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Emission price, output-based allocation and consumption tax: Optimal climate policy in the presence of another country's climate policy

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Abstract:

The allowances in an emission trading system (ETS) are commonly allocated for free to the sector, e.g., in the form of output-based allocation (OBA). The reason is the risk of carbon leakage exposure such as relocation of emission-intensive and trade-exposed industries (EITE). A prime example of this is the EU ETS, where the policymakers have stated that they will continue this practice. However, lately a third approach, combining OBA with a consumption tax, has been proposed to mitigate carbon leakage, and it has been shown to have an unambiguously global welfare improving effect. This paper presents the potential outcome of climate policy, by examining the Nash equilibrium of a policy instrument game between regions who regulate their emissions separately. In particular, we investigate the case when a policymaker can choose to supplement her ETS with OBA and/or with a consumption tax, based on another policymaker's optimal choice for her ETS. We show analytically the optimal rate of OBA and consumption tax in the presence of a climate polices in another region. Finally, we present the results from a numerical simulation in the context of the EU ETS and the Chinese ETS.

Key words: Emission price; Output-based allocation; Consumption tax; Carbon leakage; Emission trading system; Unilateral policy

JEL classification: C70, D61, F18, H23, Q54

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1. Introduction

In the aftermath of the 2015 Paris climate agreement, most countries have strengthen their promise, alongside the European Union (EU), to tackle climate change. Many of these countries' nationally determined contributions (NDCs) includes a plan for establishing a market-based mechanism, or carbon trading system (Andresen et al. 2016). Among these countries are the world's largest energy consumer and greenhouse gas (GHG) emitter, China. The policymakers in these countries are well aware that unilateral action leads to carbon leakage, such as relocation of emission-intensive and trade-exposed industries (EITE). The affected industries in these regions claim that the emission restrictions raise their production costs, resulting in a competitive disadvantage on the world market. With production and hence emissions increasing in other regions, the policymaker achieves lower emission level locally but risks losing jobs and industry to the unregulated regions, as well as higher foreign GHG emissions (Taylor 2005).[1] Most studies suggest a carbon leakage in the range of 5-30% (Böhringer et al. 2012; Zhang 2012), with a somewhat higher rate for the EITE industry (Fischer & Fox 2012).[2]

Since carbon leakage is a concern in the public debate on policy decisions, the policymakers have either excluded the EITE sector from regulation or found other anti-leakage solutions. In the EU emission trading system (ETS) for instance, the sectors that are regulated and "exposed to a significant risk of carbon leakage", are given a large number of free allowances.[3] Similarly, the allowances for the EITE sector in China's ETS will also be allocated for free (Xiong et al. 2017). To mitigate the leakage and limit the number of free allowances, the allocation is typically based on benchmarks or requirements such as activity level or production output, to sustain emission reduction incentives per unit of output (Neuhoff et al. 2016b). Free allowance allocation based on output is often referred to as output-based allocation (OBA) (Böhringer & Lange 2005).

While OBA could mitigate carbon leakage, it ends up stimulating too much output of the EITE goods. The reason is that OBA works as an implicit production subsidy, and as a consequence the incentives to substitute from carbon-intensive to less carbon-intensive products are weakened. Furthermore, with uncertainty about leakage exposure for the sectors, policymakers may also overcompensate the sector with allowances.[4] Recently a third approach has been proposed.

[1]The leakage mainly occurs through either: i) the fossil fuel markets, or ii) markets for EITE goods. This paper focuses on leakage in the latter case.
[2]Other important contribution to the theoretical literature on leakage are Markussen (1975), Hoel (1996) and Copeland (1996).
[3]In phase 3 (2013-2020) the commission estimates that 43% of the total allowances will be handed out to industrial installations exposed to a significant risk of carbon leakage (EU 2017)
[4]Sato et al. (2015) concludes that in the EU ETS "vulnerable sectors account for small shares of emission", and Martin et al. (2014) finds for the same market that the current allocation substantially overcompensates for a given carbon leakage risk.

Particularly, Böhringer et al. (2017b) shows that it is welfare improving for a country, which has already implemented a carbon tax along with output-based rebating (OBR) to EITE goods, to introduce a consumption tax on top of the same EITE goods. Kaushal and Rosendahl (2017) also shows that it is welfare improving under certain conditions for a single region to introduce a consumption tax on EITE goods when the OBA is already implemented jointly in two regulating regions for the same EITE goods. Both Böhringer et al. (2017b) and Kaushal and Rosendahl (2017) find that the consumption tax has an unambiguously global welfare improving effect. Whereas some instruments may not be politically feasible,[5] a consumption tax does not face the same challenge (Neuhoff et al. 2016a). Moreover, if the tax is set equal to the OBA "benchmarks", the administrative cost of supplementing a consumption tax will likely be limited (Ismer & Haussner 2016; Neuhoff et al. 2016b).

This paper builds on the theoretical model and findings in Kaushal and Rosendahl (2017). However, while their paper considers two regulating regions that have a joint emission trading system with OBA to the EITE-goods, this paper examines the case when two regions regulate separately. Specifically, we present a non-cooperative game of policy instruments with the optimal choice of climate policy for one region based on climate policy choice by another region. Further, whereas only one region imposes a consumption tax in the 2017 paper by Kaushal and Rosendahl, we look at the case where both of the regions can choose to supplement their emission trading system with either OBA alone or OBA combined with consumption tax. The current situation, in which there are many separated carbon emission trading systems, motivates this approach. For instance, the EU/EEA countries have an emission trading system with climate target for 2030 and 2050, while the Chinese emission trading system is set to launch in 2018 after several local district pilot projects which started around 2013 (Xiong et al. 2017). Once they are both running simultaneously, the EU ETS and the Chinese ETS will be the world's largest emissions trading systems in terms of regulated emissions (Böhringer et al. 2018).

We first show with an analytic analysis that the effect on the optimal OBA in one region, of increasing OBA or consumption tax in another regulating region, is generally ambiguous. Further, we also find that the effect on optimal consumption tax in one region, of increasing OBA or consumption tax in another regulating region, to be ambiguous but likely reduced under certain conditions. The terms-of-trade effects are uncertain and can possibly alter these conclusions. Next, we supplement the analytical findings with a stylized numerical simulation model calibrated to data for the world

[5] Another suggested second-best policy instrument for anti-leakage is Border Carbon Adjustments (BCAs), with charges on embedded carbon imports and refunds on export. Studies have shown that BCA may outperform OBA with reducing carbon leakage (Böhringer et al. 2017a; Fischer & Fox 2012; Monjon & Quirion 2011). However experts do not agree on whether or not it is compatible with WTO rules (Horn & Mavroidis 2011; Ismer & Haussner 2016; Tamiotti 2011)

economy. Like Kaushal and Rosendahl, we divide the world into three regions with three goods. Mainly, we are interested in the game of policy instruments between EU ETS and the Chinese ETS, as both markets are planning a variant of OBA for the emission-intensive goods in their upcoming phases. The numerical results show that both regions would choose a combination of different policy instruments, depending on certain conditions. Moreover, the results shows that it is welfare improving and leakage minimizing for both regions to introduce a mixture of OBA and consumption tax on the EITE goods.

While our analytical model is based on Kaushal and Rosendahl, there are some important differences. First, we numerically examine the case for three different regions, where two of the regions have an emission trading system. Second, while Kaushal and Rosendahl consider OBA and some shares of consumption tax based on OBA, this paper considers more policy combinations with different allocation factors for both OBA and consumption tax. Last, this paper focuses on the non-cooperative policy instrument game of optimal climate policy for two regulating regions with separate emission trading systems, whereas Kaushal and Rosendahl look at two regions that are involved in a joint emission trading system and only one of them considers imposing a consumption tax.

We introduce a theoretical model in section 2, and analyze the effect of optimal OBA and consumption tax in the presence of a climate policy in another region. In section 3, we transfer the analysis to a non-cooperative policy instrument game, with a stylized CGE multi-region multi-sector numerical model. The numerical model is based on the theoretical model in section 2 and calibrated to data for the world economy. Finally, section 4 concludes.

2. Theoretical model

The model builds on the framework in Böhringer et al. (2017b) and Kaushal and Rosendahl (2017). However, we also include a broader range of policy combinations across regions, and extend the model to examine the optimal OBA and consumption tax between two regions.

Consider 3 regions, $j = \{1,2,3\}$, and three goods x, y, and z. Good x is emission-free and tradable, y is emission-intensive and tradable (EITE) (e.g. chemicals, metal and other minerals), and z is emission-intensive and non-tradable (e.g. electricity and transport). While produced in different regions, the same types of goods are assumed homogenous with no trade cost (for x and y). Relocating production of the y good may occur due to trade exposure, and thus OBA is considered for this sector. The market price for the goods in region j are denoted p^{xj}, p^{yj} and p^{zj}. The representative consumer's utility in region j is given by $u^j(\bar{x}^j, \bar{y}^j, \bar{z}^j)$, where the bar indicates consumption of the three goods. The utility function follows the normal assumptions.[6]

We denote the production of good x in region j as $x^j = x^{1j} + x^{2j} + x^{3j}$, where x^{ij} is produced goods in region j and sold in region i, and similarly for the y good. The production cost of goods in region j is given by $c^{xj}(x^j)$, $c^{yj}(y^j, e^{yj})$ and $c^{zj}(z^j, e^{zj})$, where e^{yj} and e^{zj} is the emission from good y and z in the region j. The cost is assumed increasing in production, i.e., c_x^{xj}, c_y^{yj}, $c_z^{zj} > 0$ (where $\frac{\partial c^{xj}}{\partial x^j} \equiv c_x^{xj}$ etc.). Further, the cost of producing good y and z is decreasing in emissions, i.e., c_e^{yj}, $c_e^{zj} \leq 0$ with strict inequality when emission is regulated, cost is twice differentiable and strictly convex. All derivatives are assumed to be finite.

Supply and demand give us the following market equilibrium conditions:

$$\begin{gathered}
\bar{x}^1 + \bar{x}^2 + \bar{x}^3 = x^1 + x^2 + x^3 \\
\bar{y}^1 + \bar{y}^2 + \bar{y}^3 = y^1 + y^2 + y^3 \\
\bar{z}^j = z^j.
\end{gathered} \tag{1}$$

2.1. Climate policies

We now assume that regions $j = 1, 2$ have already implemented a cap-and-trade system, regulating emissions from production of the goods y and z:

$$\bar{E}^j = e^{yj} + e^{zj},$$

where $\bar{E}^j$ is the binding cap on total emission in region j. The emission price t^j is determined through the emission market. We assume that the two regions can choose whether to implement OBA or not to producers of the EITE good y, in order to mitigate carbon leakage to region 3, i.e., there is no climate policy imposed in region 3. With OBA the producers in sector y receives free allowances in proportion to their output, which we denote s^j to production of good y in regions $j = 1,2$. The region determines s^j with the share α^j, such that $s^j = \alpha^j t^j \left(e^{yj} / y^j \right)$, where the number of free allowances to producers of the y good equals the total emissions from this sector times the subsidy share. With α^j=1, we have the special case of 100% allocation of free allowances to this sector. Since good z is not trade-exposed, there is no OBA to producers of this good.

[6] Twice differentiable, increasing and strictly concave, i.e., the Hessian matrix is negative definite and we have a local maximum.

Regions 1 and 2 can also choose to combine OBA with a consumption tax v^j on consumption of the y good, $\bar{y}^j$. The regions determines v^j as a fraction of OBA rate s^j, i.e., $v^j = \gamma^j s^j$, where γ^j is the fraction of OBA rate in region j.

The competitive producers in region j=1,2,3 maximize profits π^j:[7]

$$Max_{x^{ij}}\, \pi_j^x = \sum_{i=1}^{3} [p^{xi} x^{ij}] - c^{xj}(x^j)$$

$$Max_{y^{ij},e^{yj}}\, \pi_j^y = \sum_{i=1}^{3} [(p^{yi} + s^j) y^{ij}] - c^{yj}(y^j, e^{yj}) - t^j e^{yj}$$

$$Max_{z^j,e^{zj}}\, \pi_j^z = [p^{zj} z^j - c^{zj}(z^j, e^{zj}) - t^j e^{zj}].$$

We have $t^3 = s^3 = 0$, since region 3 does not undertake any environmental policy. Assuming interior solution, we have the following first order conditions:

$$\begin{gathered} p^{x1} = p^{x2} = p^{x3} = c_x^{x1} = c_x^{x2} = c_x^{x3} \\ p^{y1} + s^1 = p^{y2} + s^1 = p^{y3} + s^1 = c_y^{y1} \\ p^{y1} + s^2 = p^{y2} + s^2 = p^{y3} + s^2 = c_y^{y2} \\ p^{y3} = c_y^{y3} \\ p^{zj} = c_z^{zj} \\ c_e^{y1} = c_e^{z1} = -t^1 \;\; ; \;\; c_e^{y2} = c_e^{z2} = -t^2 \;\; ; \;\; c_e^{y3} = c_e^{z3} = 0. \end{gathered} \tag{2}$$

The interior solution it requires a global price for each of the two tradable goods x and y, since both are homogenous with no cost of trade:

$$p^x \equiv p^{xj}, \qquad p^y \equiv p^{yj}$$

The representative consumer in region j maximizes utility given consumption prices and an exogenous budget restriction M^j:

$$\mathcal{L}^j = u^j(\bar{x}^j, \bar{y}^j, \bar{z}^j) - \lambda^j\left(p^x \bar{x}^j + (p^y + v^j)\bar{y}^j + p^z \bar{z}^j - M^j\right)$$

We get the following first-order conditions when differentiating the *Lagrangian* function:

$$\frac{\partial \mathcal{L}}{\partial \bar{x}^j} = u_{\bar{x}}^j - p^x = 0,\; \frac{\partial \mathcal{L}}{\partial \bar{y}^j} = u_{\bar{y}}^j - (p^y + v^j) = 0,\; \frac{\partial \mathcal{L}}{\partial \bar{z}^j} = u_{\bar{z}}^j - p^{zj} = 0, \tag{3}$$

[7] To simplify notation, we replace $\sum_{i=1}^{3} x^{ij}$ with x^j in the equations.

assuming an interior solutio, and normalized the utility functions so that $\lambda^j = 1$.

The regions have a balance-of-payment constraint, i.e., the import expenditures from other regions must equal export revenues. Assuming one global price for each of the tradable goods, we have from (2) that

$$p^y(y^j - \bar{y}^j) + p^x(x^j - \bar{x}^j) = 0. \tag{4}$$

2.2. Second-best OBA policy and consumption tax in region 1

To better understand how the sensitivity of optimal OBA and consumption tax in region 1 is affected in the presence of region 2's climate policy, we first present the optimal rate of OBA and consumption tax in region 1 when policies are kept fixed in the other regions. The analyses and results in this section are well-known and discussed in for instance Böhringer et al. (2017a) and Kaushal and Rosendahl (2017).[8]

We assess the different combinations of climate policies in the two regions, by specifying the welfare function in region j as:

$$W^j = u^j(\bar{x}^j, \bar{y}^j, \bar{z}^j) - c^{xj}(x^j) - c^{yj}(y^j, e^{yj}) - c^{zj}(z^j, e^{zj}) - \tau^j(e^{y1} + e^{y2} + e^{y3} + e^{z1} + e^{z2} + e^{z3}), \tag{5}$$

where τ^j is the valuation in region j of reduced global emissions, i.e., the *Pigouvian* tax.[9] Hence, the Pigouvian tax can be different from the permit price t^j. The welfare function consists of a utility of consumption; costs of production; and costs of emissions. Given that an emission trading system has already been implemented for regions 1 and 2, we want first to derive the optimal level of OBA in region 1.

We differentiate (5) with respect to s^1, subject to (4), and assume that all other policy instruments are kept fixed. The expression for the optimal level of OBA subsidy s^{1*} in region 1, is then:

$$s^{1*} = \underbrace{\left(\frac{\partial y^1}{\partial s^1}\right)^{-1}}_{(a)} \left[\underbrace{-\tau^1\left(\frac{\partial e^{y3}}{\partial y^3}\frac{\partial y^3}{\partial s^1} + \frac{\partial e^{z3}}{\partial z^3}\frac{\partial z^3}{\partial s^1}\right)}_{(b)} + \underbrace{\frac{\partial p^y}{\partial s^1}(y^1 - \bar{y}^1) + \frac{\partial p^x}{\partial s^1}(x^1 - \bar{x}^1)}_{(c)}\right]. \tag{6}$$

The first term *(a)* is positive as an introduction of s^1 will implicitly subsidize the production of good y in region 1 and consequently increase the production of y^1.

[8] See appendix A for derivation

[9] The Pigouvian tax is defined as the global marginal external costs of emissions. For the analytical results, it does not matter whether τ^j reflects the global or only domestic costs of global emissions.

Part *(b)* describes the emission effect in region 3. As the market price of good y falls because of lower production cost and reallocation of production back to region 1, emissions associated with the same good in region 3 also declines, $\frac{\partial e^{y3}}{\partial y^3}\frac{\partial y^3}{\partial s^1} < 0$. How this affects the emissions related to production of good z in region 3 is uncertain. However, it seems likely that term *(b)* is negative as the second order effect on good z is presumably dominated by the first order effect on y. Hence, emissions in region 3 declines with s^1:[10]

$$\left(\frac{\partial e^{y3}}{\partial y^3}\frac{\partial y^3}{\partial s^1} + \frac{\partial e^{z3}}{\partial z^3}\frac{\partial z^3}{\partial s^1}\right) < 0. \tag{7}$$

In the last term, the consumption of good y increases with s^1, since the price related to the same good decreases, i.e., $\frac{\partial p^y}{\partial s^1} < 0$. The consumer now buys less of the relatively expensive good x, and therefore $\frac{\partial p^x}{\partial s^1} < 0$. Term *(c)* captures the terms-of-trade effects for region 1, and is ambiguous. If we assume however that this term is zero, then we can elaborate that $s^1 > 0$ if the leakage is positive, and s^1= 0 if the leakage is non-positive. As a result, if region 1 is a net-importer of good y, then $s^1 > 0$, because $\frac{\partial p^y}{\partial s^1} < 0$ and result in leakage reduction. If region 1 is a net-exporter of good y, then the sign of s^1 is ambiguous.

Thus, the optimal second-best OBA policy is in general ambiguous. However, if we assume that region 1 is a net-importer of good y, then the optimal OBA policy in region 1 is positive.

Region 1 can also supplement their OBA with a consumption tax v^1, in the presence of an emission trading system in region 2. By differentiating (5) with respect to v^1 instead, we arrive at a result very similar to Böhringer et al. (2017b):

$$v^{1*} = \underbrace{\left(\frac{\partial \bar{y}^1}{\partial v^1}\right)^{-1}}_{(d)} \left[\underbrace{s^1\frac{\partial y^1}{\partial v^1}}_{(e)} \underbrace{- \frac{\partial p^y}{\partial v^1}(y^1 - \bar{y}^1) - \frac{\partial p^x}{\partial v^1}(x^1 - \bar{x}^1)}_{(f)} + \tau^1 \underbrace{\left(\frac{\partial e^{y3}}{\partial y^3}\frac{\partial y^3}{\partial v^1} + \frac{\partial e^{z3}}{\partial z^3}\frac{\partial z^3}{\partial v^1}\right)}_{(g)}\right]. \tag{8}$$

The first term *(d)* is negative since a consumption tax in region 1 will decrease consumption of good y in the same region. Henceforth, terms inside the bracket with negative (positive) sign tends to increase (decrease) the optimal v^1.

(e) reflects the correction by the consumption tax of an implicit OBA subsidy, which causes too much consumption of this good. The term is negative since a consumption tax in region 1 reduces

[10] The numerical simulation in the context of EU ETS and Chinese ETS confirms that part b) is negative.

the demand for good y. As a result, the global market price and hence production of good y falls in all the three regions.

The next term *(f)* is the familiar terms-of-trade effect for the region. We know that $\frac{\partial p^y}{\partial v^1} < 0$, from our previous discussion. With good y now being relatively more expensive than good x for consumers in region 1, the demand, and hence price, increases for good x, $\frac{\partial p^x}{\partial v^1} > 0$. Whether *(f)* is negative or positive will depend on whether region 1 is a net exporter or importer of the two goods. As a net exporter of good x and net importer of good y, the term becomes negative.

The emission effect in region 3 is captured in the last term *(g)*. Global demand and the market price of good y drops, hence emissions related to producing in region 3 also decrease, $\frac{\partial e^{y3}}{\partial y^3}\frac{\partial y^3}{\partial v^1} < 0$. The effect on good z in region 3 is ambiguous. However like in term *(b)*, also here it seems likely that emissions in region 3 decline when the consumption tax is imposed on good y in region 1 (Kaushal & Rosendahl 2017):

$$\left(\frac{\partial e^{y3}}{\partial y^3}\frac{\partial y^3}{\partial v^1} + \frac{\partial e^{z3}}{\partial z^3}\frac{\partial z^3}{\partial v^1}\right) < 0. \tag{9}$$

Hence, in general the sign of the optimal consumption tax is ambiguous. However, if region 1 is a net exporter of the x good and net importer of the y good, then the optimal consumption tax in region 1 is unambiguously positive in the presence of an emission trading system in region 2.

In the following two sections, we will first show how the optimal OBA rate in region 1 is affected by the presence of climate policy in region 2, and then how optimal consumption tax in region 1 is affected by the presence of climate policy in region 2. The sensitivity for the optimal OBA and consumption tax rate with respect to carbon policies in region 2 is inspired by the model set-up in Böhringer et al. (2017a). They investigate how carbon taxes in an open economy combined with OBR performs in the presence of carbon policies in a large neighboring trading partner.

We consider the optimal OBA and consumption tax rate in region 1 with the following two outcomes: i) region 2 supplements the emission price t^2 with OBA s^2, and ii) the s^2 is supplemented by a consumption tax v^2 on consumption of the y good. Furthermore, in the spirit to make the theoretical analysis more informal, we leave out the terms-of-trade effect from the expression of optimal OBA and consumption tax rate and focus on the leakage effect.

2.3. Second-best OBA policy in region 1, in the presence of climate policy in region 2

We simplify the notation from (6) and (8) in the following discussion by writing $\frac{\partial y^1}{\partial s^1} = y_s^1$, $\frac{\partial e^{y3}}{\partial s^1} = e_s^{y3}$ and $\frac{\partial e^{z3}}{\partial s^1} = e_s^{z3}$, and same for the derivative with respect to v^1. In (6) and (8) we presented the first order derivative with respect to s^1 and v^1, which we describe as the first order effect. The second order effect is then the second derivative of these with respect to either s^2 and v^2. Furthermore, the main assumption in the following discussion is that lower (higher) quantity of respectively domestic production and consumption leads to reduced (stronger) effect of s and v, as we look at the effect of these policies on the corresponding quantity. The same reasoning applies to impacts on leakage too, where both s and v reduces leakage.

The total differentiation of (6) with respect to s^2 and v^2 and inserting for s^1, gives us:

$$ds^1 = \underbrace{\frac{\tau^1}{y_s^1}}_{(h)}\left(\underbrace{\frac{\partial y_s^1}{\partial s^2}\left(\frac{e_s^{y3}}{y_s^1}+\frac{e_s^{z3}}{y_s^1}\right)}_{(i)} - \underbrace{\left(\frac{\partial e_s^{y3}}{\partial s^2}+\frac{\partial e_s^{z3}}{\partial s^2}\right)}_{(j)}\right) ds^2 + \underbrace{\frac{\tau^1}{y_s^1}}_{(h)}\left(\underbrace{\frac{\partial y_s^1}{\partial v^2}\left(\frac{e_s^{y3}}{y_s^1}+\frac{e_s^{z3}}{y_s^1}\right)}_{(k)} - \underbrace{\left(\frac{\partial e_s^{y3}}{\partial v^2}+\frac{\partial e_s^{z3}}{\partial v^2}\right)}_{(l)}\right) dv^2, \qquad (10)$$

where we first consider only an OBA policy in region 2, such that $ds^2 > 0$ and $dv^2 = 0$.

We initially know that *(h)* is positive since $y_s^1 > 0$, see (6) term *(a)*. The bracket in term *(i)* is familiar from (6) term *(b)* and is the emission effect in region 3 of introducing s^1, which is negative. Though $\frac{\partial y_s^1}{\partial s^2}$ is more uncertain, we can elaborate that while the first order effect is positive, the second order effect would likely be negative. s^2 reduces the production cost of y^2 in region 2, and p^y and y^1 are most likely reduced. Hence, the effect of s^1 on y^1 would be eased. The magnitude of this effect would depend on region 2 and its y sectors size, its cost structure and demand responsiveness as well. Hence, term *(i)* is ambiguous but likely positive.

The last term *(j)* captures the emission effect in region 3, and is the derivative of *(b)* in (6) with respect to s^2. s^2 will reduce the emission leakage from region 2 to region 3, but how significant this would impact the leakage reduction done by s^1 is ambiguous. However, the negative effect of s^1 on emissions in region 3 would likely be moderated as the leakage is likely smaller with s^2, indicating that term *(j)* is positive. With a negative sign in front of *(j)*, the term is negative. Therefore, the effect on the optimal level of s^1 of an increase in s^2 is ambiguous.

Now we introduce a carbon consumption tax while keeping s^2 fixed in region 2, ($dv^2 > 0$). The bracket inside of term *(k)* is negative from our previous discussion. We know that v^2 reduces the demand of y in region 2, and thereby the production of y in all regions drops. Hence, the effect of

s^1 on y^1 would be eased and term *(k)* then becomes positive (two negative factors). The magnitude of v^2 would again depend on region 2's size, initial demand and responsiveness.

From (6) in term *(b)*, we know that the first order effect in term *(l)* is negative. Since v^2 reduces the leakage from region 2, the likely outcome would be that the effect of s^1 on emissions in region 3 are reduced. Hence, term *(l)* is likely positive, similar to term *(j)*.

With a negative sign in front of *(l)*, we find the overall effect on the optimal s^1 of either increasing s^2 or v^2 to be ambiguous.

2.4. Optimal consumption tax in region 1, in the presence of climate polices in region 2

We now test the sensitivity of optimal consumption tax rate in region 1 with respect to carbon policies in region 2, by holding OBA rate s^1 fixed. We total differentiate (8) with respect to s^2 and v^2, and insert for v^1:

$$dv^1 = \underbrace{\bar{y}_v^{1\,-1}}_{(m)} \left[\underbrace{s^1 \frac{\partial y_v^1}{\partial s^2}}_{(n)} + \underbrace{\tau^1 \left(\frac{\partial e_v^{y3}}{\partial s^2} + \frac{\partial e_v^{z3}}{\partial s^2} \right)}_{(o)} - \underbrace{\frac{\partial \bar{y}_v^1}{\partial s^2} \left(\frac{s^1 y_v^1 + \tau^1 \left(e_v^{y3} + e_v^{z3} \right)}{\bar{y}_v^1} \right)}_{(p)} \right] ds^2$$
$$+ \underbrace{\bar{y}_v^{1\,-1}}_{(m)} \left[\underbrace{s^1 \frac{\partial y_v^1}{\partial v^2}}_{(q)} + \underbrace{\tau^1 \left(\frac{\partial e_v^{y3}}{\partial v^2} + \frac{\partial e_v^{z3}}{\partial v^2} \right)}_{(r)} - \underbrace{\frac{\partial \bar{y}_v^1}{\partial v^2} \left(\frac{s^1 y_v^1 + \tau^1 \left(e_v^{y3} + e_v^{z3} \right)}{\bar{y}_v^1} \right)}_{(s)} \right] dv^2. \tag{11}$$

First, we let $ds^2 > 0$ and $dv^2 = 0$. The term *(m)* outside of the main bracket is negative from our discussion of (8) term *(d)*, as consumption tax reduces the demand for good y.

In term *(n)*, the first order effect is negative from the discussion of (8) term *(e)*. The second order effect by s^2 is less obvious. The introduction of s^2 reduces the production cost of y^2 and thereby lowering the price p^y and production of y^1. Thus, it is reasonable that this term would be positive, as lower y^1 could mean less negative effect of v^1 on the production of the same good.

In the next term *(o)*, we know from (8) term *(g)* that our first order effects is negative, and that v^1 reduces the leakage from region 1. s^2 reduces the leakage from region 2. Since there is less leakage to region 3 with both s^2 and v^1, term *(o)* would likely be positive (the negative effect is dampened).

In the bracket of term *(p)*, we recall that both term *(g)* from (8) and y_v^1 is negative. With the numerator and denominator being negative, this part becomes positive. Outside of the bracket, the first order effect is negative as v^1 reduces the demand for y in region 1. When it comes to the second order effect s^2 reduces p^y, and reduced price of good y increases $\bar{y}^1$ to some extent. Since the quantity of demanded y in region 1 is higher in the presence of s^2, it could indicate that the effect of v^1 on $\bar{y}^1$ is more negative in the presence of s^2. Hence, term *(p)* is likely negative. So with a negative sign in front of *(p)*, the term becomes positive and we find the overall effect on the optimal level of v^1 of an increase in s^2 to be ambiguous but likely negative.

Assume now that region 2 imposes a consumption tax while keeping the other instrument fixed. In term *(q)* we know that y_v^1 is negative. v^2 reduces the demand for y in region 2, which reduces the price of the same good and hence the production of y. Hence, while the term is ambiguous, if we follow the same reasoning as in *(n)*, then the term could likely be positive, i.e., v^2 could reduce the negative effect of v^1 on production of y^1.

In term *(r)* the first order effect inside the bracket is negative from (8) term *(g)*. v^2 reduces the leakage to region 3 and hence probably also from region 1 and 2. Thus, the term *(r)* is ambiguous but likely be positive since v^1 now has less negative effect on the emission in region 3.

The bracket inside of term *(s)* is knowingly positive from our earlier discussion. We know that v^1 reduces $\bar{y}^1$, and that reduced $\bar{y}$ in region 1 and 2, reduces p^y. So although $\frac{\partial \bar{y}_v^1}{\partial v^2}$ is ambiguous, we could use the same way of reasoning as we did for term *(p)*. Hence, as p^y decreases with v^2, causing $\bar{y}^1$ to increase, we likely expect v^1 to have a more negative effect on $\bar{y}^1$, i.e. $\frac{\partial \bar{y}_v^1}{\partial v^2} < 0$. Hence, the last term *(s)* is negative and with the negative sign in front the whole term is likely positive. Therefore, our analytical result suggest that the effect on the optimal v^1 of increasing v^2 is ambiguous but likely negative.

In general, (11) shows the effect of optimal v^1 is ambiguous but likely negative with increasing s^2 and v^2, i.e., (dv^1/dv^2, $dv^1/ds^2 < 0$). The overall ambiguous results from chapter 2.3 and 2.4 however, strongly suggests that a numerical simulation is essential to give more robust results. In the next chapter, we present the numerical simulations based on the theoretical model from section 2.1, and the paper by Kaushal and Rosendahl (2017).

3. Numerical analysis

Numerical simulations are useful for examining the ambiguous outcomes from the theoretical analysis. The main purpose for this analysis is to assess the Nash equilibrium outcomes in a non-cooperative game of policy instruments. Particularly, we are interested in a non-cooperative game of policy instruments in a world economy consisting of a Chinese and a European Union ETS, where each region can choose to have a different variant of OBA or carbon consumption tax for the emission-intensive and trade-exposed goods. The choice of climate policy in both regions are based on the following indicators: *i)* region maximizes regional welfare, *ii)* region minimizes leakage rate *iii)* region maximizes global market share of good y, *iv)* region maximizes global market share of good x, and *v)* different combination of *i)* to *iv)*. The motivation for looking at a policy instrument game with different indicators is that a region's choice may be limited when making policy decisions. For example, policymakers could be influenced by strong lobbying groups who are more concerned for their global production share than regional welfare. Or, the EITE good could be of a substantially large share for the region, resulting in less flexibility for ambitious climate policies (Sterner & Coria 2012).

3.1 Model summary

The numerical simulation model is based on the Computable General Equilibrium (CGE) model in Kaushal and Rosendahl (2017), with the assumption of the following three regions: the European Union (EU)[11], China (CHN) and rest of the world (ROW). As in the theoretical model in section 2, we find the same three goods in the different regions: a carbon free and tradable good x, carbon-intensive and tradable good y, and carbon-intensive and non-tradable production z. These goods are produced and consumed in all of the three regions, and they can only be used in the final consumption. We also include a fourth production sector, fossil energy production f, which can only be used in energy related production y and z, and cannot be traded between regions[12]. The tradable goods are assumed homogenous with a global price and no transportation cost.

Capital, labor, fossil energy and resources are the input factors in production. Moreover, capital, labor and fossil energy are mobile between sectors but immobile between regions. The resource is only used in the fossil energy production and is immobile between regions. The producers minimizes the cost subject to technological constraints, by combining the use of input factors. We describe the production of x, y, z as a two level CES cost function, with the demand sensitivity for capital, labor and fossil energy input. The two level CES cost functions for f consists of capital, labor and resource instead. At the top level, we have the CES with substitution between energy/resource and value-added (capital and labor) composite. At the second level, the CES between value-added composite includes the substitution between capital and labor[13]. Moreover, the emission is proportionally related to the use of energy as input for production. Thus, emission reduction in the sectors are either through; i) substituting energy with value-added composite, or ii) scaling down the production output.

We define the final consumption in each region by a representative agent who maximizes utility subject to a budget constraint. The budget constraint is determined by the monetary value of regional

[11] This includes all the 28 EU member states plus Iceland, Norway, and Liechtenstein.
[12] Hence in accordance with the theoretical model, we focus on the carbon leakage related to the competitive channel.
[13] See appendix B for summary of the CGE model and nesting in different sectors.

endowment of capital, labor and resource, and net revenues from emission regulation[14]. The agent's utility is given as a constant-elasticity-of-substitution (CES) combination of final consumption goods.

3.2 Calibration procedure and dataset

The calibration procedure is based on standard method in applied general equilibrium simulations, where the exogenous parameters are defined by base-year data information. Like in Kaushal and Rosendahl, the other parameters are either estimated from other different studies, calibrated based on simulations of a well-established CGE-model (Böhringer et al. 2017b; Böhringer et al. 2018).

The numerical model is based on the World Input Output Database (WIOD), with data base-year from 2009. [15] The empirical data from the WIOD is then reconstructed, which is based on 43 regions and 56 sectors with related CO_2-emission from each sector, and we merge them into the three regions and four sectors; x, y, z, and f[16]. The emissions level in sector x is set equal to zero, and thus follow the same assumption from the theoretical analysis that there are no carbon related emissions in this sector[17]. Next, we measure the net exports in the tradable sectors in the base-year and incorporate the balance of payment constraint in the numerical model, by measuring the domestic production and consumption in each region. The calibrated z sector is non-tradable in the theoretical model, yet consists of multiple sectors with limited trade in the dataset. Thus, we assume that produced and consumed quantity in the same region is equal.

The utility maximizing agent in each region is assumed to have a CES utility function calibrated to the share form, with exogenous parameters set to base-year shares from WIOD data. Like Böhringer et al. (2017b) and Kaushal and Rosendahl (2017) , we set the substitution elasticity of 0.5 between goods x, y and z, with perfect substitution between locally produced and imported goods.

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[14] The net revenues from emission regulation consists of emission price plus consumption tax, minus the cost of OBA
[15] The model is implemented as a Mixed Complementarity Problem in GAMS, using the PATH-solver.
[16] See appendix C for mapping of WIOD sectors.
[17] Sector x accounted for 14-15% of the global CO2 emissions in 2009, according to the dataset.

	Production (billion $)	*Consumption* (billion $)	*CO_2* (billion ton)
x^{EU}	25 066	24 610	-
y^{EU}	5 025	5 111	0.90
z^{EU}	1 998	1 998	1.78
x^{CHN}	9 059	8 786	-
y^{CHN}	5 030	5 020	2.11
z^{CHN}	949	949	3.60
x^{ROW}	51 101	51 830	-
y^{ROW}	14 271	14 194	4.21
z^{ROW}	4 871	4 871	8.24

Table 1: Base-year WIOD data values and calibrated parameters in the numerical model

3.3 Climate policy strategies and scenarios

In the following, we will consider that $j = \{CHN, EU\}$, and that calibrated base-year data from 2009 is the business-as-usual scenario. The first policy strategy (t^j) is where the region j implements an emission trading system with full auctioning. The EU ETS was already in place in 2009 with the average ETS price of €13 per ton CO_2. Thus, the considered case is where an additional emission reduction target of 20 percent is set relative to the base-year emission in the EU ETS[18]. The assumption is not unreasonable since the EU has set new and more ambitious targets for 2030 and 2050 (Andresen et al. 2016). China however, did not have an active emission trading system in 2009. Also here, the emission reduction target is set to 20 percent relative to base-year emission.

The next policy strategy is where region j allocates a number of allowances for free to the emission-intensive and trade-exposed (EITE) industries y, i.e. OBA (s^j). The allowances in this sector are allocated with the allocation factor α^j, ranging from 20% to 100% allocation for the industries based on output, i.e., $s^j = \alpha^j t^j \left({e^{yj}}/{y^j} \right)$. In accordance with the theoretical analysis, sector z does not receive allowances for free.

The last policy strategy considered is where region j supplement the OBA with a consumption tax. Under this strategy, the consumption tax ranges from 20% to 100% as a fraction of the OBA rate s^j, i.e., $v^j = \gamma^j s^j$, where γ^j is the fraction of OBA rate in region j. Hence, different combinations of OBA allocation and consumption tax can be achieved.

[18] The reported permit price in this chapter comes in addition to the price of €13 per ton CO_2 in 2009.

In line with the theoretical model, the welfare in each region consists of the regional utility and global emission reduction. We use the regional emission price t^j under the first policy strategy, to calculate the benefit of global emission reduction felt by each region under different policies. Since there are two emission trading systems in our model that are not linked, the emission price in each region is therefore different. Further, the main assumption is that negative global emission caused by one regions action, is beneficial for the other region as well.

3.4 Numerical simulations and the optimal strategies

We investigate the optimal climate policy strategy for each region by looking at the following key indicators: *i)* maximizing regional welfare, *ii)* minimizing leakage rate *iii)* maximizing global market share of y, *iv)* maximizing global market share of x, and *v)* a combination of indicators *i) – iv)*. We assume a simultaneous non-cooperative game with two players, the EU and China, who choose their climate policy based on the specific key indicators above. The optimal climate policy for each region in this game, or Nash equilibrium outcome, would then be the best choice they make given the other region's choice (Varian 2010). To simulate all the outcomes for the different combination of policies, the model is run 961 times. The pay-off matrices are listed in Appendix D.

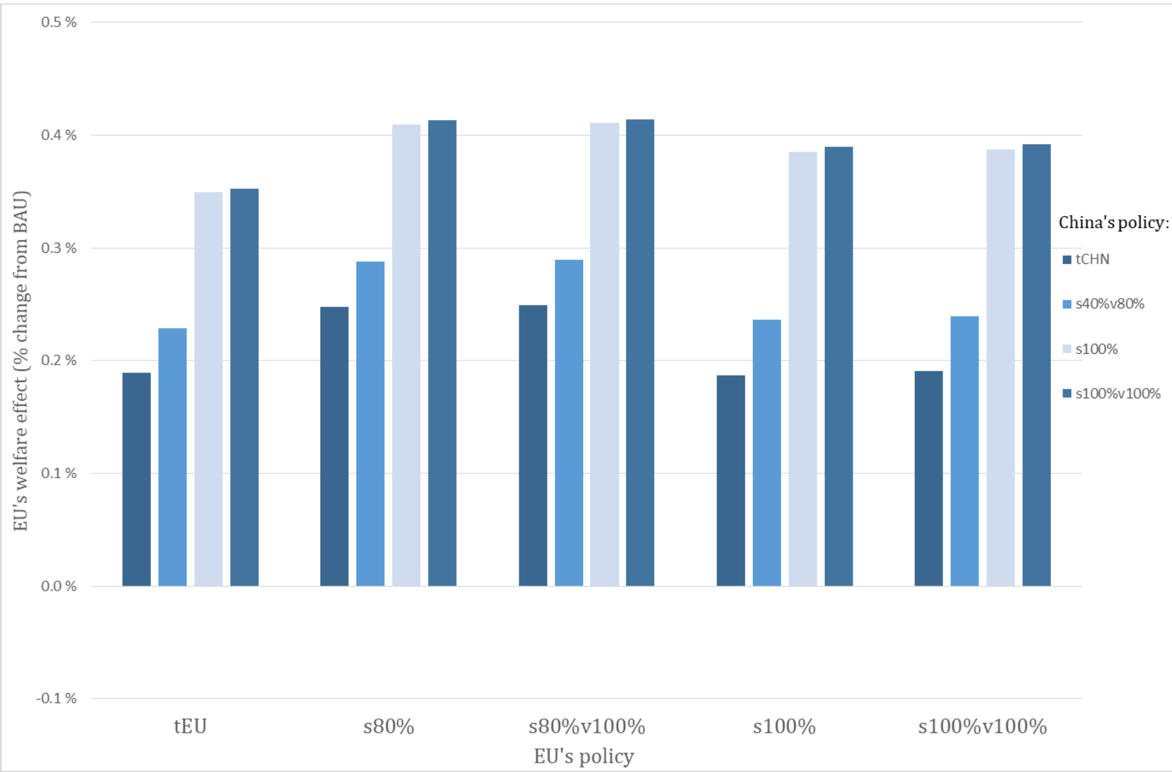

Figure 1: EU's welfare effect with different combinations of policies in EU and China.

Results from figure 1 and 2 shows the effect on welfare in EU and China in the presence of different combinations of policies, i.e., indicator *i)*. In figure 1 (figure 2) policy choices by EU (China) are on the horizontal axis, while policy choices by China (EU) are listed on the right side. *tEU* and *tCHN* is the scenario with only emission price in EU and China respectively. s and v with percent values is the correspondingly allocation factor in sector y of OBA, and consumption tax rate as a fraction of OBA[19]. The result shows that the optimal strategy when both regions maximizes welfare is to supplement OBA with a consumption tax on the EITE good, i.e., our Nash equilibrium. This outcome is in line with previous results (Kaushal and Rosendahl 2017) since a consumption tax reduces the leakage and thereby increases the regional welfare. The Nash equilibrium outcome is $s_{40\%}v_{80\%}$ for China and $s_{80\%}v_{100\%}$ for EU. A likely reason for the lower optimal OBA in China, is their higher emission intensity in sector y. Further, EU is the only net exporter of good x. Therefore, the higher consumption tax rate is optimal in the EU. The emission price in region j without any supplementing policies, are equal to the valuation of reduced global GHG emissions in the same region, i.e., $t^j = \tau^j$. For $j = \{CHN, EU\}$, the numerical simulation suggests t^{CHN} = \$78.39 and t^{EU} = \$99.64. The figures further shows that if one region's policy is kept fixed, the local welfare increases when another region introduces a combination of OBA with a consumption tax. The main driver for the welfare increase here, is the reduction in leakage rate which benefits both regions.

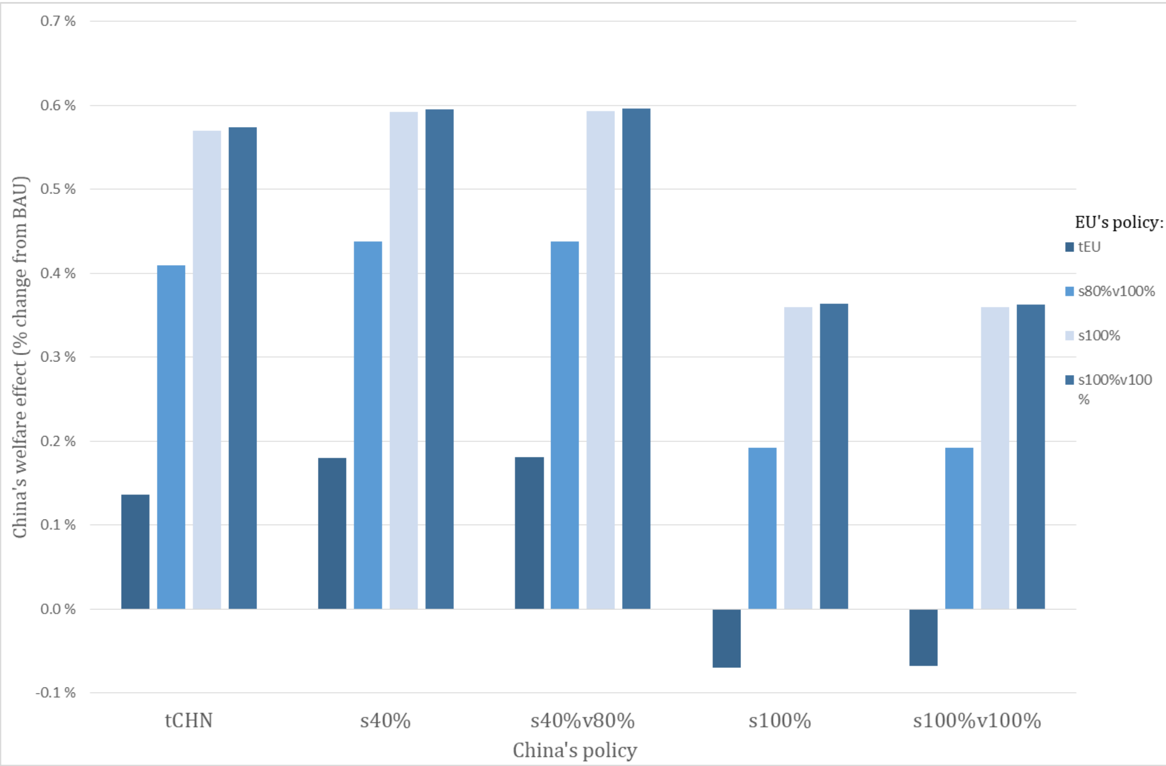

Figure 2: China's welfare effect with different combinations of policies in EU and China.

[19] So with $s_{80\%}v_{100\%}$, we have $\alpha = 0.8$ and $v = s$.

The theoretical analysis in section 2 suggested in general ambiguous effects on the optimal OBA and consumption tax, when another region implements OBA or OBA with a consumption tax. In the numerical simulation however, we find the optimal rate of OBA and consumption tax for both regions. The result suggests that the optimal rate is unaffected by an introduction of supplementing policy in the other region. The largest welfare change compared to the BAU scenario for China is approximately 0.6%. In this case, China's optimal policy is $s_{40\%}v_{80\%}$ meanwhile EU's is $s_{100\%}v_{100\%}$. The largest welfare change for EU is around 0.4%, if they choose $s_{80\%}v_{100\%}$ and China choose $s_{100\%}v_{100\%}$. Thus, the result suggests that the optimal strategies in this Nash equilibrium game are dominant strategies.

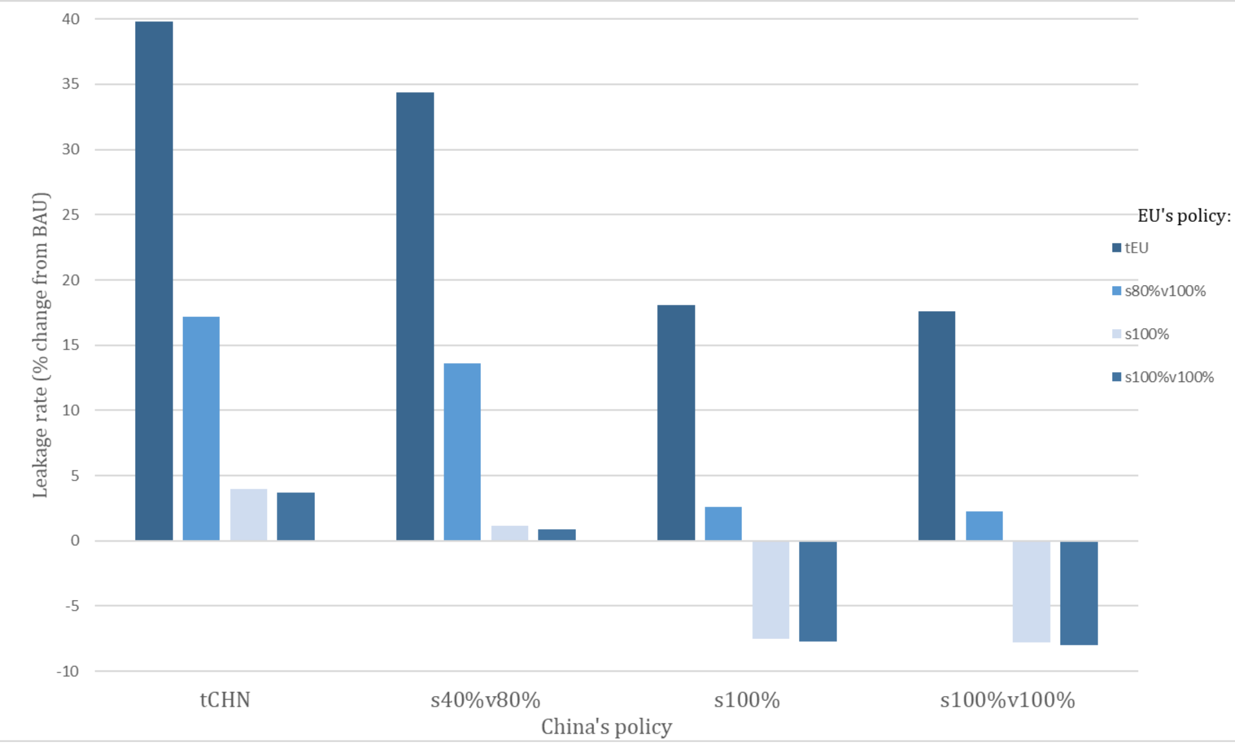

Figure 3: Leakage rate with different combinations of policies in EU and China.

Figure 3 shows the leakage rate from the regulated regions EU and China, presuming that the they minimize leakage rate as their indicator, i.e., indicator *ii)*. The leakage rate is measured as the change in foreign emission over the change in the regulating region's emission, where the BAU emission is the baseline.[20] A positive (negative) number results in a positive (negative) leakage rate. Given no energy trade in our model, leakage only happens through the market for EITE-goods (y). The figure illustrates an outcome with 100% OBA and consumption tax to at least 100% of OBA for both regions, i.e., $s_{100\%}v_{100\%}$. The consumption tax reduces demand for good y and thereby

[20] Since the regulated regions are only concerned of the increase in emissions in the unregulated region, we express the leakage rate as $\frac{\Delta(E^{ROW})}{-\Delta(E^{EU}+E^{CHN})}$, where $E^j = e^{y^j} + e^{z^j}$.

production and emissions in the unregulated region. Hence, in Nash equilibrium given indicator *ii)*, both region supplements the 100% OBA with 100% consumption tax on the EITE good. The highest leakage rate of around 40% is obtained when no complementing policies are introduced in the regulating regions. The lowest leakage rate is obtained in the Nash equilibrium, around -8% leakage rate. The results shows that a combined effort to mitigate leakage from regulated regions, results in a higher global emission reduction.

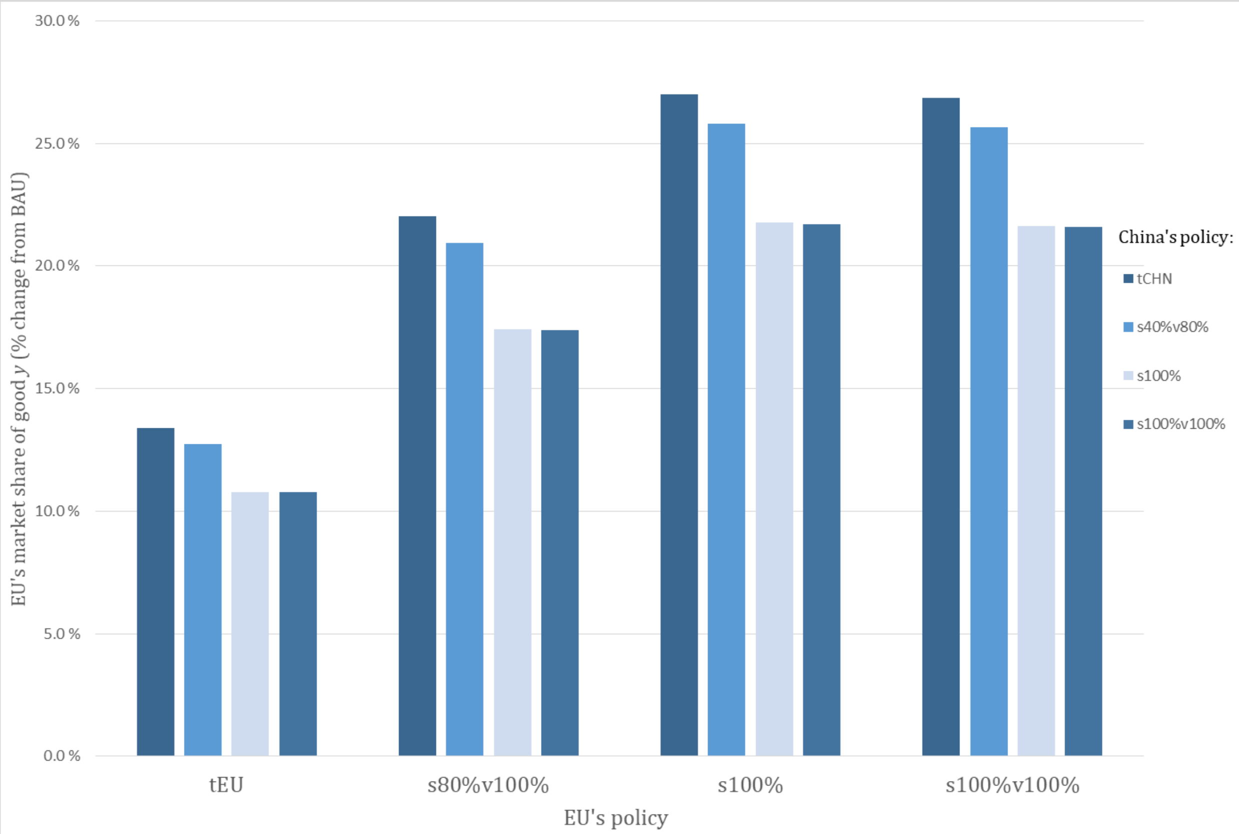

Figure 4: EU's global market share of good y with different combinations of policies in EU and China.

In accordance with earlier papers, we referred to OBA as an implicit production subsidy for sector y. If the region's main indicator had been to maximize the net production of good y, the result would consequently also have been to supplement their ETS with 100% OBA. A more interesting approach is to observe the global market share of good y, since the producers could compromise on at least maintaining the market share as the net global demand for good y declines. Figure 4 and 5 shows global market share of good y for EU and China (respectively). The highest market share of sector y is obtained when the region allocates at least 100% OBA to the producer of EITE-good, which is also the Nash equilibrium in this game. Hence, given indicator *iii)*, the regions would supplement their ETS with at least 100% OBA. The market share in the Nash equilibrium is approximately 22.13% for China and 21.8% for EU. The highest market share a region can achieve is when only that region supplements the ETS with OBA. Hence, this strategy for EU and China, is also a dominant strategy. The market shares for both regions are higher than a situation without any climate policy. In the BAU scenario, the result suggests a market share of 20.7% for both regions.

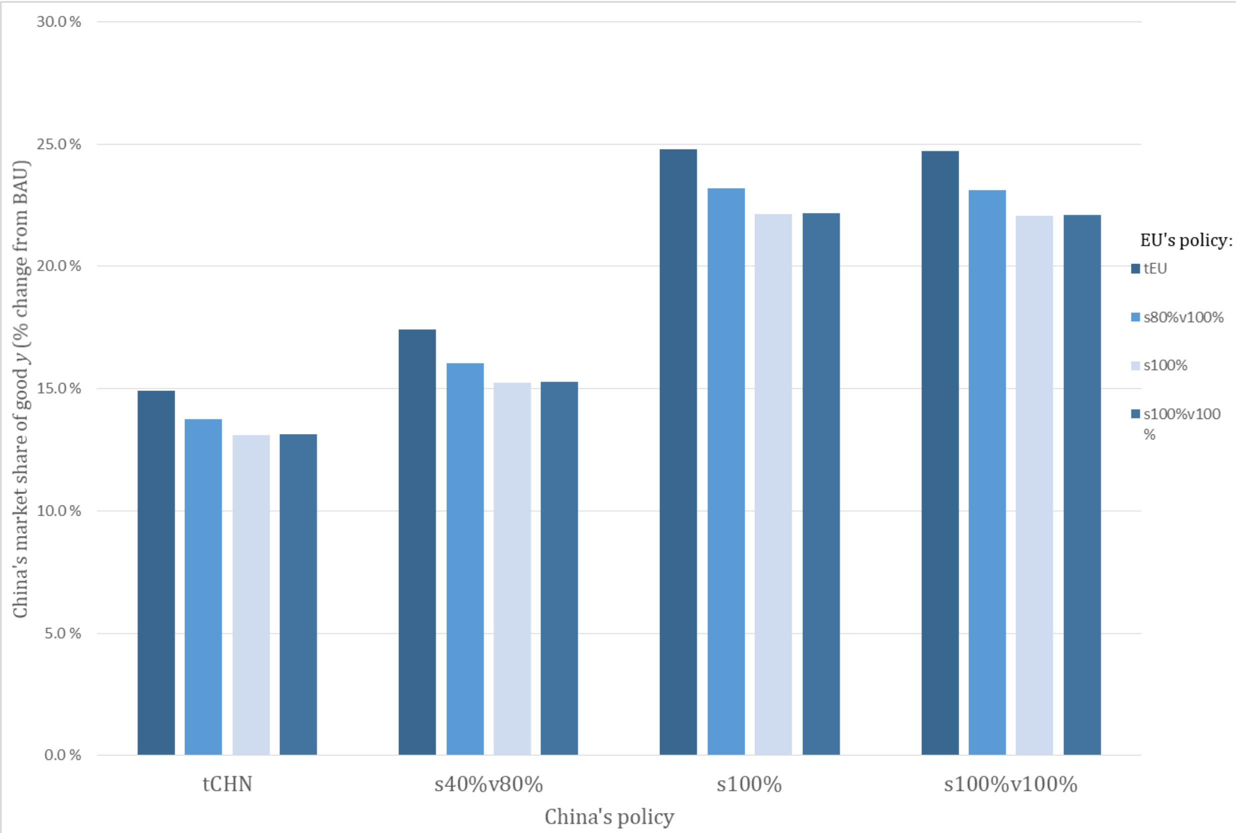

Figure 5: China's global market share of good y with different combinations of policies in EU and China.

If both regions maximize global market share of good x, indicator *iv)*, the results shows that the they would not supplement their ETS. The emission price increases the production cost for the producer of good y and z. More demand shifts towards the relatively cheaper good x, and thereby the production of the same good increases as well. In this Nash equilibrium, the regions achieves a higher market share of good x (12.3% for China and 31.5% for EU) than the BAU scenario (10.7% for China and 29.7% for EU). The share of good x for one region increases as the other region supplements her ETS to at least 100% OBA. Further, the share falls somewhat if the other region introduces a consumption tax on top of the OBA. The strategies in this Nash equilibrium outcome is also the dominant strategies for the regions.

		EU			
		i)	*ii)*	*iii)*	*iv)*
CHN	*i)*	$(s_{40}^{CHN}v_{80}^{CHN}, s_{80}^{EU}v_{100}^{EU})$	$(s_{40}^{CHN}v_{80}^{CHN}, s_{100}^{EU}v_{100}^{EU})$	$(s_{40}^{CHN}v_{80}^{CHN}, s_{100}^{EU})$	$(s_{40}^{CHN}v_{80}^{CHN}, t^{EU})$
	ii)	$(s_{100}^{CHN}v_{100}^{CHN}, s_{80}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}v_{100}^{CHN}, s_{100}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}v_{100}^{CHN}, s_{100}^{EU})$	$(s_{100}^{CHN}v_{100}^{CHN}, t^{EU})$
	iii)	$(s_{100}^{CHN}, s_{80}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}, s_{100}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}, s_{100}^{EU})$	(s_{100}^{CHN}, t^{EU})
	iv)	$(t^{CHN}, s_{80}^{EU}v_{100}^{EU})$	$(t^{CHN}, s_{100}^{EU}v_{100}^{EU})$	(t^{CHN}, s_{100}^{EU})	(t^{CHN}, t^{EU})

Table 2: Summary of the Nash equilibriums based on indicators *i) – iv)*.

In table 2, we present all the Nash equilibrium outcomes from the numerical analysis, as well as the outcomes with other combinations of indicators. EU's indicators are listed on the right side, and China on the left. The numerical analysis showed that the region's strategy in the Nash equilibrium outcome is also the dominant strategy for the region. This is noticeable in table 2 as well. That is, given an indicator, the region choses the same strategy no matter what the other region choses.

3.5 Sensitivity analysis

To check to what degree the numerical results are robust, we now examine the effects of changing some of the main assumptions. We first relax the assumption that goods produced in different regions are homogenous, and assume that domestic and foreign goods are distinguished by origin. Next, we keep the same assumptions from our base case simulation, but assume that the substitution elasticity for the representative agent is set to 2. Finally we test for a Pigouvian tax being higher than the emission price.

First consider the heterogeneous goods approach by Armington (1969) when relaxing the assumption that good produced in different regions are homogenous, and distinguish between domestic and foreign produced goods ("Armington goods"). We keep the same assumption at the top level of the utility function, when substituting between the goods x, y and z. At the second level, we include substitution between domestic and imported goods x and y, and finally at the third level we distinguish between the origins of the foreign produced goods.[21]

		EU			
		i)	*ii)*	*iii)*	*iv)*
CHN	*i)*	$(s_{100}^{CHN} v_{100}^{CHN}, s_{100}^{EU} v_{100}^{EU})$	$(s_{100}^{CHN} v_{100}^{CHN}, s_{100}^{EU} v_{100}^{EU})$	$(s_{100}^{EU} v_{100}^{EU}, s_{100}^{EU})$	$(s_{100}^{EU} v_{100}^{EU}, t^{EU})$
	ii)	$(s_{100}^{CHN} v_{100}^{CHN}, s_{100}^{EU} v_{100}^{EU})$	$(s_{100}^{CHN} v_{100}^{CHN}, s_{100}^{EU} v_{100}^{EU})$	$(s_{100}^{CHN} v_{100}^{CHN}, s_{100}^{EU})$	$(s_{100}^{CHN} v_{100}^{CHN}, t^{EU})$
	iii)	$(s_{100}^{CHN}, s_{100}^{EU} v_{100}^{EU})$	$(s_{100}^{CHN}, s_{100}^{EU} v_{100}^{EU})$	$(s_{100}^{CHN}, s_{100}^{EU})$	(s_{100}^{CHN}, t^{EU})
	iv)	$(t^{CHN}, s_{100}^{EU} v_{100}^{EU})$	$(t^{CHN}, s_{100}^{EU} v_{100}^{EU})$	(t^{CHN}, s_{100}^{EU})	(t^{CHN}, t^{EU})

Table 3: Summary of Nash equilibriums based on indicators *i) – iv)*, assuming Armington goods.

In table 3 we show the different Nash equilibriums, with the assumption of Armington goods. The welfare effects under all combinations of policies are higher with Armington goods than with the homogenous goods. Mainly this is a result of further limited leakage than with homogenous goods, and hence the global benefits of emission reductions are bigger. Compared with table 2 the only different strategy in a Nash equilibrium outcome, is when the region maximizes welfare. The new outcome is $(s_{100}^{CHN} v_{100}^{CHN}, s_{100}^{EU} v_{100}^{EU})$, which is also the dominant strategy for both regions in this game.

[21] We assume a substitution of elasticity at the top level of 0.5 (as before), at the second level of 4, and at the third level of 8. The heterogeneous goods case transforms into the case of homogenous goods with an infinite Armington elasticity setting on the second and third levels.

The welfare improves monotonically with the consumption tax to at least 100% of the OBA rate for both regions, with Armington goods. With indicator *ii)*, *iii)* or *iv)* assuming Armington goods, the results shows the same outcome as table 2. Further, like in the base case simulation the strategy choice in the Nash equilibrium outcomes are also dominant strategies for the region.

		EU			
		i)	*ii)*	*iii)*	*iv)*
CHN	*i)*	$(s_{40}^{CHN}v_{60}^{CHN}, s_{60}^{EU}v_{100}^{EU})$	$(s_{40}^{CHN}v_{60}^{CHN}, s_{100}^{EU}v_{100}^{EU})$	$(s_{40}^{CHN}v_{60}^{CHN}, s_{100}^{EU})$	$(s_{40}^{CHN}v_{60}^{CHN}, t^{EU})$
	ii)	$(s_{100}^{CHN}v_{100}^{CHN}, s_{60}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}v_{100}^{CHN}, s_{100}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}v_{100}^{CHN}, s_{100}^{EU})$	$(s_{100}^{CHN}v_{100}^{CHN}, t^{EU})$
	iii)	$(s_{100}^{CHN}, s_{60}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}, s_{100}^{EU}v_{100}^{EU})$	$(s_{100}^{CHN}, s_{100}^{EU})$	(s_{100}^{CHN}, t^{EU})
	iv)	$(t^{CHN}, s_{60}^{EU}v_{100}^{EU})$	$(t^{CHN}, s_{100}^{EU}v_{100}^{EU})$	(t^{CHN}, s_{100}^{EU})	(t^{CHN}, t^{EU})

Table 4: Summary of Nash equilibriums based on indicators *i) – iv)*, of alternative substitution elasticity.

We go back to the homogenous good assumption for the next tests, and in table 4 we list the outcome when assuming different substitution elasticity for the representative agent. The tests are conducted with substitution elasticity change in all three regions, and the substitution elasticity listed in the table is 2. With higher elasticity for the representative agent, the Nash equilibrium outcome given indicator *i)* is $(s_{40}^{CHN}v_{60}^{CHN}, s_{60}^{EU}v_{100}^{EU})$. That is somewhat lower OBA than in the base case simulation for EU, and a lower consumption tax rate for China. With higher substitution elasticity, the emission price in both regions are lower. However, the difference is bigger in EU then China when comparing with base assumption. Thus, a lower optimal OBA in EU. The welfare improvement compared to BAU scenario are in general higher with higher substitution elasticity. However, the leakage rate is now less of a concern. We can see from table 4 that the tests support the findings from our analysis in section 3.4 for indicator *ii)*, *iii)* and *iv)*. Moreover, the strategies in the Nash equilibrium outcome, are dominant strategies for the region.

The theoretical analysis in section 2.2 also discussed the possibility of the *Pigouvian* tax being different from the emission price observed under the scenario without supplementing policies to the ETS. We have assumed that the two are equal in the benchmark simulations. In the EU Emission Trading System for instance, the emission price have been fairly low over the last years. Thus, one could argue that the *Pigouvian* tax is higher than the current CO_2 price. We test for a *Pigouvian* tax that is 50 % higher (in EU and China) than the estimated carbon price from section 3.4. The increased *Pigouvian* tax does not alter our main result from section 3.4. The benefits of the climate policy, however, is now bigger as global emission reductions would have a greater impact on welfare.

4. Concluding remarks

As rest of the world closely follows the unilateral initiatives by EU and China, the policymakers in these markets are well aware that their unilateral action leads to carbon leakage without a global initiative to reduce emissions. There are many different approaches in the economic literature to mitigate carbon leakage. A very common anti-leakage solution in emission trading systems is output-based allocation (OBA) to emission-intensive and trade-exposed (EITE) industries. OBA, however, works as an implicit production subsidy to domestic production of EITE goods. Hence, an approach to supplement OBA with a consumption tax on all use of EITE goods have been proposed.

In this paper we have examined the choice of a climate policy instrument for a region, in the presence of another region's climate policy. First we showed analytically that the effect on the optimal OBA and optimal consumption tax for a country is ambiguous if another country introduces an OBA or a consumption tax. However, we also showed that under certain conditions the optimal consumption tax for a country is reduced, if another country introduces an OBA or a OBA and consumption tax. Next, we examined the choice of policy instrument for two separate countries with a stylized numerical model calibrated to real world data, where we considered the situation of the EU ETS and the Chinese ETS. The results showed that depending on certain conditions, the countries would choose different variation of policy combinations. In the context of maximizing welfare and minimizing leakage rate, both countries would implement a consumption tax on top of the OBA. Further, the numerical results showed that the strategies in all the Nash equilibrium outcomes were also the dominant strategy for the region.

The tax implementing countries were consistently better off in terms of welfare and leakage rate. Thus, the paper conclude that complimenting output-based allocation with a consumption tax is likely a strong policy strategy to mitigate carbon leakage, even in the presence of other region's climate policy.

Appendix A, Derivations

A1: Region welfare maximization with output-based allocation

By differentiating the regional welfare (5) with respect to output-based allocation, we get

$$\frac{\partial W^1}{\partial s^1} = u_x^1 \frac{\partial \bar{x}^1}{\partial s^1} + u_y^1 \frac{\partial \bar{y}^1}{\partial s^1} + u_z^1 \frac{\partial \bar{z}^1}{\partial s^1} - c_x^{x1} \frac{\partial x^1}{\partial s^1} - c_y^{y1} \frac{\partial y^1}{\partial s^1} - c_z^{z1} \frac{\partial z^1}{\partial s^1} - c_e^{y1} \frac{\partial e^{y1}}{\partial s^1} - c_e^{z1} \frac{\partial e^{z1}}{\partial s^1}$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{y2}}{\partial s^1} + \frac{\partial e^{y3}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} + \frac{\partial e^{z2}}{\partial s^1} + \frac{\partial e^{z3}}{\partial s^1} \right]$$

Recall the conditions and assumptions from (2) and (3), and we then get

$$= p^x \frac{\partial \bar{x}^1}{\partial s^1} + p^y \frac{\partial \bar{y}^1}{\partial s^1} + p^{z1} \frac{\partial \bar{z}^1}{\partial s^1} - p^x \frac{\partial x^1}{\partial s^1} - (p^y + s^1) \frac{\partial y^1}{\partial s^1} - p^{z1} \frac{\partial z^1}{\partial s^1} + t^1 \frac{\partial e^{y1}}{\partial s^1} + t^1 \frac{\partial e^{z1}}{\partial s^1}$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{y2}}{\partial s^1} + \frac{\partial e^{y3}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} + \frac{\partial e^{z2}}{\partial s^1} + \frac{\partial e^{z3}}{\partial s^1} \right]$$

We further simplify the equation

$$= p^x \frac{\partial \bar{x}^1}{\partial s^1} - p^x \frac{\partial x^1}{\partial s^1} + p^y \frac{\partial \bar{y}^1}{\partial s^1} + p^{z1} \frac{\partial \bar{z}^1}{\partial s^1} - p^{z1} \frac{\partial z^1}{\partial s^1} - (p^y + s^1) \frac{\partial y^1}{\partial s^1} + t^1 \left(\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} \right)$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{y2}}{\partial s^1} + \frac{\partial e^{y3}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} + \frac{\partial e^{z2}}{\partial s^1} + \frac{\partial e^{z3}}{\partial s^1} \right]$$

$$= p^x \left(\frac{\partial \bar{x}^1}{\partial s^1} - \frac{\partial x^1}{\partial s^1} \right) + p^y \frac{\partial \bar{y}^1}{\partial s^1} + p^{z1} \left(\frac{\partial \bar{z}^1}{\partial s^1} - \frac{\partial z^1}{\partial s^1} \right) - (p^y + s^1) \frac{\partial y^1}{\partial s^1} + t^1 \left(\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} \right)$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{y2}}{\partial s^1} + \frac{\partial e^{y3}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} + \frac{\partial e^{z2}}{\partial s^1} + \frac{\partial e^{z3}}{\partial s^1} \right]$$

Since there is no trade of the good z, i.e. $\left(\frac{\partial \bar{z}^1}{\partial v^1} = \frac{\partial z^1}{\partial v^1} \right)$:

$$= p^x \left(\frac{\partial \bar{x}^1}{\partial s^1} - \frac{\partial x^1}{\partial s^1} \right) + p^y \frac{\partial \bar{y}^1}{\partial s^1} - (p^y + s^1) \frac{\partial y^1}{\partial s^1} + t^1 \left(\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} \right)$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial s^1} + \frac{\partial e^{y2}}{\partial s^1} + \frac{\partial e^{y3}}{\partial s^1} + \frac{\partial e^{z1}}{\partial s^1} + \frac{\partial e^{z2}}{\partial s^1} + \frac{\partial e^{z3}}{\partial s^1} \right]$$

Recall (4), further we differentiate (4) w.r.t. consumption tax, remembering the product rule:

$$\frac{\partial p^y}{\partial s^1}(y^1-\bar{y}^1)+p^y\left(\frac{\partial y^1}{\partial s^1}-\frac{\partial \bar{y}^1}{\partial s^1}\right)+\frac{\partial p^x}{\partial s^1}(x^1-\bar{x}^1)+p^x\left(\frac{\partial x^1}{\partial s^1}-\frac{\partial \bar{x}^1}{\partial s^1}\right)=0$$

solving this for p^x

$$p^x=\frac{\left(p^y\left(\frac{\partial y^1}{\partial s^1}-\frac{\partial \bar{y}^1}{\partial s^1}\right)+\frac{\partial p^y}{\partial s^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial s^1}(x^1-\bar{x}^1)\right)}{-\left(\frac{\partial x^1}{\partial s^1}-\frac{\partial \bar{x}^1}{\partial s^1}\right)}$$

we insert this into our equation for p^x

$$\begin{aligned}\frac{\partial W^1}{\partial s^1}=&\left[\frac{\left(p^y\left(\frac{\partial y^1}{\partial s^1}-\frac{\partial \bar{y}^1}{\partial s^1}\right)+\frac{\partial p^y}{\partial s^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial s^1}(x^1-\bar{x}^1)\right)}{-\left(\frac{\partial x^1}{\partial s^1}-\frac{\partial \bar{x}^1}{\partial s^1}\right)}\right]\left(\frac{\partial \bar{x}^1}{\partial s^1}-\frac{\partial x^1}{\partial s^1}\right)+p^y\frac{\partial \bar{y}^1}{\partial s^1}\\&-(p^y+s^1)\frac{\partial y^1}{\partial s^1}+t^1\left(\frac{\partial e^{y1}}{\partial s^1}+\frac{\partial e^{z1}}{\partial s^1}\right)\\&-\tau^1\left[\frac{\partial e^{y1}}{\partial s^1}+\frac{\partial e^{y2}}{\partial s^1}+\frac{\partial e^{y3}}{\partial s^1}+\frac{\partial e^{z1}}{\partial s^1}+\frac{\partial e^{z2}}{\partial s^1}+\frac{\partial e^{z3}}{\partial s^1}\right]\end{aligned}$$

and since

$$-\frac{\left(\frac{\partial \bar{x}^1}{\partial s^1}-\frac{\partial x^1}{\partial s^1}\right)}{\left(\frac{\partial x^1}{\partial s^1}-\frac{\partial \bar{x}^1}{\partial s^1}\right)}=\frac{\left(\frac{\partial \bar{x}^1}{\partial s^1}-\frac{\partial x^1}{\partial s^1}\right)}{\left(\frac{\partial \bar{x}^1}{\partial s^1}-\frac{\partial x^1}{\partial s^1}\right)}=1$$

We can further simplify:

$$\begin{aligned}=&\,p^y\left(\frac{\partial y^1}{\partial s^1}-\frac{\partial \bar{y}^1}{\partial s^1}\right)+\frac{\partial p^y}{\partial s^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial s^1}(x^1-\bar{x}^1)+p^y\frac{\partial \bar{y}^1}{\partial s^1}-(p^y+s^1)\frac{\partial y^1}{\partial s^1}+t^1\left(\frac{\partial e^{y1}}{\partial s^1}+\frac{\partial e^{z1}}{\partial s^1}\right)\\&-\tau^1\left[\frac{\partial e^{y1}}{\partial s^1}+\frac{\partial e^{y2}}{\partial s^1}+\frac{\partial e^{y3}}{\partial s^1}+\frac{\partial e^{z1}}{\partial s^1}+\frac{\partial e^{z2}}{\partial s^1}+\frac{\partial e^{z3}}{\partial s^1}\right]\end{aligned}$$

$$\begin{aligned}=&\,p^y\left(\frac{\partial y^1}{\partial s^1}-\frac{\partial \bar{y}^1}{\partial s^1}+\frac{\partial \bar{y}^1}{\partial s^1}-\frac{\partial y^1}{\partial s^1}\right)+\frac{\partial p^y}{\partial s^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial s^1}(x^1-\bar{x}^1)-s^1\frac{\partial y^1}{\partial s^1}+t^1\left(\frac{\partial e^{y1}}{\partial s^1}+\frac{\partial e^{z1}}{\partial s^1}\right)\\&-\tau^1\left[\frac{\partial e^{y1}}{\partial s^1}+\frac{\partial e^{z1}}{\partial s^1}+\frac{\partial e^{y2}}{\partial s^1}+\frac{\partial e^{z2}}{\partial s^1}+\frac{\partial e^{y3}}{\partial s^1}+\frac{\partial e^{z3}}{\partial s^1}\right]\end{aligned}$$

Recall the constraint on emission in region $j = \{1,2\}$, $\bar{E}^j = e^{yj} + e^{zj}$. By differentiating this w.r.t the consumption tax, we have that:

$$\frac{\partial \bar{E}^j}{\partial s^1} = \frac{\partial e^{yj}}{\partial s^1} + \frac{\partial e^{zj}}{\partial s^1} = 0$$

By this assumption, our equation can now be expressed as:

$$= p^y\left(\frac{\partial y^1}{\partial s^1} - \frac{\partial \bar{y}^1}{\partial s^1} + \frac{\partial \bar{y}^1}{\partial s^1} - \frac{\partial y^1}{\partial s^1}\right) + \frac{\partial p^y}{\partial s^1}(y^1 - \bar{y}^1) + \frac{\partial p^x}{\partial s^1}(x^1 - \bar{x}^1) - s^1\frac{\partial y^1}{\partial s^1} - \tau^1\left[\frac{\partial e^{y3}}{\partial s^1} + \frac{\partial e^{z3}}{\partial s^1}\right]$$

and simplified to

$$= -s^1\frac{\partial y^1}{\partial s^1} + \frac{\partial p^y}{\partial s^1}(y^1 - \bar{y}^1) + \frac{\partial p^x}{\partial s^1}(x^1 - \bar{x}^1) - \tau^1\left[\frac{\partial e^{y3}}{\partial s^1} + \frac{\partial e^{z3}}{\partial s^1}\right]$$

And we finally arrive at (6), by moving s^1 on the other side of the equal sign

$$s^{1*} = \left(\frac{\partial y^1}{\partial s^1}\right)^{-1}\left[-\tau^1\left(\frac{\partial e^{y3}}{\partial y^3}\frac{\partial y^3}{\partial s^1} + \frac{\partial e^{z3}}{\partial z^3}\frac{\partial z^3}{\partial s^1}\right) + \frac{\partial p^y}{\partial s^1}(y^1 - \bar{y}^1) + \frac{\partial p^x}{\partial s^1}(x^1 - \bar{x}^1)\right] \tag{6}$$

A2: Region welfare maximization with consumption tax

By differentiating the regional welfare (5) with respect to consumptions tax, we get

$$\frac{\partial W^1}{\partial v^1} = u_x^1 \frac{\partial \bar{x}^1}{\partial v^1} + u_y^1 \frac{\partial \bar{y}^1}{\partial v^1} + u_z^1 \frac{\partial \bar{z}^1}{\partial v^1} - c_x^{x1} \frac{\partial x^1}{\partial v^1} - c_y^{y1} \frac{\partial y^1}{\partial v^1} - c_z^{z1} \frac{\partial z^1}{\partial v^1} - c_e^{y1} \frac{\partial e^{y1}}{\partial v^1} - c_e^{z1} \frac{\partial e^{z1}}{\partial v^1}$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{y2}}{\partial v^1} + \frac{\partial e^{y3}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} + \frac{\partial e^{z2}}{\partial v^1} + \frac{\partial e^{z3}}{\partial v^1} \right]$$

Recall the conditions and assumptions from (2) and (3), and we then get

$$= p^x \frac{\partial \bar{x}^1}{\partial v^1} + (p^y + v^1) \frac{\partial \bar{y}^1}{\partial v^1} + p^{z1} \frac{\partial \bar{z}^1}{\partial v^1} - p^x \frac{\partial x^1}{\partial v^1} - (p^y + s^1) \frac{\partial y^1}{\partial v^1} - p^{z1} \frac{\partial z^1}{\partial v^1} + t^1 \frac{\partial e^{y1}}{\partial v^1} + t^1 \frac{\partial e^{z1}}{\partial v^1}$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{y2}}{\partial v^1} + \frac{\partial e^{y3}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} + \frac{\partial e^{z2}}{\partial v^1} + \frac{\partial e^{z3}}{\partial v^1} \right]$$

We further simplify the equation

$$= p^x \frac{\partial \bar{x}^1}{\partial v^1} - p^x \frac{\partial x^1}{\partial v^1} + (p^y + v^1) \frac{\partial \bar{y}^1}{\partial v^1} + p^{z1} \frac{\partial \bar{z}^1}{\partial v^1} - p^{z1} \frac{\partial z^1}{\partial v^1} - (p^y + s^1) \frac{\partial y^1}{\partial v^1} + t^1 \left(\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} \right)$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{y2}}{\partial v^1} + \frac{\partial e^{y3}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} + \frac{\partial e^{z2}}{\partial v^1} + \frac{\partial e^{z3}}{\partial v^1} \right]$$

$$= p^x \left(\frac{\partial \bar{x}^1}{\partial v^1} - \frac{\partial x^1}{\partial v^1} \right) + (p^y + v^1) \frac{\partial \bar{y}^1}{\partial v^1} + p^{z1} \left(\frac{\partial \bar{z}^1}{\partial v^1} - \frac{\partial z^1}{\partial v^1} \right) - (p^y + s^1) \frac{\partial y^1}{\partial v^1} + t^1 \left(\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} \right)$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{y2}}{\partial v^1} + \frac{\partial e^{y3}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} + \frac{\partial e^{z2}}{\partial v^1} + \frac{\partial e^{z3}}{\partial v^1} \right]$$

Since there is no trade of the good z, i.e. $\left(\frac{\partial \bar{z}^1}{\partial v^1} = \frac{\partial z^1}{\partial v^1} \right)$:

$$= p^x \left(\frac{\partial \bar{x}^1}{\partial v^1} - \frac{\partial x^1}{\partial v^1} \right) + (p^y + v^1) \frac{\partial \bar{y}^1}{\partial v^1} - (p^y + s^1) \frac{\partial y^1}{\partial v^1} + t^1 \left(\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} \right)$$
$$- \tau^1 \left[\frac{\partial e^{y1}}{\partial v^1} + \frac{\partial e^{y2}}{\partial v^1} + \frac{\partial e^{y3}}{\partial v^1} + \frac{\partial e^{z1}}{\partial v^1} + \frac{\partial e^{z2}}{\partial v^1} + \frac{\partial e^{z3}}{\partial v^1} \right]$$

Recall (4), further we differentiate (4) w.r.t. consumption tax, remembering the product rule:

$$\frac{\partial p^y}{\partial v^1}(y^1-\bar{y}^1)+p^y\left(\frac{\partial y^1}{\partial v^1}-\frac{\partial \bar{y}^1}{\partial v^1}\right)+\frac{\partial p^x}{\partial v^1}(x^1-\bar{x}^1)+p^x\left(\frac{\partial x^1}{\partial v^1}-\frac{\partial \bar{x}^1}{\partial v^1}\right)=0$$

solving this for p^x

$$p^x=\frac{\left(p^y\left(\frac{\partial y^1}{\partial v^1}-\frac{\partial \bar{y}^1}{\partial v^1}\right)+\frac{\partial p^y}{\partial v^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial v^1}(x^1-\bar{x}^1)\right)}{-\left(\frac{\partial x^1}{\partial v^1}-\frac{\partial \bar{x}^1}{\partial v^1}\right)}$$

we insert this into our equation for p^x

$$\begin{aligned}\frac{\partial W^1}{\partial v^1}=&\left[\frac{\left(p^y\left(\frac{\partial y^1}{\partial v^1}-\frac{\partial \bar{y}^1}{\partial v^1}\right)+\frac{\partial p^y}{\partial v^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial v^1}(x^1-\bar{x}^1)\right)}{-\left(\frac{\partial x^1}{\partial v^1}-\frac{\partial \bar{x}^1}{\partial v^1}\right)}\right]\left(\frac{\partial \bar{x}^1}{\partial v^1}-\frac{\partial x^1}{\partial v^1}\right)+(p^y+v^1)\frac{\partial \bar{y}^1}{\partial v^1}\\&-(p^y+s^1)\frac{\partial y^1}{\partial v^1}+t^1\left(\frac{\partial e^{y1}}{\partial v^1}+\frac{\partial e^{z1}}{\partial v^1}\right)\\&-\tau^1\left[\frac{\partial e^{y1}}{\partial v^1}+\frac{\partial e^{y2}}{\partial v^1}+\frac{\partial e^{y3}}{\partial v^1}+\frac{\partial e^{z1}}{\partial v^1}+\frac{\partial e^{z2}}{\partial v^1}+\frac{\partial e^{z3}}{\partial v^1}\right]\end{aligned}$$

and since

$$-\frac{\left(\frac{\partial \bar{x}^1}{\partial v^1}-\frac{\partial x^1}{\partial v^1}\right)}{\left(\frac{\partial x^1}{\partial v^1}-\frac{\partial \bar{x}^1}{\partial v^1}\right)}=\frac{\left(\frac{\partial \bar{x}^1}{\partial v^1}-\frac{\partial x^1}{\partial v^1}\right)}{\left(\frac{\partial \bar{x}^1}{\partial v^1}-\frac{\partial x^1}{\partial v^1}\right)}=1$$

We can further simplify:

$$\begin{aligned}=&\,p^y\left(\frac{\partial y^1}{\partial v^1}-\frac{\partial \bar{y}^1}{\partial v^1}\right)+\frac{\partial p^y}{\partial v^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial v^1}(x^1-\bar{x}^1)+(p^y+v^1)\frac{\partial \bar{y}^1}{\partial v^1}-(p^y+s^1)\frac{\partial y^1}{\partial v^1}\\&+t^1\left(\frac{\partial e^{y1}}{\partial v^1}+\frac{\partial e^{z1}}{\partial v^1}\right)-\tau^1\left[\frac{\partial e^{y1}}{\partial v^1}+\frac{\partial e^{y2}}{\partial v^1}+\frac{\partial e^{y3}}{\partial v^1}+\frac{\partial e^{z1}}{\partial v^1}+\frac{\partial e^{z2}}{\partial v^1}+\frac{\partial e^{z3}}{\partial v^1}\right]\end{aligned}$$

$$\begin{aligned}=&\,p^y\left(\frac{\partial y^1}{\partial v^1}-\frac{\partial \bar{y}^1}{\partial v^1}+\frac{\partial \bar{y}^1}{\partial v^1}-\frac{\partial y^1}{\partial v^1}\right)+\frac{\partial p^y}{\partial v^1}(y^1-\bar{y}^1)+\frac{\partial p^x}{\partial v^1}(x^1-\bar{x}^1)+v^1\frac{\partial \bar{y}^1}{\partial v^1}-s^1\frac{\partial y^1}{\partial v^1}\\&+t^1\left(\frac{\partial e^{y1}}{\partial v^1}+\frac{\partial e^{z1}}{\partial v^1}\right)-\tau^1\left[\frac{\partial e^{y1}}{\partial v^1}+\frac{\partial e^{z1}}{\partial v^1}+\frac{\partial e^{y2}}{\partial v^1}+\frac{\partial e^{z2}}{\partial v^1}+\frac{\partial e^{y3}}{\partial v^1}+\frac{\partial e^{z3}}{\partial v^1}\right]\end{aligned}$$

Recall the constraint on emission in region $j = \{1,2\}$, $\bar{E}^j = e^{yj} + e^{zj}$. By differentiating this w.r.t the consumption tax, we have that:

$$\frac{\partial \bar{E}^j}{\partial v^1} = \frac{\partial e^{yj}}{\partial v^1} + \frac{\partial e^{zj}}{\partial v^1} = 0$$

By this assumption, our equation can now be expressed as:

$$= p^y \left(\frac{\partial y^1}{\partial v^1} - \frac{\partial \bar{y}^1}{\partial v^1} + \frac{\partial \bar{y}^1}{\partial v^1} - \frac{\partial y^1}{\partial v^1} \right) + \frac{\partial p^y}{\partial v^1}(y^1 - \bar{y}^1) + \frac{\partial p^x}{\partial v^1}(x^1 - \bar{x}^1) + v^1 \frac{\partial \bar{y}^1}{\partial v^1} - s^1 \frac{\partial y^1}{\partial v^1} - \tau^1 \left[\frac{\partial e^{y3}}{\partial v^1} + \frac{\partial e^{z3}}{\partial v^1} \right]$$

and simplified to

$$= v^1 \frac{\partial \bar{y}^1}{\partial v^1} - s^1 \frac{\partial y^1}{\partial v^1} + \frac{\partial p^y}{\partial v^1}(y^1 - \bar{y}^1) + \frac{\partial p^x}{\partial v^1}(x^1 - \bar{x}^1) - \tau^1 \left[\frac{\partial e^{y3}}{\partial v^1} + \frac{\partial e^{z3}}{\partial v^1} \right]$$

And we finally arrive at (8), by moving v^1 on the other side of the equal sign

$$v^{1*} = \left(\frac{\partial \bar{y}^1}{\partial v^1} \right)^{-1} \left[s^1 \frac{\partial y^1}{\partial v^1} - \frac{\partial p^y}{\partial v^1}(y^1 - \bar{y}^1) - \frac{\partial p^x}{\partial v^1}(x^1 - \bar{x}^1) + \tau^1 \left(\frac{\partial e^{y3}}{\partial y^3} \frac{\partial y^3}{\partial v^1} + \frac{\partial e^{z3}}{\partial z^3} \frac{\partial z^3}{\partial v^1} \right) \right] \quad (8)$$

Appendix B: Summary of the numerical CGE model

Indices and sets:

Set of regions	R	CHN, EU, ROW
Set of goods	g	x, ,z
r (alias j)		Index for regions

Variables:

S^{gr}	Production of good g in r
S_{FE}^{r}	Production of fossil energy (FE) in r
D^{gr}	Aggregated consumer demand of good g in r
KL^{gr}	Value-added composite for g in r
KLF^{r}	Value-added composite for FE in r
A^{gr}	Armington aggregate of g in r
IM^{gr}	Import aggregate of g in r
W^{r}	Consumption composite in r

$p^{g,r}$	Price of g in r
p_{FE}^{r}	Price of Primary fossil FE in r
p_{KL}^{gr}	Price of value added for g in r
p_{KLF}^{r}	Price of value added for FE in r
p_{L}^{r}	Price of labor (wage rate) in r
p_{K}^{r}	Price of capital (rental rate) in r
p_{Q}^{r}	Rent for primary energy resource in r
p_{A}^{gr}	Price of Armington aggregate of g in r
p_{IM}^{gr}	Price of aggregate imports of g in r
p_{CO2}^{r}	Price of CO2 emission in r
p_{W}^{r}	Price of consumption composite in r
o^{gr}	Output-Based Allocation on g in r
v^{gr}	Consumption tax on g in r

Parameters:

σ_{KLE}^{r}	Substitution between value-added and energy g in r

σ_{KL}^{r}	Substitution between value-added g in r
σ_{Q}^{r}	Substitution between value-added and natural resource in FE in r
σ_{LN}^{r}	Substitution between value-added in FE in r
σ_{A}^{gr}	Substitution between import and domestic g in r
σ_{IM}^{gr}	Substitution between imports from different g in r
σ_{W}^{r}	Substitution between goods to consumption
θ_{FE}^{gr}	Cost Share of FE in production of g in r
θ_{KL}^{gr}	Cost Share of labor in production of g in r
θ_{Q}^{r}	Cost Share of natural resource in production of FE in r
θ_{LN}^{r}	Cost Share of labor in production of FE in r
θ_{A}^{gr}	Cost Share of domestic goods g in consumption in r
θ_{IM}^{gr}	Cost Share of different imports goods g in consumption in r
L_{0}^{gr}	Labor endowment in sector g in region r
$L_{0,FE}^{r}$	Labor endowment in FE in region r
K_{0}^{gr}	Capital endowment in sector g in region r
$K_{0,FE}^{r}$	Capital endowment in FE in region r
Q_{0}^{r}	Resource endowment of primary fossil energy in region r
$CO2_{MAX}^{r}$	CO_2 emission allowance in region r
κ_{CO2}^{r}	Coefficient for primary fossil energy of CO_2 emission in region r

Zero Profit Conditions

Production of goods except for fossil primary energy:

$$\pi_S^{gr} = \left(\theta_{FE}^{gr}\left(p_{FE}^{r} + \kappa_{CO2}^{r} p_{CO2}^{gr}\right)^{(1-\sigma_{KLE}^{r})} + \left(1-\theta_{FE}^{gr}\right) p_{KL}^{gr\,(1-\sigma_{KLE}^{r})}\right)^{\left(\frac{1}{1-\sigma_{KLE}^{r}}\right)} \geq p^{gr} + o^{gr} \qquad \perp S^{gr}$$

Sector specific value-added aggregate for x, y and z:

$$\pi_{KL}^{gr} = \left(\theta_{KL}^{gr} p_L^{r\,(1-\sigma_{KL}^{gr})} + \left(1-\theta_{KL}^{gr}\right) p_K^{r\,(1-\sigma_{KL}^{gr})}\right)^{\left(\frac{1}{1-\sigma_{KL}^{gr}}\right)} \geq p_{KL}^{gr} \qquad \perp KL^{gr}$$

Production of fossil primary energy:

$$\pi_{FE}^{r} = \left(\theta_{Q}^{r} p_{Q}^{r\,(1-\sigma_{Q}^{r})} + (1-\theta_{Q}^{r}) p_{KLF}^{r}{}^{(1-\sigma_{Q}^{r})}\right)^{\left(\frac{1}{1-\sigma_{Q}^{r}}\right)} \quad \geq p_{FE}^{r} \qquad \perp S_{FE}^{r}$$

Sector specific value-added aggregate for FE:

$$\pi_{KLF}^{r} = \left(\theta_{LN}^{r} p_{L}^{r\,(1-\sigma_{LN}^{r})} + (1-\theta_{LN}^{r}) p_{K}^{r\,(1-\sigma_{LN}^{r})}\right)^{\left(\frac{1}{1-\sigma_{LN}^{r}}\right)} \quad \geq p_{KLF}^{r} \qquad \perp KLF^{r}$$

Armington aggregate except for FE:

$$\pi_{A}^{gr} = \left(\theta_{A}^{gr} (p^{gr} + v^{gr})^{(1-\sigma_{A}^{gr})} + (1-\theta_{A}^{gr}) p_{IM}^{gr\,(1-\sigma_{A}^{gr})}\right)^{\left(\frac{1}{1-\sigma_{A}^{gr}}\right)} \quad \geq p_{A}^{gr} \qquad \perp A^{gr}$$

Import Composite except for FE:

$$\pi_{IM}^{gr} = \left(\sum_{j\neq r} \theta_{IM}^{gjr} \left(p^{gj} + v^{gr}\right)^{(1-\sigma_{IM}^{gr})}\right)^{\left(\frac{1}{1-\sigma_{IM}^{gr}}\right)} \quad \geq p_{IM}^{gr} \qquad \perp IM^{gr}$$

Consumption composite:

$$\pi_{W}^{r} = \left(\theta_{W}^{xr} p_{A}^{xr\,(1-\sigma_{W}^{r})} + \theta_{W}^{yr} p_{A}^{yr\,(1-\sigma_{W}^{r})} + \theta_{W}^{zr} p_{A}^{zr\,(1-\sigma_{W}^{r})}\right)^{\left(\frac{1}{1-\sigma_{W}^{r}}\right)} \quad \geq p_{W}^{r} \qquad \perp W^{r}$$

Market Clearing Conditions

Labor:

$$\sum_{g} L_{0}^{gr} + L_{0,FE}^{r} \geq \sum_{g} KL^{gr} \frac{\partial \pi_{KL}^{gr}}{\partial {p_{L}}^{r}} + KLF^{r} \frac{\partial \pi_{KLF}^{r}}{\partial {p_{L}}^{r}} \qquad \perp {p_{L}}^{r}$$

Capital:

$$\sum_{g} K_{0}^{gr} + K_{0,FE}^{r} \geq \sum_{g} KL^{gr} \frac{\partial \pi_{KL}^{gr}}{\partial {p_{K}}^{r}} + KLF^{r} \frac{\partial \pi_{KLF}^{r}}{\partial {p_{K}}^{r}} \qquad \perp {p_{K}}^{r}$$

Primary fossil energy resource:

$$Q_{0}^{r} \geq S_{FE}^{r} \frac{\partial \pi_{FE}^{r}}{\partial p_{Q}^{r}} \qquad \perp {p_{Q}}^{r}$$

Value-added except FE:

$$KL^{gr} \geq S^{gr} \frac{\partial \pi_{S}^{gr}}{\partial p_{KL}^{gr}} \qquad \perp p_{KL}^{gr}$$

Value-added FE:

$$KLF^r \geq S_{FE}^r \frac{\partial \pi_{FE}^r}{\partial p_{KLF}^r} \qquad \perp p_{KLF}^r$$

Armington Aggregate:

$$A^{gr} \geq W^r \frac{\partial \pi_W^r}{\partial p_A^{gr}} \qquad \perp p_A^{gr}$$

Import Aggregate:

$$IM^{gr} \geq A^{gr} \frac{\partial \pi_A^{gr}}{\partial p_{IM}^{gr}} \qquad \perp p_{IM}^{gr}$$

Supply-demand balance of goods, except FE:

$$S^{gr} \geq A^{gr} \frac{\partial \pi_A^{gr}}{\partial p^{gr}} + \sum_{j \neq r} IM^{gj} \frac{\partial \pi_{IM}^{gj}}{\partial p^{gj}} \qquad \perp p^{gr}$$

Supply-demand balance of FE:

$$S_{FE}^r \geq \sum_g S^{gr} \frac{\partial \pi_S^{gr}}{\partial \left(p_{FE}^r + \kappa_{CO2}^r p_{CO2}^{gr}\right)} \qquad \perp p_{FE}^r$$

Demand of goods:

$$D^{gr} \geq A^{gr} \frac{\partial \pi_A^{gr}}{\partial p^{gr}} + IM^{gr} \frac{\partial \pi_{IM}^{gr}}{\partial p^{gr}} \qquad \perp D^{gr}$$

CO_2 Emission in region:

$$CO2_{MAX}^r \geq \kappa_{CO2}^r S_{FE}^r \qquad \perp p_{CO2}^r$$

Consumption by consumers

$$p_W^r W^r \geq p_L^r \left(\sum_g L_0^{gr} + L_{0,FE}^r \right) + p_K^r \left(\sum_g K_0^{gr} + K_{0,FE}^r \right) + p_Q{}^r Q_0^r + p_{CO2}^r CO2_{MAX}^r - S^{gr} o^{gr} + D^{gr} v^{gr} \qquad \perp p_W^r$$

Elasticities: $\sigma_{KLE} = 0.5 \quad \sigma_{KL} = 1$

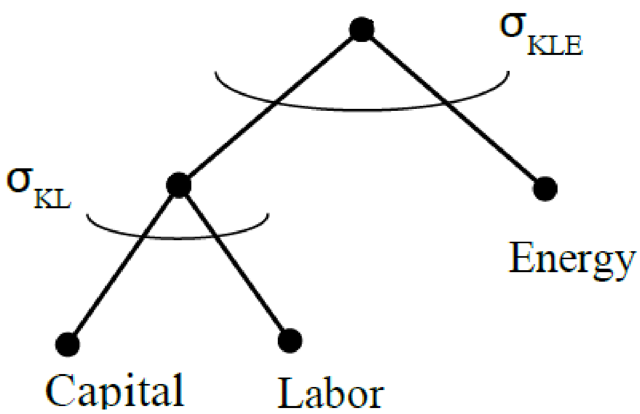

Figure B1: Nesting in production, except for fossil fuel energy

Elasticities: $\sigma_Q = 0.9 \qquad \sigma_{KL} = 1$

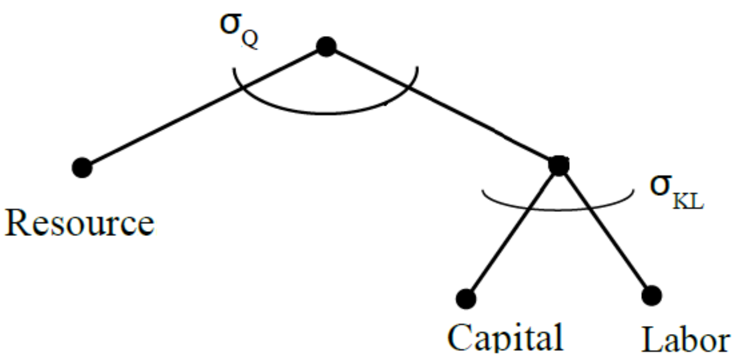

Figure B2: Nesting in production of fossil fuel energy

Elasticity: $\sigma_W = 0.5$

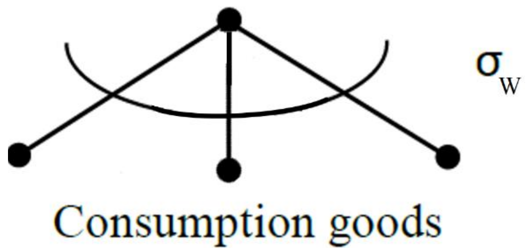

Figure B3: Nesting in consumption

Appendix C: Mapping of WIOD sectors

Model Sectors	**WIOD Sectors**
y: emission-intensive and tradable goods	Oil, Mining and Quarrying; Chemicals and Chemical Products; Basic Metals and Fabricated Metal; Other Non-Metallic Mineral; Transport Equipment; Textiles and Textile Products; Food, Beverages and Tobacco; Pulp, Paper, Paper , Printing and Publishing
z: emission-intensive and non-tradable goods	Transport Sector (air, water, rail, road); Electricity
x: emission-free and tradable goods	All remaining goods and services

Table C1: Mapping of WIOD sectors to model sectors

Table C1 shows the mapping of the 56 WIOD sectors to three composite sectors in our model.

Appendix D: Payoff matrices

The table listed below shows the payoffs for China and EU, given the base assumption and particular indicators in section 3.4.

	t^{EU}	$s_{20\%}$	$s_{20\%v20\%}$	$s_{20\%v40\%}$	$s_{20\%v60\%}$	$s_{20\%v80\%}$	$s_{20\%v100\%}$	$s_{40\%}$	$s_{40\%v20\%}$	$s_{40\%v40\%}$	$s_{40\%v60\%}$	$s_{40\%v80\%}$	$s_{40\%v100\%}$	$s_{60\%}$	$s_{60\%v20\%}$	$s_{60\%v40\%}$	$s_{60\%v60\%}$	$s_{60\%v80\%}$	$s_{60\%v100\%}$	$s_{80\%}$	$s_{80\%v20\%}$	$s_{80\%v40\%}$	$s_{80\%v60\%}$	$s_{80\%v80\%}$	$s_{80\%v100\%}$	$s_{100\%}$	$s_{100\%}V_{20\%}$	$s_{100\%}V_{40\%}$	$s_{100\%}V_{60\%}$	$s_{100\%}V_{80\%}$	$s_{100\%}V_{100\%}$
t^{CHN}	0.14 %	0.18 %	0.18 %	0.18 %	0.18 %	0.18 %	0.18 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.57 %	0.57 %	0.57 %	0.57 %	0.57 %	0.57 %
$s_{20\%}$	0.16 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %
$s_{20\%v20\%}$	0.16 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %
$s_{20\%v40\%}$	0.16 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %
$s_{20\%v60\%}$	0.16 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %
$s_{20\%v80\%}$	0.16 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %
$s_{20\%v100\%}$	0.16 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.43 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %
$s_{40\%}$	0.18 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.33 %	0.33 %	0.33 %	0.33 %	0.34 %	0.34 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.59 %	0.59 %	0.59 %	0.59 %	0.59 %	0.60 %
$s_{40\%v20\%}$	0.18 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.33 %	0.33 %	0.33 %	0.34 %	0.34 %	0.34 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.59 %	0.59 %	0.59 %	0.59 %	0.60 %	0.60 %
$s_{40\%v40\%}$	0.18 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.33 %	0.33 %	0.33 %	0.34 %	0.34 %	0.34 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.59 %	0.59 %	0.59 %	0.59 %	0.60 %	0.60 %
$s_{40\%v60\%}$	0.18 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.33 %	0.33 %	0.34 %	0.34 %	0.34 %	0.34 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.59 %	0.59 %	0.59 %	0.59 %	0.60 %	0.60 %
$s_{40\%v80\%}$	0.18 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.33 %	0.33 %	0.34 %	0.34 %	0.34 %	0.34 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.59 %	0.59 %	0.59 %	0.59 %	0.60 %	0.60 %
$s_{40\%v100\%}$	0.18 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.22 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.33 %	0.33 %	0.34 %	0.34 %	0.34 %	0.34 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.44 %	0.59 %	0.59 %	0.59 %	0.59 %	0.60 %	0.60 %
$s_{60\%}$	0.17 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.25 %	0.25 %	0.26 %	0.26 %	0.26 %	0.26 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.42 %	0.42 %	0.42 %	0.42 %	0.42 %	0.42 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %
$s_{60\%v20\%}$	0.17 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.42 %	0.42 %	0.42 %	0.42 %	0.43 %	0.43 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %
$s_{60\%v40\%}$	0.17 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.33 %	0.42 %	0.42 %	0.42 %	0.43 %	0.43 %	0.43 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %
$s_{60\%v60\%}$	0.17 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.32 %	0.32 %	0.32 %	0.32 %	0.33 %	0.33 %	0.42 %	0.42 %	0.42 %	0.43 %	0.43 %	0.43 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %
$s_{60\%v80\%}$	0.17 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.32 %	0.32 %	0.32 %	0.32 %	0.33 %	0.33 %	0.42 %	0.42 %	0.42 %	0.43 %	0.43 %	0.43 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %
$s_{60\%v100\%}$	0.17 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.33 %	0.42 %	0.42 %	0.42 %	0.43 %	0.43 %	0.43 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %	0.58 %
$s_{80\%}$	0.11 %	0.14 %	0.14 %	0.14 %	0.14 %	0.14 %	0.14 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.52 %	0.52 %	0.52 %	0.52 %	0.52 %	0.52 %
$s_{80\%v20\%}$	0.11 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.52 %	0.52 %	0.52 %	0.52 %	0.53 %	0.53 %
$s_{80\%v40\%}$	0.11 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.19 %	0.19 %	0.19 %	0.20 %	0.20 %	0.20 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.36 %	0.36 %	0.36 %	0.36 %	0.37 %	0.37 %	0.52 %	0.52 %	0.52 %	0.53 %	0.53 %	0.53 %
$s_{80\%v60\%}$	0.11 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.19 %	0.20 %	0.20 %	0.20 %	0.20 %	0.20 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.36 %	0.36 %	0.36 %	0.36 %	0.37 %	0.37 %	0.52 %	0.52 %	0.52 %	0.53 %	0.53 %	0.53 %
$s_{80\%v80\%}$	0.11 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.19 %	0.19 %	0.20 %	0.20 %	0.20 %	0.20 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.36 %	0.36 %	0.36 %	0.36 %	0.37 %	0.37 %	0.52 %	0.52 %	0.52 %	0.53 %	0.53 %	0.53 %
$s_{80\%v100\%}$	0.11 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.15 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.26 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.52 %	0.52 %	0.52 %	0.52 %	0.52 %	0.53 %
$s_{100\%}$	-0.07 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	0.01 %	0.01 %	0.01 %	0.01 %	0.01 %	0.02 %	0.08 %	0.08 %	0.08 %	0.08 %	0.09 %	0.09 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %
$s_{100\%}V_{20\%}$	-0.07 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.37 %
$s_{100\%}V_{40\%}$	-0.06 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.19 %	0.19 %	0.19 %	0.19 %	0.20 %	0.20 %	0.36 %	0.36 %	0.36 %	0.37 %	0.37 %	0.37 %
$s_{100\%}V_{60\%}$	-0.06 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.19 %	0.19 %	0.19 %	0.19 %	0.20 %	0.20 %	0.36 %	0.36 %	0.36 %	0.36 %	0.37 %	0.37 %
$s_{100\%}V_{80\%}$	-0.07 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.09 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %
$s_{100\%}V_{100\%}$	-0.07 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	-0.03 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.02 %	0.08 %	0.08 %	0.09 %	0.09 %	0.09 %	0.09 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %

Table C1: China’s welfare effect (change from BAU) with different policy combinations in China (left) and EU (top).

t^{CHN} \ t^{EU}	t^{EU}	$s_{20\%}$	$s_{20\%v20\%}$	$s_{20\%v40\%}$	$s_{20\%v60\%}$	$s_{20\%v80\%}$	$s_{20\%v100\%}$	$s_{40\%}$	$s_{40\%v20\%}$	$s_{40\%v40\%}$	$s_{40\%v60\%}$	$s_{40\%v80\%}$	$s_{40\%v100\%}$
t^{CHN}	0.19 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %
$s_{20\%}$	0.21 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %
$s_{20\%v20\%}$	0.21 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %
$s_{20\%v40\%}$	0.21 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %
$s_{20\%v60\%}$	0.21 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %
$s_{20\%v80\%}$	0.21 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %
$s_{20\%v100\%}$	0.21 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %
$s_{40\%}$	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{40\%v20\%}$	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{40\%v40\%}$	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{40\%v60\%}$	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{40\%v80\%}$	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{40\%v100\%}$	0.23 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{60\%}$	0.26 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %
$s_{60\%v20\%}$	0.26 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %
$s_{60\%v40\%}$	0.26 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %
$s_{60\%v60\%}$	0.26 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %
$s_{60\%v80\%}$	0.26 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %
$s_{60\%v100\%}$	0.26 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.28 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %	0.30 %
$s_{80\%}$	0.30 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %
$s_{80\%v20\%}$	0.30 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %
$s_{80\%v40\%}$	0.30 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %
$s_{80\%v60\%}$	0.30 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %
$s_{80\%v80\%}$	0.30 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %
$s_{80\%v100\%}$	0.30 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %	0.33 %
$s_{100\%}$	0.35 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %
$s_{100\%}V_{20\%}$	0.35 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %
$s_{100\%}V_{40\%}$	0.35 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %
$s_{100\%}V_{60\%}$	0.35 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %
$s_{100\%}V_{80\%}$	0.35 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %	0.38 %
$s_{100\%}V_{100\%}$	0.35 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %

t^{CHN} \ t^{EU}	$s_{60\%}$	$s_{60\%v20\%}$	$s_{60\%v40\%}$	$s_{60\%v60\%}$	$s_{60\%v80\%}$	$s_{60\%v100\%}$	$s_{80\%}$	$s_{80\%v20\%}$	$s_{80\%v40\%}$	$s_{80\%v60\%}$	$s_{80\%v80\%}$	$s_{80\%v100\%}$	$s_{100\%}$	$s_{100\%}V_{20\%}$	$s_{100\%}V_{40\%}$	$s_{100\%}V_{60\%}$	$s_{100\%}V_{80\%}$	$s_{100\%}V_{100\%}$
t^{CHN}	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.25 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %	0.19 %
$s_{20\%}$	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %
$s_{20\%v20\%}$	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %
$s_{20\%v40\%}$	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %
$s_{20\%v60\%}$	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %
$s_{20\%v80\%}$	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %
$s_{20\%v100\%}$	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %	0.21 %
$s_{40\%}$	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %
$s_{40\%v20\%}$	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %
$s_{40\%v40\%}$	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %
$s_{40\%v60\%}$	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %
$s_{40\%v80\%}$	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %
$s_{40\%v100\%}$	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.29 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %	0.24 %
$s_{60\%}$	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{60\%v20\%}$	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{60\%v40\%}$	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %	0.27 %
$s_{60\%v60\%}$	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.27 %	0.27 %	0.27 %	0.27 %	0.28 %	0.28 %
$s_{60\%v80\%}$	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.27 %	0.27 %	0.27 %	0.28 %	0.28 %	0.28 %
$s_{60\%v100\%}$	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.31 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.27 %	0.27 %	0.27 %	0.28 %	0.28 %	0.28 %
$s_{80\%}$	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %
$s_{80\%v20\%}$	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %
$s_{80\%v40\%}$	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %
$s_{80\%v60\%}$	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %
$s_{80\%v80\%}$	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %
$s_{80\%v100\%}$	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.35 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.36 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %	0.32 %
$s_{100\%}$	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %
$s_{100\%}V_{20\%}$	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %
$s_{100\%}V_{40\%}$	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %
$s_{100\%}V_{60\%}$	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %
$s_{100\%}V_{80\%}$	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %
$s_{100\%}V_{100\%}$	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.40 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.41 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %	0.39 %

Table C2: EU's welfare effect (change from BAU) with different policy combinations in China (left) and EU (top).

	t^{EU}	$s_{20\%}$	$s_{40\%}$	$s_{60\%}$	$s_{80\%}$	$s_{100\%}$	$v_{20\%}$	$v_{40\%}$	$v_{60\%}$	$v_{80\%}$	$v_{100\%}$
t^{CHN}	14.90 %	14.73 %	14.51 %	14.20 %	13.75 %	13.09 %	13.09 %	13.10 %	13.10 %	13.11 %	13.12 %
$s_{20\%}$	16.01 %	15.83 %	15.58 %	15.25 %	14.76 %	14.03 %	14.04 %	14.04 %	14.05 %	14.06 %	14.06 %
$s_{40\%}$	17.40 %	17.21 %	16.95 %	16.58 %	16.05 %	15.24 %	15.25 %	15.26 %	15.27 %	15.27 %	15.28 %
$s_{60\%}$	19.20 %	18.99 %	18.71 %	18.32 %	17.74 %	16.85 %	16.86 %	16.87 %	16.87 %	16.88 %	16.89 %
$s_{80\%}$	21.57 %	21.35 %	21.06 %	20.64 %	20.02 %	19.04 %	19.05 %	19.06 %	19.06 %	19.07 %	19.08 %
$s_{100\%}$	24.79 %	24.57 %	24.27 %	23.84 %	23.19 %	22.13 %	22.14 %	22.15 %	22.16 %	22.17 %	22.17 %
$v_{20\%}$	24.77 %	24.55 %	24.25 %	23.83 %	23.17 %	22.12 %	22.13 %	22.14 %	22.14 %	22.15 %	22.16 %
$v_{40\%}$	24.75 %	24.53 %	24.24 %	23.81 %	23.16 %	22.11 %	22.11 %	22.12 %	22.13 %	22.14 %	22.15 %
$v_{60\%}$	24.73 %	24.52 %	24.22 %	23.79 %	23.14 %	22.09 %	22.10 %	22.11 %	22.12 %	22.12 %	22.13 %
$v_{80\%}$	24.71 %	24.50 %	24.20 %	23.77 %	23.13 %	22.08 %	22.09 %	22.09 %	22.10 %	22.11 %	22.12 %
$v_{100\%}$	24.69 %	24.48 %	24.18 %	23.76 %	23.11 %	22.06 %	22.07 %	22.08 %	22.09 %	22.10 %	22.10 %

Table C3: China's market share of good *y* with different policy combinations in China (left) and EU (top).

	t^{EU}	$s_{20\%}$	$s_{40\%}$	$s_{60\%}$	$s_{80\%}$	$s_{100\%}$	$v_{20\%}$	$v_{40\%}$	$v_{60\%}$	$v_{80\%}$	$v_{100\%}$
t^{CHN}	13.40 %	14.68 %	16.37 %	18.69 %	22.03 %	27.01 %	26.98 %	26.95 %	26.92 %	26.89 %	26.86 %
$s_{20\%}$	13.12 %	14.35 %	16.00 %	18.27 %	21.55 %	26.48 %	26.45 %	26.42 %	26.39 %	26.36 %	26.33 %
$s_{40\%}$	12.75 %	13.94 %	15.52 %	17.73 %	20.93 %	25.79 %	25.76 %	25.73 %	25.70 %	25.68 %	25.65 %
$s_{60\%}$	12.27 %	13.39 %	14.91 %	17.02 %	20.12 %	24.87 %	24.84 %	24.82 %	24.79 %	24.76 %	24.73 %
$s_{80\%}$	11.64 %	12.68 %	14.08 %	16.07 %	19.01 %	23.60 %	23.57 %	23.55 %	23.52 %	23.49 %	23.46 %
$s_{100\%}$	10.78 %	11.69 %	12.94 %	14.73 %	17.44 %	21.76 %	21.74 %	21.71 %	21.68 %	21.66 %	21.63 %
$v_{20\%}$	10.78 %	11.69 %	12.94 %	14.73 %	17.43 %	21.75 %	21.73 %	21.70 %	21.67 %	21.65 %	21.62 %
$v_{40\%}$	10.77 %	11.68 %	12.93 %	14.72 %	17.42 %	21.75 %	21.72 %	21.69 %	21.67 %	21.64 %	21.61 %
$v_{60\%}$	10.77 %	11.68 %	12.93 %	14.71 %	17.41 %	21.74 %	21.71 %	21.68 %	21.66 %	21.63 %	21.60 %
$v_{80\%}$	10.77 %	11.68 %	12.92 %	14.71 %	17.40 %	21.73 %	21.70 %	21.67 %	21.65 %	21.62 %	21.59 %
$v_{100\%}$	10.77 %	11.67 %	12.92 %	14.70 %	17.40 %	21.72 %	21.69 %	21.66 %	21.64 %	21.61 %	21.59 %

Table C4: EU's market share of good *y* with different policy combinations in China (left) and EU (top).

	t^{EU}	$s_{20\%}$	$s_{40\%}$	$s_{60\%}$	$s_{80\%}$	$s_{100\%}$	$v_{20\%}$	$v_{40\%}$	$v_{60\%}$	$v_{80\%}$	$v_{100\%}$
t^{CHN}	12.30 %	12.36 %	12.42 %	12.50 %	12.62 %	12.80 %	12.80 %	12.79 %	12.79 %	12.79 %	12.79 %
$s_{20\%}$	12.01 %	12.06 %	12.13 %	12.21 %	12.34 %	12.54 %	12.54 %	12.54 %	12.54 %	12.54 %	12.54 %
$s_{40\%}$	11.63 %	11.69 %	11.76 %	11.85 %	12.00 %	12.21 %	12.21 %	12.21 %	12.21 %	12.21 %	12.21 %
$s_{60\%}$	11.14 %	11.20 %	11.27 %	11.38 %	11.53 %	11.78 %	11.78 %	11.78 %	11.77 %	11.77 %	11.77 %
$s_{80\%}$	10.49 %	10.54 %	10.62 %	10.74 %	10.91 %	11.18 %	11.18 %	11.17 %	11.17 %	11.17 %	11.17 %
$s_{100\%}$	9.58 %	9.64 %	9.73 %	9.84 %	10.02 %	10.32 %	10.32 %	10.32 %	10.32 %	10.32 %	10.31 %
$v_{20\%}$	9.59 %	9.65 %	9.73 %	9.85 %	10.03 %	10.32 %	10.32 %	10.32 %	10.32 %	10.32 %	10.32 %
$v_{40\%}$	9.60 %	9.66 %	9.74 %	9.86 %	10.04 %	10.33 %	10.33 %	10.33 %	10.33 %	10.33 %	10.33 %
$v_{60\%}$	9.61 %	9.66 %	9.75 %	9.86 %	10.04 %	10.33 %	10.33 %	10.33 %	10.33 %	10.33 %	10.33 %
$v_{80\%}$	9.61 %	9.67 %	9.75 %	9.87 %	10.05 %	10.34 %	10.34 %	10.34 %	10.34 %	10.34 %	10.34 %
$v_{100\%}$	9.62 %	9.68 %	9.76 %	9.88 %	10.05 %	10.34 %	10.34 %	10.34 %	10.34 %	10.34 %	10.34 %

Table C5: China's market share of good x with different policy combinations in China (left) and EU (top).

	t^{EU}	$s_{20\%}$	$s_{40\%}$	$s_{60\%}$	$s_{80\%}$	$s_{100\%}$	$v_{20\%}$	$v_{40\%}$	$v_{60\%}$	$v_{80\%}$	$v_{100\%}$
t^{CHN}	31.50 %	31.11 %	30.65 %	30.00 %	29.07 %	27.67 %	27.68 %	27.69 %	27.69 %	27.70 %	27.71 %
$s_{20\%}$	31.54 %	31.20 %	30.75 %	30.12 %	29.20 %	27.82 %	27.83 %	27.83 %	27.84 %	27.85 %	27.85 %
$s_{40\%}$	31.64 %	31.31 %	30.88 %	30.26 %	29.37 %	28.01 %	28.02 %	28.02 %	28.03 %	28.04 %	28.04 %
$s_{60\%}$	31.77 %	31.46 %	31.04 %	30.46 %	29.60 %	28.26 %	28.27 %	28.28 %	28.28 %	28.29 %	28.30 %
$s_{80\%}$	31.94 %	31.66 %	31.27 %	30.72 %	29.91 %	28.62 %	28.63 %	28.63 %	28.64 %	28.64 %	28.65 %
$s_{100\%}$	32.19 %	31.93 %	31.59 %	31.09 %	30.34 %	29.14 %	29.14 %	29.15 %	29.15 %	29.16 %	29.16 %
$v_{20\%}$	32.18 %	31.93 %	31.59 %	31.09 %	30.34 %	29.14 %	29.14 %	29.15 %	29.15 %	29.16 %	29.16 %
$v_{40\%}$	32.18 %	31.93 %	31.59 %	31.09 %	30.34 %	29.14 %	29.14 %	29.15 %	29.16 %	29.16 %	29.17 %
$v_{60\%}$	32.18 %	31.93 %	31.58 %	31.09 %	30.34 %	29.14 %	29.15 %	29.15 %	29.16 %	29.16 %	29.17 %
$v_{80\%}$	32.17 %	31.92 %	31.58 %	31.09 %	30.34 %	29.14 %	29.15 %	29.15 %	29.16 %	29.16 %	29.17 %
$v_{100\%}$	32.17 %	31.92 %	31.58 %	31.09 %	30.34 %	29.14 %	29.15 %	29.15 %	29.16 %	29.17 %	29.17 %

Table C6: EU's market share of good x with different policy combinations in China (left) and EU (top).

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