Title

Trade, Politics,and the Environment: Tailpipe vs. Smokestack

Author

McAusland, Carol

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Carol McAusland[1,2]
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Abstract: Economists interested in the interaction between trade, politics and the environment have restricted their attention almost exclusively to the problem of production related—"smokestack"—pollution. We instead consider consumption related—"tailpipe"—pollution and show that this can reverse a number of core results. For example, we show that the impact of regulation on trade patterns depends on the type of pollution being regulated: while strict smokestack regulation dampens exports of pollution intensive goods, tailpipe regulation may promote these exports. Similarly, we show that pollution type may fundamentally alter the impact of openness on political opposition to environmental regulation: while openness may make dirty industry oppose smokestack regulation more vociferously, it can make industry a less ardent enemy of tailpipe regulation.

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1 Introduction

Consider a list of pressing environmental problems in both the industrialized and developing world: air pollution, solid waste accumulation, climate change, ozone depletion, acidic deposition. Each can be linked to the production or consumption of dirty goods, goods that are often traded. Accordingly, concern for the environment has played a significant role in recent debates over trade liberalization: former U.S. President Bill Clinton declared that he would not support the North American Free Trade Agreement without a side-agreement protecting the environment; environmentalists and other protesters at the 1999 World Trade Organization meetings in Seattle toppled talks to initiate a new round of trade

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[1] Department of Economics, University of California, Santa Barbara, CA 93106. Phone: (805) 893-4823; fax: (805) 893-8830; email: mcauslan@econ.ucsb.edu.

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negotiations.

Economists have devoted much attention to the impact of globalization on the environment, establishing along the way several rules of thumb concerning interactions between trade, politics, and environmental quality. Yet the literature on trade and the environment is markedly incomplete. With few exceptions, this literature has focused exclusively on cases of production-related pollution, which we will call "smokestack" pollution; the problem of consumer related pollution—hereafter referred to as "tailpipe" pollution—has been almost entirely ignored.[3] This omission is not trivial. As noted above, consumption behavior has contributed to many past and ongoing environmental problems. Consider the following examples. Residential waste constitutes between 55 and 65 percent of municipal solid waste (EPA 2002), and accounts for approximately a third of waste deposited in landfill. Accelerated depletion of stratospheric ozone has been linked to the use of Chlorofluorocarbons, which, prior to regulation, were ubiquitous in home refrigeration units and household aerosol products. And prior to the phase-out mandated by the US EPA, residential applications of the pesticide Diazinon accounted for approximately three quarters of its use; Diazinon was one of the leading causes of acute insecticide poisoning for humans and wildlife and one of the top causes of bird kill incidents (EPA 2001). And finally, in the United States motor vehicles are responsible for up to half of the smog-forming volatile organic compounds (VOCs) and nitrogen oxides (NO_x); passenger vehicles also release more than 50 percent of the hazardous air pollutants and up to 90 percent of the carbon monoxide found in U.S.

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[3] Exceptions include Krutilla (1991), López (1994), Copeland and Taylor (1995), Rauscher (1997), Haupt (2000), Schleich (1999), Schleich and Orden (2000), Copeland (2001) and McAusland (2002). López (1994) shows that lowering tariffs on manufactured goods will likely reduce local producer-generated pollution in developing countries, but will likely raise consumer generated pollution and so have an ambiguous net impact on total pollution. Copeland (2001) examines strategic incentives to manipulate environmentally related product standards when cost structures vary for domestic and overseas firms or where producing a variety of product types imposes a re-tooling cost at the firm level. Haupt (2000) examines how firms in open economies choose expenditures on research and development to reduce the pollution intensity of consumption goods. The remaining works are discussed elsewhere in this paper.

urban air (EPA 1993). Nevertheless, excluding consumer generated pollution in analyses of trade and environment interactions would not be a problem if tailpipe and smokestack pollution were effectively equivalent, i.e. if regulating either had an identical effect on political incentives and on trade patterns. However we find that the opposite is true: we show that simply considering a different source of pollution—consumers instead of producers—can reverse several core results on the relationship between politics, environmental regulation and international trade in dirty goods.[4]

The rules of thumb from the trade and environment literature in which we are interested are as follows. Firstly, strict domestic environmental regulation will reduce the competitiveness of pollution intensive industries and thereby hurt a country's exports of dirty goods. Secondly, and following from the first, there is an expectation that producers of dirty goods will oppose strict environmental regulation more vociferously when exposed to overseas competition than when protected by trade barriers. And thirdly, governments without access to tariffs have incentives to distort local environmental policies so as to manipulate the terms of international trade. As Krutilla (1991) provides an extensive analysis of the (mis-)use of environmental policy for terms of trade objectives[5], we focus only on the first two rules of thumb: the relationship between policy stringency and the pattern of trade, and the effect of openness on the policy preferences of a political agent who is captured by dirty industry. As mentioned previously, we find that each of these rules of thumb can be reversed when we consider tailpipe pollution in lieu of smokestack.

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[4] In what follows, the catch-all phrase "dirty goods" will refer to goods generating pollution during production or consumption; we do not analyze the case of a good which is dirty during both production *and* consumption.

[5] If a country cannot use tariffs to manipulate its terms of trade—i.e. raise the world price of its exports and lower the world price of its imports—it has an incentive to distort local environmental policy for this purpose. Krutilla (1991) finds that considering consumption taxes (aimed at consumption related externalities) instead of production taxes (aimed at production related externalities) reverses the direction of these incentives. For example, a country exporting dirty goods wants inefficiently high environmental taxes on production related externalities (so as to curtail world supply) but inefficiently low taxes on consumption related externalities (so as to bolster world demand).

Regarding the relationship between exports and the stringency of environmental policy, the reason for the reversal is straightforward. Strict smokestack regulation in the Home country lowers the productivity of all Home firms, reducing Home's supply of dirty goods, or, alternately, the attractiveness of Home goods abroad: Home's exports fall.[6] But with tailpipe pollution, strict regulation in the Home country makes the Home market a less attractive place to sell goods. This encourages all producers (including Home's dirty goods producers) to sell their wares elsewhere: Home exports rise. This intuition is borne out in our model. We find that strict smokestack regulation unambiguously decreases both capacity allocated to production of goods for export and the volume of exports, and derive conditions under which strict tailpipe regulation unambiguously raises the value of both these variables. In sum, stricter tailpipe regulation may raise a country's exports of dirty goods, while stricter smokestack regulation reduces them. This result has not previously been recognized explicitly. However similar results are implicit in Copeland and Taylor (1995) and Rauscher (1997), who each assume emission taxes are set so as to maximize the welfare of representative agents. In Copeland and Taylor (1995), stricter regulation in the North induces its consumers to demand relatively less of the dirty good and so North, the country with stricter regulation, exports the dirty good. Rauscher (1997) finds that countries with higher degrees of environmental concern will have lower producer prices for dirty (consumption) goods, and so have an advantage in export markets.

Similarly, the type of pollution being regulated also affects how special interest groups view regulatory stringency. This follows from General Agreement on Tariffs and Trade (GATT) prohibitions on extraterritorial pollution regulation: governments may not regulate

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[6] As Chau (2003) points out, this result will not necessarily hold if abatement services are provided by an industry distinct from those producing dirty goods. Raising pollution taxes causes the abatement services sector to expand. This may raise input prices for a country's relatively clean industry, with ambiguous implications for the country's relative supply of dirty and clean final goods.

activities that generate pollution overseas. For smokestack, the GATT ban on extraterritoriality means that governments may regulate only local production processes; for tailpipe, it means that governments may regulate the attributes of all goods consumed within their country[7]. The sensitivity of goods prices and factor returns to environmental regulation varies strikingly with the territorial restrictions allowed.

Consider smokestack regulation. Once open to trade, local consumers are insulated from the burden of local smokestack regulation because they can always buy dirty goods from abroad. Local producers, on the other hand, will suffer the productivity shocks associated with local regulation without any compensatory increase in retail prices. Accordingly, holding the price level constant, openness shifts some of the incidence of smokestack policy away from consumers and onto producers, raising industry opposition to local smokestack regulation relative to autarky.

Compare the impact of openness on the incidence of tailpipe regulation. Tailpipe regulation applies to all goods sold within a country's market, whether that country is open to trade or not. Moreover, because immobile production capacity can escape local tailpipe regulation by producing goods for overseas consumers, in the open economy tightening tailpipe regulation drives goods out of the Home market. Consequently, prices of dirty goods are more responsive—and so consumers are more exposed—to local tailpipe regulation in the open than the closed economy. Conversely, because producers can avoid local tailpipe regulation by producing dirty goods for export, factor returns are less sensitive to—and so producers are better insulated from—tailpipe regulation in the open economy than in au-

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[7] With respect to product regulation, GATT rules also require that regulations satisfy the principle of National Treatment—product rules must not vary across goods depending on their country of origin—and that the regulations have scientific foundation. One controversial case of a product standard satisfying the National Treatment clause but failing to meet the burden of scientific proof is the European Union ban on sales of beef from hormone treated cows. The World Trade Organization sided with the United States in its complaint against the ban on the grounds that there exists no scientific evidence that the health of humans consuming said beef is adversely affected.

tarky; holding the price level constant, openness may therefore reduce industry opposition to tailpipe regulation.

In sum, openness may make producers of dirty goods more fervent opponents of smokestack regulation but less ardent enemies of tailpipe regulation than they would be in autarky. These results contribute to the growing literature on the political economy of environmental regulation in open economies. In this literature, only Schleich (1999), Schleich and Orden (2000) and McAusland (2002) consider consumption related pollution[8], and only McAusland (2003) and Gulati (2003) examine the impact of opening up a closed economy.[9] We follow McAusland (2002) in using a standardized treatment of political economy, and show that the effect of openness on political opposition to environmental policy can depend critically on the type of pollution being regulated.

The paper is laid out as follows. Section 2 gives the basic setup and solves for the political agent's preferred level of smokestack and tailpipe regulation in the closed economy. Section 3 examines the agent's preferred emission cap when the economy is small and open to free trade; we begin with the standard case of smokestack regulation and then show how considering tailpipe regulation instead can reverse some key results. Section 4 revisits the impact of openness on regulation when emission taxes are used instead of direct emission

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[8] Treating emissions as one for one with production, Schleich (1999) examines a small open economy and shows that government will not use trade taxes to transfer rents to firms when pollution is production related, but will when it is consumption related. Schleich and Orden (2000) re-consider this question in a large economy context and find governments will exploit trade taxes in the presence of each type of pollution. McAusland (2002) examines how harmonizing tailpipe policies affects the welfare of identical countries.

[9] Fredriksson (1997) and Bommer and Schulze (1999) each model small open economies and consider the effect of an exogenous increase in the price of dirty goods, obtaining opposite results. In Fredriksson (1997) the price increase raises the opportunity cost of abatement, thereby inducing dirty industry to increase its bid for weak environmental regulation; hence the price increase reduces the pollution tax and raises total pollution. In Bommer and Schulze (1999) the price increase pacifies dirty industry, enabling the government to favor its environmental lobby with more environmental quality via stricter regulation. McAusland (2003) compares policy preferences in a small open economy with their autarkic equivalent, and finds that producers of dirty goods want weaker smokestack regulation in the small open economy provided the world price of dirty goods is not sufficiently low. Gulati (2003) finds that whether trade liberalization weakens environmental policy depends in part on the fraction of dirty goods that are consumed by citizens not represented by lobby groups.

caps. Section 5 discusses caveats to our analysis while Section 6 concludes. Appendices B and C offer companion analyses of smokestack and tailpipe regulation in a large open economy.

2 Model

The country considered, Home, is endowed with gross capacity X to produce dirty goods Q, with net output increasing in the emissions, e, associated with a unit of the good: $Q = f(e)X$ where f is increasing and concave. For simplicity we assume f is iso-elastic with elasticity $\sigma \equiv \frac{f'(e)e}{f(e)} > 0$. In the case of tailpipe pollution, e is the emissions generated per unit of the dirty good consumed; for smokestack e is emissions per unit produced. Regarding tailpipe pollution, it is implicit in this structure that the pollution intensity of goods is determined *at the factory*, as would be the case with the installation of catalytic converters or more fuel efficient engines in passenger vehicles for example. Note, however, that the analytics would be essentially unchanged if we instead considered abatement undertaken by consumers directly; see footnote 21.

So as to round out the model, we assume there is also a numeraire clean good for which productive capacity, Y, equals output. All capacity is owned by Home's N citizens, with X_i, Y_i denoting the endowment portfolio of some citizen i. We assume that a citizen's entire consumption must be financed out of earnings from her factor endowments, and that factor markets are perfectly competitive such that, if the retail price of a unit of dirty goods is P, then citizen i's income and budget for financing her own consumption is $I_i = \pi X_i + Y_i$ where

$$\pi = Pf(e) \tag{1}$$

is the return paid to a unit of dirty capacity.

We assume that pollution has no transboundary component: the externality is purely local. We further assume that each citizen's utility is quasi-linear in the dirty and clean goods, and linear in local pollution:

$$U_i = v(q_i) + y_i - \beta Z$$

where q_i and y_i are individual consumptions of dirty and clean goods, β is the marginal disutility from pollution, and Z is local pollution with $Z = e\sum_i^N q_i$ when pollution is tailpipe and $Z = eQ$ when pollution is smokestack.

Consumer optimization yields

$$P = v'(q), \tag{2}$$

$y_i = I_i - Pq$ where we drop the individual subscripts on q from here forward.[10] For future reference define $\epsilon = -\frac{dq}{dP}\frac{P}{q}$ as the price elasticity of demand for dirty goods. So as to facilitate future comparisons, we assume from here forward that the price elasticity of demand for dirty goods, ϵ, is a constant.

Using expressions for q and y_i we rewrite i's individual welfare as

$$W_i = C + I_i - \beta Z \tag{3}$$

where $C = v(q) - Pq$ is individual consumer surplus, which depends on e only indirectly via P:

$$\frac{dC}{de} = \frac{dC}{dP}\frac{dP}{de} = -q\frac{dP}{de}. \tag{4}$$

Now consider the emission cap preferred by citizen i. Differentiating eq. 3 with respect to e gives

$$\frac{dW_i}{de/e} = -qP\frac{\hat{P}}{\hat{e}} + X_i\pi\frac{\hat{\pi}}{\hat{e}} - \beta Z\frac{\hat{Z}}{\hat{e}} \tag{5}$$

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[10] By dropping the i subscripts on q we implicitly assume each citizen i has a sufficiently large endowment Y_i to afford dirty good consumption at level q.

where ˆ indicates percentage change, for example $\hat{P} = \frac{dP}{P}$. Since eq. 5 is twice continuously differentiable and locally concave in e—this is confirmed in Appendix A—then $i's$ preferences over e are single peaked. From eq. 5 we see that i's preferred emission cap balances the impacts of environmental regulation on i's consumer surplus from consuming dirty goods, i's income, and the disutility i suffers from pollution. In the sections to follow we analyze how openness and pollution type alter the size of these impacts. We do so by showing how the sensitivity of prices, factor returns, and total pollution to environmental regulation—measured by $\frac{\hat{P}}{\hat{e}}$, $\frac{\hat{\pi}}{\hat{e}}$ and $\frac{\hat{Z}}{\hat{e}}$ respectively—vary with the trade regime and the type of pollution regulated. We then show how changes in sensitivity feed through to affect the stringency of environmental policy itself.

2.1 Politics

So far we have examined only the preferences of individual Home citizens; we now specify how policy is actually set. Given that we assume individual preferences are quasi-linear in private goods and linear in pollution, then in a variety of political economy models—majority rules, an incumbent government influenced by contributions from a single lobby group, or a political elite—the objective function for the decision maker is a monotonic transformation of eq. 3 when evaluated at "represented" endowments X_D, Y_D.[11] Furthermore, these represented endowments are invariant in the model to both the instrument level and the trade regime and so can be treated as parameters of political economy. With this

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[11] For example, in a majority rules framework with costless voting X_D is simply the endowment of the median voter; when policy is set by an uncontested minority elite with $M < N$ members as in Deacon (1999) then $X_D = \frac{\sum_{m=1}^{M} X_m}{M}$ where X_m is the endowment of member m of the elite; when policy is set by an incumbent government that maximizes a weighted sum of local Utilitarian welfare and contributions from a single lobby group—a simplification of the Grossman and Helpman (1994) model—then $X_D = \frac{X+\gamma\sum_{l=1}^{L} X_l}{N+\gamma L}$ where L is the (exogenously determined) number of members in the lobby group, X_l represents the endowment of lobby group member l, and γ is the weight assigned by the government to contributions. These values are derived in McAusland (2002).

in mind, we define a politically motivated decision maker D and assume that D sets Home's emission cap e_D so as to maximize eq. 3 when evaluated at X_D, Y_D. Thus e_D solves

$$\frac{dW_D}{de/e} = -Pq\frac{\hat{P}}{\hat{e}} + \pi X_D \frac{\hat{\pi}}{\hat{e}} - \beta Z \frac{\hat{Z}}{\hat{e}} = 0\,. \tag{6}$$

For the sake of variety we will alternately refer to D as Home's political agent or Home's captured regulator, and to X_D as the dirty capacity represented by D or as the vested interests of D's constituents. Treatments of political economy in the literature on environmental policy commonly assume that representatives of dirty industry unduly influence environmental policy; in our framework this is consistent with a decision maker who has an above average interest in the polluting industry, i.e. $X_D > \frac{X}{N}$. However, the tools of our analysis are equally valid when $X_D < \frac{X}{N}$, that is, for a decision maker with constituents who are linked to the dirty good sector predominately as consumers.

Using eq. 6 and the envelope theorem, we also see that $\text{sgn}\left[\frac{de_D}{dX_D}\right] = \text{sgn}\left[\frac{d\pi}{de}\right]$ and so the relationship between X_D and e_D—the regulatory stringency D prefers—depends solely on whether the return to dirty capacity is increasing or decreasing in the emission cap. We anticipate results from sections below by pointing out here that $\frac{d\pi}{de} \geq 0$ whenever demand for dirty goods is price elastic (i.e. $\epsilon > 1$); see equations 7, 11 and 17. However, if instead demand for dirty goods were price inelastic, in autarky stricter regulation would *raise* π.[12] The possibility that environmental regulation may be *beneficial* to the polluting industry is not new; see, for example, Buchanan and Tullock (1975) and Hoekman and Leidy (1993). It arises in the present model because environmental regulation can mimic collusion when demand is price inelastic, since the supply reduction that results from reduced e generates a price increase that more than compensates for lost productivity when $\epsilon < 1$. Moreover, this relationship is not exclusive to command-and-control regulation; as we show in footnote 26,

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[12] Indeed, if Home is large then $\frac{d\pi}{de}$ may be negative in the open economy as well when $\epsilon < 1$; see equations 31 and 35 in Appendices B and C to confirm.

even when emission taxes are used the relationship between π and regulatory stringency is positive in our model when $\epsilon < 1$. However, because we are interested in the conventional scenario in which regulating pollution *harms* producers of dirty goods, we assume from here forward that $\epsilon > 1$; we discuss cases in which demand is inelastic in Section 5.

2.2 Autarky

We now characterize the political agent's preferred policy level in the closed economy; in order to facilitate later comparisons, denote all autarkic values by a superscript a. Goods market clearance requires domestic supply and demand for dirty goods be equal; this implies $q^a = \frac{f(e)X}{N}$. Differentiating equations 1 and 2 and converting to percentage changes gives

$$\frac{\hat{P}^a}{\hat{e}} = -\frac{\sigma}{\epsilon} \tag{7}$$

$$\frac{\hat{\pi}^a}{\hat{e}} = \frac{\sigma[\epsilon - 1]}{\epsilon}. \tag{8}$$

Because Home is closed to trade all goods produced locally are also consumed locally, and so the amount of pollution created locally, $Z^a = ef(e)X$, is identical regardless of whether pollution is a by-product of production or consumption. The sensitivity of pollution to regulation is similarly identical across the pollution types:

$$\frac{\hat{Z}^a}{\hat{e}} = 1 + \sigma. \tag{9}$$

Substitute these values into eq. 6 to get

$$\frac{dW_D^a}{de/e} = P^a q^a \frac{\sigma}{\epsilon} + P^a f(e) X_D \frac{\sigma[\epsilon - 1]}{\epsilon} - \beta e f(e) X[1 + \sigma]. \tag{10}$$

When set equal to zero, eq. 10 implicitly defines e_D^a, D's preferred emission cap in autarky.

3 The Small Open Economy

Next we consider the open economy. We focus on two things: how strict environmental regulation affects exports, and how openness affects each of the competing concerns dictating the decision maker's choice of e. Denote values for the Rest of the World (ROW) by asterisks. So as to focus our study we restrict our attention to the case of a small open economy; accordingly, Home treats ROW values as exogenous; Appendices B and C analyze smokestack and tailpipe regulation when Home is instead large.

We begin our analysis with the case of smokestack pollution, since most prior research on trade and environment interactions has focused on this type of pollution. Section 3.3 provides comparable analysis for the case of tailpipe pollution.

3.1 Trade and Smokestack Regulation

Because Home is small, the local price of dirty goods P^s equals the fixed world price P^*, and so individual consumption is independent of e. Define by E Home's net exports of dirty goods; with smokestack regulation $E^s = f(e)X - Nq^s$.

Proposition 1 *Stricter smokestack regulation reduces Home's exports of dirty goods.*

Proof. Differentiating gives $\frac{dE^s}{de/e} = f(e)X\sigma > 0$. ■

Proposition 1 replicates the result, common in the literature on trade and environment interactions, that weaker smokestack regulation promotes exports of dirty goods. This relationship arises because an increase in the emission cap raises the productivity of Home firms, thereby increasing Home supply of dirty goods. Since consumer prices are fixed demand is unchanged and so exports necessarily rise.[13]

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[13] If Home were instead large then the increase in Home supply would lower the world price. Equation 29 in Appendix B confirms that the resulting increase in demand would be smaller than the expansion of Home supply. Footnote 18 similarly confirms $\frac{dE^s}{de/e} > 0$ when capacities X and Y are produced using domestically mobile intermediate inputs.

3.2 Openness and Smokestack Politics

We now turn our attention to examining how openness affects the preferences of the political agent. For this we must derive $\frac{\hat{P}}{\hat{e}}^s$, $\frac{\hat{\pi}}{\hat{e}}^s$ and $\frac{\hat{Z}}{\hat{e}}^s$ in the open economy. Since prices in the small open economy are, by definition, independent of Home behavior then $\frac{\hat{P}}{\hat{e}}^s = 0$ and so

$$\frac{\hat{\pi}}{\hat{e}}^s = \sigma. \tag{11}$$

And because pollution derives from production of goods, then regardless of the pattern and volume of trade $Z^s = ef(e)X$ and so $\frac{\hat{Z}}{\hat{e}}^s = 1 + \sigma$, exactly as in autarky.[14]

Substitute these values into eq. 6 to characterize the decision maker's preferred cap on smokestack emissions, e^s_D, in the open economy. e^s_D solves

$$\frac{dW^s_D}{de/e} = P^* f(e) X_D \sigma - \beta Z^s [1 + \sigma] \tag{12}$$

when set equal to zero; the local concavity of W^s_D in e is confirmed in Appendix A.

Proposition 2 *The impact of openness on the smokestack emission cap is unambiguous if* $(P^* - P^a)\left(X_D - \frac{X}{N}\right) > 0$. *In particular,*

1. *if* $P^* \geq P^a$ *and* $X_D > \frac{X}{N}$ *then* $e^a_D < e^s_D$;
2. *if* $P^* \leq P^a$ *and* $X_D < \frac{X}{N}$ *then* $e^a_D > e^s_D$.

Proof. Evaluate $\frac{dW^s_D}{de/e}$ at $e = e^a_D$; if this expression is positive then the single-peakedness of W^s_D in e indicates that D perceives e^a_D as too strict in the open economy and so chooses $e^s_D > e^a_D$; if instead $\left.\frac{dW^s_D}{de/e}\right|_{e=e^a_D} < 0$ then again by the single-peakedness of W^s_D in the emission cap $e^s_D < e^a_D$. Subtract $\frac{dW^a_D}{de/e}$ from $\frac{dW^s_D}{de/e}$ and evaluate the entire expression at $e = e^a_D$ (recall $\left.\frac{dW^a_D}{de/e}\right|_{e=e^a_D} = 0$ by construction). This gives

$$\begin{aligned}\left.\frac{dW^s_D}{de/e}\right|_{e=e^a_D} &= P^* f(e^a_D) X_D \sigma - \beta Z^s \frac{\hat{Z}}{\hat{e}}^s - \left.\frac{dW^a_D}{de/e}\right|_{e=e^a_D} \\ &= q^a \sigma \left[(P^* - P^a) \frac{X_D/X}{1/N} + \frac{P^a}{\epsilon} \left[\frac{X_D/X}{1/N} - 1 \right] \right]. \end{aligned} \tag{13}$$

When $P^* \geq P^a$ and $X_D > \frac{X}{N}$ the bracketed terms in eq. 13 are each non-negative and eq. 13 is positive; if instead $P^* \leq P^a$ and $X_D < \frac{X}{N}$ eq. 13 is negative. ■

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[14] If instead production capacity were internationally mobile, $\frac{\hat{Z}}{\hat{e}}^s$ would no longer be identical in autarky and the open economy. This is addressed in Appendix D.

Corollary 1 *If openness leaves the price of dirty goods unchanged and the regulator is captured by dirty industry, then openness induces a weaker cap on smokestack emissions: if* $P^s = P^a$ *and* $X_D > \frac{X}{N}$ *then* $e^s_D > e^a_D$.

Proposition 2 outlines how openness affects the stringency of the cap on smokestack emissions. The relationship between e^s_D and e^a_D depends on both the extent of D's vested interests in the dirty industry and on the world price vis-a-vis the autarkic price level. To understand this, view each factor in isolation.

Consider the case where D is a representative agent (i.e. $\frac{X_D/X}{1/N} = 1$) and so domestic politics do not come into play. From eq. 13 then openness affects the emission cap only via a *price-level* effect: the price level measures the direct opportunity cost of abatement—the higher the market price for dirty goods, the higher the opportunity cost of curtailing productivity by way of a strict emission cap. *Ceteris paribus*, this makes any decision maker with non-zero vested interest in the polluting industry (i.e. $X_D > 0$) want weaker smokestack policy.[15]

But if Home's political agent does not represent average interests then there is a con-

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[15] Income effects are notably absent in this model; this follows from our maintained assumption that preferences are effectively linear in personal income. Had we analyzed the alternate utility function $\tilde{U}_D = G(v(q_D) + y_D) - \beta Z$ with $G' > 0$, $G'' < 0$, for example, it is possible that D would respond to higher P^* by setting *stricter* policy simply because she demands relatively more environmental quality as her income—and hence her base level of consumption—rises. More concretely, holding the trade regime constant and assuming utility function $\tilde{U}$, it is straightforward to show D responds to a higher P^* by setting *stricter* environmental policy if and only if

$$\mu\frac{\pi X_D}{C + I_D}\left[1 - \frac{q}{f(e)X_D}\right] > 1, \tag{14}$$

where $\mu \equiv -\frac{G''[C+I_D]}{G'} > 0$ serves as the elasticity of substitution between D's private consumption and environmental quality. Empirical evidence on the size of μ is hard to come by; instead valuation studies estimate the income elasticity of either willingness-to-pay and/or demand for environmental improvements. In our model, the relationship between μ and the income elasticity of demand for environmental quality—denoted hereafter as $\psi \equiv -\frac{dZ(e_D)}{dI_D}\frac{I_D}{Z(e_D)}$—is straightforward: for smokestack pollution in the open economy, $\mu = \psi\frac{C+I_D}{I_D}\frac{1}{1+\sigma}$. Substituting this in eq. 14 implies $\frac{de_D}{dP^*} < 0$ if and only if $\psi\frac{1}{1+\sigma}\frac{\pi X_D}{I_D}\left[1 - \frac{q}{f(e)X_D}\right] > 1$. As $\frac{1}{1+\sigma}$, $\frac{\pi X_D}{I_D}$ and $\left[1 - \frac{q}{f(e)X_D}\right]$ are each less than unity, a necessary condition for income effects to dominate is then that $\psi > 1$. This conflicts with the empirical evidence. Surveying the literature, Kriström and Riera (1996) conclude that willingness to pay for environmental improvements increases less than proportionately with income; Deacon and Norman (2003) similarly conclude there is "no clear evidence that the income elasticity of demand for clean air or other environmental amenities exceeds unity." (p.15) founding factor. In the closed economy, consumers and producers share the incidence of environmental regulation: recalling equations (4), (7) and (8), in autarky both consumer surplus and factor returns are hurt when the emission cap is tightened. In contrast, in the small open economy consumers are perfectly insulated from smokestack regulation via a fixed world price for dirty goods; this leaves producers bearing all the burden. Whether this *incidence-shifting* effect of openness induces D to prefer a weaker or stricter cap on smokestack emissions depends on whether D predominately represents the producers or consumers of dirty goods: from eq. 13 we see D wants a weaker cap in the open economy than autarky if $X_D > \frac{X}{N}$, other things—notably the price level—being equal.[16]

Combined, the price-level and incidence-shifting effects of openness may have complimentary or opposing effects on regulatory stringency. As proposition 2 lays out, if openness raises the price level and government is captured by dirty industry then openness leads to weaker smokestack regulation; if instead the world price is lower than Home's autarky price and government predominately represents the consumers of dirty goods, openness will induce stricter smokestack regulation. Finally, if $(P^* - P^a)\left(X_D - \frac{X}{N}\right) < 0$ then openness has an ambiguous effect on the emission cap as the price-level and incidence-shifting effects work in opposing directions.

3.3 Trade and Tailpipe Regulation

We now turn our attention to tailpipe pollution, pollution generated as a by-product of the consumption of dirty goods. Open economy values when tailpipe pollution is regulated are

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[16] If Home was instead large the incidence-shifting effect would be muted in magnitude but retain the same flavor. Comparing equations (7) and (8) with their counterparts in a large open economy as given by equations (30) and (31) (see Appendix B) reveals that consumer prices are less responsive, and factor returns more responsive, to changes in the cap on smokestack emissions in the large open economy than in autarky. Equation (32) confirms that, even in the large open economy, if the price level were unchanged then $e_D^s > e_D^a$ if and only if $X_D > \frac{X}{N}$.

denoted by a superscript t.

Governments bound by GATT rules are entitled to regulate all domestic sources of pollution, provided that regulations do not discriminate between goods based on country of origin. When pollution is a by-product of consumption, this means that Home may regulate the pollution intensity of all goods consumed within its borders—i.e. Home's emission cap applies to all goods consumed by Home citizens, regardless of where the goods were produced. Similarly, the pollution intensity of goods produced by Home firms but consumed in the Rest of the World must meet the overseas emission cap e^*.[17] Accordingly, goods sold in Home and ROW may differ in their emission intensity and so in equilibrium consumer prices will be different in Home and ROW. Define by X_E Home capacity allocated to production of goods for export; then $q^t = \frac{f(e)[X-X_E]}{N}$; if Home imports dirty goods then $X_E < 0$. Then free trade in goods implies that the return, π^*, paid to a unit of capacity employed in the production of goods for export be the same as paid for a unit producing goods for domestic consumption: $\pi^* \equiv P^* f(e^*) = P^t f(e)$, where P^t solves eq. 2 when evaluated at q^t.

We continue by inspecting how X_E changes with e. Differentiate the condition $P^t f(e) = \pi^*$ using eq. 2 and the definition of q^t; this gives

$$\frac{dX_E}{de/e} = -\sigma[\epsilon - 1][X - X_E], \tag{15}$$

which is negative under our maintained assumption that $\epsilon > 1$. Equation eq. 15 reveals that strict tailpipe regulation leads Home firms to reallocate dirty capacity away from the production of goods for domestic consumption and toward production for export so long as demand for dirty goods is elastic. This has implications for the effect of tailpipe regulation on the volume of Home exports.

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[17] In our model the unit cost of production is falling in the pollution intensity of output, and firms face no re-tooling costs when producing goods with different pollution intensities. As a result, firms will not over-comply with regulation. See Copeland (2001) for a discussion of governments' strategic incentives when re-tooling costs are positive.

Proposition 3 *When dirty good demand is price elastic, stricter tailpipe regulation raises exports of the dirty good:* $\frac{dE^t}{de} < 0$ *if* $\epsilon > 1$.

Proof: When $X_E \geq 0$ then Home's exports are $E^t = f(e^*)X_E$ and so $\frac{dE^t}{de} = f(e^*)\frac{dX_E}{de} < 0$. When $X_E \leq 0$ then $E^t = f(e)X_E < 0$ and so $\frac{dE^t}{de/e} = f(e)\left[\sigma X_E + \frac{dX_E}{de/e}\right]$ which is again negative.

Propositions 1 and 3 illustrate that environmental regulation's impact on exports of dirty goods may be qualitatively *opposite* when we consider tailpipe instead of smokestack pollution. As outlined in Proposition 1, stricter smokestack regulation hurts exports because it reduces the productivity of Home firms, thereby reducing their supply to world markets. However, when Home demand for dirty goods is elastic, stricter tailpipe regulation lowers returns paid to capacity employed producing dirty goods for the Home market, regardless of where production is located. Accordingly, as the tailpipe cap is tightened, firms in both Home and abroad respond by utilizing more of their capacity to produce goods for the ROW market (recall $\frac{dX_E}{de/e} < 0$). Consequently, Home exports (imports) of dirty goods rise (fall) as Home tightens its tailpipe cap.[18]

Together, Propositions 1 and 3 have implications for empirical tests of trade and environment relationships. Consider, for example, the ongoing debate surrounding the Pollution Haven hypothesis—the proposition that polluting behavior migrates to regions with weak

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[18] The flavor of Proposition 3 is not an artifact of the endowment structure of the economy. To confirm this, suppose instead that X and Y are the outputs of intermediate goods sectors that employ locally mobile inputs V, the supply and productivity (in the intermediate goods sector) of which are independent of e and Z:

$$X = X(V_X), \quad Y = Y(V_Y) \quad \text{with } V_X + V_Y = V.$$

Define by P_X the relative price of intermediate good X. The equivalent to Proposition 1 becomes $\frac{dE^s}{de/e} = f(e)X\sigma\left[1 + \frac{\hat{X}}{\hat{P_X}}\frac{\hat{P_X}}{\hat{e}}\right]$ while $\frac{dE^t}{de/e} = f(e^*)\frac{dX_E}{de/e}$ if $X_E > 0$ and $\frac{dE^t}{de/e} = f(e)\left[X_E\sigma + \frac{dX_E}{de/e}\right]$ if $X_E < 0$. Note that under the usual assumptions, supply of X depends only on and is increasing in its relative price: $\frac{\hat{X}}{\hat{P_X}} > 0$. Moreover, because $Q = f(e)X$ then $P_X = Pf(e)$ and so in the small open economy $\frac{\hat{P^s_X}}{\hat{e}} = \sigma$ when pollution is smokestack and $\frac{\hat{P^t_X}}{\hat{e}} = 0$ when pollution is tailpipe (since $P^t f(e) = P^* f(e^*)$ which is pegged internationally). Using these, $\frac{dE^s}{de/e} > 0$ is trivial; however to sign $\frac{dE^t}{de/e}$ we must derive $\frac{dX_E}{de/e}$. Since X_E is defined by the condition $v'\left(\frac{f(e)[X-X_E]}{N}\right)f(e) = P^* f(e^*)$ then $\frac{dX_E}{de/e} = X\frac{\hat{X}}{\hat{P^t_X}}\frac{\hat{P^t_X}}{\hat{e}} - \sigma[X - X_E][\epsilon - 1]$. Given $\frac{\hat{P^t_X}}{\hat{e}} = 0$ then $\frac{dX_E}{de/e} = -\sigma[X - X_E][\epsilon - 1]$, exactly as in eq. 15. Consequently, $\frac{dE^t}{de/e} < 0$ and the proof of Proposition 3 laid out above continues to hold even when the supply of X is endogenous.

environmental regulation. This is an hypothesis with much intuitive appeal but until recently only scant empirical support. Our results may provide an explanation. Some tests of the Pollution Haven hypothesis attempt to proxy shifts in the location of polluting behavior by examining changes in the trade patterns of dirty goods—the export competitiveness hypothesis. Moreover, there is also a precedence of using general indices of environmental policy stringency and performance as a proxy for stringency in smokestack regulation.[19] Our results suggest that tests bundling evidence of tailpipe and smokestack regulation would either fail to find or mis-estimate the extent to which environmental regulation affects trade flows, simply because different types of regulation should have opposing effects on trade volumes to begin with. Studies which instead restrict attention to only one type of regulation—either smokestack or tailpipe—will avoid this problem. Indeed, recent studies which have restricted attention to smokestack regulation only—as proxied by compliance cost expenditures as measured by the U.S. Census Bureau's Pollution Abatement and Control Expenditures (PACE) survey—do find statistically and economic significant impacts of regulation on patterns of US exports.[20]

3.3.1 Openness and Tailpipe Politics

Next we focus on the broader question of how openness affects the decision maker's preferred emission cap. For this we again examine how local prices and factor returns respond to changes in e. Substitute the expression for q^t into eq. 2, differentiate employing eq. 15, and

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[19] For example, several authors use Dasgupta et al.'s (1995) composite environmental index as a proxy for stringency in smokestack regulation. This index is based on country surveys of environmental policy and performance along four environmental dimensions—Air, Water, Land and Living Resources—and five Sectors/Activities—Agriculture, Industry, Energy, Transport, and Urban—but does not appear to distinguish between tailpipe and smokestack regulations involved.

[20] See Levinson and Taylor (2003), who also provide a comprehensive analysis of several outstanding empirical issues involved in testing the Pollution Haven hypothesis.

convert to percentage changes:

$$\frac{\hat{P}^t}{\hat{e}} = -\sigma \tag{16}$$

while

$$\frac{\hat{\pi}^t}{\hat{e}} = 0. \tag{17}$$

Comparing equations 7 to 16 and 8 to 17 reveals that prices are more responsive to tailpipe regulation in the open economy than in autarky, but factor returns less so. This arises in part because Home is able to regulate the characteristics of all goods consumed in its borders, and so has effective jurisdiction over its entire consumer market just as it did in autarky. But, as Proposition 3 indicates, weak regulation of tailpipe pollution also expands Home's imports, raising the number of goods sold in Home which further reduces the price. As we discuss below, this has implications for how the incidence of pollution policy is distributed in the open economy, and so alters the emission cap favored by a politically motivated decision maker.

Also different in the open economy is the pollution base Z and how it responds to tailpipe regulation. Home's total tailpipe pollution depends on the pollution intensity of goods consumed there:

$$Z^t = eNq^t = ef(e)[X - X_E]; \tag{18}$$

differentiating, making use of eq. 15, and converting to percentage changes gives

$$\frac{\hat{Z}^t}{\hat{e}} = 1 + \sigma\epsilon > 0\,. \tag{19}$$

We are now able to characterize D's preferred cap, e^t_D, on tailpipe emissions in the open economy. e^t_D solves

$$\frac{dW^t_D}{de/e} = q^t \left[P^t\sigma - \beta Ne[1 + \sigma\epsilon]\right] \tag{20}$$

when set equal to zero; (20) is derived by substituting expressions 16, 18 and 19 into eq. 6 and rearranging.[21]

Proposition 4 *Assume* $\epsilon > 1$*; then the impact of openness on the tailpipe emission cap is unambiguous if* $\left(\frac{X_D/X}{1/N} - \frac{1}{1+\sigma\epsilon}\right)(\pi^a - \pi^*) \geq 0$*. In particular,*

1. *if* $\frac{X_D/X}{1/N} \geq \frac{1}{1+\sigma\epsilon}$ *and* $\pi^a \geq \pi^*$ *then* $e_D^a \geq e_D^t$*; while*
2. *if* $\frac{X_D/X}{1/N} \leq \frac{1}{1+\sigma\epsilon}$ *and* $\pi^a \leq \pi^*$ *then* $e_D^a \leq e_D^t$*.*

Proof. By definition, $\pi^a \equiv P^a f(e_D^a)$. Substituting this definition into eq. 10 and employing the functional form $f(e) = e^\sigma$ to solve for e_D^a as a function of π^a gives $e_D^a(\pi^a) = \left[\frac{\pi^a\sigma[1+\frac{X_D/X}{1/N}[\epsilon-1]]}{\beta N\epsilon[1+\sigma]}\right]^{\frac{1}{1+\sigma}}$. Similarly, use $\pi^* = P^t f(e_D^t)$ to solve for e_D^t as a function of π^* using (20): $e_D^t(\pi^*) = \left[\frac{\pi^*\sigma}{\beta N[1+\sigma\epsilon]}\right]^{\frac{1}{1+\sigma}}$. Comparing the two terms we see $e_D^a > e_D^t$ if and only if $\frac{1+\sigma\epsilon}{\epsilon[1+\sigma]}[1 + \frac{X_D/X}{1/N}[\epsilon - 1]] > \frac{\pi^*}{\pi^a}$. Assuming $\epsilon > 1$, then if and only if $\frac{X_D/X}{1/N} > 1/[1 + \sigma\epsilon]$ the left hand term is greater than unity; if and only if $\pi^* < \pi^a$ then the right hand term is less than unity. ■

Corollary 2 *Assume* $\epsilon > 1$*. If* $\pi^* = \pi^a$ *then* $e_D^t < e_D^a$ *whenever* $X_D \geq \frac{X}{N}$*.*

Corollary 2 highlights the impact of openness on the tailpipe emission cap when the rate of return paid to dirty capacity is unchanged: we see that D wants an unambiguously *stricter* cap on tailpipe emissions whenever D represents constituents with at or above average vested interests in the dirty industry. The logic is as follows. Firstly, there is again *incidence-shifting*, although of a different nature than with smokestack regulation. Openness insulates dirty good producers from local tailpipe regulation, since producers are free to avoid stricter local regulation by simply producing goods for export. Consumers,

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[21] Modeling tailpipe abatement as occurring at the household instead of at the factory would leave our results unchanged. Household abatement could be modeled as follows. Consumer i buys "raw" consumer goods x_i from sellers at price ρ, and employs these raw goods in a domestic production function, generating private value $v(f(e)x_i)$ which is increasing in the pollution intensity of use. Atomistic behavior by consumers implies $v'(f(e)x_i)f(e) = \rho$ for all i in equilibrium (and so drop the i subscript here forward). Individual welfare would again be given by eq. 3 but with $C = v(f(e)x) - \rho x$ while $\pi = \rho$. Evaluating at X_D and differentiating, we find D's preferred cap on household emissions would solve $\frac{W_D}{de/e} = \frac{dC}{\hat{e}} + X_i\pi\frac{\hat{\pi}}{\hat{e}} - \beta Z\frac{\hat{Z}}{\hat{e}} = 0$. In autarky we would have $\frac{dC}{\hat{e}}^a = \frac{f(e)X}{N}v'\left(\frac{f(e)X}{N}\right)\frac{\sigma}{\epsilon}$, $\frac{\hat{\pi}}{\hat{e}}^a = \frac{\sigma[\epsilon-1]}{\epsilon}$ and $\frac{\hat{Z}}{\hat{e}}^a = 1 + \sigma$ and so e_D^a would solve $\frac{f(e)X}{N}v'\left(\frac{f(e)X}{N}\right)\frac{\sigma}{\epsilon} + X_i f(e)v'\left(\frac{f(e)X}{N}\right)\frac{\sigma[\epsilon-1]}{\epsilon} - \beta e f(e)X[1 + \sigma] = 0$ which is equivalent to eq. 10 given $P^a = v'(fX/N)$. In the small open economy with tailpipe regulation we would see $\frac{dC}{\hat{e}}^t = \frac{X-X_E}{N}\rho\sigma$, $\frac{\hat{\pi}}{\hat{e}}^t = 0$ and $\frac{\hat{Z}}{\hat{e}}^t = 1 + \sigma\epsilon$ and so e_D^t would solve $\frac{f(e)[X-X_E]}{N}\left[v'\left(\frac{f(e)[X-X_E]}{N}\right)\sigma - \beta N e[1 + \sigma\epsilon]\right]$ which is equivalent to eq. 20 given $P^t = v'\left(\frac{f(e)[X-X_E]}{N}\right)$.

on the other hand, are constrained to purchase only goods complying with local tailpipe regulations. Other things equal, this induces D to prefer stricter regulation a stricter cap on tailpipe emissions in the open economy than in autarky provided D represents constituents who are predominately the producers of dirty goods. Secondly, because stricter local tailpipe regulation drives polluting behavior abroad, caps on tailpipe pollution are more productive in the open economy than autarky—notice $\frac{\hat{Z}}{\hat{e}}^t > \frac{\hat{Z}}{\hat{e}}^a$ when $\epsilon > 1$. Other things being equal, this *policy-productivity* effect induces regulators of all stripes to prefer stricter tailpipe policy in the open economy than in autarky. Moreover, the policy-productivity and incidence-shifting effects of openness work in complementary directions when $X_D > \frac{X}{N}$ and thus we see $e_D^t < e_D^a$ whenever $X_D > \frac{X}{N}$ if $\pi^* = \pi^a$.[22]

Corollaries 1 and 2 can be combined to asses how openness affects the emission cap that

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[22] When openness changes rates of return on dirty capacity, i.e. if $\pi^* \neq \pi^a$, then other effects of openness are also at play. To see this, examine $\frac{dW_D}{de/e}^t\Big|_{e=e_D^a}$ by again subtracting $\frac{dW_D^a}{de/e}$ from $\frac{dW_D^t}{de/e}$ and evaluating all terms at $e = e_D^a$ (recall $\frac{dW^a}{de/e} = 0$ at $e = e_D^a$ by construction). This gives

$$\begin{aligned} \frac{dW_D}{de/e}^t\Bigg|_{e=e_D^a} &= q^a\sigma[P^t - P^a] - q^a\sigma P^a \tfrac{\epsilon-1}{\epsilon}\left[\tfrac{X_D/X}{1/N} - 1\right] - q^a\sigma\beta N e_D^a[\epsilon - 1] \\ &\quad + \beta e_D^a f(e_D^a) X_E[1 + \sigma\epsilon] - \tfrac{P^t\sigma}{N} f(e_D^a) X_E. \end{aligned} \tag{21}$$

The first term of (21) again represents a price-level effect: if openness raises the price of dirty goods it thereby raises the opportunity cost of achieving environmental gains at the expense of consumable output, making any decision maker prefer weaker policy, other things being equal. The second and third terms of (21) are the incidence-shifting and policy-productivity effects as described above. Finally, the fourth and fifth terms reflect openness' impact on pollution and consumption levels to begin with. If $X_E > 0$ then the base level of Home's polluting behavior is smaller in the open economy than autarky. This reduces the need for environmental regulation in the first place (and so makes strict regulation less attractive). But $X_E > 0$ reduces the consumption base as well and so there is less consumer surplus endangered by strict regulation (thereby making strict regulation more attractive). Evaluating eq. 21 at $\pi^* = \pi^a$ (and so $P^t = P^a$ and $X_E = 0$ when $e = e_D^a$) gives

$$\frac{dW_D}{de/e}^t\Bigg|_{e=e_D^a,\pi^*=\pi^a} = -q^a\sigma[\epsilon - 1]\left[\frac{P^a}{\epsilon}\left[\frac{X_D/X}{1/N} - 1\right] + \beta N e_D^a\right] \tag{22}$$

which is negative if $\frac{X_D/X}{1/N} \geq 1$, confirming Corollary 2 when $\epsilon > 1$.

Finally, we note that under alternate specification of individual utility $\tilde{U}$—recall discussion in footnote 15—changes in π would have income effects as well as price-level effects. It is straightforward to show that, holding the trade regime constant, an increase in ROW profits would lower e_D^t—i.e. income effects would dominate price-level effects—if and only if $\psi\frac{1+\sigma}{1+\sigma\epsilon}\frac{\pi^* X_D}{I_D}\left[1 - \frac{q}{f(e)X_D}\right] > 1$; under our maintained assumption $\epsilon > 1$ then a necessary condition for $\frac{de_D^t}{d\pi^*} < 0$ is again $\psi > 1$, which conflicts with the empirical evidence.

would be set by a regulator who is captured by dirty industry. In the absence of price level effects, we find that the difference is stark.

Corollary 3 *If* $\epsilon > 1$ *and* $X_D > \frac{X}{N}$*, then in the open economy with* $P^s = P^t = P^a$ *when* $e = e^a_D$*, the political agent regards* e^a_D *as too lax if regulating tailpipe emissions but too strict if regulating smokestack.*

Corollary 3 establishes that, under reasonable assumptions, openness can have qualitatively opposite effects on the stringency of environmental policy depending on whether the pollutant regulated is a by-product of consumption or production. The source of this reversal lies in the incidence-shifting effect of openness. Essentially, openness insulates consumers while raising the exposure of producers to local smokestack regulation. Openness does this by allowing consumers to import dirty goods from exogenously regulated ROW firms. Conversely, openness insulates *producers* and raises the exposure of consumers to local tailpipe regulation by allowing producers to manufacture for export to exogenously regulated ROW consumers.[23] And by insulating producers, openness reduces industry opposition to local tailpipe regulation. Accordingly, a government captured by dirty industry responds to trade liberalization by tightening the cap on tailpipe emissions.

There is a growing empirical literature which tests relationships between openness, trade, and environmental regulation—see for example Damania, Fredriksson and List (2003)—for which Corollary 3 has immediate implications. Simply, when economists model industry opposition to regulations concerning industrial emissions, it is imperative that we test these hypotheses using evidence on smokestack, not tailpipe, regulation. True, it is likely that a particular government's propensity to set strict smokestack and tailpipe regulations is

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[23] If Home were instead large then openness' incidence-shifting effect would again be muted (footnote 16 discusses this in the context of smokestack pollution). Comparing equations (7) and (8) with their counterparts in a large open economy as given by equations (34) and (35) (see Appendix C) reveals that consumer prices are more responsive, and factor returns less responsive, to changes in the cap on tailpipe emissions in the large open economy than in autarky. Equation (36) confirms that, even in the large open economy, if the rate of return were unchanged then $e^t_D < e^a_D$ whenever $X_D \geq \frac{X}{N}$.

positively correlated; indeed, our analysis suggests pollution caps are non-decreasing in X_D regardless of pollution type. However, because openness' may impact those propensities in opposite ways, measures of regulatory stringency concerning tailpipe regulation—lead in gasoline for example—may be a poor if not outright misleading proxy for stringency in smokestack regulation.

Throughout this paper we have emphasized the emission cap that would be chosen by a political agent captured by the *producers* of dirty goods. However it is conceivable that Home's decision maker may instead represent constituents with below average vested interests in the polluting industry. In that case, the greater sensitivity of consumer prices to environmental regulation in the open economy makes D want, ceteris paribus, *weaker* environmental policy. But the heightened responsiveness of the pollution base to regulation works on D's preferences in the opposite direction. Thus, unlike in the case of smokestack regulation, the net impact of openness on the tailpipe policy preferred by a decision maker with below average vested interest in the polluting industry is ambiguous. However, using Proposition 4, if $\pi^* = \pi^a$ then D views e_D^a as too strict if and only if $\frac{X_D/X}{1/N} < \frac{1}{1+\sigma\epsilon}$.

4 Taxes

The sections above focus on a particular type of regulation: a cap on emissions per unit of production/consumption. In some senses, an emission cap can be interpreted as a *real* regulation, as it is measured in units of the public bad—pollution—that governments aim to reduce.[24] Alternately, we could consider a nominal instrument, taxes, which influence the pollution intensity of goods produced in a competitive market, and whose impact depends

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[24] Moreover, because inputs are immobile between industries, regulating pollution via direct controls instead of taxes imposes no inherent inefficiency.

on the size of the instrument relative to the price of dirty goods. In this section we revisit the impact of openness on regulatory stringency when government manages pollution via emission taxes instead of a direct cap on per unit emissions. We show that when stringency is instead measured via the nominal value of the pollution tax, that openness' impact on regulatory stringency depends only on the degree of the regulator's vested interests in the dirty industry.

Let τ denote the emission tax collected from firms when units are sold and so $\pi \equiv Pf(e) - \tau e f(e)$. As in Section 3 we assume Home does not engage in extraterritorial regulation: Home only taxes emissions generated within its borders. Profit maximization by price taking firms implies

$$e = \frac{P}{\tau}\frac{\sigma}{1+\sigma} \tag{23}$$

which is increasing in the price of dirty goods and decreasing in the emission tax.[25] We assume Home tax revenues are rebated lump sum to Home citizens on a per capita basis and so individual income $I_i = \pi X_i + Y_i + \frac{\tau Z}{N}$. Substituting I_i into the utility function gives

$$W_i(\tau) = v(q) + \pi X_i + Y_i + \frac{\tau Z}{N} - Pq - \beta Z. \tag{24}$$

Maximizing this with respect to τ defines $i's$ preferred tax rate τ_i on emissions:

$$\frac{dW_i}{d\tau/\tau} = \pi X_i \frac{\hat{\pi}}{\hat{\tau}} - qP\frac{\hat{P}}{\hat{\tau}} + [\tau - \beta N]\frac{Z}{N}\frac{\hat{Z}}{\hat{\tau}} + \frac{\tau Z}{N}. \tag{25}$$

To solve for τ_i explicitly, equate eq. 25 with zero, recognize that $P = e\tau[1+\sigma]/\sigma$ and $\pi = ef(e)\tau/\sigma$ by eq. 23, substitute in values for $\frac{\hat{\pi}}{\hat{\tau}}$, $\frac{\hat{P}}{\hat{\tau}}$ and $\frac{\hat{Z}}{\hat{\tau}}$ in each of the scenarios

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[25] We acknowledge our emission production function $f(e) = e^{\sigma}$ on which (23) is based abstracts from the real world constraint that society cannot pollute itself to infinite material prosperity. A more reasonable construction of $f(e)$ would be $f(e) = \left\{\begin{matrix} 0 \\ e^{\sigma} \\ \bar{e}^{\sigma} \end{matrix}\right\}$ for $e \left\{\begin{matrix} \leq 0 \\ \in [0,\bar{e}] \\ \geq \bar{e} \end{matrix}\right\}$ for some $\bar{e} < \infty$. Under this formulation the emission tax would be non-binding whenever $\tau < \frac{P}{\bar{e}}\frac{\sigma}{1+\sigma}$ and relations $\frac{\hat{P}}{\hat{e}}$, $\frac{\hat{Z}}{\hat{e}}$ and $\frac{\hat{\pi}}{\hat{e}}$ would be piecewise. However we would be able to abstract from these difficulties if either βN were sufficiently large relative to P or $\bar{e}$ was sufficiently high to begin with.

considered[26] and rearrange to obtain the following:

$$\tau_i^a = \frac{\beta N[1+\sigma]\epsilon}{1+\epsilon\sigma+\frac{X_i/X}{1/N}[\epsilon-1]}, \tag{26}$$

$$\tau_i^s = \frac{\beta N[1+\sigma]}{\sigma+\frac{X_i/X}{1/N}}, \tag{27}$$

$$\tau_i^t = \beta N. \tag{28}$$

Note τ_i^a and τ_i^s are each positive, decreasing in X_i, and less than the Pigouvian tax rate βN whenever $X_i > X/N$. We also point out that, just as when emissions are regulated directly, tailpipe policy in the open economy (τ_i^t) is independent of X_i; this follows because local tailpipe regulation has no impact on the rate of return earned by dirty capacity since owners can always earn π^* by exporting.

Evaluating τ_i^a, τ_i^s and τ_i^t at the endowment of the political agent[27] X_D, we obtain the following proposition concerning the impact of openness on equilibrium emission taxes.

Proposition 5 *Assume $\epsilon > 1$. Then openness induces higher tailpipe taxes but lower smokestack taxes if and only if D has an above average endowment of dirty capacity. In particular*

1. $\tau_D^t > \tau_D^a$ *if and only if* $X_D > \frac{X}{N}$ *whenever* $\epsilon > 1$*;*
2. $\tau_D^s < \tau_D^a$ *if and only if* $X_D > \frac{X}{N}$*.*

Proof:

1. From equations (26) and (28), $\tau_D^t > \tau_D^a$ if and only if $\beta N > \frac{\beta N[1+\sigma]\epsilon}{1+\epsilon\sigma+\frac{X_D/X}{1/N}[\epsilon-1]}$. When $\epsilon - 1 > 0$, as is our maintained assumption, this is equivalent to the condition $\frac{X_D/X}{1/N} > 1$.
2. Using equations (26) and (27) $\tau_D^s < \tau_D^a$ if and only if $\frac{\beta N[1+\sigma]\epsilon}{1+\epsilon\sigma+\frac{X_D/X}{1/N}[\epsilon-1]} > \frac{\beta N[1+\sigma]}{\sigma+\frac{X_D/X}{1/N}}$, or, equivalently, $\frac{X_D/X}{1/N} > 1$.

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[26] In autarky $q = \frac{fX}{N}$ yielding $\frac{\hat{P}}{\hat{\tau}}^a = \frac{\sigma}{\sigma+\epsilon}$, $\frac{\hat{e}}{\hat{\tau}}^a = -\frac{\epsilon}{\sigma+\epsilon}$, $\frac{\hat{\pi}}{\hat{\tau}}^a = -\frac{\sigma[\epsilon-1]}{\sigma+\epsilon}$, and $\frac{\hat{Z}}{\hat{\tau}}^a = -\frac{[1+\sigma]\epsilon}{\sigma+\epsilon}$ when pollution is of either type. In the small open economy with smokestack pollution, arbitrage requires $P = P^*$, implying $\frac{\hat{P}}{\hat{\tau}}^s = 0$, $\frac{\hat{e}}{\hat{\tau}}^s = -1$, $\frac{\hat{\pi}}{\hat{\tau}}^s = -\sigma$, and $\frac{\hat{Z}}{\hat{\tau}}^s = -[1+\sigma]$. Finally, when Home is small and open and faces tailpipe pollution, $q = \frac{f[X-X_E]}{N}$ and arbitrage requires $\pi = \pi^*$ where π^* is fixed abroad. This implies $\frac{\hat{P}}{\hat{\tau}}^t = \frac{\sigma}{1+\sigma}$, $\frac{\hat{e}}{\hat{\tau}}^t = -\frac{1}{1+\sigma}$, $\frac{\hat{\pi}}{\hat{\tau}}^t = 0$, $\frac{dX_E}{d\tau/\tau}^t = \frac{\sigma}{1+\sigma}[\epsilon-1][X-X_E]$, and $\frac{\hat{Z}}{\hat{\tau}}^t = -\frac{1+\sigma\epsilon}{1+\sigma}$.

[27] As with direct controls, when emissions are regulated via taxes the endowment, X_D, represented by the political agent is independent of the trade regime and the instrument level. Moreover, the relationship between X_D and endowments of individual citizens are identical in each of the three models of political economy discussed earlier—majority rules, uncontested minority elite, or a political contributions approach with a single lobby group—to those described in footnote 11.

Proposition 5 confirms that openness has a qualitatively opposite impact on smokestack and tailpipe taxes whenever demand is elastic. Moreover, openness' impact on the tax rate is independent of the world price of dirty goods. This contrasts—but does not contradict—our results concerning openness' impact when emissions per unit are instead regulated directly. This follows because pollution taxes are nominal instruments, while actual emissions depend on the *real* tax rate τ/P—recall eq. 23. Thus, even if for example $\tau_D^a > \tau_D^s$—i.e. openness lowers the tax rate—it may well be the case that per unit smokestack emissions are greater in autarky than in the open economy if the world price is markedly higher than the autarkic price. Accordingly, while we can make definitive predictions as to whether openness will induce stricter or weaker pollution taxes contingent upon the vested interests represented by the political agent (relative to the average for Home citizens) and the type of pollution considered, we cannot make the same unconditional statements concerning actual emission behavior.

5 Caveats

Throughout this paper we have maintained the assumption that demand for dirty goods is price elastic, as this is a necessary condition for autarkic factor rents to be negatively correlated with stringent environmental regulation. As we indicate in Section 2, if demand were instead price inelastic then environmental regulation would actually be beneficial to dirty industry as the regulation would mimic a collusive mechanism raising industry profits. In this section we consider how results from Section 3 would vary if we instead allowed $\epsilon \leq 1$.

When dirty good demand is price inelastic, the price increase accompanying supply contractions concomitant with stricter environmental regulation dominate productivity losses so that stringent environmental regulation *raises* returns to dirty capacity. This makes

Home a more profitable places in which to produce/sell dirty goods. In the absence of trade this would generate $\frac{\hat{\pi}}{\hat{e}}^a < 0$ when $\epsilon < 1$. That is, with inelastic demand environmental regulation is good for dirty industry.

Now consider how this positive correlation between factor returns and regulatory stringency would play out in the open economy. With tailpipe regulation, the higher returns associated with stricter regulation would induce producers to shift dirty capacity into production for the Home market. Specifically, $\frac{dX_E}{de/e} > 0$ when $\epsilon < 1$: strict Home tailpipe regulation makes Home a more attractive place to sell dirty goods, thereby raising Home imports.

How would this affect openness' impact on industry opposition to regulation? Again consider tailpipe regulation. In autarky $\frac{\hat{\pi}}{\hat{e}}^a < 0$ when $\epsilon < 1$ and so a government captured by dirty industry sets excessively *strict* tailpipe policy. However in the small open economy $\frac{\hat{\pi}}{\hat{e}}^t = 0$, eliminating opportunities for government to aid its industrial constituents by manipulating environmental policy. As a result, the captured government will set weaker tailpipe policy in the open economy than autarky provided price-level effects are not sufficiently strong.[28]

In sum, in our model with firm level abatement occurring either by mandate (as when the pollution cap is set directly) or in response to emission taxes, we find that the relationship between tailpipe regulation, openness, exports and industry opposition to regulation depends critically on the price elasticity of demand. We point out though that this need not always be the case. Consider the following example in which dirty goods are supplied by an industry with variable supply $Q(P)$ with $dQ/dP > 0$ but in which abatement is not possible; i.e. consider the case in which the emissions to consumption (output) ratio is

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[28] Note also that when $\epsilon < 1$ then $\frac{\hat{Z}}{\hat{e}}^t < \frac{\hat{Z}}{\hat{e}}^a$ (because $\frac{X_E}{de/e}$); this reduced sensitivity of pollution to regulation further reduces the attractiveness of strict tailpipe regulation in the open economy.

constant. In this case a tax on tailpipe emissions is equivalent to a consumption tax (and a tax on smokestack emissions equivalent to a production tax) and net industry profits would be decreasing in the emission tax regardless of the demand elasticity. It is straightforward to show in such a case that when government assigns industry net profits extra weight in its welfare function, that government will set stricter tailpipe policy (but weaker smokestack policy) in the open economy relative to autarky if price-level effects are small, regardless of the magnitude of ϵ. [29]

Finally, as the magnitude of ϵ plays a pivotal role in several of our results, we conclude this section by discussing estimates of ϵ as provided by the empirical literature on consumer demand. Regarding fuel use, Pindyck (1979) calculates the own price elasticities of residential fuel use of -1 to -1.12 for coal, -1 to -1.38 for oil, and -1.28 to -2.09 for gas (p.160). Regarding other consumer goods likely to generate tailpipe pollution, Houthakker and Taylor (1970), find, for example, that the long run price elasticities of boats, pleasure aircraft and sports equipment is -2.3889 (p.125) while for tobacco the long run price elasticity is -1.8919 (p.66). Regarding transportation, Houthakker and Taylor (1970) find that long run demand for transportation services is elastic (-1.47 to -1.57 in Canada, p.213) while Hymans (1970) calculates the short run elasticity of automobile expenditures to be between -0.78 and -1.17 and the long run elasticity of between -0.30 and -0.46 (p.181). Finally, Graham and Gleister (2002) survey the literature on gasoline demand and find long run price elasticities of demand for gasoline ranging from -0.23 in the US to -1.35 in the OECD countries; however they conclude “the overwhelming evidence . . . suggests the long-run price elasticities will typically tend to fall in the -0.6 to -0.8 range.” (p.22) These numbers suggest that our maintained assumption of $\epsilon > 1$ may be reasonable for a host of (potentially) dirty

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[29] We thank Larry Karp for providing this example.

consumer goods, but likely not for gasoline.

6 Conclusions

This paper examines the relationship between politics, openness to free trade in goods, and environmental regulation when pollution arises as a by-product of consumption, instead of production, of dirty goods. We find that two commonly accepted rules of thumb—that strict pollution policy reduces exports and that producers of dirty goods are more opposed to environmental regulation in the open economy—can be reversed in the case of consumption related pollution.

The reason why tailpipe regulation promotes rather than hinders the export of dirty goods is simple: when tailpipe regulation reduces profits from sales in the regulated market, it encourages producers to shift their supply to other markets, thereby promoting exports.

The interaction between openness and politics is more complicated. Some of the effects of openness on policy preferences are invariant to the type of pollution regulated. For example the effect of high world prices on the opportunity cost of abatement is the same for either smokestack or tailpipe regulation. But the way that openness affects the sensitivity of prices and factor rents to changes in regulation is qualitatively opposite. In the open economy, prices are less sensitive—and factor rents more responsive—to local smokestack regulation than in autarky. As a result, producers bear a larger share of the regulatory burden from smokestack regulation when the economy is open rather than closed. In contrast, with tailpipe regulation it is local consumer prices that are more sensitive—and factor rents less responsive—in the open economy than in autarky. Accordingly, openness shifts the incidence of tailpipe regulation *away* from producers and onto local consumers. Holding the price level constant this incidence-shifting induces governments that are captured by dirty industry to set weaker caps on smokestack emissions—but stricter caps on tailpipe emissions—in the open economy than in autarky.

Alternately, if we instead consider regulation via taxes, we see that openness unambiguously reduces the smokestack tax but raises the tailpipe tax that would be set by a political agent representing above average vested interests in the dirty industry. In sum, while openness may make dirty good producers more fervent opponents of smokestack regulation, it may make them more accepting of tailpipe regulation.

The wider implications of this research are that several key aspects of the relationship between openness, politics and environmental regulation may be fundamentally different for externalities arising from the consumption rather than the production of dirty goods. In terms of theory, this means that propositions derived from analyses of production related pollution in open economies need to be re-evaluated before assumed true for consumption related pollution as well. We have examined only two such propositions—the impact of regulation on exports and the relationship between openness and environmental politics—and under reasonable assumptions find that traditional relationships can be reversed. Our results may also provide general guidance for empirical analysis. Because relationships between trade patterns, politics, and environmental regulation may vary qualitatively with the type of externality being regulated, it is critical that empiricists not bundle together data on smokestack and tailpipe regulation/outcomes as a generic proxy for regulatory stringency.

References

Bommer, Rolf and Gunther G. Schulze. 1999. "Environmental improvement with trade liberalization," *European Journal of Political Economy* 15: 639-661.

Buchanan, J. and G. Tullock. 1975. "Polluters' profits and political response: direct controls versus taxes," *American Economic Review* 65: 139-147.

Chau, Swee. 2003. "Does tighter environmental policy lead to a comparative advantage in less polluting goods?" *Oxford Economic Papers* 55: 25-35.

Copeland, Brian R. and M. Scott Taylor. 1995. "Trade and the Environment: A Partial Synthesis" *American Journal of Agricultural Economics* 77: 765-771.

Copeland, Brian R. 2001. "Trade and the Environment: Product Standards in a National Treatment Regime," *mimeo*, University of British Columbia.

Dasgupta, Susmita, Ashoka Mody, Subhendu Roy and David Wheeler. 1995. "Environmental Regulation and Development: A Cross-Country Empirical Analysis," *World Bank Policy Research Working Paper* No. 1448.

Deacon, Robert T. 1999. "The Political Economy of Environment-Development Relationships: A Preliminary Framework." Department of Economics, University of California at Santa Barbara, Departmental Working Paper 11-99.

Deacon, Robert T. and Catherine S. Norman. 2003. "Is the environmental Kuznets curve an empirical regularity?" Department of Economics, University of California at Santa Barbara, Departmental Working Paper 22-03.

Damania, Richard, Per G. Fredriksson and John A. List. 2003. "Trade liberalization, corruption, and environmental policy formation: theory and evidence." *Journal of Environmental Economics and Management* 46(3): 490-512.

EPA. 1993. "Plain English Guide to the Clean Air Act." United States Environmental Protection Agency Document EPA-400-K-93-001.

EPA. 2000. "EPA announces elimination of all indoor uses of widely-used pesticide Diazinon; begins phase-out of lawn and garden use," United States Environmental Protection Agency Headquarters Press Release 12/05/2000.

EPA. 2002. "Municipal Solid Waste in the United States: 2000 Facts and Figures," United States Environmental Protection Agency Document EPA530-R-02-001.

Fredriksson, Per. 1997. "The Political Economy of Pollution Taxes in a Small Open Economy," *Journal of Environmental Economics and Management* 33: 44-58.

Graham, Daniel J. and Stephen Gleister. 2002. "The Demand for Automobile Fuel: A Survey of Elasticities," *Journal of Transport Economics and Policy* 36(1): 1-25.

Grossman, Gene and Elhanen Helpman. 1994. "Protection for Sale," *American Economic Review* 84(4):833-850.

Gulati, Sumeet. 2003. "The effect of choosing free trade on pollution policy and welfare," *mimeo*, University of British Columbia.

Haupt, Alexander. 2000. "Environmental Product Standards, International Trade and Monopolistic Competition," *International Tax and Public Finance* 7; 585-608.

Houthakker, H.S. and Lester D. Taylor. 1970. *Consumer Demand in the United States:*

Analyses and Projections. Cambridge, MA: Harvard University Press.

Hymans, Saul H. 1970. "Consumer Durable Spending: Explanation and Prediction," *Brookings Papers on Economic Activity* 2: 173-206.

Kriström, Bengt and Pere Riera. 1996. "Is the Income Elasticity of Environmental Improvements Less Than One?" *Environmental and Resource Economics* 7: 45-55.

Krutilla, Kerry. 1991. "Environmental Regulation in an Open Economy," *Journal of Environmental Economics and Management* 20: 127-142.

Leidy, M.P. and B.M. Hoekman. 1993. "'Cleaning up' while cleaning up? Pollution abatement, interest groups, and contingent trade policies," *Public Choice* 78: 241-258.

Levinson, Arik and M. Scott Taylor. 2003. "Unmasking the Pollution Haven Effect," *mimeo*, University of Wisconsin.

López, Ramón. 1994. "The Environment as a Factor of Production: The Effects of Economic Growth and Trade Liberalization," *Journal of Environmental Economics and Management* 27: 163-184.

McAusland, Carol. 2002. "Harmonizing Emissions Policy in Symmetric Countries: Improve the Environment, Improve Welfare?" Department of Economics, University of California at Santa Barbara, Departmental Working Paper 21-02.

McAusland, Carol. 2003. "Voting for Pollution Policy: The Importance of Income Inequality and Openness to Trade," *Journal of International Economics* 61(2): 425-451.

Pindyck, Robert S. 1979. *The Structure of World Energy Demand.* Cambridge, MA: MIT Press.

Rauscher, Michael. 1997. *International Trade, Factor Movements, and the Environment.* Oxford: Clarendon Press.

Schleich, Joachim. 1999. "Environmental Quality with Endogenous Domestic and Trade Policies," *European Journal of Political Economy* 15: 53-71.

Schleich, Joachim and David Orden. 2000. "Environmental Quality and Industry Protection with Noncooperative Versus Cooperative Domestic Trade Policies," *Review of International Economics* 8: 681-697.

Appendix A: Second order conditions

The second order conditions—$\frac{d^2W_D}{de^2} < 0$—in autarky and the small open economy are confirmed as follows. Since $\frac{d^2W_D}{de^2} = -\frac{1}{e^2}\frac{dW_D}{de/e} + \frac{1}{e}\frac{d}{de}\frac{dW_D}{de/e}$ then at e_D for each scenario satisfying the second order condition requires $\frac{d}{de}\frac{dW_D}{de/e}$ be negative. Differentiating eq. 6 in each scenario gives $\frac{d}{de}\frac{dW_D^a}{de/e}^a = -\frac{Z^a}{e}\frac{1+\sigma}{e}[\sigma+\epsilon] < 0$ in autarky, and in the small open economy

$\frac{d}{de}\frac{dW_D^t}{de/e} = -[X - X_E]\frac{\sigma\pi^*[1+\sigma]}{N} < 0$ for tailpipe pollution while for smokestack pollution $\frac{d}{de}\frac{dW_D^s}{de/e} = Pf''(e)X_D - [1+\sigma] - [1+\sigma]^2\frac{Z^s}{e}$ which is negative by concavity of f.

Appendix B: Smokestack Regulation in a Large Open Economy

This appendix presents the comparison case of smokestack pollution when Home is large; Home as a small open economy is a limiting case of this and values for it are obtained by setting Home's share of the world population and dirty good output, defined as $n \equiv \frac{N}{N+N^*}$ and $\lambda \equiv \frac{f(e)X}{f(e)X+f(e^*)X^*}$, equal to zero in what follows.

Free trade in goods implies $P^s = P^{*s}$ and so $q^s = q^{*s} = \frac{Xf(e)+f(e^*)X^*}{N+N^*}$. With smokestack regulation $E^s = f(e)X - Nq^s$; substituting in for q^s gives $E^s = f(e)X\left[1 - \frac{n}{\lambda}\right]$. Differentiating gives

$$\frac{dE^s}{de} = \frac{f(e)X\sigma[1-n]}{e} > 0\,, \tag{29}$$

which is opposite in sign to Proposition 3 and eq. 33.

Substitute for q^s in eq. 2 and differentiate to get

$$\frac{\hat{P}^s}{\hat{e}} = -\frac{\sigma\lambda}{\epsilon} \tag{30}$$

and so

$$\frac{\hat{\pi}^s}{\hat{e}} = \frac{\sigma[\epsilon-\lambda]}{\epsilon}. \tag{31}$$

Because pollution arises from production, even if $X_E \neq 0$ then Z^s and $\frac{\hat{Z}^s}{\hat{e}}$ have the same form as in autarky: $Z^s = ef(e)X$ with $\frac{\hat{Z}^s}{\hat{e}} = 1+\sigma$.

The counterpart to eq. 12 for smokestack in the large open economy is then

$$\frac{dW_D^s}{de/e} = Pq\frac{\sigma\lambda}{\epsilon} + X_DPf(e)\frac{\sigma[\epsilon-\lambda]}{\epsilon} - \beta Z[1+\sigma]$$

while the counterpart to eq. 13 is

$$\left.\frac{dW_D^s}{de/e}\right|_{e=e_D^a} = \frac{\sigma}{\epsilon}\left\{[P^sq^s\lambda - P^aq^a] + X_Df(e_D^a)\left[P^s[\epsilon-\lambda] - P^a[\epsilon-1]\right]\right\}.$$

If $P^s = P^a$ when $e = e^a_D$ then we again see that D views e^a_D as too strict in the open economy if and only if D has above average vested interests in the polluting industry:

$$\left.\frac{dW^s_D}{de/e}\right|_{e=e^a_D,\ P^s=P^a} = P^a q^a \frac{\sigma}{\epsilon}[1-\lambda]\left[\frac{X_D/X}{1/N} - 1\right] \tag{32}$$

the sign of which depends only on whether $X_D > \frac{X}{N}$.

Appendix C: Tailpipe Regulation in a Large Open Economy

This appendix examines tailpipe regulation when Home is large; values when Home is small are found by setting the share of world capacity allocated to production of dirty goods for the Home market, defined as $\psi \equiv \frac{X-X_E}{X+X^*}$, equal to zero in what follows.

When Home is large then returns to exports depend on local regulation and equilibrium is defined by $v'\left(\frac{f(e)[X-X_E]}{N}\right) f(e) = v'\left(\frac{f(e^*)[X^*+X_E]}{N^*}\right) f(e^*)$. Differentiating gives the condition

$$\frac{dX_E}{de} = -\frac{\sigma[\epsilon-1]}{e}[X-X_E][1-\psi] \tag{33}$$

which is negative as in Proposition 3. Use this to derive

$$\frac{\hat{P}^t}{\hat{e}} = -\frac{\sigma}{\epsilon}\left[1+[\epsilon-1][1-\psi]\right] \tag{34}$$

$$\frac{\hat{\pi}^t}{\hat{e}} = \sigma\psi\frac{\epsilon-1}{\epsilon} \tag{35}$$

and $\frac{\hat{Z}^t}{\hat{e}} = [1+\sigma] + \sigma[\epsilon-1][1-\psi] > 0$.

The rather unwieldy counterpart to eq. 20 is

$$\frac{dW^t_D}{de/e} = q^t\left[P^t\sigma\psi\frac{X_D/X}{1/N}\frac{X}{X-X_E}\frac{\epsilon-1}{\epsilon} + P^t\sigma\frac{\epsilon[1-\psi]+\psi}{\epsilon} - \beta N e\left[1+\sigma\epsilon+\sigma\psi[1-\epsilon]\right]\right].$$

If $P^t = P^a$ when $e = e^a_D$ then

$$\left.\frac{dW^t_D}{de/e}\right|_{e=e^a_D,\ P^t=P^a} = -[1-\psi]q^a\sigma[\epsilon-1]\left[\frac{P^a}{\epsilon}\left[\frac{X_D/X}{1/N}-1\right] + \beta N e^a_D\right] \tag{36}$$

which is eq. 22 multiplied by the share term $1-\psi$.

Appendix D: Regulation with Internationally Mobile Capacity

Since this paper focuses on goods trade, we have assumed throughout that production capacity is internationally immobile. For tailpipe regulation this question is essentially moot since factor returns depend on where goods are sold, not where they are produced; the same is not true for smokestack regulation. In fact, in our simple model all capacity would move to a single country unless $e^s = e^*$ (where e^* is the overseas emission cap) and both p and Z would respond discontinuously to changes in local smokestack regulation. However the following variation on the production function would generate finite movements of productive capacity: $Q = f(e)g(X - x)$ where x is Home capacity installed in ROW and $g' > 0$, $g'' < 0$. Using this specification, equilibrium in international factor markets would require $f(e)g'(X-x)$ equal some fixed rate, π^*, available abroad if Home is small, and equal $\pi^* = f(e^*)g'(X^* + x)$ where X^* is overseas production capacity if Home were instead large. Differentiating the arbitrage condition $f(e)g'(X - x) = \pi^*$ gives $\frac{dx}{\hat{e}} = \frac{\sigma}{g''/g'} < 0$ if Home is small and $\frac{dx}{\hat{e}} = \frac{\sigma}{\frac{g''}{g'} + \frac{g''(*)}{g'(*)}} < 0$ if Home is instead large, where $g'(*) = g'(X^* + x)$ etcetera. In this setup, market prices to changes in e exactly as when there is no capital mobility: $\frac{\hat{P}}{\hat{e}}^s = 0$ when Home is small and $\frac{\hat{P}}{\hat{e}}^s = -\frac{\sigma\lambda}{\epsilon}$ if Home is large, where λ is the share of dirty good production occurring in Home; this is identical to eq. 30 for the large open economy case without factor mobility.

This does not mean, however, that the stringency level preferred by a politically motivated decision maker is also unaffected by factor mobility. For example, when capacity is mobile, Home's government has an extra incentive to set stringent policy because this drives polluting behavior abroad, effectively raising $\hat{Z}/\hat{e}$ relative to the immobile capacity case. In particular, when capacity is internationally mobile then $Z = ef(e)g(X - x)$ while

${\frac{\hat{Z}}{\hat{e}}}^{s} = 1 + \sigma - \frac{\sigma g'}{g\left[\frac{g''}{g'}\right]} > 1 + \sigma$ if Home is small and ${\frac{\hat{Z}}{\hat{e}}}^{s} = 1 + \sigma - \frac{\sigma g'}{g\left[\frac{g''}{g'} + \frac{g''(*)}{g'(*)}\right]} > 1 + \sigma$ if Home is large.

Because ${\frac{\hat{Z}}{\hat{e}}}^{s} > {\frac{\hat{Z}}{\hat{e}}}^{a}$ when pollution is mobile, eq. 13 is no longer a valid evaluation of how e_D^a and e_D^s compare. In particular, although openness continues to make prices less responsive to smokestack regulation in the open than in the closed economy, since openness also makes pollution more responsive, even when $X_D > \frac{X}{N}$ and $P^* = P^a$ we cannot be certain whether e_D^s is greater or less than e_D^a if capacity is internationally mobile.