Insensitive Multinationals?
Competitive Subsidies and Carbon and Corporate Income Taxes

Emilson Caputo Delfino Silva
Department of Economics, Faculty of Business and Economics, University of Auckland,
12 Grafton Road, Auckland, New Zealand, 1010, e-mail: emilson.silva@auckland.ac.nz

Vander Mendes Lucas
Department of Economics/FACE, Universidade de Brasília,
Brasília – DF, Brazil, 70910-900, e-mail: vlucas@unb.br

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Abstract

One of the crucial aspects of international mobility of firms that we wish to consider is the fiscal stimulus that a nation may offer to multinationals but not to domestic firms. The subsidy is the policy instrument that allows each nation to control the size of its industry. Our simple international economy enables us to identify the effects that international mobility cause to the allocation of resources. We examine two scenarios, one in which multinationals are insensitive and another in which multinationals are sensitive. Multinationals are insensitive if their mobility decisions do not depend on subsidies and taxes. In the Nash equilibrium with insensitive multinationals, each nation overprovides its national public good. With symmetric tax bases, both nations provide equal amounts of public goods and set their relative carbon taxes efficiently. We find that if nations need to make efforts to attract multinationals, they will be more sensitive to the tax burden that its taxes cause to multinationals. The optimal national subsidy policies nullify the excessive burden that multinationals face relative to domestic firms. As the optimal national policies for provision of public goods and control of carbon emissions demonstrate, the nations essentially treat multinationals as domestic firms in the setting with sensitive multinationals. The relative carbon tax rate in the resource-poor nation exceeds the efficient rate, and the latter exceeds the relative carbon tax rate the resource-rich nation charges.

Keywords: insensitive multinationals, corporate income tax, carbon tax, subsidies.

JEL: D21, H2, H3, Q5

1. Introduction

Globalization has increased the movement of capital and trade and multinational enterprises (MNEs) have taken advantage to expand into new markets. MNEs are also an important source of investment in innovation, technology and skilled labour.

Canada provides a good example. Only 0.8% of all enterprises operating in Canada were MNEs but they held 67% of all assets in the Canadian economy. MNEs in the extraction (Mining and Quarrying, Oil and Gas Extraction and Support Activities), manufacturing industries and finances had the highest share of operating revenue of all industries (above than 65%) and utilities, transportation and warehousing, and distributive had around 50%. In Canada, 25% of all employees worked for MNEs in 2016 and the employment share of MNEs was the largest (65.5%) for the extraction industry (Schaffter and Fortier-Labonte, 2016). The corporate income tax in Canada is imposed on the gain of a corporation and there are also exceptions and credits that can be applied to certain structures and sectors. The case of the province of Alberta is especially noteworthy. It is Canada's major energy producer and the second-least attractive jurisdiction to invest mainly due to regulatory restrictions, licenses, royalties and high taxation. The Alberta government led by the New Democratic Party, elected in 2015, increased the corporate income tax rate, implemented a carbon tax, and introduced a cap on emissions from oil sands production. The subsequent government led by the United Conservative Party, elected in 2019, repealed the carbon tax. Just like Alberta, jurisdictions around the world face political pressure to regulate dirty industries by imposing a carbon tax, create a cap-and-trade market for emission permits or limiting production directly through quantity restrictions. But, they also face political pressure to attract foreign investment to facilitate job creation and economic growth, and to use its tax revenue to provide public goods. This tension creates interesting trade-offs, which need to be fully analyzed.

Several international organizations have studied the adoption of a coordinated tax policy among countries on the corporate income tax (CIT), with the intent of preventing the well known race to the bottom. In 2021, for example, around 137 countries joined up the OECD/G20 proposal on a two-pillar solution in terms of taxation on domestic tax base erosion and profit shifting (BEPS) due to multinational enterprises (MNEs) exploiting gaps and mismatches between different countries' tax systems affects all countries. The terms of the OECD for CIT co-operation are to reallocate taxable profits of MNEs, mitigate double taxation of profits to increase efficient trade, and avoid a harmful tax competition. According to the OECD's Corporate Tax Statistics, BEPS practices cost countries 100-240 billion USD in lost revenue annually, which is the equivalent to 4-10% of the global corporate income tax revenue, OECD (2021).

According to the OECD/G20 proposal, under Pillar One, taxing rights on about USD 200 billion in profits are expected to be reallocated to market jurisdictions each year, and this is expected to lead to annual global tax revenue gains of between USD 17-32 billion mainly leading to gains for low and middle income countries. Pillar Two introduces a model for the global minimum tax that countries may implement by ensuring an effective tax rate of 15% on their profits in every jurisdiction where they operate. With this tax rate, it is expected an additional tax revenue of up to USD 200 billion annually, OECD (2023).

In this paper, we consider a game where two independent jurisdictions (nations) compete to attract foreign investment (MNEs) and provide public goods. In their arsenal of instruments, there are subsidies supplied to entrant MNEs, and carbon and corporate income taxes. Firms are mobile but heterogeneous in terms of their moving costs. Since moving costs for heavy industries may be quite high, we consider a benchmark case where all firms are immobile, given the feasible incentives that the jurisdictions provide. We call these firms "insensitive." We show that the global optimum with insensitive multinationals yields equal national public expenditures consistent with the efficient conditions for reduction of global carbon emissions. The global optimum implies equalization of national relative carbon taxes. For comparison, we also analyze a setting where some firms are mobile; that is, they are "sensitive." With sensitive multinationals, the industry expands as the nation increases the amount of subsidy and contracts as the nation increases either the nominal carbon tax or the corporate-income-tax rate. The subsidy decreases while each type of tax increases the tax burden for a representative multinational that operates in this nation. In the Nash equilibrium with insensitive multinationals, each nation overprovides its national public good. With symmetric tax bases, both nations provide equal amounts of public goods and set their relative carbon taxes efficiently. We find that if nations need to make efforts to attract multinationals, they will be more sensitive to the tax burden that its taxes cause to multinationals. The optimal national subsidy policies nullify the excessive burden that multinationals face relative to domestic firms. As the optimal national policies for provision of public goods and control of carbon emissions demonstrate, the nations essentially treat multinationals as domestic firms in the setting with sensitive multinationals. The relative carbon tax rate in the resource-poor nation exceeds the efficient rate, and the latter exceeds the relative carbon tax rate the resource-rich nation charges.

Section 2 we describe initially the carbon tax revenue around the world. The theoretical literature is analyzed in Section 3 and we take into account an economy with tradeable and non-tradeable private goods, two nations by producing national public goods each one, and global pollution (carbon dioxide) in Section 4.

2. Carbon tax revenue around the world

Carbon tax revenue has increased in many countries. Following a number of different types of carbon policies, this revenue increased to near USD 95 billion in 2022 from USD 26 billion in 2015. It is important to note that such revenue more than tripled since the Paris Agreement. It is also important to note that 94% of global carbon revenues have been used for climate and the overall environmental transition (I4CE/EU, 2024).

There is no consensus regarding how this kind of revenue should be spent or distributed. Bowen (2015) highlights some possibilities as for spending on complementary green policies, to reduce negative impacts of the distortionary taxes (double taxation), to help improve the tax-benefit system, to finance additional spending on other government green objectives or even to reduce public debt. Experts in public economics, for example, have argued that this green revenue could *open the door* to reduce excessive taxation of corporate income by again appealing to the *double dividend hypothesis* (Auerbach et al, 2008).

Carbon tax revenues have been used to reduce other taxes, to increase public spending to implement climate-related policies or sometimes to fund implement unrelated to climate change. According to the World Bank Guide (2017), the Danish carbon tax has been used to reduce tax on labor, to subsidize energy efficiency, to subsidize small companies, to use for environmental incentives and to reduce social insurance and pension contributions. In Switzerland, the revenue is redistributed through the health insurance system and reduced social insurance contributions for businesses. In Australia, the carbon tax revenue is used to financial assistance for pensioners and low-income households and, also as rebates to industries. Revenue neutrality by reducing non-carbon taxes (“tax recycling”) has been applied broadly in jurisdictions such as British Columbia, France, Norway, Sweden, and South Africa. In British Columbia, we observe personal income and business taxes reductions specifically to compensate carbon taxes implementation.

In Denmark and India, the governments implement expanded public spending to subsidize programs in renewable energy and energy conservation. On the other hand, some countries add carbon tax revenues to their general budgets (e.g., United Kingdom, Iceland, Mexico, and South Africa). As earmarks, India and Japan use carbon tax revenues to finance their environmental expenditures, France and Ireland use carbon tax revenues to promote redistribution to tax-affected groups and to assistance programs to improve their energy efficiency. In Spain, the Catalonia government provides funds for environmentally affected groups. In Japan, carbon tax revenues are used to promote low-carbon technologies, energy efficiency improvements, and renewable energy. Recently, the French government indicated that carbon tax revenues should be allocated to decrease labor taxes through the "*tax credit for encouraging competitiveness and jobs*." In Norway, carbon tax revenues are used to finance the pension fund and in Chile the tax revenues are spent on improvements to the education system. In California (USA), any revenue raised by an environmental tax or charge must be allocated to protecting, restoring, or managing the environment.

JURISDICTION USE OF CARBON TAX REVENUE	
Country	Carbon Tax Revenue Allocation
Australia	Assistance for low-income households, including income tax reform Jobs and competitiveness, including emissions-intensive trade-exposed (EITE) companies Compensation for coal-fired electricity Use of offsets Clean Energy Finance Corporation (a green bank)
British Columbia	Income tax reductions and credits Property tax reductions and credits
Chile	General budget, intended for spending on education and health
Denmark	Reduced taxes on labor Energy efficiency and environmental programs Reduced industry contributions to government programs
Finland	Income tax reductions Decreased employer social security payments General budget
France	Reduced corporate income taxes Reduced labor taxes Energy assistance for low-income households
Iceland	General budget
India	Clean energy and environment
Ireland	General budget / deficit reduction / debt payments
Japan	Clean energy technology Energy efficiency
Mexico	General budget
Norway	General budget Reduced labor taxes Decreased capital income taxes Pension plan for low-income individuals
Portugal	Income tax reductions for low-income households General budget
South Africa	Electricity levy reduction

	Energy efficiency Solar tax credit Renewable energy Energy services for low-income individuals Public transport Rail freight transport
Sweden	General budget Reduced labor and corporate taxes
Switzerland	Reduced health insurance premiums Decreased social security contributions Building energy efficiency Technology development
United Kingdom	General budget

Souce: World Bank Guide (2017)

3. Theoretical Literature

The topic of this paper is related to three branches of the literature: (i) international tax competition, (ii) double dividends in public economics, and (iii) the pollution haven hypothesis in environmental economics.

3.1. International Tax Competition

Keen (2001) considers two symmetric countries with leviathan governments (the objective of each country is to maximize tax revenues) competing for two distinct tax bases in terms of their degree of international mobility. He shows that a total ban on this kind of preferential treatment reduces both countries' revenues. To get this result, Keen obtains two equilibria, *one that emerges when each country may offer preferential treatment and one that emerges when each country must charge the same rate on both tax bases*. Keen also considers a setting in which the two governments derive some benefit not merely from tax revenue but also from some kind of home bias (*the location of tax base within their country*). The conclusion, however, remains the same; namely, "welfare" is raised with differentiation of the tax regime. Janeba and Smart (2003) generalize Keen's framework by endogenizing the total size of each of the two tax bases. The levels of the aggregate bases depend on the two countries' absolute tax burdens rather than on the differences between them. They show that a limitation of the preferential regimes influences the total size of the bases, and this might counteract and dominate the impact analyzed in Keen (2001). Haupt and Peters (2005) consider a world with two symmetric countries with regional preferences of a home bias – investors keep most of their mobile capital in their home country. Both governments offer foreign investors a discount to attract their mobile capital. Leviathan governments compete for two internationally mobile and fixed capital tax bases. They show that, even in cases in which a total renunciation of preferential regimes is not desirable, competition without any constraints on the regulations allowed always yields lower revenues than competition with moderately restricted tax differentials. In the Nash equilibrium, both governments implement a preferential regime, and higher taxes are levied on investments of residents than on investments of non-residents. With restricted preferential regimes, each country yields at equilibrium higher taxes on FDIs with ambiguous result of the tax levied on the domestic base. To summarize, Keen (2001) shows that restrictions on preferential treatment reduces the countries' tax revenues but if the total tax base is variable (Janeba and Smart, 2003) or if tax bases are home-biased (Haupt and Peters, 2005) then this possible outcome is less likely to occur. Moreover, countries can always benefit from marginal restrictions on preferential regimes.

Bucovetsky and Haufler (2007) analyze discriminatory vs. non–discriminatory tax competition between countries with size asymmetries. Their models do not capture tax regimes that discriminate between foreign–owned and domestically owned firms and their results show that the smaller country unambiguously has lower tax rates, but higher per–capita tax revenue, under either restricted or unrestricted tax competition. Imposing a non–discrimination constraint hurts not only the small country, but also the large one.

Marceau, Mongrain and Wilson (2010) model an economy first constrained to use a non-preferential regime which imposes the same tax rate on immobile and perfectly mobile capital. This leads to an equilibrium in which there is nevertheless differential taxation of mobile and immobile capital, not within individual countries, but rather because mobile capital locates in countries with low tax rates on all capital. When countries are allowed to individually levy different tax rates on immobile and mobile capital, tax havens do not emerge, but tax competition for mobile capital intensifies, causing a large revenue loss in the form of lower tax rates on mobile capital. They conclude that tax competition in the non-preferential regime leads to a lower aggregate loss in tax revenue, compared with tax competition in the preferential regime and that revenue would be higher in the non-preferential regime if there were no tax havens.

Mongrain and Wilson (2017) investigate the conditions under which limiting preferential treatment of particular tax bases is desirable. They consider an economy in which regions also care about the "surplus" obtained in the private sector (benevolent government) and distinguish domestically owned (home-bias effect) by a relocating cost from one region to another. Initially, both regions choose their tax rates and all firms draw a moving cost. Then firms choose whether to stay or to move. Finally, firms produce, and taxes are levied. With uniform distribution of moving costs, they obtain that the non-preferential regime is preferred, and the region raises its tax revenue yielding higher total welfare (Proposition 5). With asymmetric regions in terms of size they obtain that regions differ in their preferences over regimes when the size difference is sufficiently large. So, a region may prefer the preferential regime over the non-preferential one if it is sufficiently small. With non-uniform differences in moving costs the preferential regime produces higher welfare than the preferential regime.

Zucman (2014) surveys the theory underlying profit shifting, describes the history of the corporate income tax and its reforms as well as provides nice examples of countries around the world in which firms and individuals benefit from tax havens, low-tax jurisdictions. With thousands of bilateral agreements, firms and individuals try to avoid taxes by legal actions (*treaty shopping*) or even artificial profit shifting. The author describes the needs of multilateral agreements in terms of information and/or corporate and individual income taxes, with penalties for noncompliance, to eliminate tax evasion. Johannesen and Zucman (2014), on the other hand, show that some countries have incentives to deviate from such agreements.

As we mentioned in the *Introduction*, international organizations have been working on a proposal for a *global minimum corporate tax*. Naturally, some academic studies have addressed this topic. By considering economies with coordination over the corporate income tax, Johannesen (2022) studies a *global minimum tax* and the consequent welfare impacts with a formal model of international tax competition with heterogeneous countries and fiscal havens. According with this analysis, the net welfare effect is ambiguous from the perspective of non-havens, but the *global minimum tax* lowers their welfare by increasing equilibrium tax rates in tax havens. The net welfare effect is unambiguously positive when the global minimum rate is sufficiently high such that profit shifting ends. Also by considering a *global minimum tax,* Harbous and Keen (2023) analyze the possibility of implementing a *global income tax* previously agreed between countries. They consider the traditional Kanbur-Keen model of asymmetric tax competition by taking a minimum corporate income tax into account and then analyze the welfare impact on low and high tax countries. They show that there are welfare gains in both countries.

3.2. Double Dividends

The possibility of a better environment and lower tax costs characterizes the double dividend hypothesis when a revenue-neutral tax reform takes place. Pearce (1991) was the first author to state that g*overnments should use revenues to finance reductions in incentive-distorting taxes such as income tax, or even corporation tax.* Bovenberg and de Mooij (1994) and Parry (1994) show that environmental taxes affect resource use in any other markets with implications for gross costs. Bovenberg and Goulder (1996) incorporate intermediate inputs, and the results above prevail. So, the effects of environmentally motivated taxes on 'dirty" intermediate goods and on "dirty" consumption goods are analyzed and the strong double dividend claim fails. When we analyze an economy with labor income tax and capital the gross costs of a revenue-neutral environmental tax will be lower under some conditions. So, an incremental environmental tax with a reduced labor tax leading to higher revenues could have a zero gross cost (Bovenberg and de Mooij, 1994). Goulder (1995) also analyzes an economy keeping *in mind a revenue neutral-experiment that raises environmental quality.* Bovenberg (1999) considers the efficiency and equity effects of green tax reforms by showing the traditional first dividend (better a cleaner environment) and, in a general equilibrium model, the impacts of an environmental tax reform on a distorted labor market (the second and strong dividends). Fullerton and Metcalf (1998) alert that we need to observe the use of these tax revenues by considering environmental regulatory restrictions on the polluting activities such as deficit reduction, specific spending program, specific tax reduction and public good provision and taking in mind that d*ifferent environmental instruments lead to different outcomes in relation to the double dividends*. Fullerton and Gravelle (1999) review some problems with this concept of the "Double Dividend Hypothesis (DDH) and conclude that i) the DDH is not well defined or at least not commonly stated; ii) The DDH as a theoretical proposition when its very nature is empirical. So, the DDH is valid only for certain circumstances (starting points and certain parameter values; iii) The DDH is debated as a probabilistic statement, and the models are deterministic; iv) Some of this debate is on the number of dividends instead of the net social impact; and v) These analytical models cannot address the complexity of actual environmental tax policies[1].

3.3. Pollution Haven Hypothesis

Copeland and Taylor (1994, 1995) developed a model to analyze income differences between countries, the pattern of international trade and the pollution incidence. So, higher income

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[1] Freire-González (2018) surveys the empirical literature of DDH that consider CGE models in an environmental tax reform. Half of the literature concludes that *the economic dividend still remains an ambiguous question.*

countries would choose stricter pollution regulations and higher income countries would endogenously develop a comparative advantage in relative clean goods, while lower income countries would develop a comparative advantage in pollution-intensive goods. Because trade shifted the location of the most pollution intensive industries to countries with the weakest pollution regulations, the model predicts that trade liberalization could increase world pollution. Copeland and Taylor (1997) include differences in factor abundance with an intuition that normally richer countries are more capital abundant than poorer countries and this characteristic should affect trade patterns. They conclude again that pollution rises in the South, and falls in the North when income differences are large and world pollution rises with the shift in pollution intensive industry to the relatively low income region. Copeland and Taylor (2004) is a good essay on this literature. Gill et all (2018) survey the theoretical and empirical support to the pollution haven hypothesis (PHH) and them show us that this literature on the PHH has mixed outcome and it claims empirical evidence against or in the support of the PHH. As we see there are no consensus about the PHH.

Forslid, Okubo and Sanctuary (2017), for example, consider a monopolistic competitive economy and show that the Home Market Effect (HME) dominates the PHH with large market and easy abatement that decreases global emissions. On the other hand, the HME is weak when trade liberalization concentrates in countries with lower emission taxes leading to higher global emissions. By considering endogenous emission taxes and a Nash game between two governments, the government considers its market size advantage to set a higher Nash emission tax than its smaller trade partner. Trade liberalization leads to concentration in the larger high-tax economy, and this promotes an increase in global emissions.

4. Basic Model

Consider an economy with tradeable and non-tradeable (numeraire) private goods, 2 nations and national public goods, and global pollution (carbon dioxide). Let L_j denote the fixed amount of land in nation j, $j=1,2$. Let $\omega_j=\phi\left(\alpha L_j\right)>0$ be the initial endowment of numeraire good in nation j, where $\phi(.)$ is the function that transforms a fixed share $\alpha>0$ of the nation's fixed land resource into units of numeraire, $j = 1, 2$. We assume that $\phi' > 0$ and $L_1 > L_2$. Then, $\omega_1 > \omega_2$. We refer to nations 1 and 2 as "resource-rich" and "resource-poor", respectively.

In nation j, a mass of I_j atomistic firms produce the tradeable good ("output") and pollution abatement ("abatement"). Output production generates carbon dioxide emissions as by-products. Firms produce abatement because both nations tax carbon emissions. The industry in nation j contains firms from both nations. Let $n_j > 0$ denote the number of domestic firms in nation j. Let $m_k = I_j - n_j > 0$ be the number of multinational firms that operate in nation j, $j, k = 1, 2$, $k \neq j$. Consistent with the ordering of national resources, we assume that $n_1 \geq n_2$. Although we do not model the firms' start-up process, it is reasonable to postulate that the resource-rich nation has more financial resources to cover start-up costs than the resource-poor nation and thus there should be at least as many competitive firms in the resource-rich nation.

The representative firm in nation j produces q_j units of output and a_j units of abatement at a cost $c(a_j, q_j, l_j)$, where $l_j \equiv (1-\alpha) L_j / N$. Land is a joint input and the amount of land available for production of output and abatement in nation j, $(1-\alpha) L_j$, is shared equally by firms. The representative firm in nation j emits $e_j = q_j - a_j$ units of carbon dioxide. We assume that $c(.)$ is twice continuously differentiable and satisfies $c_a^j > 0$, $c_q^j > 0$, $c_{aa}^j > 0$, $c_{qq}^j > 0$, $c_{aq}^j = 0$, $c_l^j < 0$, $c_{al}^j < 0$, $c_{ql}^j < 0$ and $c_{al}^j c_{qq}^j > c_{ql}^j c_{aa}^j$. The technology features decreasing returns to scale due to the utilization of a fixed amount of land. An expansion in land utilization decreases the cost of production, $c_l^j < 0$, and the marginal abatement and output costs, $c_{al}^j < 0$ and $c_{ql}^j < 0$, respectively. As we show below, the assumption $c_{al}^j c_{qq}^j > c_{ql}^j c_{aa}^j$ implies that emission increases with land utilization in equilibrium.

Let $p > 0$ denote the global price of output. The representative firm's profit (corporate income) after taxes in nation j is $\pi_j = (1-\tau_j) v_j - t_j e_j$, where τ_j and t_j are nation j's corporate-income-tax rate and carbon tax, respectively, and $v_j = pq_j - c(a_j, q_j, l_j)$ is the firm's corporate income before taxes. Assume that $0 < \tau_j < 1$ and $t_j > 0$, $j = 1, 2$. Later, we show the circumstances under which the equilibria satisfy these assumptions. As multinational firms operate in both nations, the corporate income after taxes for a representative multinational firm is $\Pi = \sum_{j=1}^{2} \pi_j$.

The representative firm in nation j chooses non-negative $\{a_j, q_j\}$ to maximize π_j, taking price, taxes and all other firms' choices as given. Assuming an interior solution, the first order conditions yield (for $j = 1, 2$)

$$r_j = c_a^j , \tag{1}$$

$$p = c_q^j + r_j , \tag{2}$$

where $r_j \equiv t_j / (1 - \tau_j) > 0$, the carbon tax measured in after-income-tax units of numeraire, is the effective carbon tax. To avoid confusion henceforth, we refer to t_j and r_j as "nominal" and "relative" carbon taxes, respectively. Note that $r_j > t_j$, since $0 < \tau_j < 1$, $\forall j$. The equations inform us that each firm chooses abatement and output at levels that equate marginal revenues to marginal costs, all measured in after-income-tax units of numeraire. The marginal revenue from abatement provision (left side of equation (1)) is the amount that the firm saves in terms of the emission cost it faces. The marginal cost of producing output (right side of equation (2)) is the sum of the technological marginal cost and the effective carbon tax. Since r_j is a relative price, equations (1) and (2) clearly demonstrate that each firm's responses to the corporate-income-tax rate and the carbon tax are co-dependent: they account for the interaction between the two policy instruments.

The strict convexity of the cost function implies that the sufficient second order conditions are satisfied, the solution to each firm's maximization problem is unique and each firm makes positive profits. Let $a_j = a_j(r_j; l_j, p)$ and $q_j = q_j(r_j; p, l_j)$ denote the response functions for the representative firm in nation j.[2] The following results are important (for $j = 1, ..., J$):

$$a_r^j = \frac{1}{c_{aa}^j} > 0 , \qquad q_r^j = -\frac{1}{c_{qq}^j} < 0 , \qquad e_r^j = -\frac{c_{aa}^j + c_{qq}^j}{c_{aa}^j c_{qq}^j} < 0 , \tag{3}$$

$$a_l^j = -\frac{c_{al}^j}{c_{aa}^j} > 0 , \qquad q_l^j = -\frac{c_{ql}^j c_{aa}^j}{c_{qq}^j} > 0 , \qquad e_l^j = \frac{c_{al}^j c_{qq}^j - c_{ql}^j c_{aa}^j}{c_{aa}^j c_{qq}^j} > 0 . \tag{4}$$

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[2] Plugging the firm's response functions into equations (1) and (2) and then differentiating the implied identities with respect to r_k yields $\partial a_j / \partial r_k = \partial q_j / \partial r_k = 0,\ j, k = 1, ..., J,\ k \neq j$.

where $a_r^j \equiv \partial a_j / \partial r_j$, $q_r^j \equiv \partial q_j / \partial r_j$ and $e_r^j \equiv \partial e_j / \partial r_j$. We assume that $e_j\left(r_j; l_j, p\right) > 0$, $\forall j$. The results in (3) are consistent with economic intuition, since each firm's responses to an increase in the relative carbon tax should be an increase in abatement, a reduction in output and a reduction in carbon emission. Note that $\partial a_j / \partial \tau_j = r_j a_r^j / \left(1-\tau_j\right) > 0$, $\partial q_j / \partial \tau_j = r_j q_r^j / \left(1-\tau_j\right) < 0$, $\partial e_j / \partial \tau_j = r_j \left(q_r^j - a_r^j\right) / \left(1-\tau_j\right) < 0$, $\partial a_j / \partial t_j = a_r^j / \left(1-\tau_j\right) > 0$, $\partial q_j / \partial t_j = q_r^j / \left(1-\tau_j\right) < 0$ and $\partial e_j / \partial t_j = \left(q_r^j - a_r^j\right) / \left(1-\tau_j\right) < 0$. Then, $\partial a_j / \partial \tau_j = r_j \left(\partial a_j / \partial t_j\right)$, $\partial q_j / \partial \tau_j = r_j \left(\partial q_j / \partial t_j\right)$ and $\partial e_j / \partial \tau_j = r_j \left(\partial e_j / \partial t_j\right)$. These results demonstrate that, in absolute terms, the marginal responses with respect to a change in the corporate-income-tax rate are higher than (lower than or equal to) the marginal responses with respect to a change in the nominal carbon tax if $r_j > (\leq) 1$.

The first two results in (4) are also intuitive. As the amount of land available for production of abatement and output increases, each firm responds by increasing production of both abatement and output. As abatement and output expand with land utilization, the impact on the firm's carbon emission is, in principle, ambiguous. However, we consider throughout the case where the net effect is positive.

Let $\hat{\pi}_j\left(\tau_j, t_j; l_j, p\right) \equiv \left(1-\tau_j\right)\hat{v}_j(.) - t_j e_j(.)$, where $\hat{v}_j(.) \equiv p q_j(.) - c\left(a_j(.), q_j(.), l_j\right)$, $j = 1,2$. Let $\hat{\Pi}\left(\boldsymbol{\tau}, \mathbf{t}; \mathbf{l}, p\right) \equiv \sum_{j=1}^{2} \hat{\pi}_j(.)$, where $\boldsymbol{\tau} \equiv \left(\tau_1, \tau_2\right)$, $\mathbf{t} \equiv \left(t_1, t_2\right)$ and $\mathbf{l} \equiv \left(l_1, l_2\right)$. Note that $\partial\hat{\Pi}/\partial\tau_k = \partial\hat{\pi}_k/\partial\tau_k = -\hat{v}_k < 0$, $\partial\hat{\Pi}/\partial t_k = \partial\hat{\pi}_k/\partial t_k = -e_k < 0$ and $\partial\hat{\Pi}/\partial l_k = \partial\hat{\pi}_k/\partial l_k = -c_l^k > 0$, $k = 1,2$. It is also important to note that $\partial\hat{v}_k/\partial l_k = r_k e_l^k - c_l^k > 0$, $k = 1,2$.

One of the crucial aspects of international mobility of firms that we wish to consider is the stimulus that a nation may offer to multinationals but not to domestic firms. Let $s_j \in \left[0, \tau_j \hat{v}_j + t_j e_j\right]$ denote a subsidy that any multinational that operates in nation j receives, $j = 1,2$. Domestic firms do not receive any subsidy. As we show below, the subsidy is the policy instrument that allows each nation to control the size of its industry. The corporate income after taxes and subsidy for the representative multinational that operates in nation j is $\hat{\pi}_j + s_j$.

Suppose that firms are heterogeneous with respect to their inherent abilities of becoming multinationals. A firm of type $\theta \in \left[0, n_j\right]$ in nation j faces an idiosyncratic cost $\theta\chi$ of operating internationally. The parameter θ is the efficiency rate that a firm possesses in reducing the individual cost $\chi > 0$ of being a multinational. The more efficient the firm the lower it is this parameter. In any nation, firm $\theta = 0$ is the most efficient one. Its cost of being a multinational is zero. In nation j, firm $\theta = n_j$ is the least efficient. Its cost of being a multinational is $n_j \chi$. Firm θ from nation j operates internationally if and only if

$$\hat{\Pi} + s_k - \theta\chi \geq \hat{\pi}_j \;\Rightarrow\; \hat{\pi}_k + s_k \geq \theta\chi , \qquad j,k = 1,2 , \qquad k \neq j . \tag{5}$$

We examine two scenarios: (i) insensitive multinationals; and (ii) sensitive multinationals. Multinationals are insensitive if their mobility decisions do not depend on subsidies and taxes. In scenario (i), all multinationals are insensitive. In such a setting, even the least efficient firm from nation j decides to become a multinational without any subsidy:

$$\hat{\pi}_k > n_j \chi , \qquad j,k = 1,2 , \qquad k \neq j . \tag{6}$$

Condition (6) implies that $m_j = n_j$, $j = 1,2$.

In scenario (ii), some firms from nation j are sensitive to nation k's subsidy and taxes. In this setting, some inefficient firms from nation j decide against becoming multinational even in the presence of a subsidy in nation k:

$$n_j \chi > \hat{\pi}_k + s_k , \qquad j,k = 1,2 , \qquad k \neq j . \tag{7}$$

Letting m_j denote the firm that is indifferent between being a multinational and operating in nation j only in the setting with sensitive multinationals, conditions (5) and (7) imply

$$n_j > m_j = \left(\hat{\pi}_k + s_k\right) / \chi , \qquad j,k = 1,2 , \qquad k \neq j , \tag{8}$$

In this paper, $\hat{\pi}_k > 0$ and $s_k \geq 0$, $k = 1,2$. Hence, condition (8) implies that $m_j > 0$, $j = 1,2$. Since m_j is also the number of multinationals from nation j, we know that it always pays for a firm $\theta \in \left[0, m_j\right)$ from nation j to operate internationally. On the other hand, it always pays for a firm $\theta \in \left(m_j, n_j\right]$ from nation j to operate at home only.

The disposable income in nation j, w_j, is the sum of this nation's initial endowment of numeraire good and its total corporate income after taxes and subsidies net of mobility costs:

$$w_j = \omega_j + n_j \hat{\pi}_j + m_j \left(\hat{\pi}_k + s_k\right) - \chi \int_0^{m_j} \theta \, d\theta = \omega_j + n_j \hat{\pi}_j + m_j \left(\hat{\pi}_k + s_k\right) - \frac{\chi m_j^2}{2} , \; j,k = 1,2 , \; j \neq k . \tag{9}$$

Consider now the economy's consumption side. For simplicity, we assume that there is a single consumer in each nation. The consumer in nation j derives utility $u\left(x_j, y_j, G_j, E\right)$ from consumption of x_j units of the numeraire good, y_j units of the tradeable private good, G_j units of a national public good and E units of carbon dioxide. To facilitate comparisons, we assume that $u\left(x_j, y_j, G_j, E\right) = x_j + b\left(y_j\right) + f\left(G_j\right) - h\left(E\right)$, where $b' > 0$, $b'' < 0$, $f' > 0$, $f'' < 0$, $h' > 0$ and $h'' > 0$. The assumptions that utility is quasilinear and separable in consumption of private and public good or bad quantities are standard in public and environmental economics.

The consumer in nation j chooses non-negative $\left\{x_j, y_j\right\}$ to maximize $u\left(x_j, y_j, G_j, E\right)$ subject to

$$x_j + py_j = w_j, \tag{10}$$

taking G_j, E, p and w_j as given. Assuming an interior solution to the consumer's maximization problem, the first order conditions are the budget constraint (10) and

$$b'\left(y_j\right) = p, \quad j = 1, \ldots, J, \tag{11}$$

For each j, equation (11) informs us that the consumer equates the marginal utility from consumption of tradeable good to its price. Strict concavity of the sub-utility $b\left(.\right)$ implies that the sufficient second order condition is satisfied, the solution to each utility maximization problem is unique and we can implicitly define $y_j\left(p\right)$, the demand function for the tradeable good in nation j. Note that equations (11) imply $y_j\left(p\right) = y\left(p\right)$, $j = 1, 2$. The consumer in nation j consumes $x_j\left(p, w_j\right)$ units of numeraire good, where $x_j\left(p, w_j\right) = w_j - y\left(p\right)$. Plugging the optimal functions into the utility function yields $\hat{u}\left(w_j, G_j, E\right) \equiv u\left(x_j\left(p, w_j\right), y\left(p\right), G_j, E\right)$, $j = 1, 2$.

The global market for the tradeable good clears if and only if

$$Jy\left(p\right) = \sum_{j=1}^{J} Q_j\left(p, r_j, l_j\right) \equiv Q\left(p, \mathbf{r}, \mathbf{l}\right), \tag{12}$$

where $Q_j\left(.\right) \equiv Nq_j\left(.\right)$ is nation j's supply and $Q\left(.\right)$ is the global supply. On the left side of equation (12) we have the global demand for the tradeable good. Nation j is a net exporter (importer) of the tradeable good if $Q_j\left(.\right) > \left(<\right) y\left(.\right)$.

Each nation has a benevolent government. The objective function of the government in nation j is $\hat{u}\left(w_j, G_j, E\right)$. For comparison purposes, we also consider allocations in which a utilitarian global planner maximizes global welfare. Its objective function is $\sum_{j=1}^{2} \hat{u}\left(w_j, G_j, E\right)$.

Each nation finances the provision of its national public good with the entire revenue it collects with carbon and corporate income taxes. We assume that it takes one unit of numeraire good to provide one unit of public good in each nation. The fiscal budget balances in nation j if and only if

$$n_j\left(\tau_j \hat{v}_j + t_j e_j\right) + m_k\left(\tau_j \hat{v}_j + t_j e_j - s_j\right) = G_j, \quad j,k = 1,2, \qquad k \neq j. \tag{13}$$

The left side of equation (13) is the total revenue from collection of both taxes in nation j. The right side of equation (13) is nation j's public expenditure.

4.1. Global Optima

We first consider the global welfare maximization problem in the setting with insensitive multinationals. As firms are immobile in this case, the analysis is simpler and provides a useful benchmark for comparisons, which enable us to identify the effects that international mobility cause to the allocation of resources.

4.1.1. Insensitive Multinationals

Since firms are immobile, $s_1 = s_2 = 0$. The planner's constraint set satisfies feasibility constraints for the instruments, $G_j \geq 0$, $0 \leq \tau_j \leq 1$, $0 \leq t_j \leq \left(1-\tau_j\right)\hat{v}_j / e_j$, $j = 1,2$, equations (9) and (13). Plugging equations (9) and (13) into the objective function, the planner chooses feasible $\{\tau_1, \tau_2, t_1, t_2\}$ to maximize $\sum_{j=1}^{J} \hat{u}\left(\omega_j + n_j\hat{\Pi} - \frac{\chi n_j^2}{2}, N\left(\tau_j \hat{v}_j + t_j e_j\right), N\sum_{i=1}^{J} e_i\right)$, taking p as given, where $N = \sum_{i=1}^{2} n_i$. Assuming an interior solution, the first order conditions yield (for $k = 1,2$):[3]

$$\left(1-\tau_k\right)\hat{v}_k\left[f'\left(G_k\right)-1\right] = -r_j e_r^k\left[r_k f'\left(G_k\right) - 2h'\left(E\right)\right], \tag{14}$$

$$\left(1-\tau_k\right)e_k\left[f'\left(G_k\right)-1\right] = -e_r^k\left[r_k f'\left(G_k\right) - 2h'\left(E\right)\right]. \tag{15}$$

[3] The strict convexity of the cost function and strict concavity of the utility function imply that the sufficient second order conditions are satisfied in all welfare maximization problems in this paper. All solutions are unique.

Since $1 > \tau_k$ and $\hat{v}_k - r_k e_k = \hat{\pi}_k / (1-\tau_k) > 0$, combining equations (14) and (15) imply

$$f'(G_k) = 1, \qquad k = 1,2, \tag{16}$$

$$r_k = \frac{2h'(E)}{f'(G_k)} = 2h'(E), \qquad k = 1,2. \tag{17}$$

Equations (16) are the efficient conditions for provision of the national public goods. In each nation, the efficient level of the public good solves the equalization of marginal utility from consumption of the public good to the good's marginal cost. Since $f'' < 0$, equations (16) imply $G_1^* = G_2^* = G^*$.[4] The global optimum yields equal national public expenditures.

Equations (17) are the efficient conditions for reduction of global carbon emissions. For each k, the first equation in (17) demonstrates that the efficient relative carbon tax should be equal to the efficient marginal rate of substitution between consumption of the reduction in global carbon emission and consumption of the national public good. For each k, the last equation in (17) follows from equation (16). Given equations (16), the efficient relative carbon taxes equal the sum of marginal damages from global carbon emission. Since $h'' > 0$, equations (17) imply $r_1^* = r_2^* = r^*$. The global optimum implies equalization of national relative carbon taxes.

Given r^*, the efficient output price, p^*, solves $Jy^*(p) = Q(p, r^*(p), \mathbf{l})$. Let $a_j^* = a_j(r^*; l_j, p^*)$, $q_j^* = q_j(r^*; l_j, p^*)$, $e_j^* = e_j(r^*; l_j, p^*)$, $\hat{v}_j^* = \hat{v}_j(r^*; l_j, p^*)$ and $\hat{\pi}_j^* = \hat{\pi}_j(r^*; l_j, p^*)$ denote nation j's levels of abatement, output, carbon emission and corporate income before and after taxes for the representative firm in the global optimum, respectively.

Given G^*, p^* and r^*, the following equations determine the efficient nominal carbon tax, t_j^*, and corporate-income-tax rate, τ_j^*, in nation j (for $j = 1,2$):

$$\tau_j^* \hat{v}_j^* + t_j^* e_j^* = g^*, \tag{18}$$

$$\tau_j^* r^* + t_j^* = r^*, \tag{19}$$

where $g^* \equiv G^*/N$. For $j = 1,2$, the solution to equations (18) and (19) is

$$t_j^* = \frac{r^*(\hat{v}_j^* - g^*)}{\hat{v}_j^* - r^* e_j^*}, \tag{20}$$

[4] We let superscript "*" denote the globally optimal quantities. In the Nash equilibria, we use the superscript "**".

$$\tau_j^* = \frac{g^* - r^* e_j^*}{\hat{v}_j^* - r^* e_j^*}. \tag{21}$$

Consistent with our assumption that the global optimum is interior, equations (20) and (21) inform us that we must have $\hat{v}_j^* > g^* > r^* e_j^*$, $j = 1,2$. The global optimum is interior if and only if $\hat{v}_2^* > g^* > r^* e_1^*$, since $\hat{v}_1^* > \hat{v}_2^*$ and $e_1^* > e_2^*$. The global optimum does not feature equal nominal carbon taxes and corporate-income-tax rates across nations. If $t_1^* > t_2^*$, then $\tau_1^* < \tau_2^*$.

The global optimum involves asymmetric national products and international trade. Since $r_j^* = r^*$, $j = 1,2$, the results $a_l^j > 0$ and $q_l^j > 0$, $j = 1,2$, imply $a_1^* > a_2^*$ and $q_1^* > q_2^*$. Then, $A_1^* > A_2^*$ and $Q_1^* > Q_2^*$, where $A_j^* \equiv N a_j^*$, $j = 1,2$. The market-clearing condition (12) implies that $Q_j^* > y^*$ if $Q_j^* > Q^*/2$. The resource-rich nation exports output to the resource-poor nation.

4.1.2. Sensitive Multinationals

Suppose now that some multinationals from nation j are sensitive to nation k's subsidy and taxes. With mobile firms, the size of the industry in any nation is variable. The size of nation j's industry is

$$I_j = n_j + m_k = n_j + \left(\hat{\pi}_k + s_k\right)/\chi, \qquad j,k = 1,2, \qquad k \neq j. \tag{22}$$

Since all firms that operate in nation j share the land resource available for production equally, the corporate incomes (before and after subsidy and taxes) of the representative firm in nation j depend on this nation's industry size. The amount of land that each firm utilizes in nation j is

$$l_j\left(I_j\right) = \left(1-\alpha\right) L_j / I_j, \qquad j = 1,2. \tag{23}$$

Since L_j is fixed, there is crowding in industrial land in nation j, $j = 1,2$. An expansion in industry size in nation j reduces the amount of land that the representative firm utilizes which increases its operating cost and reduces its abatement and output supplies and its carbon emission.

Given equations (22) and (23), a unilateral change in each of the policy instruments in nation j produces the following effects on the size of nation j's industry ($j,k = 1,2,\ k \neq j$):

$$\frac{\partial I_j}{\partial s_j} = \frac{\beta I_j}{D_j} > 0, \quad \frac{\partial I_j}{\partial \tau_j} = -\frac{\beta I_j \hat{v}_j}{D_j} < 0, \quad \frac{\partial I_j}{\partial t_j} = -\frac{\beta I_j e_j}{D_j} < 0, \tag{24}$$

$$\frac{\partial I_j}{\partial s_k} = \frac{\partial I_j}{\partial \tau_k} = \frac{\partial I_j}{\partial t_k} = 0\,, \tag{25}$$

where $D_j \equiv I_j - \beta\left(1-\tau_j\right) l_j c_l^j > 0$. According to results (24), the industry in nation j expands as the nation increases the amount of subsidy and contracts as the nation increases either the nominal carbon tax or the corporate-income-tax rate. The subsidy decreases while either type of tax increases the tax burden for a representative multinational that operates in the nation. According to results (25), the industry in nation j is unaffected by any policy change that nation k implements. This inaction follows from the fact that the corporate income after taxes that the representative firm earns in nation j is unaffected by any type of policy change in nation k.

The planner's constraint set satisfies feasibility constraints for the policy variables, and equations (9), (13), (22) and (23). Combining equations (9) and (22) yields

$$w_j = \omega_j + n_j \hat{\pi}_j + \frac{m_j\left(\hat{\pi}_k + s_k\right)}{2}, \qquad j,k = 1,2\,, \qquad k \neq j\,. \tag{26}$$

Plugging equations (13) and (26) into the objective function, we obtain

$$\sum_{j=1}^{2} \hat{u}\left(\omega_j + n_j \hat{\pi}_j + \frac{m_j\left(\hat{\pi}_k + s_k\right)}{2}, n_j\left(\tau_j \hat{v}_j + t_j e_j\right) + m_k\left(\tau_j \hat{v}_j + t_j e_j - s_j\right), N_1 e_2 + N_2 e_2\right), \tag{27}$$

where $k = 2$ if $j = 1$ and vice versa. The planner chooses feasible $\{s_1, s_2, \tau_1, \tau_2, t_1, t_2\}$ to maximize (27), accounting for equations (22) and (23) and taking p as given. Assuming an interior solution, the first order conditions yield equations (16), (17) and the following ($i = 1,2$):

$$\tau_i \hat{v}_i + t_i e_i - s_i = r_i e_i - l_i c_l^i\,. \tag{28}$$

For each i, $i = 1,2$, equation (28) informs us that the efficient subsidy in nation i is the subsidy amount that equates this nation's marginal benefit of expanding its industry size (left side of equation (28)) to this nation's marginal cost of doing so (right side of equation (28)). Any nation's marginal benefit from expanding its industry size is the net tax revenue that it collects from the marginal multinational that comes from the other nation. Any nation's marginal cost is the sum of the pollution damage and crowding cost that the marginal entrant causes.

In addition to equations (16), (17) and (28), the global optimum satisfies equations (13), (22) and (23). The derivation of the efficient conditions for the nominal carbon taxes and corporate-income-tax rates are a bit more complex here than in the previous subsection because there are many more equations to solve. However, the procedure is similar.

4.2 Nash Equilibria

We now consider settings in which each nation implements its optimal national policy unilaterally. We first examine the scenario where all multinationals are insensitive.

4.2.1. Insensitive Multinationals

Since firms are immobile, $s_j = 0$, $j = 1,2$. Nation j chooses $\{\tau_j, t_j\}$ to maximize $\hat{u}\left(\omega_j + n_j\hat{\Pi} - \frac{\chi n_j^2}{2}, N\left(\tau_j\hat{v}_j + t_j e_j\right), N\sum_{i=1}^{2} e_i\right)$ subject to the feasibility constraints for the policy variables, taking the price of output and all other nations' choices as given. Assuming an interior solution, the first order conditions yield (for $j = 1,2$):

$$\left(1-\tau_j\right)\hat{v}_j\left[f'\left(G_j\right) - \frac{n_j}{N}\right] = -r_j e_r^j\left[r_j f'\left(G_j\right) - h'\left(E\right)\right], \tag{29}$$

$$\left(1-\tau_j\right)e_j\left[f'\left(G_j\right) - \frac{n_j}{N}\right] = -e_r^j\left[r_j f'\left(G_j\right) - h'\left(E\right)\right]. \tag{30}$$

Since $1 > \tau_j$ and $\hat{v}_j - r_j e_j = \hat{\pi}_j / \left(1-\tau_j\right) > 0$, $j = 1,2$, equations (29) and (30) imply

$$f'\left(G_j\right) = \frac{n_j}{N}, \qquad j = 1,2, \tag{31}$$

$$r_j = \frac{h'\left(E\right)}{f'\left(G_j\right)} = \frac{Nh'\left(E\right)}{n_j}, \qquad j = 1,2. \tag{32}$$

Equations (31) inform us that the nations provide national public goods at levels that equate their marginal utilities from consumption of the national public good to the national shares of domestic firms in the national tax bases. Remember that each nation's tax base is equal to the total number of firms that operate in the nation, N. Since national incomes account for profits of domestic firms only, the opportunity cost associated with provision of each unit of public good equals the national share of domestic firms in the national tax base. Since $f'' < 0$, we can appeal to the implicit function theorem to define $G_j^{**}\left(n_j\right)$, the optimal public expenditure in nation j in the Nash equilibrium as a function of this nation's number of domestic firms, for $j = 1,2$. Then, we obtain the following important result:

$$\frac{dG_j^{**}}{dn_j} = \frac{1}{Nf''\left(G_j^{**}\right)} < 0, \qquad j = 1,2. \tag{33}$$

Each nation's optimal public expenditure in the Nash equilibrium decreases as its number of domestic firms increases. If $n_1 = n_2 = n$, then $G_j^{**} = G^{**}$, $j = 1,2$. If $n_1 > n_2$, we obtain $G_1^{**} < G_2^{**}$. Utilizing result (33), a comparison between equations (16) and (31) yields $G_j^{**} > G^{*}$, $j = 1,2$. The nations overprovide the national public goods in the Nash equilibrium.

For each j, the first equation in (32) states that each nation sets its relative carbon tax equal to the marginal rate of substitution between consumption of the reduction in global carbon emission and consumption of the national public good. This clearly captures each nation's trade-off between reduction of global carbon emission and provision of the national public good. For each j, the second equation in (32) shows that each nation sets the relative carbon taxes at a rate that exceeds the national marginal damage from global carbon emission. This occurs because the nations overprovide the national public goods.

Equations (32) reveal that if $n_1 = n_2 = n$, then $r_j^{**} = r^{**}$, $j = 1,2$. Since $n = N/J$, we obtain $r^{**} = r^{*}$ by comparing equations (17) and (32). Thus, in the Nash equilibrium with insensitive multinationals and symmetric tax bases, all nations behave efficiently with respect to their choices of relative carbon taxes. If $n_1 > n_2$, we obtain $r_1^{**} < r_2^{**}$. For $n_j > (\leq) n$, $r_j^{**} < (\geq) 2h'\left(E^{**}\right)$. In sum, in the Nash equilibrium with insensitive multinationals, the larger the nation's domestic share of the tax base the lower it is its relative carbon tax, and the resource-rich (resource-poor) nation taxes carbon emissions at a lower (higher) rate than the efficient one.

The following proposition summarizes our findings so far.

Proposition 1. In the Nash equilibrium with insensitive multinationals, each nation overprovides its national public good. With symmetric tax bases, both nations provide equal amounts of public goods and set their relative carbon taxes efficiently. With asymmetric tax bases, the resource-rich nation provides less public good than the resource-poor nation. The relative carbon tax rate that the resource-poor nation charges exceeds the efficient rate, and the latter exceeds the relative carbon tax rate the resource-rich nation charges.

4.2.2. Sensitive Multinationals

Acting unilaterally, nation j chooses feasible $\{s_j, \tau_j, t_j\}$ to maximize

$$\hat{u}\left(\omega_j + n_j\hat{\pi}_j + \frac{m_j\left(\hat{\pi}_k + s_k\right)}{2}, n_j\left(\tau_j\hat{v}_j + t_je_j\right) + m_k\left(\tau_j\hat{v}_j + t_je_j - s_j\right), N_je_j + N_ke_k\right).$$

taking equations (22) and (23) into account, and taking the other nation's choices and the price of output as given. Assuming an interior solution, the first order conditions yield ($j = 1,2$):

$$\tau_j\hat{v}_j + t_je_j - s_j = r_je_j - l_jc_l^j + \chi m_k, \tag{34}$$

$$f'\left(G_j\right) = 1, \tag{35}$$

$$r_j = \frac{h'\left(E\right)}{f'\left(G_j\right)} = h'\left(E\right). \tag{36}$$

Nation j takes the net benefit that its subsidy produces in nation k as given. As such, its optimal subsidy policy satisfies the equality of the benefit that the marginal entrant in its industry brings to the nation (left side of equation (34)) to the cost that this marginal entrant causes to the nation, which includes a compensation for the mobility cost that the marginal entrant faces (right side of equation (34)). Nation j's optimal policy regarding provision of its national public good satisfies the equality of the marginal benefit of consumption of the public good (left side of equation (35)) to this good's marginal cost of provision (right side of equation (35)). Finally, as the equations (36) make it clear, nation j's optimal policy to control carbon emissions satisfies the equality of the relative carbon tax to the nation's marginal damage from carbon emissions.

While nation j's optimal public good policy is efficient, its optimal subsidy and relative carbon tax are inefficient. The efficiency of nation j's optimal public good policy follows immediately from a comparison between equations (16) and (35): they are identical. Turning to nation j's optimal subsidy policy, we compare equations (28) and (34). We find that the national marginal cost (right side of equation (34)) includes an extra component relative to the global marginal cost (right side of equation (28)). This occurs because the planner takes the marginal benefit that a subsidy provided by nation j produces in nation k, which in the global optimum exactly matches the mobility cost that the marginal entrant in nation j's industry faces. As the national marginal cost is higher than the global marginal cost, while national and global marginal benefits are the same, there is too little entry in nation j 's industry in the Nash equilibrium. The national industries are larger in the global optimum. Comparing equations (17) and (36), we see that nation j 's optimal relative carbon tax is inefficient because its policy to control carbon emissions neglects the marginal damage that its carbon emissions cause in nation k .

Comparing the Nash equilibria, we find that if nations need to make efforts to attract multinationals, they will be more sensitive to the tax burden that its taxes cause to multinationals. The optimal national subsidy policies nullify the excessive burden that multinationals face relative to domestic firms. As the optimal national policies for provision of public goods and control of carbon emissions demonstrate, the nations essentially treat multinationals as domestic firms in the setting with sensitive multinationals. The optimal national policies for public goods and control of carbon emissions in the setting with sensitive multinationals are exactly what they would be in a hypothetical setting where all firms that operate in each nation are domestic firms. The optimal national policies for public goods and control of carbon emissions in the setting with insensitive multinationals demonstrate that there is excessive tax burden in both nations.

4.3. Extension: Ban on Subsidies

Suppose that, for political reasons, both nations ban subsidy policies that attract multinationals. The ban has no impact on the allocation of resources if multinationals are insensitive. However, the ban is inefficient if multinationals are sensitive. As we demonstrate below, in the second best, the planner distorts the efficient policies for provision of national public goods and control of carbon emissions “downwards”; that is, the planner reduces the public good levels and the relative carbon tax rates in order to imperfectly accommodate the absence of the essential instruments to control national industry sizes. Acting unilaterally, each nation also distorts its national policy for provision of public goods. The nations underprovide public goods and subsequently reduce their relative carbon tax rates in order to be more competitive in attracting multinationals.

4.3.1. Second Best

Facing $s_1 = s_2 = 0$ as additional constraints in its maximization problem, the planner chooses feasible $\{\tau_1, \tau_2, t_1, t_2\}$ to maximize (27), accounting for equations (22) and (23), and taking p as given. Assuming an interior solution, the first order conditions yield (for $j = 1, 2$)

$$f'\left(G_j\right)=\frac{I_j}{I_j-\left(\tau_j\hat{v}_j+t_je_j+l_jc_l^j-r_je_j\right)/\chi}>1, \tag{37}$$

$$r_j=\frac{2h'(E)}{f'\left(G_j\right)}=\frac{2h'(E)\left[I_j-\left(\tau_j\hat{v}_j+t_je_j+l_jc_l^j-r_je_j\right)/\chi\right]}{I_j}<2h'(E). \tag{38}$$

From the first best problem, we know that $\tau_j\hat{v}_j+t_je_j+l_jc_l^j-r_je_j>0$ when the planner's first order condition is evaluated at $s_j=0$. Hence, for each j, the denominator of the ratio in the right side of the equation in (37) is smaller than I_j, implying that the ratio is larger than one. Relative to its first-best policies for provision of national public goods, the planner in the second best finds it optimal to underprovide the national public goods. As for control of carbon emissions, for each j, the planner in the second best adopts the same rule that it uses in the first best, as the first equation in (38) demonstrates. However, since the planner distorts the provision of the public good in each nation in the second best, the relative carbon tax rate in each nation ends up being lower than the first-best rate, as the inequality for each j in (38) shows.

4.3.2. Nash Equilibrium

Facing $s_j=0$, the optimal unilateral policies in nation j satisfy the following conditions:

$$f'\left(G_j\right)=\frac{n_j}{I_j-\left(\tau_j\hat{v}_j+t_je_j+l_jc_l^j-r_je_j\right)/\chi}>1, \qquad j=1,2, \tag{39}$$

$$r_j=\frac{h'(E)}{f'\left(G_j\right)}=\frac{h'(E)\left[I_j-\left(\tau_j\hat{v}_j+t_je_j+l_jc_l^j-r_je_j\right)/\chi\right]}{n_j}<h'(E), \qquad j=1,2. \tag{40}$$

From the maximization problem that nation j solves in the setting in which there is no ban on the subsidy policy, we know that $\tau_j\hat{v}_j+t_je_j+l_jc_l^j-r_je_j>\chi m_k$ when the first order condition is evaluated at $s_j=0$. Hence, denominator in the right side of the equation in (39) is smaller than $I_j-m_k=n_j$, which implies that the ratio in the right side of the equation in (39) is greater than one. It follows that nation j underprovides its national public good. As for the rule that nation j utilizes to set its relative carbon tax, we see that it is identical to the rule that it uses in the setting in which there is no ban on the subsidy policy – compare the first equation in (40) with the first equation in (36). However, as nation j finds it optimal to underprovide its national public good in the absence of the subsidy, the effective relative carbon tax rate is lower in the absence of the subsidy.

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