alpha_{Gj} grf_j, \quad j=I, C.$$

The emission equation

$$(6') \quad e_j = \sigma_{Eyj} y_j - \sigma_{EBj} b_j$$

$$\text{where } \sigma_{Eyj} = \frac{\varepsilon_j Y_j}{\varepsilon_j Y_j - B_j} \text{ and } \sigma_{EBj} = \frac{B_j}{\varepsilon_j Y_j - B_j}$$

The linearised profit definitions are given by:

$$(7') \quad \pi f_j = \sigma_{y\pi f j} y_j - \sigma_{tj} \sigma_{y\pi f j} t_j - \sigma_{w\pi f j} (w_j + l_j)$$

$$- \sigma_{ry\pi f j} (t_{Ej} + y_j) + \sigma_{rb\pi f j} (t_{Ej} + b_j) - \sigma_{b2\pi f j} b_j + \sigma_{sb\pi f j} (s_j + b_j)$$

$$\text{where } \sigma_{y\pi f j} = \frac{(1-T_j)Y_j}{\Pi F_j}, \quad \sigma_{tj} = \frac{T_j}{1-T_j}, \quad \sigma_{w\pi f j} = \frac{W_j L_j}{\Pi F_j}, \quad \sigma_{ry\pi f j} = \frac{\varepsilon_j T_{Ej} Y_j}{\Pi F_j}, \quad \sigma_{rb\pi f j} = \frac{T_{Ej} B_j}{\Pi F_j},$$

$$\sigma_{b2\pi f j} = \frac{2\omega_j B_j^2}{\Pi F_j}, \quad \sigma_{sb\pi f j} = \frac{S_j B_j}{\Pi F_j}$$

The manufacturing industry's profit-maximisation condition in linear form is:

$$(8a') \quad y_j - \sigma_{tj} t_j - \sigma_{trj} t_{Ej} = w_j + l_j, \quad j=I, C$$

$$(8b') \quad b_j = \sigma_{bbrj} t_{Ej} + \sigma_{bbsj} s_j, \quad j=I, C$$

$$\text{where } \sigma_{tj} = \frac{T_j}{1-T_j - T_{Ej} \varepsilon_j}, \quad \sigma_{trj} = \frac{T_{Ej} \varepsilon_j}{1-T_j - T_{Ej} \varepsilon_j}, \quad \sigma_{bbrj} = \frac{T_{Ej}}{T_{Ej} + S_j}, \quad \sigma_{bbsj} = \frac{S_j}{T_{Ej} + S_j}$$

The central government's budget constraint is linearised as:

$$(9') \quad \sigma_{gclgc} (l_I + gc_I) + \sigma_{gcCgc} (l_C + gc_C) - \sigma_{gcrel} (t_{EI} + e_I)$$

$$- \sigma_{greC} (t_{EC} + e_C) + \sigma_{gcschl} (sc_I + b_I) + \sigma_{gcsbc} (sc_C + b_C) = \theta^* + t_v + \sigma_{jlj} (l_I + j_I) + \sigma_{jCj} (l_C + j_C)$$

$$\text{where } \sigma_{gclgc} = \frac{L_I GC_I}{L_I GC_I + L_C GC_C - T_{EI} E_I - \eta T_{EC} E_C + SC_I B_I + \eta SC_C B_C},$$

$$\sigma_{gcCgc} = \frac{L_C GC_C}{L_I GC_I + L_C GC_C - T_{EI} E_I - \eta T_{EC} E_C + SC_I B_I + \eta SC_C B_C}$$

$$\sigma_{gcrel} = \frac{T_{EI} E_I}{L_I GC_I + L_C GC_C - T_{EI} E_I - \eta T_{EC} E_C + SC_I B_I + \eta SC_C B_C}$$

$$\sigma_{greC} = \frac{\eta T_{EC} E_C}{L_I GC_I + L_C GC_C - T_{EI} E_I - \eta T_{EC} E_C + SC_I B_I + \eta SC_C B_C}$$

$$\sigma_{gcschl} = \frac{SC_I B_I}{L_I GC_I + L_C GC_C - T_{EI} E_I - \eta T_{EC} E_C + SC_I B_I + \eta SC_C B_C}$$

$$\sigma_{gcsbc} = \frac{\eta SC_C B_C}{L_I GC_I + L_C GC_C - T_{EI} E_I - \eta T_{EC} E_C + SC_I B_I + \eta SC_C B_C}$$

$$\sigma_{jlj} = \frac{L_I J_I}{L_I J_I + \eta L_C J_C}, \quad \sigma_{jCj} = \frac{\eta L_C J_C}{L_C J_I + \eta L_C J_C}, \quad \theta^* = d\theta/\theta,$$

The regional governments' budget constraints are linearised as:

$$(10a') \quad \sigma_{grhlgr} (l_I + grh_I) + \sigma_{grflgr} grf_I + \sigma_{grsrl} (sr_I + b_I)$$

$$= \sigma_{tlgr} (t_I + y_I) + \sigma_{vlgr} (-\sigma_\theta \theta^* + t_v + l_I + j_I)$$

where $\sigma_{grhIgr} = \frac{L_I GRH_I}{L_I GRH_I + GRF_I + SR_I B_I}$, $\sigma_{grfIgr} = \frac{GRF_I}{L_I GRH_I + GRF_I + SR_I B_I}$,

$\sigma_{grsrI} = \frac{SR_I B_I}{L_I GRH_I + GRF_I + SR_I B_I}$, $\sigma_\theta = \frac{\theta}{1-\theta}$, $\sigma_{tIgr} = \frac{T_I Y_I}{T_I Y_I + (1-\theta)T_V L_I J_I}$,

$\sigma_{tVgr} = \frac{(1-\theta)T_V N_I J_I}{T_I Y_I + (1-\theta)T_V L_I J_I}$, and

(10b') $\sigma_{grhCgr}(l_C + grh_C) + \sigma_{grfCgr}grf_C + \sigma_{grsrC}(sr_C + b_C)$
 $= \sigma_{tCgr}(t_C + y_C) + \sigma_{tVgr}(-\sigma_\theta \theta^* + t_V + l_C + j_C)$

where $\sigma_{grhCgr} = \frac{L_C GRH_C}{L_C GRH_C + GRF_C + \eta SR_C B_C}$, $\sigma_{grfCgr} = \frac{GRF_C}{L_C GRH_C + GRF_C + \eta SR_C B_C}$,

$\sigma_{grsrC} = \frac{\eta SR_C B_C}{L_C GRH_C + GRF_C + \eta SR_C B_C}$, $\sigma_{tCgr} = \frac{T_C Y_C}{T_C Y_C + (1-\theta)T_V L_C J_C}$,

$\sigma_{tVgr} = \frac{(1-\theta)T_V L_C J_C}{T_C Y_C + (1-\theta)T_V L_C J_C}$.

The definition of GH_i is linearised as:

(11') $gh_i = \sigma_{grhigh}grh_i + \sigma_{gcigh}gc_i$, $i=I, C$

where $\sigma_{grhigh} = \frac{GRH_i}{GH_i}$, $\sigma_{gcigh} = \frac{GC_i}{GH_i}$.

The definition of subsidy

(12') $\sigma_{sscj}sc_j + \sigma_{ssrj}sr_j = s_j$, $j=I, C$

where $\sigma_{sscj} = SC_j / S_j$, $\sigma_{ssrj} = SR_j / S_j$

Equations (13), the goods markets clearing conditions, are dropped from the model due to the redundancy result explained in section 2.

The profit distribution conditions can be linearised to give:

(14a') $\pi f_I = l_I + \pi h_I$,

(14b') $\pi f_C = l_C + \pi h_C$.

The balance of trade condition in linear form is:

(15') $l_C + p + c_{IC} = l_I + c_{CI}$.

The national employment constraint results in the following linearised condition:

(16') $\sigma_{ll}l_I + \sigma_{lC}l_C = l$

where $\sigma_{ll} = L_I / L$, $\sigma_{lC} = L_C / L$.

The national emission permits constraint results in the following linearised condition:

(17') $\sigma_{eI}e_I + \sigma_{eC}e_C = e$

where $\sigma_{eI} = E_I / E$, $\sigma_{eC} = E_C / E$.

Appendix 4 Calibration

The linearised model contains a number of parameters which have to be evaluated before the model can be used to simulate the effects of various shocks. These parameters fall into two groups. The first are parameters which appear in model relationships; γ_{ji} , δ_i and ρ appear in the utility function (1) and α_{Gj} and α_{Lj} appear in the production function (5). The remainder, on the other hand, are linearisation parameters which are all shares of some sort. The model parameters were evaluated as follows. For the parameters of the utility function we broadly followed the method set out in Mansur and Whalley (1984) in which the substitution elasticity $\sigma = 1/(1+\rho)$ is derived from the equation:

$$\sigma = \frac{\eta_i - \gamma_i^\sigma}{1 - \gamma_i^\sigma}$$

where η_i is the (uncompensated) own-price elasticity, values for which were derived as averages from Table 4 in Mansur and Whalley, and γ_i^σ can be derived from ratios of consumption expenditure and our assumption that $\gamma_{ti} + \gamma_{ci} + \delta_i = 1$.

The production parameters, α_{Gj} and α_{Lj} , were calibrated as follows. Using the firm's first-order condition for profit-maximisation, equation (8a) and (8b), and the assumption that the firm can choose the government expenditure to maximise profit, we can write:

$$\alpha_{Lj} = \frac{W_j L_j}{Y_j (1 - T_j - T_{Ej} \varepsilon_j)}, \text{ and}$$

$$\alpha_{Gj} = \frac{GRF_j}{Y_j (1 - T_j - T_{Ej} \varepsilon_j)}$$

and use data for the wage bill, government infrastructure expenditure and output net of tax to compute the parameters.

The linearisation parameters can be evaluated directly from their definitions, given values for C_{ji} , P , θ , μ , η , IIH_i , T_{Ej} , E_j , W_j , T_v , T_j , Y_j , IIF_j , L_j , GC_i , J_i , GRH_i , GRF_i , GH_i , B_j , SC_i , SR_i , and S_i . We normalise P and η at unity and also set the immigration parameter, μ , at unity; θ is set at 0.75 to reflect the current division of VAT revenue between the central and regional governments. We then use these assumed values and the data for C_{ji} , GRH_i , GRF_j , $T_{Ej}E_j$, GC_i , L_jW_j , B_j , SC_i , SR_i together with the model definitions to calculate the value of all other variables. The use of the model definitions ensures that the parameter values used in the simulations are consistent with the model constraints.

We therefore need data for two regions, the interior and the coast, for the variables C_{ji} , GRH_i , GRF_j , $T_{Ej}E_j$, GC_i , L_jW_j , B_j , SC_i , SR_i . The data we use are based on those for the Chinese provinces which we have allocated to the two regions as follows. The coastal region consists of Beijing, Tianjin, Hebei, Guangdong, Hainan, Shandong, Fujian, Zhejiang, Jiangsu, Shanghai, Liaoning and Guangxi with the remaining provinces being allocated to the interior region. The interior therefore consist of: Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Sichuan, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Tibet, Xinjiang. For each region we use data averaged over the 11-year period 2000-2010 to avoid cyclical influences on the share parameters.

The data for emissions were generated as follows. We first computed the CO₂ emissions in each province using the energy consumption data for coal, gas and oil and their emission factor index and then used the world market CO₂ trading price as a measure of carbon tax. The energy consumption data come from *Comprehensive Statistical Data and Materials on 60 Years of New China (SSB, 2010)* and *China Energy Statistical Year Book (SSB, various issues)*, the emission factor indexes for coal, gas and oil come from IPCC

(2006), and the CO₂ trading price come from *State and Trends of the Carbon Market* (World Bank, various issues).

We computed the abatement data for each year as $B_t = GDP_t * (E_{2000} / GDP_{2000}) - E_t$. We let the model compute the ε_i parameter with $\varepsilon_i = (E_j + B_j) / Y_j$, and computed the ω_j parameters for the abatement cost function from the first-order condition for B .

The subsidy data were collected from government documents: *Contract Management and Financial Subsidy on Energy Consumption* (NDRC, 2010).

All the other data come from *China Statistics Year Book* (SSB, various issues) except for data on area used to compute population density for the migration equilibrium condition, equation (4'), which come from *China Civil Affairs Statistical Yearbook 2005* (SSB, 2005).

Appendix 5: Full results

Variable	Simulation 1		Simulation 2		Simulation 3	
	SR	LR	SR	LR	SR	LR
v_I	-0.1090	-0.1052	-0.1090	-0.1052	-0.0307	-0.0593
v_C	-0.0965	-0.0998	-0.0965	-0.0998	-0.1261	-0.1010
c_{II}	-0.0923	-0.0891	-0.0923	-0.0891	0.0923	0.0682
c_{CI}	-0.1245	-0.1187	-0.1245	-0.1187	0.1245	0.0811
c_{IC}	-0.0513	-0.0569	-0.0513	-0.0569	0.0513	0.0934
c_{CC}	-0.0835	-0.0865	-0.0835	-0.0865	0.0835	0.1064
gh_I	-0.1034	-0.1027	-0.1034	-0.1027	-0.5322	-0.5377
gh_C	-0.1857	-0.1866	-0.1857	-0.1866	-0.8053	-0.7990
j_I	-0.0690	-0.0677	-0.0690	-0.0677	0.0690	0.0588
j_C	-0.0999	-0.1015	-0.0999	-0.1015	0.0999	0.1130
πh_I	-0.1230	-0.1217	0.4032	0.4045	0.1230	0.1127
πh_C	-0.1803	-0.1819	0.2665	0.2649	0.1803	0.1934
y_I	0.0000	-0.0010	0.0000	-0.0010	0.0000	0.0080
y_C	0.0000	0.0014	0.0000	0.0014	0.0000	-0.0106
l_I	0.0000	-0.0024	0.0000	-0.0024	0.0000	0.0182
l_C	0.0000	0.0031	0.0000	0.0031	0.0000	-0.0236
t_{EI}	0.0000	0.0000	12.5494	12.5494	0.0000	0.0000
t_{EC}	0.0000	0.0000	12.5494	12.5494	0.0000	0.0000
e_I	-0.7235	-0.7246	-0.7235	-0.7246	-0.7235	-0.7145
e_C	-1.2588	-1.2571	-1.2588	-1.2571	-1.2588	-1.2718
e	-1.0000	-0.9997	-1.0000	-0.9997	-1.0000	-1.0024
πf_I	-0.1230	-0.1241	0.4032	0.4021	0.1230	0.1309
πf_C	-0.1803	-0.1788	0.2665	0.2680	0.1803	0.1698
w_I	0.0000	0.0013	-0.6724	-0.6710	0.0000	-0.0101
w_C	0.0000	-0.0017	-0.5552	-0.5569	0.0000	0.0130
p	-0.0732	-0.0672	-0.0732	-0.0672	0.0732	0.0294
grh_I	-0.0837	-0.0821	-0.0837	-0.0821	-0.0283	-0.0400
grf_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
grh_C	-0.2438	-0.2449	-0.2438	-0.2449	-0.1377	-0.1296
grf_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gc_I	-0.1364	-0.1371	-0.1364	-0.1371	-1.3725	-1.3677
gc_C	-0.1364	-0.1371	-0.1364	-0.1371	-1.3725	-1.3677
t_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
q	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
b_I	6.2906	6.2906	6.2906	6.2906	6.2906	6.2906
b_C	5.6767	5.6767	5.6767	5.6767	5.6767	5.6767
sc_I	16.2393	16.2393	0.0000	0.0000	16.2393	16.2393
sc_C	16.2393	16.2393	0.0000	0.0000	16.2393	16.2393
sr_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
s_I	12.6131	12.6131	0.0000	0.0000	12.6131	12.6131
s_C	10.3655	10.3655	0.0000	0.0000	10.3655	10.3655

Notes: Simulation 1: central government abatement subsidy with recycling. Simulation 2: emissions tax with recycling. Simulation 3: central government abatement subsidy, no recycling, GC endogenous in CGBC.

Appendix 5: Full results contd

Variable	Simulation 4		Simulation 5		Simulation 6	
	SR	LR	SR	LR	SR	LR
v_I	-0.0628	-0.0750	-0.0751	-0.0811	0.0035	-0.0424
v_C	-0.1037	-0.0930	-0.0951	-0.0899	-0.1500	-0.1097
c_{II}	-0.0815	-0.0916	-0.4872	-0.4923	-0.0618	-0.0997
c_{CI}	-0.0493	-0.0677	-0.3318	-0.3409	0.0936	0.0247
c_{IC}	-0.1225	-0.1041	-0.6849	-0.6761	-0.2595	-0.1907
c_{CC}	-0.0903	-0.0802	-0.5296	-0.5248	-0.1042	-0.0664
gh_I	-0.0613	-0.0644	1.0738	1.0726	-0.0787	-0.0903
gh_C	-0.1057	-0.1040	1.6187	1.6201	-0.0937	-0.0875
j_I	-0.1048	-0.1090	-0.5997	-0.6018	-0.1743	-0.1898
j_C	-0.0739	-0.0680	-0.4505	-0.4477	-0.0251	-0.0031
πh_I	0.1230	0.1186	-0.5428	-0.5450	-0.5428	-0.5593
πh_C	0.1803	0.1859	-0.3662	-0.3634	-0.3662	-0.3450
y_I	0.0000	0.0035	0.0000	0.0017	0.0000	0.0129
y_C	0.0000	-0.0046	0.0000	-0.0022	0.0000	-0.0171
l_I	0.0000	0.0078	0.0000	0.0038	0.0000	0.0293
l_C	0.0000	-0.0101	0.0000	-0.0050	0.0000	-0.0380
t_{EI}	0.0000	0.0000	12.5494	12.5494	12.5494	12.5494
t_{EC}	0.0000	0.0000	12.5494	12.5494	12.5494	12.5494
e_I	-0.7235	-0.7196	-0.7235	-0.7216	-0.7235	-0.7091
e_C	-1.2588	-1.2644	-1.2588	-1.2615	-1.2588	-1.2797
e	-1.0000	-1.0010	-1.0000	-1.0005	-1.0000	-1.0038
πf_I	0.1230	0.1264	-0.5428	-0.5412	-0.5428	-0.5301
πf_C	0.1803	0.1758	-0.3662	-0.3683	-0.3662	-0.3830
w_I	0.0000	-0.0044	-0.6724	-0.6745	-0.6724	-0.6887
w_C	0.0000	0.0056	-0.5552	-0.5525	-0.5552	-0.5343
p	0.0732	0.0544	0.3531	0.3439	0.3531	0.2826
grh_I	-0.0981	-0.1030	-0.2968	-0.2993	-0.1260	-0.1445
grf_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
grh_C	-0.2300	-0.2264	-0.4302	-0.4285	-0.2041	-0.1905
grf_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gc_I	0.0000	0.0000	3.3593	3.3603	0.0000	0.0000
gc_C	0.0000	0.0000	3.3593	3.3603	0.0000	0.0000
t_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
q	0.2627	0.2623	0.0000	0.0000	-0.6430	-0.6444
t_V	0.7881	0.7869	0.0000	0.0000	-1.9289	-1.9333
b_I	6.2906	6.2906	6.2906	6.2906	6.2906	6.2906
b_C	5.6767	5.6767	5.6767	5.6767	5.6767	5.6767
sc_I	16.2393	16.2393	0.0000	0.0000	0.0000	0.0000
sc_C	16.2393	16.2393	0.0000	0.0000	0.0000	0.0000
sr_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
s_I	12.6131	12.6131	0.0000	0.0000	0.0000	0.0000
s_C	10.3655	10.3655	0.0000	0.0000	0.0000	0.0000

Notes: Simulation 4: central government abatement subsidy, no recycling, Tv endogenous in CGBC. Simulation 5: emissions tax, no recycling, GC endogenous in CGBC. Simulation 6: emissions tax, no recycling, Tv endogenous in CGBC.

Appendix 5: Full results contd

Variable	Simulation 7		Simulation 8		Simulation 9	
	SR	LR	SR	LR	SR	LR
v_I	-0.0318	-0.0598	-0.0970	-0.0993	-0.0782	-0.0824
v_C	-0.1254	-0.1008	-0.1051	-0.1030	-0.0929	-0.0892
c_{II}	0.0923	0.0686	-0.0295	-0.0316	-0.0178	-0.0217
c_{CI}	0.1245	0.0819	-0.0523	-0.0559	-0.0311	-0.0377
c_{IC}	0.0513	0.0926	-0.0004	0.0031	-0.0008	0.0055
c_{CC}	0.0835	0.1059	-0.0232	-0.0212	-0.0142	-0.0105
gh_I	-0.5372	-0.5427	-0.2906	-0.2904	-0.2658	-0.2655
gh_C	-0.8019	-0.7957	-0.4191	-0.4189	-0.3833	-0.3829
j_I	0.0690	0.0590	-0.0129	-0.0140	-0.0081	-0.0101
j_C	0.0999	0.1127	-0.0349	-0.0336	-0.0209	-0.0187
πh_I	0.1230	0.1129	0.0414	0.0404	0.0462	0.0442
πh_C	0.1803	0.1932	0.0465	0.0477	0.0603	0.0626
y_I	0.0000	0.0079	-0.0823	-0.0818	0.0000	0.0013
y_C	0.0000	-0.0104	-0.1360	-0.1368	0.0000	-0.0017
l_I	0.0000	0.0178	0.0000	0.0016	0.0000	0.0030
l_C	0.0000	-0.0231	0.0000	-0.0021	0.0000	-0.0038
t_{EI}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_{EC}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
e_I	-0.7235	-0.7147	-0.8153	-0.8146	-0.7235	-0.7220
e_C	-1.2588	-1.2715	-1.4249	-1.4259	-1.2588	-1.2609
e	-1.0000	-1.0023	-1.1302	-1.1304	-1.0000	-1.0004
πf_I	0.1230	0.1307	0.0414	0.0420	0.0462	0.0472
πf_C	0.1803	0.1700	0.0465	0.0456	0.0603	0.0587
w_I	0.0000	-0.0099	-0.0823	-0.0834	-0.0775	-0.0795
w_C	0.0000	0.0127	-0.1360	-0.1347	-0.1219	-0.1196
p	0.0732	0.0303	-0.0520	-0.0553	-0.0303	-0.0364
grh_I	-0.5306	-0.5422	0.0000	0.0000	0.0000	0.0000
grf_I	0.0000	0.0000	-0.6355	-0.6367	0.0000	0.0000
grh_C	-1.1006	-1.0927	0.0000	0.0000	0.0000	0.0000
grf_C	0.0000	0.0000	-1.4031	-1.4022	0.0000	0.0000
gc_I	-0.5481	-0.5435	-0.7751	-0.7747	-0.7089	-0.7082
gc_C	-0.5481	-0.5435	-0.7751	-0.7747	-0.7089	-0.7082
t_I	0.0000	0.0000	0.0000	0.0000	1.4087	1.4138
t_C	0.0000	0.0000	0.0000	0.0000	1.2485	1.2470
q	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
b_I	6.2906	6.2906	6.2906	6.2906	6.2906	6.2906
b_C	5.6767	5.6767	5.6767	5.6767	5.6767	5.6767
sc_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sc_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_I	56.4846	56.4846	56.4846	56.4846	56.4846	56.4846
sr_C	28.6577	28.6577	28.6577	28.6577	28.6577	28.6577
s_I	12.6131	12.6131	12.6131	12.6131	12.6131	12.6131
s_C	10.3656	10.3656	10.3656	10.3656	10.3656	10.3656

Notes: Simulation 7: regional government subsidy, no recycling, GRH endogenous. Simulation 8: regional government subsidy, no recycling, GRF endogenous. Simulation 9: regional government subsidy, no recycling, Tj endogenous.

Appendix 6: Robustness tests: Full results for a model with mobile capital

Variable	Simulation 1		Simulation 2		Simulation 3	
	SR	LR	SR	LR	SR	LR
v_I	-0.1259	-0.1075	-0.0162	-0.0754	-0.0138	-0.0608
v_C	-0.0733	-0.0920	-0.1857	-0.1255	-0.1494	-0.1016
c_{II}	-0.0925	-0.0828	-0.0747	-0.1059	0.0925	0.0673
c_{CI}	-0.1682	-0.1326	0.0963	-0.0181	0.1682	0.0780
c_{IC}	0.0038	-0.0349	-0.2924	-0.1676	-0.0038	0.0946
c_{CC}	-0.0719	-0.0848	-0.1213	-0.0798	0.0719	0.1052
gh_I	-0.0916	-0.0946	-0.1542	-0.1445	-0.5440	-0.5368
gh_C	-0.1826	-0.1856	-0.1718	-0.1622	-0.8085	-0.8007
j_I	-0.0377	-0.0467	-0.1986	-0.1695	0.0377	0.0596
j_C	-0.1104	-0.1101	-0.0343	-0.0351	0.1104	0.1106
πh_I	-0.2590	-0.2576	1.4684	1.4639	0.2590	0.2529
πh_C	-0.2531	-0.2571	0.6542	0.6670	0.2531	0.2648
y_I	0.0000	-0.0045	-0.0389	-0.0243	0.0000	0.0119
y_C	0.0000	0.0044	0.0233	0.0090	0.0000	-0.0117
l_I	0.0000	-0.0068	0.0000	0.0218	0.0000	0.0178
l_C	0.0000	0.0088	0.0000	-0.0283	0.0000	-0.0231
r_{KI}	0.0000	0.0010	-0.6024	-0.6056	0.0000	-0.0026
r_{KC}	0.0000	0.0010	-0.6024	-0.6056	0.0000	-0.0026
k_I	0.0000	-0.0055	-0.1753	-0.1575	0.0000	0.0145
k_C	0.0000	0.0034	0.1087	0.0977	0.0000	-0.0090
t_{EI}	0.0000	0.0000	12.4704	12.4704	0.0000	0.0000
t_{EC}	0.0000	0.0000	12.4704	12.4704	0.0000	0.0000
e_I	-0.7235	-0.7285	-0.7623	-0.7460	-0.7235	-0.7102
e_C	-1.2588	-1.2534	-1.2225	-1.2399	-1.2588	-1.2730
e	-1.0000	-0.9996	-1.0000	-1.0012	-1.0000	-1.0009
πf_I	-0.2590	-0.2644	1.4684	1.4857	0.2590	0.2707
πf_C	-0.2531	-0.2483	0.6542	0.6387	0.2531	0.2417
w_I	0.0000	0.0022	-0.7776	-0.7848	0.0000	-0.0059
w_C	0.0000	-0.0044	-0.4936	-0.4796	0.0000	0.0114
p	-0.1720	-0.1133	0.3887	0.1996	0.1720	0.0242
grh_I	-0.0711	-0.0725	-0.1509	-0.1464	-0.0408	-0.0379
grf_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
grh_C	-0.2494	-0.2493	-0.1861	-0.1866	-0.1321	-0.1320
grf_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gc_I	-0.1258	-0.1315	-0.1598	-0.1414	-1.3830	-1.3688
gc_C	-0.1258	-0.1315	-0.1598	-0.1414	-1.3830	-1.3688
t_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
q	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
b_I	6.2906	6.2906	6.2510	6.2510	6.2906	6.2906
b_C	5.6767	5.6767	5.6410	5.6410	5.6767	5.6767
sc_I	16.2393	16.2393	0.0000	0.0000	16.2393	16.2393
sc_C	16.2393	16.2393	0.0000	0.0000	16.2393	16.2393
sr_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
s_I	12.6131	12.6131	0.0000	0.0000	12.6131	12.6131
s_C	10.3655	10.3655	0.0000	0.0000	10.3655	10.3655

Notes: Simulation 1: central government abatement subsidy with recycling. Simulation 2: emissions tax with recycling. Simulation 3: central government abatement subsidy, no recycling, GC endogenous in CGBC.

Appendix 6: Robustness tests: Full results for a model with mobile capital contd

Variable	Simulation 4		Simulation 5		Simulation 6	
	SR	LR	SR	LR	SR	LR
v_I	-0.0461	-0.0740	0.1119	-0.0361	0.1879	-0.0043
v_C	-0.1268	-0.0984	-0.3154	-0.1648	-0.3685	-0.1725
c_{II}	-0.0826	-0.0966	-0.4661	-0.5455	-0.0544	-0.1508
c_{CI}	-0.0070	-0.0598	0.1356	-0.1488	0.5474	0.1829
c_{IC}	-0.1790	-0.1191	-1.2320	-0.9218	-0.8202	-0.4072
c_{CC}	-0.1033	-0.0823	-0.6302	-0.5251	-0.2185	-0.0735
gh_I	-0.0695	-0.0681	0.9481	0.9707	-0.1675	-0.1581
gh_C	-0.1034	-0.1031	1.6020	1.6264	-0.0556	-0.0537
j_I	-0.1375	-0.1233	-0.9019	-0.8329	-0.4902	-0.3924
j_C	-0.0648	-0.0635	-0.3239	-0.3231	0.0879	0.0964
πh_I	0.2590	0.2554	-0.5043	-0.5235	-0.5043	-0.5294
πh_C	0.2531	0.2601	-0.2311	-0.1943	-0.2311	-0.1830
y_I	0.0000	0.0071	-0.0389	-0.0014	-0.0389	0.0101
y_C	0.0000	-0.0070	0.0233	-0.0135	0.0233	-0.0248
l_I	0.0000	0.0106	0.0000	0.0560	0.0000	0.0732
l_C	0.0000	-0.0138	0.0000	-0.0727	0.0000	-0.0951
r_{KI}	0.0000	-0.0016	-0.6024	-0.6107	-0.6024	-0.6132
r_{KC}	0.0000	-0.0016	-0.6024	-0.6107	-0.6024	-0.6132
k_I	0.0000	0.0087	-0.1753	-0.1295	-0.1753	-0.1154
k_C	0.0000	-0.0054	0.1087	0.0803	0.1087	0.0716
t_{EI}	0.0000	0.0000	12.4704	12.4704	12.4704	12.4704
t_{EC}	0.0000	0.0000	12.4704	12.4704	12.4704	12.4704
e_I	-0.7235	-0.7156	-0.7623	-0.7205	-0.7623	-0.7076
e_C	-1.2588	-1.2673	-1.2225	-1.2673	-1.2225	-1.2811
e	-1.0000	-1.0006	-1.0000	-1.0030	-1.0000	-1.0039
πf_I	0.2590	0.2660	-0.5043	-0.4675	-0.5043	-0.4562
πf_C	0.2531	0.2463	-0.2311	-0.2670	-0.2311	-0.2781
w_I	0.0000	-0.0035	-0.7776	-0.7961	-0.7776	-0.8018
w_C	0.0000	0.0068	-0.4936	-0.4577	-0.4936	-0.4466
p	0.1720	0.0837	1.3676	0.9017	1.3676	0.7583
grh_I	-0.1112	-0.1090	-0.4333	-0.4241	-0.2680	-0.2530
grf_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
grh_C	-0.2252	-0.2245	-0.3400	-0.3398	-0.1212	-0.1169
grf_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gc_I	0.0000	0.0000	3.2517	3.2966	0.0000	0.0000
gc_C	0.0000	0.0000	3.2517	3.2966	0.0000	0.0000
t_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
q	0.2647	0.2631	0.0000	0.0000	-0.6224	-0.6336
t_V	0.7941	0.7893	0.0000	0.0000	-1.8672	-1.9009
b_I	6.2906	6.2906	6.2510	6.2510	6.2510	6.2510
b_C	5.6767	5.6767	5.6410	5.6410	5.6410	5.6410
sc_I	16.2393	16.2393	0.0000	0.0000	0.0000	0.0000
sc_C	16.2393	16.2393	0.0000	0.0000	0.0000	0.0000
sr_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
s_I	12.6131	12.6131	0.0000	0.0000	0.0000	0.0000
s_C	10.3655	10.3655	0.0000	0.0000	0.0000	0.0000

Notes: Simulation 4: central government abatement subsidy, no recycling, T_v endogenous in CGBC. Simulation 5: emissions tax, no recycling, G_C endogenous in CGBC. Simulation 6: emissions tax, no recycling, T_v endogenous in CGBC.

Appendix 6: Robustness tests: Full results for a model with mobile capital contd

Variable	Simulation 7		Simulation 8		Simulation 9	
	SR	LR	SR	LR	SR	LR
v_I	-0.0149	-0.0612	-0.0860	-0.0949	-0.0651	-0.0786
v_C	-0.1486	-0.1015	-0.1115	-0.1024	-0.1039	-0.0902
c_{II}	0.0925	0.0677	-0.0258	-0.0305	-0.0150	-0.0221
c_{CI}	0.1682	0.0792	-0.0306	-0.0476	-0.0035	-0.0293
c_{IC}	-0.0038	0.0932	-0.0198	-0.0012	-0.0296	-0.0013
c_{CC}	0.0719	0.1048	-0.0245	-0.0183	-0.0181	-0.0085
gh_I	-0.5490	-0.5419	-0.2899	-0.2888	-0.2663	-0.2648
gh_C	-0.8050	-0.7974	-0.4181	-0.4166	-0.3841	-0.3819
j_I	0.0377	0.0593	-0.0224	-0.0181	-0.0233	-0.0168
j_C	0.1104	0.1106	-0.0270	-0.0270	-0.0123	-0.0122
πh_I	0.2590	0.2530	0.1750	0.1740	0.1792	0.1776
πh_C	0.2531	0.2646	0.1260	0.1281	0.1388	0.1421
y_I	0.0000	0.0117	-0.0857	-0.0834	0.0049	0.0082
y_C	0.0000	-0.0115	-0.1300	-0.1322	-0.0029	-0.0062
l_I	0.0000	0.0175	0.0000	0.0033	0.0000	0.0050
l_C	0.0000	-0.0228	0.0000	-0.0043	0.0000	-0.0065
r_{KI}	0.0000	-0.0026	-0.1131	-0.1135	-0.1034	-0.1041
r_{KC}	0.0000	-0.0026	-0.1131	-0.1135	-0.1034	-0.1041
k_I	0.0000	0.0143	0.0273	0.0301	0.0219	0.0261
k_C	0.0000	-0.0089	-0.0170	-0.0187	-0.0136	-0.0162
t_{EI}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_{EC}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
e_I	-0.7235	-0.7104	-0.8191	-0.8165	-0.7181	-0.7143
e_C	-1.2588	-1.2728	-1.4177	-1.4203	-1.2623	-1.2664
e	-1.0000	-1.0009	-1.1283	-1.1284	-0.9992	-0.9995
πf_I	0.2590	0.2705	0.1750	0.1773	0.1792	0.1826
πf_C	0.2531	0.2419	0.1260	0.1239	0.1388	0.1356
w_I	0.0000	-0.0058	-0.0857	-0.0867	-0.0815	-0.0830
w_C	0.0000	0.0113	-0.1300	-0.1279	-0.1169	-0.1137
p	0.1720	0.0262	-0.0108	-0.0388	0.0261	-0.0165
grh_I	-0.5432	-0.5403	0.0000	0.0000	0.0000	0.0000
grf_I	0.0000	0.0000	-0.6410	-0.6403	0.0000	0.0000
grh_C	-1.0950	-1.0950	0.0000	0.0000	0.0000	0.0000
grf_C	0.0000	0.0000	-1.3926	-1.3926	0.0000	0.0000
gc_I	-0.5587	-0.5446	-0.7732	-0.7705	-0.7104	-0.7063
gc_C	-0.5587	-0.5446	-0.7732	-0.7705	-0.7104	-0.7063
t_I	0.0000	0.0000	0.0000	0.0000	1.4191	1.4167
t_C	0.0000	0.0000	0.0000	0.0000	1.2464	1.2465
q	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
b_I	6.2906	6.2906	6.2906	6.2906	6.2906	6.2906
b_C	5.6767	5.6767	5.6767	5.6767	5.6767	5.6767
sc_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sc_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_I	56.4846	56.4846	56.4846	56.4846	56.4846	56.4846
sr_C	28.6577	28.6577	28.6577	28.6577	28.6577	28.6577
s_I	12.6131	12.6131	12.6131	12.6131	12.6131	12.6131
s_C	10.3656	10.3656	10.3656	10.3656	10.3656	10.3656

Notes: Simulation 7: regional government subsidy, no recycling, GRH endogenous. Simulation 8: regional government subsidy, no recycling, GRF endogenous. Simulation 9: regional government subsidy, no recycling, Tj endogenous.

Appendix 7: Robustness tests: Full results for regionally-differentiated policy

Variable	Simulation 1		Simulation 2		Simulation 3	
	SR	LR	SR	LR	SR	LR
v_I	-0.1350	-0.1104	-0.0317	-0.0803	-0.0039	-0.0579
v_C	-0.0645	-0.0896	-0.1710	-0.1215	-0.1598	-0.1049
c_{II}	-0.0942	-0.0812	-0.0778	-0.1034	0.0942	0.0652
c_{CI}	-0.1906	-0.1431	0.0563	-0.0378	0.1906	0.0868
c_{IC}	0.0286	-0.0233	-0.2483	-0.1457	-0.0286	0.0847
c_{CC}	-0.0679	-0.0852	-0.1143	-0.0801	0.0679	0.1063
gh_I	-0.0849	-0.0889	-0.1388	-0.1309	-0.5466	-0.5384
gh_C	-0.1861	-0.1901	-0.1817	-0.1737	-0.8126	-0.8037
j_I	-0.0243	-0.0364	-0.1748	-0.1509	0.0243	0.0495
j_C	-0.1170	-0.1167	-0.0461	-0.0467	0.1170	0.1173
πh_I	-0.2411	-0.2392	1.3434	1.3396	0.2411	0.2341
πh_C	-0.2625	-0.2678	0.6781	0.6886	0.2625	0.2760
y_I	0.0000	-0.0061	-0.0213	-0.0094	0.0000	0.0137
y_C	0.0000	0.0059	0.0128	0.0010	0.0000	-0.0134
l_I	0.0000	-0.0091	0.0000	0.0179	0.0000	0.0204
l_C	0.0000	0.0118	0.0000	-0.0233	0.0000	-0.0265
r_{KI}	0.0000	0.0013	-0.5928	-0.5955	0.0000	-0.0030
r_{KC}	0.0000	0.0013	-0.5928	-0.5955	0.0000	-0.0030
k_I	0.0000	-0.0074	-0.0961	-0.0815	0.0000	0.0167
k_C	0.0000	0.0046	0.0596	0.0505	0.0000	-0.0104
t_{EI}	0.0000	0.0000	11.2699	11.2699	0.0000	0.0000
t_{EC}	0.0000	0.0000	13.1709	13.1709	0.0000	0.0000
e_I	-0.6735	-0.6803	-0.6735	-0.6601	-0.6735	-0.6583
e_C	-1.3056	-1.2983	-1.3056	-1.3199	-1.3056	-1.3219
e	-1.0000	-0.9995	-1.0000	-1.0010	-1.0000	-1.0011
πf_I	-0.2411	-0.2483	1.3434	1.3575	0.2411	0.2545
πf_C	-0.2625	-0.2561	0.6781	0.6653	0.2625	0.2494
w_I	0.0000	0.0030	-0.6890	-0.6949	0.0000	-0.0068
w_C	0.0000	-0.0058	-0.5332	-0.5217	0.0000	0.0131
p	-0.2192	-0.1406	0.3046	0.1491	0.2192	0.0491
grh_I	-0.0619	-0.0637	-0.1290	-0.1253	-0.0423	-0.0390
grf_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
grh_C	-0.2600	-0.2598	-0.2128	-0.2132	-0.1357	-0.1356
grf_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gc_I	-0.1232	-0.1308	-0.1553	-0.1402	-1.3876	-1.3712
gc_C	-0.1232	-0.1308	-0.1553	-0.1402	-1.3876	-1.3712
t_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
q	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
b_I	0.0000	0.0000	0.0000	0.0000	5.8561	5.8561
b_C	0.0000	0.0000	0.0000	0.0000	5.8876	5.8876
sc_I	5.8561	5.8561	5.6492	5.6492	15.1177	15.1177
sc_C	5.8876	5.8876	5.9578	5.9578	16.8426	16.8426
sr_I	15.1177	15.1177	0.0000	0.0000	0.0000	0.0000
sr_C	16.8426	16.8426	0.0000	0.0000	0.0000	0.0000
s_I	0.0000	0.0000	0.0000	0.0000	11.7419	11.7419
s_C	0.0000	0.0000	0.0000	0.0000	10.7506	10.7506

Notes: Simulation 1: central government abatement subsidy with recycling. Simulation 2: emissions tax with recycling. Simulation 3: central government abatement subsidy, no recycling, GC endogenous in CGBC.

Appendix 7: Robustness tests: Full results for regionally-differentiated policy contd

Variable	Simulation 4		Simulation 5		Simulation 6	
	SR	LR	SR	LR	SR	LR
v_I	-0.0363	-0.0711	0.0222	-0.0626	0.0972	-0.0314
v_C	-0.1372	-0.1016	-0.2227	-0.1364	-0.2752	-0.1440
c_{II}	-0.0815	-0.0990	-0.4718	-0.5173	-0.0654	-0.1300
c_{CI}	0.0149	-0.0512	-0.0759	-0.2389	0.3305	0.0866
c_{IC}	-0.2043	-0.1294	-0.9758	-0.7980	-0.5694	-0.2930
c_{CC}	-0.1078	-0.0816	-0.5798	-0.5195	-0.1734	-0.0764
gh_I	-0.0706	-0.0689	0.9759	0.9888	-0.1251	-0.1189
gh_C	-0.1052	-0.1049	1.5563	1.5703	-0.0796	-0.0783
j_I	-0.1514	-0.1337	-0.7586	-0.7190	-0.3522	-0.2868
j_C	-0.0587	-0.0572	-0.3782	-0.3778	0.0282	0.0338
πh_I	0.2411	0.2366	-0.4422	-0.4532	-0.4422	-0.4590
πh_C	0.2625	0.2712	-0.2556	-0.2345	-0.2556	-0.2234
y_I	0.0000	0.0089	-0.0213	0.0001	-0.0213	0.0115
y_C	0.0000	-0.0087	0.0128	-0.0083	0.0128	-0.0194
l_I	0.0000	0.0133	0.0000	0.0321	0.0000	0.0490
l_C	0.0000	-0.0172	0.0000	-0.0417	0.0000	-0.0636
r_{KI}	0.0000	-0.0020	-0.5928	-0.5976	-0.5928	-0.6001
r_{KC}	0.0000	-0.0020	-0.5928	-0.5976	-0.5928	-0.6001
k_I	0.0000	0.0109	-0.0961	-0.0699	-0.0961	-0.0561
k_C	0.0000	-0.0067	0.0596	0.0434	0.0596	0.0348
t_{EI}	0.0000	0.0000	11.2699	11.2699	11.2699	11.2699
t_{EC}	0.0000	0.0000	13.1709	13.1709	13.1709	13.1709
e_I	-0.6735	-0.6636	-0.6735	-0.6495	-0.6735	-0.6369
e_C	-1.3056	-1.3162	-1.3056	-1.3313	-1.3056	-1.3448
e	-1.0000	-1.0007	-1.0000	-1.0017	-1.0000	-1.0026
πf_I	0.2411	0.2498	-0.4422	-0.4211	-0.4422	-0.4100
πf_C	0.2625	0.2540	-0.2556	-0.2762	-0.2556	-0.2871
w_I	0.0000	-0.0044	-0.6890	-0.6995	-0.6890	-0.7051
w_C	0.0000	0.0085	-0.5332	-0.5126	-0.5332	-0.5017
p	0.2192	0.1088	0.8999	0.6328	0.8999	0.4922
grh_I	-0.1129	-0.1102	-0.3634	-0.3581	-0.2002	-0.1902
grf_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
grh_C	-0.2291	-0.2283	-0.3893	-0.3892	-0.1733	-0.1705
grf_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gc_I	0.0000	0.0000	3.2092	3.2349	0.0000	0.0000
gc_C	0.0000	0.0000	3.2092	3.2349	0.0000	0.0000
t_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
q	0.2656	0.2636	0.0000	0.0000	-0.6143	-0.6218
t_V	0.7968	0.7907	0.0000	0.0000	-1.8427	-1.8653
b_I	5.8561	5.8561	5.6492	5.6492	5.6492	5.6492
b_C	5.8876	5.8876	5.9578	5.9578	5.9578	5.9578
sc_I	15.1177	15.1177	0.0000	0.0000	0.0000	0.0000
sc_C	16.8426	16.8426	0.0000	0.0000	0.0000	0.0000
sr_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
s_I	11.7419	11.7419	0.0000	0.0000	0.0000	0.0000
s_C	10.7506	10.7506	0.0000	0.0000	0.0000	0.0000

Notes: Simulation 4: central government abatement subsidy, no recycling, Tv endogenous in CGBC. Simulation 5: emissions tax, no recycling, GC endogenous in CGBC. Simulation 6: emissions tax, no recycling, Tv endogenous in CGBC.

Appendix 7: Robustness tests: Full results for regionally-differentiated policy contd

Variable	Simulation 7		Simulation 8		Simulation 9	
	SR	LR	SR	LR	SR	LR
v_I	0.0000	-0.0563	-0.0793	-0.0853	-0.0671	-0.0794
v_C	-0.1625	-0.1052	-0.0964	-0.0903	-0.1025	-0.0899
c_{II}	0.0942	0.0640	-0.0236	-0.0268	-0.0154	-0.0219
c_{CI}	0.1906	0.0825	-0.0335	-0.0449	-0.0074	-0.0310
c_{IC}	-0.0286	0.0894	-0.0111	0.0014	-0.0256	0.0002
c_{CC}	0.0679	0.1079	-0.0209	-0.0167	-0.0176	-0.0089
gh_I	-0.5292	-0.5206	-0.2569	-0.2562	-0.2665	-0.2651
gh_C	-0.8245	-0.8152	-0.3705	-0.3695	-0.3844	-0.3823
j_I	0.0243	0.0506	-0.0165	-0.0136	-0.0212	-0.0153
j_C	0.1170	0.1173	-0.0260	-0.0260	-0.0135	-0.0135
πh_I	0.2411	0.2338	0.1469	0.1462	0.1706	0.1692
πh_C	0.2625	0.2765	0.1148	0.1163	0.1425	0.1455
y_I	0.0000	0.0143	-0.0684	-0.0668	0.0065	0.0096
y_C	0.0000	-0.0140	-0.1208	-0.1222	-0.0039	-0.0069
l_I	0.0000	0.0213	0.0000	0.0022	0.0000	0.0046
l_C	0.0000	-0.0276	0.0000	-0.0029	0.0000	-0.0060
r_{KI}	0.0000	-0.0032	-0.1007	-0.1010	-0.1038	-0.1044
r_{KC}	0.0000	-0.0032	-0.1007	-0.1010	-0.1038	-0.1044
k_I	0.0000	0.0174	0.0323	0.0342	0.0291	0.0330
k_C	0.0000	-0.0108	-0.0201	-0.0212	-0.0181	-0.0205
t_{EI}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_{EC}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
e_I	-0.6735	-0.6576	-0.6735	-0.6718	-0.6735	-0.6701
e_C	-1.3056	-1.3226	-1.3056	-1.3073	-1.3056	-1.3092
e	-1.0000	-1.0011	-1.0000	-1.0001	-1.0000	-1.0002
πf_I	0.2411	0.2551	0.1469	0.1484	0.1706	0.1738
πf_C	0.2625	0.2489	0.1148	0.1134	0.1425	0.1395
w_I	0.0000	-0.0070	-0.0684	-0.0690	-0.0746	-0.0760
w_C	0.0000	0.0137	-0.1208	-0.1193	-0.1218	-0.1189
p	0.2192	0.0420	-0.0224	-0.0412	0.0182	-0.0207
grh_I	-0.5100	-0.5065	0.0000	0.0000	0.0000	0.0000
grf_I	0.0000	0.0000	-0.5273	-0.5268	0.0000	0.0000
grh_C	-1.1344	-1.1343	0.0000	0.0000	0.0000	0.0000
grf_C	0.0000	0.0000	-1.2829	-1.2829	0.0000	0.0000
gc_I	-0.5612	-0.5442	-0.6852	-0.6834	-0.7109	-0.7071
gc_C	-0.5612	-0.5442	-0.6852	-0.6834	-0.7109	-0.7071
t_I	0.0000	0.0000	0.0000	0.0000	1.3326	1.3305
t_C	0.0000	0.0000	0.0000	0.0000	1.2894	1.2894
q	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
b_I	5.8561	5.8561	5.1935	5.1935	5.9188	5.9188
b_C	5.8876	5.8876	5.2223	5.2223	5.8663	5.8663
sc_I	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sc_C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sr_I	52.5832	52.5832	46.6334	46.6334	53.1460	53.1460
sr_C	29.7223	29.7223	26.3638	26.3638	29.6148	29.6148
s_I	11.7419	11.7419	10.4133	10.4133	11.8676	11.8676
s_C	10.7506	10.7506	9.5358	9.5358	10.7117	10.7117

Notes: Simulation 7: regional government subsidy, no recycling, GRH endogenous. Simulation 8: regional government subsidy, no recycling, GRF endogenous. Simulation 9: regional government subsidy, no recycling, Tj endogenous.