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Environmental Regulation of a Global Pollution Externality in a Bilateral Trade Framework: The Case of Global Warming, China and the US

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Abstract
Bilateral trade and capital flows have increased substantially between the United States and China yielding economic gains to both countries. However, these beneficial bilateral relations also bring about global environmental consequences including greenhouse gas emissions. We develop a footloose capital model of international trade between the North (United States) and the South (China) in the presence of a global pollution externality. Each country's share of global pollution depends on its share of world capital. We show that, if the disutility of pollution in the United States is high, there will be pressure on the US to raise environmental regulations on industry. Capital will move to China. Because the increased pollution in China has global effects, the US may not benefit from the environmental restrictions and a joint regulation of pollution by both parties may be a preferred outcome. We also show that the implementation of differential control policies by the parties may also be optimal.

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Keywords global pollution externality, agglomeration, environmental regulation, global warming, greenhouse gas emissions

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1 Introduction

One of the few bright spots in recent international negotiations to replace the expiring Kyoto Protocol on curbing global greenhouse gas (GHG) emissions has been the framework agreement concluded at the 17th Conference of the Parties (COP17) that took place in Durban, South Africa in December 2011. In addition to extending the Kyoto Protocol, COP17 produced the Durban Platform for Enhanced Action as the foundation for a prospective and comprehensive climate change agreement in 2015. However, the Durban Platform is most notable for securing the tentative inclusion of the United States and China – the world's two biggest GHG emitters – who were not signatories to the Kyoto Protocol (Ewing 2012). The signing of the Durban Platform by United States and China accords with the view expressed by some scholars that closer bilateral trade and economic ties between the two countries would foster their cooperation on a number of global issues, including combating climate change (Antholis 2009; Foot 2010; Foot and Walter 2013; Lieberthal and Sandalow 2009). As argued by Foot and Walter (2012, p.20), "…globalization…has greatly raised the importance of the bilateral China-US relationship. Both countries have increasingly assessed the merits of behavioural convergence with a range of global norms."

The purpose of the following paper is to explore how bilateral trade and capital relationships might provide the incentives for increased cooperation over a global pollution problem. We consider the United States and China to be the prime examples of this bilateral framework, and greenhouse gas emissions and global warming to be the transboundary pollution problem.

International trade and capital flows between countries can function as important drivers to improve efficiency and economic development by improving the allocation of resources (Krugman 2008). Industrialized countries such as the United States (US) are increasingly trading with developing countries such as China. US exports accounted for 8.42% of its GDP in 2007, with around 17% of its imports (US$323 billion) originating from its largest trading partner China (Xu et al. 2009). The bilateral trade between the US and China continues to grow substantially, as has capital flows between the two countries (Broda and Weinstein 2006). US foreign direct investment in Chinese stocks was estimated at $51.4 billion in 2013, and Chinese investment in the US was US$5.2 billion in 2012 (USTR 2014).

The United States and China benefit enormously from these bilateral trade and capital flows. However, international trade also brings considerable environmental consequences in both the country of origin and destination (Xu et al. 2009, Peters and Hertwich 2008, Shui and Harriss 2006). The US and China dominate global greenhouse gas (GHG) emissions from carbon dioxide and similar pollutants. In the past century, the US emitted more GHGs than any other country (Lieberthal and Sandalow 2009). The US has been responsible for approximately 29% of energy-related carbon dioxide emissions since 1950, and China for about 8% over the same period (Foot 2010). However, by 2007 China surpassed the US as the world's top annual emitter of carbon dioxide (Antholis 2009). The two countries are responsible for 40% of the GHGs released to the atmosphere each year.

Some scholars have suggested that the growing economic ties between the United States and China may be the key to resolving global environmental problems, such as controlling GHGs to mitigate climate change. For example, Lieberthal and Sandalow (2009) argue that the increasing bilateral trade between the US and China will eventually foster their mutual interest to engage in bilateral negotiation and cooperation on the regulation of GHGs. Lieberthal and Sandalow (2009) suggest that this incentive to cooperate will also contribute to the success of multilateral climatic negotiations, given that China and the United States account for a large share of global GHG emissions.

Similar arguments, that the close economic relations between the US and China will lead to greater cooperation on global environmental issues, have been put forth by Antholis (2009), Foot (2010) and Foot and Walter (2013). Antholis (2009) suggests that the US and China need to focus on concrete partnerships as a way of demonstrating progress and cooperation between the two nations. (Foot 2010) argues that cooperation between China and the US is vital for addressing global economic crisis and global challenges such as climatic change. Foot and Walter (2013) state the US and China are two important countries that are central to the global economy and climatic protection. The two states are very pivotal to the evolution of the global climatic control policy

Our paper seeks to analyze how the increasing bilateral trade and capital relationships between the US and China might influence their policy coordination over a global pollution externality, such as climate change. With global pollution, and international mobility of factors, environmental policies by an individual region will have an effect on its competitiveness, ability to attract capital to its jurisdiction, and positive external benefits that accrue to other region. Therefore the important question that we seek to analyze is what are the implications of unilateral and bilateral coordinated policy approaches to control of a global pollution externality in the context of a bilateral trade and capital investment relationship?

The interaction between trade and global pollution externalities has been considered by a number of studies. These include, an analysis of the effect of global pollution on trade and welfare (Benarroch and Thille 2001), the design of international schemes to control global pollution externalities (Caplan and Silva 2007), an analysis of the effect of global pollution on trade (Suga 2007; Benarroch and Weder 2006) and an analysis of non-cooperative and cooperative policy approaches to control global pollution (Duval and Hamilton 2002; Zheng and Zhao 2009; Rieber and Tran 2009). Rieber and Tran (2009) show that the unilateral action by a developed country drives industrial firms out of the region and lowers real incomes. Duval and Hamilton (2002) find that inefficient high environmental taxes may be optimal for a net exporting region in non-cooperative circumstances, as the motive to shift rents by selecting an inefficiently low tax rate is countervailed by incentives to shift the burden of the tax to foreign consumers. Zheng and Zhao (2009) show that a pollution haven may arise if environmental regulation is slightly more stringent in the larger region compared to the smaller region.

A number of studies have also explored the conditions under which international environmental cooperation is possible. For example, de Zeeuw (2008) shows that, in a dynamic game, cooperation depends on the relative costs of emission abatement of the negotiating parties. Rubio and Ulph (2007) find that cooperation between parties decreases as the steady-state pollution stock and the cost of damages rise. Carraro and Siniscalco (1998) find that partial coalitions and multiple arrangements tend to prevail among a sub-set of negotiating parties, whereas agreement among all parties is unlikely to exist.

Our paper contributes to this literature on global policy by developing a theoretical model to explore how bilateral trade and capital relationships might provide incentives for increased cooperation to control a global pollution externality, GHG emissions. We incorporate three features of US-China relations in our model: bilateral trade, capital flows and the presence of a global pollution externality between the regions. The two-region economy produces an indigenous set of goods supplied by imperfectly competitive firms. We allow for transaction costs in international trade, which raise the cost of imported goods and induce home bias in consumption. We incorporate structural differences between a relatively rich (United States) and a poor region (China) in terms of differential factor endowments and technology.

We incorporate a framework with differential factor endowments, lack of factor price equalisation and cross-country technological differences following the work of Kikuchi and Shinomura (2007) and Behrens et al. (2009). The paper applies a general equilibrium analysis approach to compare the unilateral and the coordinated bilateral equilibria's shares of manufacturing firms and tax levels. We examine the resulting welfare effects from a comparison of the unilateral and bilateral coordinated policy approaches to control a global pollution externality.

Our main results are as follows: when the disutility of pollution in the US is high, there is pressure in the US for tighter environmental regulations on industry. Capital flows to China, and pollution there increases. If the pollution in China has global effects, as the case with GHG emissions and climate change, then the US may not be better off from unilaterally imposing environmental measures that limit domestic pollution only. Instead, joint regulation of the pollution generated by both regions may be a preferred outcome. This joint regulation can be achieved by two countries taking on differential levels of investments to reduce global pollution, and thus supporting the principle of common but differentiated responsibility in global policy. The implication of the study is that it is beneficial for the US and China to engage in bilateral arrangements to control a global pollution externality, as it promotes trade and development while protecting the environment.

The modelling approach we take in this paper is different from the main tax competition literature such as Markusen et al. (1995), in that we include agglomeration and regional asymmetry to the model. Nevertheless, the results of our paper complement the main tax competition results in the literature as we find that the principle of common but differentiated responsibilities is one of the optimal policies to tackling global pollution externalities.

The paper is outlined as follows; the next section presents the economic model, section three discusses unilateral and coordinated policy choices, a numerical simulation and section four concludes.

2 The Economic Model

The model developed is a variant of the footloose capital model (Martin and Rogers 1995; Baldwin 1999; Baldwin et al. 2003). The footloose capital model is relevant given the relative free flow of capital between our two representative regions, the US and China (Blinder 2009; MacCauley 2003). We develop a linear economic geography model with mobile capital and without income effects. This choice is due to low mobility of labour between these countries. In this footloose capital model, location of mobile capital is determined by an arbitrage condition that equalises profits across countries, and we analyze the case of perfect capital mobility. The stock of capital is exogenous, and the value of capital is given by its profit.

Consider an international economy consisting of two regions, each having two sectors and two factors of production, capital and labour. Physical capital, K, is fully mobile between the two regions, but the owners of capital do not migrate. Labour, L, however, is immobile. We treat the two regions as separate nations (US and China). We will therefore refer to the two regions as “North” and “South”, and we assume that the two regions have identical preferences but differ in terms of the disutility of pollution, factor endowments and technology. In this model we will treat the North as relatively abundant in capital endowments (high K/L ratio) compared to the South. The South is abundant in labour resources compared to the North. We adopt the conventional notation of distinguishing Northern from Southern variables by denoting the latter by an asterisk.

Each economy consists of two sectors, the composite goods sector, and the differentiated manufacturing goods sector. Production of the homogenous goods occur using labour only as an input. In each region, each firm produces a differentiated manufactured variety using labour and capital as inputs. Production of differentiated manufactured varieties produces a global pollution externality that negatively affects the global citizens. A global pollution externality is defined as an externality in which consumers will bear the cost regardless of where production occurs. In each region, each firm is charged a per unit tax on emissions that is distributed as a lump sum to local consumers. The consumers own the capital and supply labour for production. They derive utility from consumption of the composite and differentiated manufacturing goods.

2.1 The Consumers

Consumers in each region are identical and factor ownership is equally distributed across households. We assume that a Northern consumer own K_o / L units of capital factor and one unit of labour factor. Each Southern consumer owns K_o^* / L^* unit of capital factor and one unit of labour factor. K is the units of capital, and L ,is the number of households in the Northern. We assume that the two regions have different levels of endowments, with the Northern region being relatively abundant in capital compared to the Southern region $K_o > K_o^*$, and the Southern region being relatively abundant in labour compared to the Northern region $L^* > L$. Let m and m^* represent the factor incomes of Northern and Southern consumers respectively. Each consumer in-elastically supplies one unit of labour. In addition, we model a tax transfer from producers to consumers. Let us assume that each industrial firm is taxed at the rate of t on the global pollution externality, and that the tax revenue is redistributed lump sum to all households in a region. A representative Northern consumer's budget constraint is

$$\int_{i=0}^{K} p_i c_i di + \int_{j=0}^{K^*} \tau p_j^* c_j dj + C_C = m \tag{1}$$

where the right hand side is income and left hand side is expenditure. C_c is the consumption of composite numeraire good, c_i is the consumption of Northern domestic differentiated manufactured good, c_j denotes the imported and consumed quantity of a Southern differentiated good, and τ is the Samuelson iceberg transport cost mark-up. If trade costs are high then a large portion of the goods produced will melt in transit, thus will not actually be consumed by the consumer. Thus p_i and p_j^* are the price of Northern and Southern goods, respectively, and K and K^* is the level of capital. The total amount of capital varieties is given by $K^w = K + K^*$. An analogous budget function holds for the Southern consumer, which is denoted by an asterisk.

In each region a representative consumer has preferences given by the following quasi-linear utility function (Neary 2006):

$$U = C_C + C_D - \varphi D(E^W) \text{ where } C_D = \frac{1}{\gamma}\int_{i=0}^{K+K^*} c_i^{\gamma} di \quad (2)$$

with $\gamma \in (0,1)$ as a measure substitutability of manufactured product varieties, such that $\gamma = 1$ denotes perfect substitutability and $\gamma = 0$ perfect complements, and $\sigma = 1/(1-\gamma) > 1$, is the elasticity of substitution between two manufactured varieties. The function φ [1] indicates the Northern consumers' disutility of pollution. D is the non-linear cost of the global emissions from the global manufacturing of differentiated industrial goods. We assume that pollution is a pure public bad with global effects, and consumers in each region are negatively affected by total current emissions from world production, E^W.

A representative consumer maximises utility by choosing to consume a continuum of the differentiated manufactured products, yielding the following inverse demand functions:

$$p_i = c_i^{\gamma-1} \qquad i \in (0, K) \quad (3a)$$

$$p_j = \tau^{-1} c_j^{\gamma-1} \qquad j \in (0, K^*) \quad (3b)$$

By symmetry, the inverse demand functions for a representative Southern consumer are analogous.

Given the identical technology and factor endowment assumptions within a particular region, the prices for these varieties are identical and therefore the arguments i can be dropped, i.e. $p_i = p$ for all $i \in [0, K]$ and $p_j = p^*$ for all $j \in [0, K^*]$.

The aggregate demand for manufactured varieties produced in the North consists of domestic demand and demand from the South. Manufactured products produced in the North are traded costless within the region, but when manufactured products are imported, a trade cost of τ is charged and the consumer price increases. The demand for the manufactured commodity produced in the North and the South equals

[1] We assume that the disutility from emission is linear, implying a constant marginal disutility from emissions. This is a standard assumption to improve tractability of the model that has been used in literature, for example Pfluger 2001.

$$c = Kp^{\frac{1}{\gamma-1}} + K^*(\tau p^*)^{\frac{1}{\gamma-1}} \quad 4a)$$

$$c^* = K(\tau p^*)^{\frac{1}{\gamma-1}} + K^* \; p^{\frac{1}{\gamma-1}} \quad (4b)$$

A region's income is composed of the wage income from labour within that region, and return to capital augmented with the lump sum redistribution of pollution externality taxes. A typical Northern household supplies one unit of labour inelastically without loss of utility, owns K_o / L units of capital and gets an equal share of the tax t on manufacturing firms. Let $s_k = K / \left(K + K^*\right)$ be the share of capital for North consumers and R be return on capital, the income of a representative household in each region m, m^*, is given by

$$m = w + K_0 R / L + Kt / L \quad (5a)$$

$$m^* = w^* + K_o^* R^* / L^* + K^* t^* / L^* \quad (5b)$$

The aggregate incomes for the North and South are respectively

$$M = wL + RK_0 + Kt \quad (6a)$$

$$M^* = w^* L^* + R^* K_o^* + K^* t^* \quad 6b)$$

The income of the representative household is greater in the North than in the South given that $K_0 / L > K_o^* / L^*$.[2] On average the aggregate incomes for the North should be larger compared to that of the South. However the incomes in the South may be larger than that of the North if a larger share of manufacturing firms locates in the former region. In this case the Southern consumers' augment their incomes from lump sum tax redistribution.

Substituting the inverse demand functions (3a, b) into utility equation (2) gives the Northern and Southern consumers' indirect utility functions,[3]

[2] The incomes in the northern region are higher compared to the southern region if $K_o / L > K_o^* / L^*$ and $w > w^*$, $R = R^*$, $t = t^*$.

[3] From the Northern consumer's utility function:

$$V = m + \left(\frac{1}{\gamma} - 1\right)\left[Kp^{\frac{\gamma}{\gamma-1}} + K^{*}\tau^{\frac{\gamma}{\gamma-1}}(p^{*})^{\frac{\gamma}{\gamma-1}}\right] - \varphi D \qquad (7a)$$

$$V^{*} = m^{*} + \left(\frac{1}{\gamma} - 1\right)\left[K^{*}p^{\frac{\gamma}{\gamma-1}} + K\tau^{\frac{\gamma}{\gamma-1}}(p^{*})^{\frac{\gamma}{\gamma-1}}\right] - \varphi^{*} D \qquad (7b)$$

Finally we provide an aggregate welfare in both regions as given by

$$W(K,K^{*}) = M + \left(\frac{1}{\gamma} - 1\right)\left[Kp^{\frac{\gamma}{\gamma-1}} + K^{*}\tau^{\frac{\gamma}{\gamma-1}}(p^{*})^{\frac{\gamma}{\gamma-1}}\right] - \varphi D(E^{w})L \qquad (8a)$$

$$W^{*}(K,K^{*}) = M^{*} + \left(\frac{1}{\gamma} - 1\right)\left[K^{*}p^{\frac{\gamma}{\gamma-1}} + K\tau^{\frac{1}{\gamma-1}}(p^{*})^{\frac{\gamma}{\gamma-1}}\right] - \varphi^{*} D(E^{w})L^{*} \qquad (8b)$$

Total welfare consists of total utility derived from consumer commodities and the expected damages from global pollution externality. Welfare from manufactured good consumption increases when the capital varieties increase. However, the consumers are negatively affected by the global pollution generated by both domestic capital and capital located in the foreign region. There is no trade-off between firm location and global pollution externality. Increasing the capital varieties in a region increases welfare to its consumers but does not alter

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$$V = \frac{1}{\gamma}Kc_i^{\gamma} + \frac{1}{\gamma}K^{*}c_j^{\gamma} + C_c$$

$$V = \frac{1}{\gamma}K\left(p^{\frac{1}{\gamma-1}}\right)^{\gamma} + \frac{1}{\gamma}K^{*}\left(\left(\tau p^{*}\right)^{\frac{1}{\gamma-1}}\right)^{\gamma} + C_c$$

$$V = \frac{1}{\gamma}Kp^{\frac{\gamma}{\gamma-1}} + Kp^{\frac{\gamma}{\gamma-1}} - Kp^{\frac{\gamma}{\gamma-1}} + \frac{1}{\gamma}K^{*}\left(\tau p^{*}\right)^{\frac{\gamma}{\gamma-1}} + K^{*}\left(\tau p^{*}\right)^{\frac{\gamma}{\gamma-1}} - K^{*}\left(\tau p^{*}\right)^{\frac{\gamma}{\gamma-1}} + C_c$$

$$V = \left(\frac{1}{\gamma} - 1\right)\left[Kp^{\frac{\gamma}{\gamma-1}} + K^{*}\left(\tau p^{*}\right)^{\frac{\gamma}{\gamma-1}}\right] + m$$

the magnitude of expected damages from global pollution. The welfare loss from the expected damages may be larger in the South where there is a larger population compared to the North.

2.2 The Composite Goods Sector

The supply side of the composite goods sector is assumed to produce a homogenous good using only labour as an input, under Walrasian conditions of constant returns to scale technology and perfect competition. The composite goods sector is extremely simple in that there are no increasing returns, perfect competition and the good is traded costlessly between the two regions. The cost function for production of the good is wa_C, where w is the labour wage rate and a_C is the unit input coefficient. We assume that the two regions have differing technologies such that $a_C / a_C^* < 1$, in which compared to the South, the North exhibits an absolute advantage in the homogenous goods sector. This provides a simple way to account for international factor price differences driven by Ricardian variations in labour productivity (Behrens et al. 2009). From equation (1), given that the composite good is a numeraire good, we have $p_c = p_c^* = 1$. Perfect competition means that equilibrium is achieved where marginal cost is equal to the marginal revenue or price, we have $1 = wa_C$ and $1 = w^* a_C^*$. Costless trade will equalize the Northern and Southern prices; and wages $w = 1/a_C$ and $w^* = 1/a_C^*$ must hold for all regions provided some numeraire production takes place everywhere. The North's wage w is greater than the South's wage w^* due to a higher labour productivity. The Northern consumers are richer than their Southern counterparts.

2.3 The Differentiated Goods Manufacturing Sector

The manufacturing sector is monopolistically competitive and faces increasing returns in production of differentiated varieties. The production of a typical variety of manufactured goods includes the services of one capital input,[4] which is the fixed cost, and a_D units of labour for each unit of output produced. We assume variations in labour productivity across regions, allowing for cross regional technological differences such that $a_D / a_D^* < 1$, in which compared to the South, the North exhibits an absolute advantage in the differentiated goods sector. The total continuum of industrial varieties is fixed through the endowment of capital. The total cost of producing x units of a typical manufactured variety is $R + wa_D x$, in which R is the reward to capital. The Southern firm has analogous cost relationships.[5]

The ratio R / a_D measures the intensity of the increasing returns to scale or the relative productivity (comparative advantage) of the North in manufacturing (Behrens et al. 2009). If $(R / a_D) > (R^* / a_D^*)$**,** compared with the South, the North exhibits a comparative advantage in the differentiated goods sector. However, if $(R / a_D) = (R^* / a_D^*)$ then no region has a comparative advantage over the other in the manufacturing goods sector.

We assume that production of differentiated varieties brings about a pollution externality that negatively affects all the global citizens. The pollution is a negative externality associated with production at the firm level. Following an approach by Elbers and Withagen (2004), Benarroch and Weder (2006), we assume a simple relationship in which the emissions are strictly related to the level of capital in a jurisdiction, i.e. $e = (1-\alpha)Kx$, and $e^* = (1-\alpha^*)K^*x^*$, where the total global pollution $E = (1-\alpha)Kx + (1-\alpha^*)K^*x^*$, and $\alpha < 1$ is the level of regional investment in pollution reduction, x is the total output produced by a firm in the Northern region. High values of α indicate stronger investments in pollution reduction effort. This may include regulations and investments in alternative sources that limit the pollution. Under this scenario, the pollution function

4 To keep the analysis simple, following Baldwin et al. (2003), each firm produces with one unit of capital.

5 Since we assume only one type of labor and perfect mobility between sectors, the same wage rate should therefore hold in both the numeraire good and the differentiated goods sector. Thus the wage rate w is solely determined by the unit labor coefficients in the numeraire goods sector.

represents or exhibits constant returns to scale with respect to the level of capital (Benarroch and Thille 2001). We assume that investments in pollution reduction increase the costs of the capital input.

In each region, the assumption that firms produce differentiated varieties using the same technology allows us to consider production and supply only by a representative firm (i.e., the indices *i* and *j* can be dropped to distinguish different firms).

2.4 The Short Run

The number of manufacturing firms in both regions is assumed to be relatively large, which allows us to assume that each firm ignores the actions of other firms in choosing its outputs. Although in the long run, profits for each firm are eventually driven to zero by free entry and exit, in the short run each manufacturing firm is a monopolist in its own market segment. Each firm has in effect two markets, a domestic and a foreign market. Denoting each firm's total revenue from sales to both markets as $\pi = pc + p^* c^*$, and t is the tax rate[6] associated with GHGs emissions, each firm's objective is to choose a level of sales given by

$$\max_{c,c^*} \Pi = \pi - (R+\alpha) - a_D w(c+c^*) - te$$
$$\Pi = c^{\gamma-1}c + \tau^{-1}c^{*\gamma-1}c^* - a_D w(c+c^*) - \left(R+\alpha\right) - t\left(1-\alpha\right)(c+c^*) \quad (9)$$

The first order conditions are given by

$$c: \qquad \gamma c^{\gamma-1} - a_D w - t\left(1-\alpha\right) = 0,$$
$$c^*: \qquad \gamma \tau^{-1} c^{*\gamma-1} - a_D w - t^*\left(1-\alpha^*\right) = 0$$

From the first-order conditions, the firm's sale prices in the local and export market are[7]

[6] The tax imposed on the firm is a per unit tax on emissions.

[7] According to Baldwin et al. (2003) the implication is that firms find it optimal to engage in so called milling price, that is, the firm charges the same producer price for sales to both markets.

$$p = \frac{wa_D + t(1-\alpha)}{\gamma} \text{ and } p^* = \frac{wa_D + t(1-\alpha)}{\gamma} \quad (10a)$$

The Southern firms have analogous price functions that are given by

$$p = \frac{w^* a_D{}^* + t^*(1-\alpha^*)}{\gamma} \text{ and } p^* = \frac{w^* a_D{}^* + t^*(1-\alpha^*)}{\gamma} \quad (10b)$$

The firm charges a mark-up greater than its marginal cost of supply to the market. The marginal cost for each firm involves the wage rate paid to the immobile labour and the per unit tax on emissions. As a result of free trade, the producer prices are equalised in the manufacturing sector. Therefore the manufacturing firm charges the same price for local and Southern markets. We assume that the iceberg tax is incorporated via the consumer budget constraint.

2.4.1 The Long Run

From international trade and the equalization of prices, we have $p = p^*$, therefore $w^* a_D^* + t^*(1-\alpha^*) = wa_D + t(1-\alpha)$, which implies payments to labour plus tax payments on emissions should be identical in the two regions. The wage rate in the South is less than that of the North,[8] labour productivity is higher in the North compared to the South. Consumers in the North have higher incomes from labour compared to the consumers in the South.

In the long run, free entry and exit will mean that a firm will produce at an equilibrium level of output where profits are zero, implying that operating profit will be sufficient to cover its fixed costs. Given that producer price is a constant mark-up over marginal cost, the operating profit earned on each unit produced is

8 $\frac{a_D^*}{a_C^*} + t^*(1-\alpha^*) = \frac{a_D}{a_C} + t(1-\alpha)$, $\frac{a_D^*}{a_C^*} - \frac{a_D}{a_C} = t(1-\alpha) - t^*(1-\alpha^*)$.

For equilibrium to hold in which the labour market and the goods market clears the magnitude of the difference between ratio of labour productivity in the manufacturing sector and composite good sectors between the regions has to equal the difference in marginal tax payments. We agree that this might be a rather restrictive assumption which could hold by chance.

also constant. The producer price mark-up can be rewritten as $p - wa_D - t\left(1-\alpha\right) = (1-\gamma)\,p$. This mark-up holds for all levels of production of the firms regardless of where output is sold. This expression is equivalent to $(p - wa_D - t\left(1-\alpha\right))x = px(1-\gamma)$, where x is the total output produced by the firm. Thus operating profit of the firm is the value of sales divided by the price elasticity of demand σ. The long run equilibrium condition of the firm is

$$(p - wa_D - t\left(1-\alpha\right))x = px(1-\gamma) = R + \alpha \,.$$

Substituting for p, the equilibrium level of sales is given by

$$x = \frac{\gamma}{1-\gamma}\frac{(R+\alpha)}{wa_D + t\left(1-\alpha\right)} \tag{11}$$

A representative Southern firm has an analogous equilibrium output function. As the North enjoys an absolute advantage in differentiated goods production, it is possible that the equilibrium output for a representative firm in the North is greater or equal to that of a representative firm in the South.

From equation (11), if $x = x^*$, we have $w^* a_D^* + t^*\left(1-\alpha^*\right) = wa_D + t\left(1-\alpha\right)$, and $R + \alpha = R^* + \alpha^*$. In equilibrium the marginal cost of investing in pollution reduction plus the rental rate of capital has to be equalized in both regions. This implies that, although the Northern region has absolute advantage in manufacturing sector compared to the Southern region, no region has comparative advantage. The output per firm is identical in both regions. Thus a firm located in the Northern (Southern) region cannot produce more output compared to a firm in the Southern (Northern) region. A firm located in the Northern region faces a higher wage rate and lower units of labour per each unit of output produced compared to a firm located in the Southern region. Similarly, a firm in the Southern region faces a lower wage rate and higher units of labour per each unit of output produced compared to the Northern region.

If $x > x^*$, then $w^* a_D^* + t^*\left(1-\alpha^*\right) = wa_D + t\left(1-\alpha\right)$, and $R + \alpha > R^* + \alpha^*$, $R / a_D > R^* / a_D^*$. In this case the marginal cost of investing in pollution reduction plus the rental rate of capital is greater in the Northern region compared to the

Southern region. The Northern region has a comparative advantage in manufacturing. Thus all the capital would locate in the Northern region. Similarly, if $x < x^*$, then $w^* a_D^* + t^*\left(1-\alpha^*\right) = wa_D + t\left(1-\alpha\right)$, and $R+\alpha < R^* + \alpha^*$, $R / a_D < R^* / a_D^*$. Although the Northern region has absolute advantage in manufacturing, in this case the Southern region has comparative advantage. All the capital will locate in the Southern region.

2.5 Costs from Global Emissions

The costs occur as a result of the current and past accumulation of GHGs into the atmosphere, which last for a long period of time (IPCC 2007; USGCRP 2009). We assume that emissions in the next period are equal to emissions from the last period, since the total capital is fixed in the model. The emission level is damaging but it is also costly to abate. Following de Zeeuw (2008) a simple cost indicator is given by $D_i = \sum_{t=0}^{T} \delta^t \left[e(t)^2 + e(t)^{2*} \right]$, where δ^t is the discount factor, t is time. The present value of costs from the global emissions are given by $D = \delta^T T\left[\left(1-\alpha\right)^2 K^2 + \left(1-\alpha^*\right)^2 K^{*2}\right]$, where T is the total time when the costs from global emissions are incurred. Inman (2008) states that about 50% of the carbon emissions will be removed from the atmosphere within 30 years, a further 30% will be removed within a few centuries, and the remaining 20% will be removed in a few centuries.

2.6 Differentiated Manufacturing Goods Sector Equilibrium

The market equilibrium conditions for the final manufactured goods and capital are given by

$$Kp^{\frac{1}{\gamma-1}} + K^*(\tau p^*)^{\frac{1}{\gamma-1}} = \frac{\gamma}{1-\gamma}\frac{(R+\alpha)}{wa_D + t\left(1-\alpha\right)} \tag{12a}$$

$$K(\tau p^*)^{\frac{1}{\gamma-1}} + K^* \ p^{\frac{1}{\gamma-1}} \quad = \frac{\gamma}{1-\gamma} \frac{(R^* + \alpha)}{w^* a_D{}^* + t^*\left(1-\alpha^*\right)} \tag{12b}$$

2.7 Rental Rate of Capital

The total supply of capital, K^w, and labour, L^w, are fixed, with total endowments expressed as $K_o > K_0^*$ and $L_0^* > L_o$, respectively. Because capital owners are immobile across regions, when the pressure arises to concentrate production in one region, physical capital will move, but all its rewards will be repatriated back to the region of its origin. Thus the region in which capital income is spent may differ from the region where it is employed. By assuming that each industrial variety requires one unit of capital, the share of world capital employed in a region equals the region's share of world industry, and thus $K = n$.

Since capital is the only component of the fixed cost that is being used in the production of the industrial varieties, reward to capital is equal to operating profit of a typical industrial variety. Since each unit of capital can be used to produce one industrial variety, the reward to capital would be bid up to the point where it equalled operating profit. Under Dixit-Stiglitz monopolistic competition, this operating profit is simply the value of sales divided by σ. This means that $R = px(1-\gamma) - \alpha$, where x is the scale of operations. The South has an analogous operating profit function. Using demand functions and the milling price functions (10a, 10b) we can express the return to capital as:

$$R = \left(1-\gamma\right)\left[Kp^{\frac{\gamma}{\gamma-1}} + \phi K^*\left(p^*\right)^{\frac{\gamma}{\gamma-1}}\right] - \alpha \tag{13a}$$

$$R^* = \left(1-\gamma\right)\left[K^* p^{\frac{\gamma}{\gamma-1}} + \phi K\left(p^*\right)^{\frac{\gamma}{\gamma-1}}\right] - \alpha^* \tag{13b}$$

where $\phi = \tau^{\frac{1}{\gamma-1}}$, with $\phi = 0$ indicating that trade is perfectly closed, $\phi = 1$ indicating that trade is perfectly open. A high investment in pollution reduction imposed by a region has the effect of reducing the return on capital, thus encouraging the capital to relocate to the other region.

2.8 Equilibrium Analysis

Taking into account equations (12a, 12b), and equations (10a, 10b), the share of firms in each region is expressed as

$$s_K = \frac{(R+\alpha)}{(1-\phi)(1-\gamma)}\left[\frac{\gamma}{wa_D + t(1-\alpha)}\right]^{\frac{\gamma}{\gamma-1}} - \frac{\phi}{1-\phi} \tag{14a}$$

$$s_K{}^* = \frac{R^* + \alpha^*}{(1-\phi)1-\gamma}\left[\frac{\gamma}{w^* a_D^* + t^*(1-\alpha^*)}\right]^{\frac{\gamma}{1-\gamma}} - \frac{\phi}{1-\phi} \tag{14b}$$

The share of capital in a region is a decreasing function of the trade costs as shown by $\partial s_K / \partial \phi < 0$.[9] When trade costs are very high, the Northern region's share of capital is low. Similarly, when trade is freer the direction of capital is eventually reversed, and firms will be attracted to the rich North and the region's share of capital is high.

There are two possible equilibria, a symmetric and co-periphery equilibrium. The core periphery equilibrium occurs if $(R+\alpha) > (R^* + \alpha^*)$, in which the North has higher rental rates of capital and investments in pollution reduction, all the capital locates in the North, and the South imports all its manufactured products. The symmetric equilibrium occurs if $R+\alpha = R^* + \alpha^*$, in which the capital factor payment and investments in pollution reduction are equalized, both regions have an equal share of capital.

To show the existence of the equilibria, we follow an approach outlined in Kikuchi and Shimomura (2007). If the firms exist in both regions, then firm profits must be identical in the two regions. Substituting the demand functions (3a, 3b) into equation (9) yields

---

9 $\frac{\partial s_K}{\partial \phi} = -\frac{1}{(1-\phi)^2}\left(\frac{(R+\alpha)}{(1-\gamma)}\left(\frac{\gamma}{wa_D + t(1-\alpha)}\right)^{\frac{\gamma}{\gamma-1}} - \phi\right) - \frac{1}{1-\phi}$

$$\Pi = p^{\frac{1}{\gamma-1}}\left(p - a_D w - t(1-\alpha)\right)\left(1+\tau^{-1}\right) - \left(R+\alpha\right) \quad (15a)$$

$$\Pi^* = p^{*\frac{1}{\gamma-1}}\left(p^* - a_D^* w^* - t^*\left(1-\alpha^*\right)\right)\left(1+\tau^{-1}\right) - \left(R^*+\alpha^*\right) \quad (15b)$$

Substituting for the mill pricing rule (10a, 10b) into $\Pi = \Pi^*$, and simplifying yields

$$\frac{(1-\gamma)\left(1+\tau^{-1}\right)}{\gamma^{\frac{\gamma}{\gamma-1}}} =$$

$$\left(\left(R+\alpha\right) - \left(R^*+\alpha^*\right)\right)\left[\left(wa_D + t(1-\alpha)\right)^{\frac{\gamma}{\gamma-1}} - \left(w^* a_D^* + t^*\left(1-\alpha^*\right)\right)^{\frac{\gamma}{\gamma-1}}\right]^{-1}$$

Substituting the RHS back into (15a) the Northern firm's profit function equation gives

$$\Pi = \left(\frac{wa_D + t(1-\alpha)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}(1-\gamma)\left(1+\tau^{-1}\right) - \left(R+\alpha\right).$$

$$\Pi = \frac{\left(wa_D + t(1-\alpha)\right)^{\frac{\gamma}{\gamma-1}}\left(\left(R+\alpha\right) - \left(R^*+\alpha^*\right)\right)}{\left[\left(wa_D + t(1-\alpha)\right)^{\frac{\gamma}{\gamma-1}} - \left(w^* a_D^* + t^*\left(1-\alpha^*\right)\right)^{\frac{\gamma}{\gamma-1}}\right]} - \left(R+\alpha\right).$$

Profits for an individual manufacturing firm in the North are proportional to marginal labour costs adjusted for the differential rental rates of capital, weighted by the differential marginal labour cost between the two regions, net the rental rate of capital in the North.

Using these results one sufficient condition for the co-existence of firms in both regions is that $\Pi = 0$, in which we have

$$\left(wa_D + t(1-\alpha)\right)^{\frac{\gamma}{\gamma-1}}\left(R^*+\alpha^*\right) = \left(w^* a_D{}^* + t^*(1-\alpha)\right)^{\frac{\gamma}{\gamma-1}}\left(R+\alpha\right) \quad (16)$$

Defining an index as $\left(\frac{wa_D + t(1-\alpha)}{w^* a_D^* + t^*(1-\alpha^*)}\right)^{\frac{\gamma}{\gamma-1}} / \left(\frac{R+\alpha}{R^* + \alpha^*}\right) = \Theta$. In the free trade equilibrium the profits must be zero. The equations are satisfied if the index $\Theta = 1$. Therefore this implies the co-existence of capital in both regions. Manufacturing takes place in both regions despite the cross regional technology difference in the monopolistic competitive sector. If the index is $\Theta < 1$, then a core periphery equilibrium exists in which all the capital is located in the North.

3 Unilateral and Bilateral Coordinated Policy Approaches

We attempt to provide an answer to the important question: what are the welfare implications between a unilateral and a bilateral coordinated policy approach in a North-South international trade model with a global pollution externality? A unilateral approach is when an individual region reinforces its own environmental regulations by constraining the capital located in its jurisdiction. A coordinated approach is a bilateral agreement between the US and China, which we consider to be similar to joint welfare maximisation by a global planner who takes into account the needs of both regions to reinforce global environmental regulations and the pollution externality. Thus, the global planner is assumed to be a proxy for bilateral coordination between the US and China on the location of capital and the level of investments in pollution reduction between their respective regions. We compare the unilateral and bilateral coordinated equilibria in terms of the share of capital and pollution control investments between two regions.[10]

[10] The general approach used is similar to one used in tax competition literature by Oates and Schwab (1998) and Kunce and Shogren (2005).

3.1 Unilateral Optimization Equilibrium

We consider that the US and China unilaterally maximize the aggregate welfare within their regions by selecting the optimal level of capital, without taking into account the effect on global pollution on the other region. The aggregate welfare functions of the North and South are respectively

$$W(K,K^*) = M + \left(\frac{1}{\gamma}-1\right)\left[Kp^{\frac{\gamma}{\gamma-1}} + K^*\tau^{\frac{1}{\gamma-1}}(p^*)^{\frac{\gamma}{\gamma-1}}\right] - \varphi D(E^w)L \qquad (17a)$$

$$W^*(K,K^*) = M^* + \left(\frac{1}{\gamma}-1\right)\left[K^*p^{\frac{\gamma}{\gamma-1}} + K\tau^{\frac{1}{\gamma-1}}(p^*)^{\frac{\gamma}{\gamma-1}}\right] - \varphi^* D(E^w)L^* \qquad (17b)$$

where $D(E^w) = \left(e+e^*\right) = \delta^T T\left(\left(1-\alpha\right)^2 K^2 + \left(1-\alpha^*\right)^2 K^{*2}\right).$

Therefore the simplified welfare functions[11] can be written as

$$W(K,K^*) = wL + t\left(1-\alpha\right)K +$$

$$\left(\frac{1}{\gamma}-1\right)\left(\frac{wa_D + t\left(1-\alpha\right)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left[K+\phi K^*\right] - \qquad (18a)^{12}$$

$$\varphi\delta^T T\left[\left(1-\alpha\right)^2 K^2 + \left(1-\alpha^*\right)^2 K^{*2}\right]L$$

[11] Hence the welfare function is quadratic in level of capital; therefore a region maximizes welfare by directly solving for the endogenous number of firms, for a given level of tax rate and pollution investment levels.

[12] We can find the unilateral optimization equilibrium without finding a Nash Equilibrium because the welfare function is additively separable in domestic and foreign firms.

$$W^*(K,K^*) = w^*L^* + t^*\left(1-\alpha^*\right)K^* +$$

$$\left(\frac{1}{\gamma}-1\right)\left(\frac{w^*a_D{}^* + t^*\left(1-\alpha^*\right)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left[K^* + \phi K\right] - \tag{18b}$$

$$\varphi\delta^T T\left[\left(1-\alpha\right)^2 K^2 + \left(1-\alpha^*\right)^2 K^{*2}\right]L^*$$

The optimal level of capital that maximizes a region's welfare is given by

$$t\left(1-\alpha\right) + \left(\frac{1}{\gamma}-1\right)\left(\frac{wa_D + t\left(1-\alpha\right)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} - 2\varphi\delta^T T\left(1-\alpha\right)^2 LK = 0 \tag{19a}$$

$$t^*\left(1-\alpha^*\right) + \left(\frac{1}{\gamma}-1\right)\left(\frac{w^*a_D{}^* + t^*\left(1-\alpha^*\right)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} - 2\varphi^*\delta^T T\left(1-\alpha^*\right)^2 L^*K^* = 0 \tag{19b}$$

Optimal conditions occur when marginal benefits equal marginal social costs. The marginal benefits include marginal labour income from firms, and the marginal benefit of the consumer's love of variety. The marginal social costs consist of local firms' marginal contribution to the global pollution externality. The marginal damage to the local households is scaled by the social investment in pollution reduction and the regional population.

The second order sufficient conditions are met as given by $-2\varphi\delta^T T\alpha^2 L < 0$. Solving the first order conditions yields the optimal level of capital in the North and South as respectively

$$K = \frac{t\left(1-\alpha\right) + \left(\left(1-\gamma\right)/\gamma\right)\left[\left(wa_D + t\left(1-\alpha\right)\right)/\gamma\right]^{\frac{\gamma}{\gamma-1}}}{2\varphi\delta^T T\left(1-\alpha\right)^2 L} \tag{20a}$$

$$K^* = \frac{t^*\left(1-\alpha^*\right) + \left(\left(1-\gamma\right)/\gamma\right)\left[\left(w^*a_D^* + t^*\left(1-\alpha^*\right)\right)/\gamma\right]^{\frac{\gamma}{\gamma-1}}}{2\varphi^*\delta^T T\left(1-\alpha^*\right)^2 L^*} \tag{20b}$$

We carry out comparative static analysis on equation (19a) to determine the effect of the change in exogenous variables on the endogenous choice variables. The effect of an increase in pollution control investment on the location of capital is unambiguous positive. An increase in the level of investments in pollution control reduces the return to capital discouraging firms from locating in the jurisdiction. However, this implies lower emissions and the magnitude that the firm pays. In this model the second effects dominates the first and firms are encouraged to locate in a jurisdiction. The effect of increasing the tax rate on the location of firms is an ambiguously negative. The increase in the tax rate reduces the firm's profits, making a foreign region more attractive for capital to locate there. Thus an increase in tax encourages the firms to relocate abroad. The location of firms abroad does not reduce the expected damages given the global nature of emissions.

An increase in the disutility of pollution has the effect of reducing the level of capital in a region. As the disutility of pollution in the North increases there is pressure to have higher environmental regulations on the industry, and thus a region would impose a higher tax to discourage capital from locating within its jurisdiction. Firms will relocate to the South. Given that pollution has global effects, the North may not be better off from unilateral environmental regulations. Similar results would hold for the South.

From the unilateral maximizations, there are three possible equilibria for the relative share of capital between the two regions, which are $s_K / s_{K^*} = 1$, $s_K / s_{K^*} < 1$, and $s_K / s_{K^*} > 1$.

$$\frac{s_K}{s_{K^*}} = \frac{\left(t\left(1-\alpha\right) + \frac{1-\gamma}{\gamma}\left[\frac{wa_D + t\left(1-\alpha\right)}{\gamma}\right]^{\frac{\gamma}{\gamma-1}} \right)\left(\varphi^*\left(1-\alpha^*\right)^2 L^*\right)}{\left(t^*\left(1-\alpha^*\right) + \frac{1-\gamma}{\gamma}\left[\frac{w^* a_D^* + t^*\left(1-\alpha^*\right)}{\gamma}\right]^{\frac{\gamma}{\gamma-1}} \right)\left(\varphi\left(1-\alpha\right)^2 L\right)} \quad (20c)$$

Note that by definition the relative share of capital in the two regions is simply K/K* which is the ratio of the capital in the North to capital in the South.

Therefore from a unilateral policy perspective, a symmetric equilibrium can occur under two conditions.[13] First, it holds when both regions have identical tax rates, investments in pollution control, marginal disutility of pollution and labour. Second, a symmetric equilibrium can occur when both regions have identical tax rates, investments in pollution control, but with different marginal disutility of pollution and labour. Under this scenario the ratio of the two disutility of pollution should equal to the inverse ratios of the labour, that is $\varphi / \varphi^* = L^* / L$.

A core-periphery equilibrium also occurs under two contrasting conditions. The first is that both regions have identical investments in pollution control, the Northern region has a higher tax rate compared to the Southern region, and the ratios of the consumer disutility of pollution is greater than the inverse labour ratio, i.e. $\varphi / \varphi^* > L^* / L$. The second is that both regions have identical tax rates, the North region has a lower investment in pollution control compared to the South region and the ratios of the consumer disutility of pollution is greater or equal to the inverse labour ratio, i.e. $\varphi / \varphi^* > L^* / L$. An analogous analysis can be applied to an equilibrium in which the core is in the Southern region. In the second case, the Northern region can invest less in pollution reduction technology and attract a larger share of capital compared to the Southern region. Therefore under a unilateral maximization, an equilibrium in which a region chooses a lower investment in pollution control compared to another region can lead to a reduction in the cost of capital and a large share of capital to locate there. If capital location decisions and environmental policies are implemented unilaterally, each region has an incentive to choose a lower pollution reduction investment level compared to

[13] For a symmetric equilibrium to occur, we have $t\left(1-\alpha\right)\left(\varphi^*\left(1-\alpha^*\right)^2 L^*\right) = t^*\left(1-\alpha^*\right)\left(\varphi\left(1-\alpha\right)^2 L\right)$. This implies that we have either $t\left(1-\alpha\right) = t^*\left(1-\alpha^*\right)$ and $\varphi^*\left(1-\alpha^*\right)L^* = \varphi\left(1-\alpha\right)L$. This holds when either (i), $t = t^*$, $\alpha = \alpha^*$, $\varphi = \varphi^*$ and $L = L^*$ or . (ii) $t = t^*$, $\alpha = \alpha^*$ and $\varphi / \varphi^* = L^* / L$.

A core periphery equilibrium holds when $t\left(1-\alpha\right) > t^*\left(1-\alpha^*\right)$ and $\varphi\left(1-\alpha\right)L > \varphi^*\left(1-\alpha^*\right)L^*$. These constraints are satisfied when either (i), $t > t^*$, $\alpha = \alpha^*$ and, $\varphi / \varphi^* > L^* / L$. or (ii) $t = t^*$, $\alpha < \alpha^*$ and $\varphi / \varphi^* \geq L^* / L$.

the other region and gain a larger share of capital locating in its jurisdiction. Each region undercuts the other in pollution reduction investment.

3.2 The Bilateral Coordinated Optimization Equilibrium

Now we consider a hypothetical global planner who takes into account the needs of both regions and pollution externality to determine the optimal distribution of manufacturing firms between the US and China. The global planner's welfare function is given by:

$$
\begin{aligned}
&W(K+K^*) = wL + w^*L^* + t(1-\alpha)K + t^*(1-\alpha^*)K^* + \\
&\left(\frac{1}{\gamma}-1\right)\left(\frac{wa_D + t(1-\alpha)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left[K+\phi K^*\right] + \\
&\left(\frac{1}{\gamma}-1\right)\left(\frac{w^*a_D{}^* + t^*(1-\alpha^*)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left[\phi K + K^*\right] - \\
&\varphi\delta^T T\left[(1-\alpha)^2K^2 + (1-\alpha^*)^2K^{*2}\right]L - \\
&\varphi^*\delta^T T\left[(1-\alpha)^2K^2 + (1-\alpha^*)^2K^{*2}\right]L^*
\end{aligned}
\qquad (21)
$$

subject to $K+K^*=1$.[14]

Assuming that the social cost of global pollution from a firm locating in a jurisdiction is λ , the optimal level of capital that maximizes a region's welfare is given by

$$1-K-K^*=0 \qquad (22a)$$

[14] Following Baldwin et al. (2003), the world endowment of capital is chosen to be a unit, with one unit of capital per firm, this implies that the world total number of firms is a unit.

$$t\left(1-\alpha\right)+\left(\frac{1}{\gamma}-1\right)\left(\frac{wa_D+t\left(1-\alpha\right)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left(1+\phi\right)-$$
$$2\delta^T T\left(1-\alpha\right)^2\left(\varphi L+\varphi^* L^*\right)K-\lambda=0 \tag{22b}$$

$$t^*\left(1-\alpha^*\right)+\left(\frac{1}{\gamma}-1\right)\left(\frac{w^* a_D{}^*+t^*\left(1-\alpha^*\right)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left(1+\phi\right)-$$
$$2\delta^T T\left(1-\alpha^*\right)^2\left(\varphi L+\varphi^* L^*\right)K^*-\lambda=0 \tag{22c}$$

The second order sufficient conditions are satisfied. Solving the first order conditions yields the coordinated optimal level of capital in the North and South respectively

$$K=\frac{t\left(1-\alpha\right)-t^*\left(1-\alpha^*\right)}{2\delta^T T\left(\varphi L+\varphi^* L^*\right)\left(\left(1-\alpha\right)^2+\left(1-\alpha^*\right)^2\right)}+\frac{\left(1-\alpha^*\right)^2}{\left(1-\alpha\right)^2+\left(1-\alpha^*\right)^2} \tag{23a}$$

$$K^*=\frac{t^*\left(1-\alpha^*\right)-t\left(1-\alpha\right)}{2\delta^T T\left(\varphi L+\varphi^* L^*\right)\left(\left(1-\alpha\right)^2+\left(1-\alpha^*\right)^2\right)}+\frac{\left(1-\alpha\right)^2}{\left(1-\alpha\right)^2+\left(1-\alpha^*\right)^2} \tag{23b}$$

In each region, the level of capital depends on the regional differentials in tax rates, global population and investments in pollution control efforts. Given the model can be analyzed in such a simple way, comparative static analysis is straightforward. The effect of an increase in taxes in one region leads to the movement of firms into the foreign region, $\partial K/\partial t<0, \quad \partial K/\partial t^*>0$. An increase in pollution control regional investments leads to capital locating into the local region away from the foreign region, $\partial K/\partial\alpha>0, \partial K/\partial\alpha^*<0$. The increase in the consumer's disutility of pollution has an ambiguous effect on the location of capital.

There are three possible coordinated equilibria,[15] which are the symmetric equilibrium and two core-periphery equilibria. A symmetric distribution of capital between the two regions occurs where

$$t(1-\alpha)-\delta^T T(1-\alpha)^2 = t^*\left(1-\alpha^*\right)-\delta^T T\left(1-\alpha^*\right)^2,$$

in which either of the following two conditions holds:

(i) $t = t^*$ and $\alpha = \alpha^*$, the investment in pollution control and the tax rate is the same for both regions. This would imply that in the South more labour is employed in the composite goods sector compared to the North.

(ii) $\alpha \neq \alpha^*$, $t = (1-\alpha)\delta^T T \quad t^* = \left(1-\alpha^*\right)\delta^T T$, the regions have different investments in pollution reduction and the tax rate is equal to the present value of marginal emissions.

A core periphery equilibrium in which most capital locates in the North region occurs when either of the following conditions hold:

(i) $\alpha < \alpha^*$ and $\frac{t-t^*}{\delta^T T} > (1-\alpha)-\left(1-\alpha^*\right)$, the North region invests less in pollution control but has a higher tax on emissions compared to the South region, and the discounted differential in taxes is greater than the differential in the marginal emissions.

(ii) $\alpha = \alpha^*$ and $\frac{t-t^*}{\delta^T T} > (1-\alpha)-\left(1-\alpha^*\right)$, both regions have identical investments in pollution control, and the North region has a higher tax on emissions

[15] From the definitions s_K and s_K^*, we have

$$s_K = \frac{t(1-\alpha)-t^*\left(1-\alpha^*\right)+2\delta^T T\left(1-\alpha^*\right)^2}{2\delta^T T\left((1-\alpha)^2+\left(1-\alpha^*\right)^2\right)} \text{ and}$$

$$s_{K^*} = \frac{t^*\left(1-\alpha^*\right)-t(1-\alpha)+2\delta^T T(1-\alpha)^2}{2\delta^T T\left((1-\alpha)^2+\left(1-\alpha^*\right)^2\right)}.$$

compared to the South region, and the discounted differential in taxes is greater than the differential in the marginal emissions.

(iii) $\alpha < \alpha^*$ and $\frac{t - t^*}{\delta^T T} = (1-\alpha) - (1-\alpha^*)$, the North region invests less in pollution control and the discounted differential in taxes is equal to the differential in the marginal emissions. Thus, a coordinated optimal outcome can be achieved in which the regions have differential shares of capital, tax rates and investments in pollution reduction.

3.3 A Comparison of the Unilateral and the Coordinated Equilibrium

In order to analyze the importance of the US-China bilateral coordination over a global pollution externality, we compare the coordinated and unilateral equilibria. From equations (19a) and (22b), the divergence between the unilateral and coordinated optima is given by:

$$F = \left(\frac{1}{\gamma} - 1\right)\left(\frac{wa_D + t(1-\alpha)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} \phi - 2\varphi\delta^T T (1-\alpha)^2 L^* K - \lambda \tag{24}$$

The first term of F represents the benefits to consumers from importing manufactured goods variety. The second term represents the marginal contribution of a local firm to foreign expected damages. The last term denotes the shadow value of having an additional unit of capital in a jurisdiction. The magnitude of the three terms determines the magnitude of divergence between the unilateral and the coordinated optimal equilibria.

The unilateral and the coordinated optima are equal if $F = 0$. This implies that the marginal benefits of importing Southern manufacturing varieties adjusted for the marginal social cost of pollution to Southern consumers from Northern production activities and the shadow value of having an additional firm is zero. Under the unilateral approach, a region is indifferent between having capital locate within or outside its jurisdiction, and its objectives coincide with that of the coordinated optimum. For policy, this implies that the unilateral optimal share of capital, taxes and the level of investments in pollution reduction coincide with that of the coordinated optimum. The unilateral equilibrium efficiently internalizes the externalities.

If $F < 0$, then the unilateral optimal share of capital is less than the coordinated optimum. This implies that the marginal benefits of local Northern consumers from importing the manufacturing varieties from abroad adjusted for the marginal social costs imposed on foreign consumers is greater than the shadow value of capital locating in a jurisdiction. Thus, from a policy perspective the unilateral equilibrium over-shoots the coordinated equilibrium by mandating higher taxes and investments in pollution reduction, and having a lower share of capital.

If $F > 0$, then the unilateral share of capital is greater than that dictated by the coordinated optimum. This means that the marginal benefits of importation adjusted for spill-over costs to foreign region from the local pollution activities, is less than the shadow value of having an additional unit of capital locate in a jurisdiction. Thus the unilateral equilibrium under-shoots the coordinated equilibrium in which firms mandate lower taxes and investments in pollution reduction so as to attract a larger share of capital compared to the coordinated optimum.

It is more likely that the share of capital under unilateral decision-making is greater than under the coordinated optimum. We expect that regions acting unilaterally to make less investment in pollution control efforts compared to the coordinated optimum, as the unilateral decision by each region does not take into account the global externalities and the spill-over effects from pollution reduction investments, F. Each individual region would unilaterally mandate lower environmental standards than those dictated by the coordinated optimal solution. This is a source of inefficiency, and thus the regions are better off in a coordinated equilibrium that internalizes the global pollution externalities and the positive spill-over benefits from pollution control efforts.

To illustrate our analysis, we conduct a numerical simulation using equilibrium conditions (20c) and (23b) to show the effects of changes in the tax rate associated with GHG emissions t and the level of regional investments in pollution reduction α, on the cooperative and non-cooperative share of capital in the Northern region.[16] The baseline parameter values for the simulation are, Northern region wage rate $w=1$, units of labour requirements for manufacturing in the North $a_D=0.5$, total time when global emission costs are incurred $T=1000$, discount factor $\delta=0.075$, substitutability between product varieties $\gamma=0.90$, degree of trade openness $\phi=0.07$, Southern region's level of investments in pollution reduction $\alpha^*=0.5$ and tax rate associated with emissions $t^*=0.3$, share of households in the Northern and Southern region is $L=0.5$ and $L^*=0.5$ respectively, Northern and Southern consumer disutility of pollution is $\varphi^*=0.4$ and $\varphi=0.4$ respectively.

From Figure 1, the region's non-cooperative share of capital is increasing in both the lump sum transfer tax payments which boost incomes; and investment in pollution reduction efforts which reduce the global pollution externality.

A comparison of Figure 1 and 2 shows that there is divergence in the equilibrium share of capital, the tax rate and investment in pollution reduction effort levels between the unilateral and cooperative equilibrium. This is further illustrated by Figures 3 and 4.

In Figure 3, the unilateral share of capital is greater than the coordinated share of capital. This captures a scenario discussed earlier in which $F>0$. The magnitude of the optimal tax rate under the unilateral equilibrium is lower than that of the co-ordinated optimum. A region mandates a lower tax rate so as to attract additional capital compared to the co-ordinated optimum.

From Figure 4, for every level of capital share the unilateral levels of investments in pollution reduction efforts are lower than the co-ordinated level,

---

[16] To get the share of capital in the northern region, we simplify (20c) by substituting for the constraint $K+K^*=1$. This yields the share of capital in the Northern region as

$$K=\frac{t\left(1-\alpha\right)+\left(\frac{1}{\gamma}-1\right)\left(\frac{wa_D+t\left(1-\alpha\right)}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left(1-\phi\right)+2\varphi\delta TL\left(1-\alpha^*\right)^2}{2\varphi\delta TL\left(\left(1-\alpha\right)^2+\left(1-\alpha^*\right)^2\right)}.$$

This result can also be obtained by substituting for the capital constraint $K+K^*=1$ into (18a) and maximizing the subsequent function get the share of capital in the Northern region.

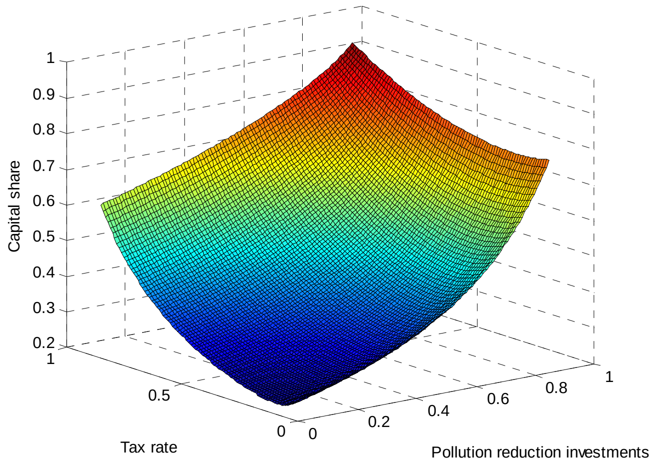

Figure 1: The relationship between the non-cooperative share of capital K, the tax rate t and investments in pollution reduction α in the Northern region.

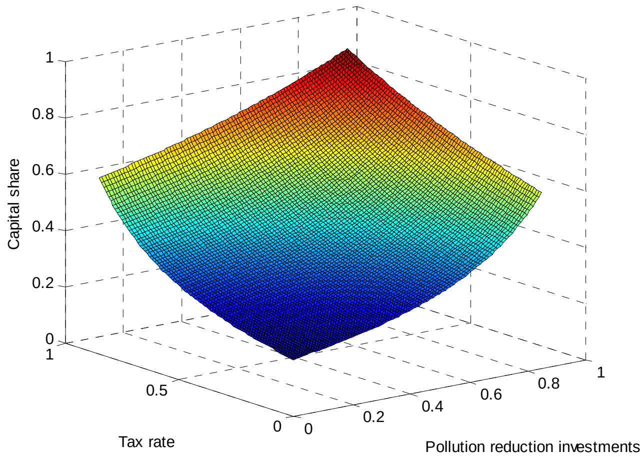

Figure 2: The effects of changes in the tax rate t and investments in pollution reduction α on the cooperative share of capital in the Northern region.

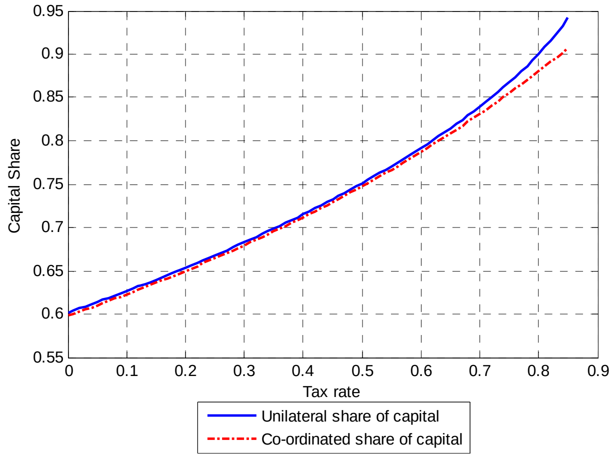

Figure 3: The effects of the tax rate associated with emissions t on the unilateral share of capital and co-ordinated share of capital.

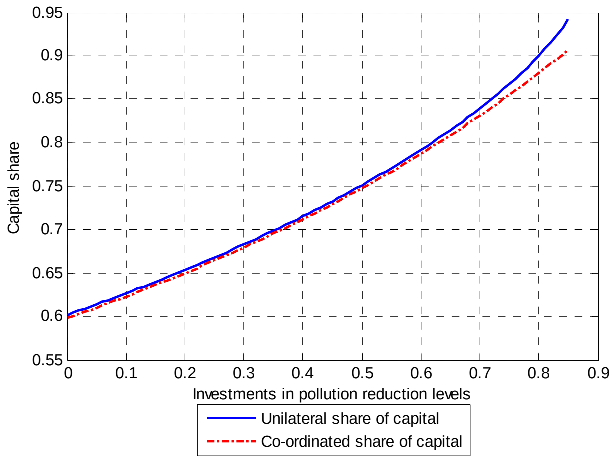

Figure 4: The effects of investments in pollution reduction effort α on allocation of capital under the co-ordinated and the unilateral equilibria.

capturing a scenario in which $F > 0$. Thus, acting unilaterally a region could require a lower level of investment in pollution reduction efforts compared to the co-ordinated optimum.

To summarize, the key outcome of our model and simulation is that, in a bilateral arrangement, regions can collaborate and implement differential commitments in environmental policy initiatives and investment mechanisms to reduce a global pollution externality. The bilateral arrangement is more efficient and leads to the improvement in the global environment, compared to unilateral decisions. The implication is that there are likely to be efficiency gains if the US and China engage in bilateral agreements to control a global pollution externality, while promoting trade and development.

4 Conclusion

Bilateral trade and capital flows between the US and China increase the varieties of manufactured goods available to their consumer and promotes development. However, this economic cooperation has environmental consequences, such as the emission of greenhouse gases (GHGs) that are a global pollution problem. If the disutility of pollution in the United States is higher, there will be pressure on the US government to impose more environmental regulations. This causes capital to migrate to China, and pollution increases there. Given the global nature of the emissions, the US may not be better-off unilaterally mandating environmental regulations because of the spill-over externality arising from a global pollutant such as GHGs. Thus a bilateral coordinated approach is more efficient in the regulation of the global pollution externality. The efficient coordinated solution can be attained between the US and China, allowing that the countries differ in pollution control investment levels, tax rates, quantities of labour employed in the manufacturing sector and the share of manufacturing. Consequently, a key contribution of our paper is to demonstrate, using a variant of a North-South footloose capital model, that economic trade and capital flows between relatively rich and poor economies is not an obstacle to but possibly an incentive for global cooperation on environmental regulation. To our knowledge, our analysis is the first to show explicitly that an important source of the efficiency gains from the US and China agreeing jointly to control a global pollution externality is the bilateral trade and capital flows that promote mutual development of both economies.

A key policy implication of our analysis is that there is scope for bilateral coordination between the developed US and developing China on efforts to effectively control global pollution. This is a win-win situation for both countries in which development and trade, and pollution reduction to protect the environment are enhanced. Such an incentive may explain the outcome at the December 2011 climate change negotiations in Durban, South Africa, which saw the US and China agreeing to a framework for a prospective and comprehensive climate change agreement in 2015 (Ewing 2012). A growing literature has argued that closer bilateral trade and economic ties between the two countries should lead them to cooperate on global issues, such as climate change (Antholis 2009; Foot 2010; Foot and Walter 2013; Lieberthal and Sandalow 2009).

The results of our paper also support the idea that efficiency in regulating the global pollution externality can be achieved within the framework of common but differentiated responsibilities between the richer US and poorer China. Areas for further research may include a study of different policy approaches to protect the environment under common pool resources or resources or insecure property rights under international trade between the developing and the developed world.

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