ESSAYS ON INTERNATIONAL TRADE AND THE ENVIRONMENT

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To my parents, Elisée and Maria Soumonni

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Chapter I

Environmental Investment and Export Dynamics

Introduction

This paper develops a dynamic model of environmental abatement and exports with heterogeneous firms. Specifically, the paper addresses the impact of firm-level actions taken to reduce deforestation in Indonesia on domestic and export performance. The model emphasizes the role of firm-level environmental investment and export decisions on the evolution of the distribution of abatement and exports in Indonesian timber industries. The model is estimated using firm-level data from Indonesian timber manufacturers. Counterfactual policy experiments are used to assess the policy implications of trade and environmental regulation.

Today, consumers are often encouraged to "think globally and act locally" when purchasing a wide range of goods. What is less clear is whether such actions have discernable impacts on global environmental choices or outcomes. That is, can increasing demand for more environmentally conscious goods change the nature of production and products on a global level? This issue is particularly difficult since many goods of environmental concern are produced in developing countries which are often characterized by weak environmental regulation. Moreover, given the sparcity of data linking environmental actions in one country with outcomes in others it is nearly impossible to quantify or evaluate the potential role of evolving environmental preferences or regulation on production, abatement and export decisions across countries. We study one of the few cases (if not the only case) where there exists producer-specific information regarding both the actions taken by producers in a developing country and outcomes of these actions in export markets. We exploit the unique structure of trade and international timber product certification during the early 1990s along with unique data on environmental decisions from the same period to document and quantify the impact of actions taken to reduce deforestation on export market demand in the Indonesian wood furniture and saw mills industries.

This is not to suggest that there is little existing literature linking trade and environmental outcomes. Rather the opposite is true, particularly in developing countries. For example, Copeland and Taylor (1994, 1995) argue that international trade may be particularly likely to increase pollution in countries that have a comparative advantage in pollution-intensive industries. Similarly, Ederington et al. (2005) and Levinson and Taylor (2008) argue that when we examine trade between developed and developing countries we often observe substantial reallocation of environmentally harmful production. In contrast, numerous authors cast doubt on the hypothesis that free trade will create pollution havens or reduce environmental quality.[1] We contribute to this literature by examining firm-level abatement and exporting activities and characterizing their behavior for a critical, resource-intensive industry in a developing country.

Recent research on export dynamics has emphasized the complementarity between investment and exporting activities. Costantini and Melitz (2008), Ederington and McCalman (2008), Atkeson and Burstein (2010), Lileeva and Trefler (2010) and Aw, Roberts and Xu (2011) highlight this link across firm-level decisions and emphasize the impact it may have on the evolution of firm-level outcomes over time. We follow this literature by examining the relationship between exporting and the investment in mitigating negative outcomes on the natural environment.

While the preceding literature has stressed the link between investment and exporting through the impact of investment on the evolution of firm-level productivity, our paper, in contrast, emphasizes the impact of environmental investment on the evolution of *export demand* at the firm-level. In this sense, our paper is also related to the literature on firm-level decisions, productivity and demand as in Foster et al (2008) or Eaton et al (2009). Using standard variation in domestic and export revenues we develop a methodology to estimate dynamic, stochastic, market-specific returns to firm-level investments even when those returns are only *partially* observed (since relatively few firms export in any given year). We examine a situation where firms may choose to make environmental investments which have differential future returns in both export and domestic markets. While exporting firms are able to directly capture the return from such actions in export markets, we also consider the possibility that non-exporting firms internalize the benefit that current environmental investments have on potential export sales in the future.

A large number of papers have studied whether environmental investment improves firm-level performance, with mixed results. Gollop and Roberts (1983), Smith and Sims (1983) and Brannlund (1995) all report large productivity declines, while Berman and Bui (2001) find significant improvements and Gray (1987) finds no significant change at all.[2] Porter and van der Linde (1995) argue that any measured productivity gain from environmental investment may actually reflect an increase in the demand for goods from "environmentally clean" sources. This interpretation is consistent with the evidence in Teisl et al. (2002) and Bjorner et al. (2004) which document that environmental labeling can have large impacts on

[1] See Grossman and Krueger (1995), Antweiler et al. (2001), or Frankel and Rose (2005) for examples.

[2] These papers study regulation in the US fossil-fueled electric power generator, Canadian brewing, Swedish pulp and paper, US oil refinery and US manufacturing industries, respectively. Further studies of environmental management on firm performance include Jaffe and Palmer (1997), Konar and Cohen (2001) and Brunnermeier and Cohen (2003). Theoretical arguments for the impact of regulation on firm-level efficiency and environmental performance can be found in Xepapadeas and de Zeeuw (1999), Ambec and Barla (2002), Campbell (2003), Bajona et al. (2010) and references therein.

consumer demand in US and European markets, respectively.

Although some of the above mentioned papers examine the impact of environmental investment on firm performance, none of them capture the impact of trade decisions on firm behavior. Kaiser and Schulze (2003) and Girma et al. (2008) explicitly examine the interaction of firm-level abatement with the decision to export abroad. While they confirm that exporting firms from Indonesia and the UK are more likely to abate, they do not study the impact of environmental expenditures or exporting on the evolution of productivity, export demand and export/abatement decisions over time. Similarly, Holladay (2010) demonstrates that exporting U.S. firms tend to emit 5.3 percent less than non-exporting firms on average. He is not, however, able to directly observe whether exporting firms have actively pursued environmental abatement. Pargal and Wheeler (1996) report that larger, more efficient firms tend to produce less local pollution on average in Indonesia. Our paper, in contrast, emphasizes the internal incentive firms may have to reduce local environmental degradation: an increase in profits. Moreover, conditional on the domestic market response to abatement behavior we are able to separately distinguish whether there are further gains in export markets. In fact, our results will suggest that exporting and environmental investment are closely linked within firms.

We build a dynamic structural model of exporting and abatement. As in the preceding exporting and abatement research we allow abatement and export decisions to influence the evolution of future productivity. However, our model adds another layer of firm-level heterogeneity, export demand, whose evolution is an endogenous function of firm decisions. The model links exporting and abatement through four mechanisms. First, the return to either activity is increasing in the firm's productivity, so that high-productivity firms self-select into both activities. Second, each activity potentially influences future productivity reinforcing the first effect. Third, we allow future export demand to depend directly on investment in abatement, encouraging future entry into export markets. Last, entry into either activity influences the return from undertaking the other activity. The decision to export directly influences the probability of abatement and vice-versa.

The data employed in this paper contain unique information detailing firm-level expenditures on environmental abatement, export decisions, and domestic and export revenues for all firms with more than 20 employees in the Indonesian manufacturing sector. While several papers have examined firm-level emissions we are not aware of any other data set that captures variation in *abatement behavior* across trade-oriented manufacturing firms. Fowlie (2010) examines firm-level abatement in the US electricity industry, but does not investigate the interaction of abatement with firm-level trade decisions given the domestic-orientation of this industry.

Our approach has a number of advantages. First, we are able to be specific regarding the environmental concern in the wood furniture and saw mills industries and tailor our model to suit these particular manufacturing industries. Second, deforestation is a leading environmental concern in Indonesia and has generated substantial interest both within Indonesia and abroad. Deforestation is a key environmental issue in Latin America, Eastern Europe, West and Central Africa and South East Asia. In almost every case deforestation and illegal timber practices are closely tied to international trade (WWF, 2008). Despite its importance, deforestation has received almost no attention in the economics literature. Third, the nature of the sustainable resource issue studied here is typical of the type of trade-off between resource depletion and development common in many developing countries. Sachs and Warner (1995) document that the economic development in Latin America has relied heavily on natural resources and the degree to which resource booms influence trade have important implications for economic growth.[3]

The model is estimated in two steps. First, the parameters governing the evolution of productivity are estimated using control function techniques as in Olley and Pakes (1996) and Doraszelski and Jaumandreu (2008). We find that abatement has little effect on firm productivity or on the evolution of domestic sales in the timber industry. The remaining dynamic parameters are estimated by Bayesian Markov Chain Monte Carlo (MCMC) methods. Our results suggest that deciding to abate has a significant positive effect on the evolution of export demand. We observe that firms which choose to start using wood in a sustainable, environmentally conscious manner observe export demand grow 1.4 to 6 percent faster than non-abating firms. Consistent with evidence from the US, we further find that industries whose main product is closer to a finished product tend to enjoy larger increases in demand from such activity (Arora and Cason, 1996).

We perform a number of counterfactual experiments in order to quantitatively assess the impact of policy on firms' decisions in a developing country. The experiments highlight that small changes in the regulatory environment can have large impacts on exporting and abatement over time. Moreover, similar to the evidence found in Ryan (2010), we demonstrate that the entry costs associated with these activities play a key role in determining aggregate outcomes over time.

The experiments suggest that trade liberalization and abatement subsidies encourage exporting and environmental investment. In the wood furniture industry increasing the size of the export market by 20 percent increases export participation rates by 22 percentage points over ten years while also increasing abatement rates by 33 percentage points. Reducing the cost of abatement by 20 percent similarly increases

[3] Similarly, McNeely (1993) indicates that increased trade in Africa has lead to substantial resource depletion across many African countries.

exports and abatement by 1 and 7 percent, respectively, in the same industry and time period. Last, we study the impact of shutting out firms which do not abate from export markets. We find that restricting export markets from environmentally non-compliant exporting firms encourages abatement, but causes export participation to fall. In the wood furniture industry the proportion of abating firms grows by 43 percentage points over ten years, but the proportion of exporting firms falls by 20 percentage points outlining a clear trade-off between these objectives. The experiments confirm that ignoring differential returns to the *same* activity on different markets can potentially lead to misleading policy conclusions.

The next section describes the importance of the Indonesian timber industry, both at home and abroad. Sections 2 and 3 present the model and describe the estimation methodology. The fourth section describes the data while sections 5 and 6 present the empirical results and policy experiments. The last section concludes.

Deforestation, Abatement and Trade in Indonesia

Deforestation and Domestic Policy

Indonesia is home to a rich endowment of natural resources, including the worlds second largest expanse of tropical forest. The timber industry accounts for almost 20 percent of total output, 33 percent of total manufactured exports and played leading role in sustaining GDP growth rates near eight percent per annum before the 1997-1998 Asian crisis (FWI/GFW, 2002). The most common timber exports include plywood, profiled wood, wood furniture and other finished wood products (WWF, 2008). The success of *manufactured* Indonesian wood products on foreign markets is often tied to numerous policies which restrict the export of whole logs in order to encourage the development of the timber manufacturing industry in export markets (Resosudarmo and Yusuf, 2006).

In 1950 forests covered over 162 million hectares of the Indonesian archipelago. By 2000 forest coverage had fallen to 98 million hectares, a 40 percent loss. During the 1980s it is estimated that 1 million hectares of forest were cleared per year, with that rate accelerating to 1.7 million hectares per year by 1990 and 2 million hectares per year by 1996. By 2000, tropical forests had been nearly cleared from the region of Sulawesi and were shrinking rapidly in both the Sumatra and Kalimantan regions of Indonesia.[4] Due to the lack of domestic enforcement, Indonesian wood manufacturers routinely ignore harvest licenses and log trees illegally in order to export timber products abroad. It is estimated that of all of the wood products manufactured in Indonesia as much as three-quarters may be from illegally logged

[4]These figures are taken from the FWI/GFW report (2002).

timber.[5]

We are most interested in the policy environment between 1994 to 1997 during which we have access to data describing firm-level abatement decisions. Indonesian manufacturers faced few domestic environmental regulations during our period of study. There were notable environmental programs in place by 1986 which encompassed a number of recommendations for air, water quality, hazardous waste control and deforestation (Afsah et al., 2000 and WWF, 2008), although compliance was extremely low since enforcement was essentially non-existent (Afsah and Vincent, 1997). Finally, in 1994 Indonesia was preparing to join the World Trade Organization (WTO). While trade barriers fell across timber manufacturing industries, tariffs in major export markets were already relatively low before trade liberalization.[6]

Saw Mills, Wood Furniture and Deforestation

Environmental impacts do vary somewhat across distinct timber industries. We focus on the two largest industries classified at the 4-digit ISIC code level, the saw mill and wood furniture industries.[7] In most timber industries, operations include the handling and transportation of logs, the drying of timber, sorting and classification, although these activities plays a larger role in the saw mills industry (McCarthy, 2002). In contrast, several rare woods, some of which are particularly close to extinction, are used intensively in the production of wood furniture.[8]

Although deforestation is by-far the primary concern in these industries, it is not the exclusive environmental concern in this sector (Resosudarmo and Yusuf, 2006 and Synnott, 2005). Other saw mills activities include the transformation (sawing) of logs into dimension lumber, boards, and beams. Aside from design, typical operations in the wood furniture manufacturing industry include finishing, gluing, cleaning, and wash-off (EPA, 1995). Timber certification schemes, as we detail below, require firms to reduce the environmental impact on these dimensions as well so that consumers can be confident that they are purchasing a product that was produced in an environmentally conscious manner over its entire life-cycle.

[5] McCarthy (2002) reports that 60 percent of saw mills in the province of South Aceh were operating without necessary licenses during the mid-1990s. Similarly, Indonesia is reportedly the largest South-Asian exporter of illegally logged wood products to Europe and the second-largest European source of illegal wood products in the world (WWF, 2008).

[6] Although the EU added environmental clauses to its generalized scheme of tariff preferences (GSP) in 1998, Brack et al. (2002) report that no country has applied for these tariff reductions due to the low rate of duties already applied to timber products in importing countries.

[7] A joint report by the World Resources Institute and Forest Watch Indonesia provide exhaustive details of environmental impacts in the Indonesian timber industries: http://pdf.wri.org/indoforest_full.pdf.

[8] For example, Merbau (or Kwila), a highly-prized tropical hardwood typically used to manufacture high-end luxury timber products, may be extinct world wide by 2042. By 2007, 83 percent of Indonesia's stock of Merbau had already been logged or was allocated for logging (Greenpeace, 2007).

Nonetheless, to check that abatement expenditures were primarily directed towards deforestation in these industries we investigated whether firm-level abatement activities have any impact on the rate at which firms use energy, intermediate materials or capital since these activities have been established as a good proxy for emissions (Cole and Elliott, 2003). Consistent with the results in Pargal and Wheeler (1996) we find no evidence that abatement has any effect on these firm-level attributes in the timber industry.[9]

Foreign Responses to Deforestation

In the mid 1980s and early 1990s, deforestation of tropical forests, began to receive greater international attention. During the 1980s international organizations such as the World Bank and Food and Agriculture Organization of the United Nations, in conjunction with numerous bilateral agencies, begin funding numerous projects to improve timber management, particularly in tropics (Synnott, 2005).[10]

The global institutional framework during the early 1990s played a key role in determining mechanism through which abatement operates in the timber products industry. In particular, Article 20 of the GATT (and later WTO agreements) obliges member countries to treat imports and domestic goods equally, regardless of the nature of production. Despite international concern over tropical deforestation there were few government actions taken to distinguish sustainably produced products. The 1992 United Nations Conference on Environment and Development resolved to encourage sustainable harvesting practices across countries, but did not bind signatories (Tarasofsky, 1994). While Indonesia signed and ratified numerous similar agreements, essentially none of these agreements were binding. While it was initially expected that these agreements would eventually become binding, no such agreements were adopted during this period.[11]

[9] Details and full results can be found in the Supplemental Appendix. Although these processes generate environmental concerns due to air toxins contained in solvents and glue adhesives, a number of inexpensive, less toxic substitutes are widely available (Pollution Prevention Resource Exchange, 2011).

[10] For example, the Tropical Forest Action Plan or the International Tropical Timber Organization.

[11] Austria and the Netherlands attempted to create national timber industry trade policies. In 1992, Austria introduced a special import duty of 70 per cent and a compulsory labeling system for tropical timber. The Netherlands sought to only allow imports of tropical timber only from regions where sustainable forestry management is practiced by 1995. The governments of Indonesia and Malaysia, primary suppliers to the Netherlands, brought these measures to the attention of the GATT. While these disagreements led to the cancelation of policies shortly after they were enacted it was expected these laws were broadly considered precursors to binding European agreements (Lee, 1997 and Patterson, 1997). However, the European Union reports that a Voluntary Partnership Agreement with Indonesia has only been signed very recently (European Union, 2011).

Corporate Responses to Deforestation

In the late 1980s many timber retailers came under increased pressure to provide sustainably harvested alternatives, as numerous NGOs called for outright boycotts of tropical timber products (Synnott, 2005). By 1992 a number of the world's largest timber retailers had developed and instituted wood purchasing policies emphasizing environmental consciousness and tropical forest sustainability. Examples include the largest Do-It-Yourself (DIY) retailers in the US and UK, *HomeDepot* and *B&Q*, respectively, and the world's largest furniture retailer, *IKEA*.[12] These policies were influential in determining the nature of timber certification which followed shortly thereafter (Synnott, 2005).

Concurrently, across Europe and North America corporations in timber-related industries joined together to form buying groups committed to purchasing sustainably harvested wood. The first such group was formed in 1991 among 18 UK timber-purchasing firms from a variety of end-product industries. By 1996 similar groups had formed in Belgium, the Netherlands, France, Ireland, Switzerland, Austria, Germany, Spain, Sweden and North America.[13] As an increasing number of firms became committed to purchasing sustainably harvested timber it became clear that there was a distinct need for an independent, global certification. In particular, purchasing firms needed a credible mechanism to evaluate a product's environmental impact over the entire course of production from harvesting to final use (Synnott, 2005). The lack of such a mechanism provided the necessary motivation for the creation of the initial forest certification bodies.

Smartwood, the FSC and LEI

In contrast to inter-governmental agreements, progress on voluntary timber certification came quickly. This provided a mechanism through which producers could voluntarily opt to distinguish their product *on the basis of how it was produced* in export markets. Moreover, because these certification schemes were operated by global, independent, non-governmental organizations, they did not run the risk of contravening GATT regulations since they were not administered by national governments (Okubo, 1998). Retailers in major export markets were quick to adopt these independent labels which allowed them to distinguish environmentally negligent and conscious suppliers on their store shelves. We document that this practice

[12] In the Supplemental Appendix we have compiled a list of more than 40 industry-leading, timber-purchasing corporations who made similar commitments during our period of study for our products of interest. Note that this list is not intended to be exhaustive. We only wish to illustrate the degree of corporate commitments to the issue of deforestation in tropical forests. Hundreds of other commitments in these industries can be readily found online with international organizations such as the Global Forest Trade Network (http://gftn.panda.org/), the TFT (formerly Tropical Forest Trust, www.tft-forests.org/) or the Rainforest Alliance (http://www.rainforest-alliance.org/).

[13] See the Supplemental Appendix for further details and various citations.

was common, particularly among the largest retailers in many of Indonesia's largest export markets for timber products.[14]

Consumer guides and timber certification began to appear as early as 1987 (Synnott, 2005). In 1989 the Rainforest Alliance had established its global "SmartWood" forest certification program and began certification in Indonesia in 1990. The "Smartwood" certification grew in Indonesia throughout 1991-1993 and has been shown to have had an important impact on producers: initial adopters of certification benefitted from a substantial rise demand traced to a export boom sustainably harvested Indonesian teak furniture (Muhtaman and Prasetyo, 2006).

By 1990 numerous international meetings were organized to explore the idea of an global, independent timber monitoring agency. In particular, in 1990 the Certification Working Group was born from meetings of numerous timber users, traders and environmental organizations in California. This group paved the way for the eventual establishment of Forest Stewardship Council (FSC) certification in 1993 (Perera and Vlosky, 2006). A key accomplishment of this group was the establishment of a criterion for evaluating sustainably produced timber products worldwide (Synnott, 2005).

There are three keys features of FSC certification that are important for our study. First, the FSC certification is required at *each stage of production*. That is, when consumers inquire about FSC certification they can assured that the product was produced in an environmentally conscious manner from harvesting to retailing. Second, although deforestation was the primary motivation for the creation of FSC certification, the FSC requires that timber producers take action to *broadly reduce their impact on the environment*. For instance, furniture producers are not just asked to use better sources of wood but also to adopt more environmentally conscious adhesives, finishes, etc. As such, any action taken by firms to reduce the environmental impact can contribute to FSC certification. Third, FSC was the most prominent global certification available to Indonesian producers during our sample period (Synnott, 2005).[15]

In 1993 the Indonesian government established the Lembaga Ekolabel Indonesia Working Group (LEI) to study the potential for a national certification scheme which would enable Indonesian producers to establish that their products were meeting international sustainability expectations. Based on the FSC guidelines, the LEI created a framework for timber certification tailored to the Indonesian context. In 1998 the group severed ties with the government and began certifying producers. While the LEI did not directly certify products between 1994 and 1997 they were working closely with Indonesian firms to help

[14]See the Supplemental Appendix for a timeline of standards adoption for firms such as *B&Q*, *Carrefour*, *Homebase*, *HomeDepot*, *IKEA* and *Walmart* among others.

[15]Numerous alternatives appeared shortly after 1996-1997 such as the PEFC and ISO 14001.

them meet international sustainability standards (Muhtaman and Prasetyo, 2006).

While certification was voluntary, numerous studies have found that voluntary certifications can have substantial impact on demand. Chen, Otsuki and Wilson (2008) find meeting foreign standards does have a significant impact on export performance among manufacturing firms in developing countries. Moreover, Arora and Cason (1996) demonstrate that these effects may be particularly important for firms which produce relatively finished products. Market studies suggest that over the 1992-1996 period tropical timber consumption fell by 36 percent in Germany, the UK and the Netherlands (Greenpeace, 1999) and that by 2000 certified wood products accounted for at least 5 percent of all timber sales in Western Europe (Brack et al., 2002).

Certification, however, can be quite costly. These expenditures often include changes in forest management, creating separate inventories of certified and non-certified products, tracking certified products through all previous stages of production and the costs directly associated with the actual certification process (Perera and Vlosky, 2006). Studies focussing on Indonesia emphasize costs associated with securing lands from illegal logging activities, redesigning the working area and allocating some land to protected area (Muhtaman and Prasetyo, 2006).[16] The actual certification process includes preparing the firm for a certification audit, paying the auditors' costs (travel, field visits, reports, annual follow-ups, certificates), and compliance costs associated with changes in management and employee training (Fischer et al, 2005). Some studies suggest that certification can increase costs by 5-25 percent (Gan (2005)), but others note these costs generally display large economies of scale (Fischer et al, 2005).

A Structural Model of Abatement and Exporting

We contribute to a rich literature that examines firm entry into exports markets such as Roberts and Tybout (1997), Clerides, Lach and Tybout (1998), Melitz (2003) and models of exporting and investment as in Costantini and Melitz (2008), Atkeson and Burstein (2010), Lileeva and Trefler (2010). Our structural model is closest to the structural models of firm entry into export markets presented in Das, Roberts and Tybout (2007) and Aw, Roberts and Xu (2011). While we will also allow abatement to influence the evolution of productivity, we do not need (or necessarily expect) that this is the primary mechanism through which abatement influences export decisions.

[16]Examples reported by Indonesian timber producers include expenditures incurred to patrol their licensed timber holdings with military or police officers and the making of guard posts. The government does not fund these operations in Indonesia. Other timber producer have noted that they needed to restructure their production area to allocate some timber sources to conversation forests and recover higher percentage from the trees that were cut Muhtaman and Prasetyo, 2006).

We prefer to emphasize the positive impact that abatement has on export demand. Our model allows us to separately identify *productivity* effects from *demand* effects in export markets, allowing us to test one version of the "Porter Hypothesis": that abatement may increase firm-specific demand (Porter and van der Linde, 1995).[17] To the extent that abatement may encourage growth in domestic demand (rather than improving firm productivity), our estimates in export markets identify the differential growth rate in demand across domestic and export markets.

Static Decisions

We first consider the total costs for each firm. Firm i's short-run marginal cost function is modeled as:

$$\ln c_{it} = \ln c(k_{it}, \omega_{it}) = \beta_0 + \beta_k \ln k_{it} + \beta_w w_t - \omega_{it} \tag{1}$$

where k_{it} is the firm's stock of productive capital, w_t is the set of relevant variable input prices and ω_{it} is firm-level productivity. Data limitations require a number of assumptions. First, we assume that each firm is a separate organizational entity and that each firm produces a single output which can be sold at home or abroad.[18] Second, there are two sources of short-run cost heterogeneity: differences in firm-level capital stocks and productivity. Abatement can only affect short-run costs through its impact on productivity. Last, we assume that marginal costs do not vary with firm-level output. As such, demand shocks in one market do not affect the static output decision in the other market.

Both domestic and export markets are assumed to be monopolistically competitive in the Dixit and Stiglitz (1977) sense. However, we allow each firm to face a different demand curve and charge different markups in each market j where $j = D$ denotes the domestic market and $j = X$ denotes the export market. Specifically, firm i faces the following demand curve q_{it}^j in market j:

$$q_{it}^j = Q_t^j (p_{it}^j / P_t^j)^{\eta_j} e^{z_{it}^j(d_{it-1})} = \frac{I_t^j}{P_t^j} \left(\frac{p_{it}^j}{P_t^j} \right)^{\eta_j} e^{z_{it}^j(d_{it-1})} = \Phi_t^j (p_{it}^j)^{\eta_j} e^{z_{it}^j(d_{it-1})} \tag{2}$$

where Q_t^j and P_t^j are the industry aggregate output and price index, I_t^j is total market size and η_j is the elasticity of demand, which is constant. The individual firm's demand in each market depends on industry aggregates Φ_t^j, the elasticity of demand, its own price p_{it}^j and a firm-specific demand shifter $z_{it}^j(d_{it-1})$. The firm-specific demand shifter $z_{it}^j(d_{it-1})$ in turn depends on the firm's history of environmental abatement

[17] See Innes (2010) for other interpretations of the Porter hypothesis we do not consider here.

[18] The first part of this assumption is not too restrictive. Blalock, Gertler and Levine (2008) report that 95% of the firms in the Indonesian manufacturing census are separate organizational entities.

decisions d_{it-1}.

Both firm-specific productivity and the export demand shock capture various sources of heterogeneity, and as such, it is important to interpret their effect cautiously. Our data will not allow us to separately identify productivity from demand effects on the *domestic market*. As such, we follow Das, Roberts and Tybout (2007) and Aw, Roberts and Xu (2011) and assume $z_{it}^j = 0$ for all i and t if $j = D$. In this case, the term ω_{it} captures any source of firm-level heterogeneity that affects the firm's revenue in both markets; this may be product quality, for example, but we will refer to it as productivity. If abatement affects domestic demand then it will show up as a productivity effect in domestic revenues. Moreover, if environmental investment affects both costs (productivity) and revenues (demand) our estimates will only reveal the net/total effect on the domestic market.

In this case z_{it}^j captures all sources of export revenue heterogeneity, arising from differences in either cost or demand, that are unique to the export market. We are particularly interested in identifying the component the export demand shifter that depends on environmental abatement. In the same sense as above if firm-level environmental investment improves product appeal or the efficiency with which the firm produces the "version" of the product for export, we cannot separately identify these effects. We will be more specific regarding the functional form of z_{it}^j in the following section.

Each period firm i decides whether or not to export, whether or not to abate and sets the price for its output in each market to maximize the discounted sum of profits. The firm's optimal price p_{it}^j implies that the log of revenue r_{it}^j in market j is:

$$\ln r_{it}^j = (\eta_j + 1)\ln\left(\frac{\eta_j}{\eta_j + 1}\right) + \ln\Phi_t^j + (\eta_j + 1)(\beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - \omega_{it}) + z_{it}^j(d_{it-1}) \qquad (3)$$

so that the firm's domestic revenue is a function of aggregate market conditions, the firm's capital stock, firm-specific productivity and demand. Export revenues will depend on abatement decisions through both firm-specific productivity and the export demand shock whereas abatement can only influence domestic revenues through productivity.

The structure of the model allows us to calculate operating profits in each market, $\pi_{it}^j = -\eta_j^{-1} r_{it}^j(\Phi_t^j, k_{it}, \omega_{it})$, and, as such, the short-run profits are observable with data on domestic and export revenues. These will be important for determining the export and environmental investment decisions over time developed in the dynamic model below.

Transition of the State Variables

We describe here the evolution of productivity, export demand shocks and the state variables Φ_t^D, Φ_t^X, and k_{it}. We assume that productivity evolves over time as a Markov process that depends on the firm's abatement decisions, its participation in the export market, and a random shock:

$$\begin{aligned}\omega_{it} &= g(\omega_{it-1}, d_{it-1}, e_{it-1}) + \xi_{it} \\ &= \alpha_0 + \alpha_1 \omega_{it-1} + \alpha_2 d_{it-1} + \alpha_3 e_{it-1} + \alpha_4 d_{it-1} e_{it-1} + \xi_{it}\end{aligned} \tag{4}$$

where d_{it-1} is the firm's abatement decision, and e_{it-1} is the firm's participation in export market in the previous period. We treat d_{it} (e_{it}) as a binary variable which takes a value of 1 if firm i abates (exports) in year t and zero otherwise. As described above, it is not unrealistic to assume that the costs associated with certification and abatement in this industry are fixed in nature. We assume that any effect abatement has on productivity occurs in the year subsequent to when the expense was incurred due to the time necessary to install new technology, for certification to be verified and processed and for upgraded product characteristics to be noticed in the market.

The inclusion of e_{it-1} allows for the possibility of learning-by-exporting and, in this case, we expect that $\alpha_3 > 0$. The term d_{it-1} captures the impact of abatement on the evolution of productivity. If environmental technology is more costly to operate (e.g. maintenance costs, emission control costs, fewer resources allocated to production) we would expect that abatement would reduce firm productivity and $\alpha_2 < 0$. However, if environmental technology is more advanced such that firms which abate also experience productivity improvements, we would expect $\alpha_2 > 0$. We further argue that there may be important interactions between exporting and abatement. For instance, if foreign contacts allow firms to make better use of new technology we would expect that $\alpha_4 > 0$. The stochastic element of productivity evolution is captured by ξ_{it}. We assume that ξ_{it} is an *iid* draw from a distribution with zero mean and variance σ_ξ^2. Note that the stochastic element of productivity is carried forward into future periods.

We also assume that the export demand shock evolves according to the following first-order Markov-process:

$$\begin{aligned}z_{it} &= h(z_{it-1}, d_{it-1}, e_{it-1}) + \mu_{it} \\ &= \gamma_0 + \gamma_1 z_{it-1} + \gamma_2 d_{it-1} + \mu_{it}\end{aligned} \tag{5}$$

where $\mu_{it} \sim N(0, \sigma_\mu^2)$. Unlike previous studies our model allows firm-level export demand to endogenously evolve separately from firm-level productivity.[19] The persistence in z captures factors such as the nature of the firm's product or destination markets that lead to persistence in export demand over time. The coefficient γ_2 captures any effect that environmental investment has on export sales over and above any effect it had on productivity. If there is an export specific boost from abatement we expect that $\gamma_2 > 0$.[20]

As in Aw, Roberts and Xu (2011) we will assume that capital is fixed over time for each firm i. Due to the short time series in our data, there is little variation over time in firm-level capital stock (particularly relative to the cross-sectional variation). We will, however, allow for cross-sectional variation in capital stock across firms. Last, we treat the aggregate state variables $\ln\Phi_t^D$ and $\ln\Phi_t^X$ as exogenous first-order Markov processes.

Abatement and Export Decisions Over Time

We next consider the firm's dynamic decisions to abate and export. We assume that the firm first observes the fixed and sunk costs of exporting, γ_{it}^F and γ_{it}^S, and decides whether or not to export in the current year. After making its export decision, the firm observes the fixed and sunk costs of abatement, γ_{it}^A and γ_{it}^D, and makes the discrete decision to abate in the current year. All four costs are assumed to be *iid* draws from the joint distribution G^γ.[21]

Denote the value of firm i in year t before it observes fixed or sunk costs by V_{it}:

$$V_{it}(s_{it}) = \int (\pi_{it}^D + \max_{e_{it}}\{(\pi_{it}^X - e_{it-1}\gamma_{it}^F - (1-e_{it-1})\gamma_{it}^S) + V_{it}^E(s_{it}), V_{it}^D(s_{it})\})dG^\gamma \tag{6}$$

where $s_{it} = (\omega_{it}, z_{it}, k_i, \Phi_t, e_{it-1}, d_{it-1})$ is a vector of state variables, V_{it}^E is the value of an exporting firm after it makes its optimal abatement decision and V_{it}^D is the value of a non-exporting firm after it makes its optimal abatement decision. The value of abating is determined by V_{it}^D and V_{it}^E:

$$\begin{aligned} V_{it}^E(s_{it}) \quad = \quad & \int \max_{d_{it}\in(0,1)}\{\delta E_t V_{it+1}(s_{it}|e_{it}=1, d_{it}=1) - d_{it-1}\gamma_{it}^A - (1-d_{it-1})\gamma_{it}^D, \\ & \delta E_t V_{it+1}(s_{it}|e_{it}=1, d_{it}=0)dG^\gamma \end{aligned} \tag{7}$$

[19] The Supplemental Appendix provides methodological details on how to simulate the endogenous z process when it is only partially observed.

[20] We experimented with versions of (4) and (5) that included higher powers of ω_{it-1} or z_{it-1}, e.g. ω_{it-1}^2, ω_{it-1}^3, etc. In either case, the coefficients on those variables were always very close to zero and statistically insignificant.

[21] An alternative assumption is that the export and environmental abatement decisions are made simultaneously. While this leads to a similar model, the computational difficulty associated with calculating the probability of each decision is substantially greater.

$$V_{it}^{D}(s_{it}) = \int \max_{d_{it}\in(0,1)} \{\delta E_t V_{it+1}(s_{it}|e_{it}=0, d_{it}=1) - d_{it-1}\gamma_{it}^{A} - (1-d_{it-1})\gamma_{it}^{D}, \quad \delta E_t V_{it+1}(s_{it}|e_{it}=0, d_{it}=0) dG^{\gamma} \tag{8}$$

The net benefit (or loss) to abating and exporting, conditional on previous decisions, is embedded in the value functions. The tradeoffs facing the firms are captured in the expected future value of any possible choice:

$$E_t V_{it+1}(s_{it}|e_{it}, d_{it}) = \int_{\Phi'} \int_{z'} \int_{\omega'} V_{it+1}(s') dF(\omega'|\omega_{it}, e_{it}, d_{it}) dF(z'|z) dG(\Phi'|\Phi) \tag{9}$$

Notably, we allow for the possibility abatement may reduce productivity and increase the cost of production. We do expect, however, that the return to exporting and abatement are both increasing with respect to export demand. In industries where this second effect is dominant we expect a typical selection effect: only highly productive firms that expect large export sales will choose to export and abate.

The model explicitly recognizes that current choices affect the evolution of export demand and productivity, and potentially influence future export and abatement decisions. It is important to emphasize that the structure of the model further implies that the return to either decision may depend very much on the other. For example, the return to abatement depends on export decisions both through the evolution of productivity and the sunk cost associated with export behavior. Similarly, the return to exporting intuitively depends on the past abatement decisions which influence the path of export demand and the productivity directly through equations (4) and (5), but also influences the export decision through the sunk cost of abatement. The marginal benefit of abating from equations (7) and (8) can then be defined as the difference in expected future returns between investing or not investing in abatement for any vector of state variables, s_{it}:

$$MBA_{it}(s_{it}|e_{it}) = E_t V_{it+1}(s_{it+1}|e_{it}, d_{it}=1) - E_t V_{it+1}(s_{it+1}|e_{it}, d_{it}=0) \tag{10}$$

As alluded to earlier, the marginal benefit of abatement will not only depend on the effect that abatement has on future productivity but also on the decision to export. The difference in the marginal benefit of abatement between both groups can be defined as:

$$\Delta MBA_{it}(s_{it}) = MBA_{it}(s_{it}|e_{it}=1) - MBA_{it}(s_{it}|e_{it}=0). \tag{11}$$

This difference will be positive if abatement is more worthwhile to exporters relative to non-exporters in which case we might expect that α_4 in equation (4) and/or γ_2 in equation (5) are positive, suggesting complementarity between the decision to export and abate. Likewise, for any given state vector, the marginal benefit of exporting can be defined as:

$$MBE_{it}(s_{it}|d_{it-1}) = \pi^X_{it}(s_{it}) + V^E_{it}(s_{it}|d_{it-1}) - V^D_{it}(s_{it}|d_{it-1}) \tag{12}$$

This reflects current export profits plus the expected gain in future export profit from being an exporter as opposed to serving only the domestic market. Analogous to the marginal benefit of abatement discussion, in general the marginal benefit of exporting will depend on past abatement decisions when there is a sunk cost to abating where $\Delta MBE_{it}(s_{it}) = MBE_{it}(s_{it}|d_{it} = 1) - MBE_{it}(s_{it}|d_{it} = 0)$ indicates the marginal effect of abating on the return to exporting. In the next section we examine how we can empirically estimate the interdependence between these decisions.

Estimation

Next we develop the empirical counterpart to the model presented in the previous section and describe the estimation procedure. We estimate the model in two steps; in the first step we employ control function techniques similar to Olley and Pakes (1996), Levinsohn and Petrin (2003) and Doraszelski and Jaumandrau (2008) to recover the parameters of the revenue function and the evolution of productivity. In the second stage, we describe a Bayesian MCMC method to estimate the dynamic parameters and capture the impact of abatement on export decisions over time.[22]

Mark-ups and Productivity

As a first step, we recover an estimate of the mark-ups at home and abroad. We exploit the fact that each firm's marginal cost, c_{it} is constant with respect to total output and equal across domestic and export output. Setting marginal revenue equal to marginal cost in each market we can write total variable cost, tvc_{it}, as a combination of domestic and export revenue weighted by their respective elasticities:

$$\begin{aligned} tvc_{it} &= q^D_{it} c_{it} + q^X_{it} c_{it} \\ &= r^D_{it}\left(1 + \frac{1}{\eta_D}\right) + r^X_{it}\left(1 + \frac{1}{\eta_X}\right) + \varepsilon_{it} \end{aligned} \tag{13}$$

[22] Our method is similar to Das, Roberts and Tybout (2007). We extend their method to allow us to estimate an endogenous, dynamic process which is only partially observed in the data. Given the generalized type II Tobit likelihood function in our model, classical estimation techniques such as Maximum Likelihood Estimation often do not perform well. Hence we choose to use Bayesian MCMC methods to estimate the dynamic parameters of the model. Methodological details can be found in the Supplemental Appendix.

where the error term ε_{it} captures measurement error in total variable cost. Estimating equation (13) by OLS we retrieve the estimates of η_D, and η_X and turn next to estimating the parameters of the productivity process.

Recall that the domestic revenue function is

$$\ln r_{it}^D = (\eta_D + 1)\ln\left(\frac{\eta_D}{\eta_D+1}\right) + \ln \Phi_t^D + (\eta_D+1)(\beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - \omega_{it}) + u_{it} \tag{14}$$

where we have added an *iid* error term to equation (3). The composite error includes both an *iid* component and firm-specific, time varying productivity: $-(\eta_D+1)\omega_{it} + u_{it}$. As in Olley and Pakes (1996) we rewrite unobserved productivity as a non-parametric function of observables that are correlated with it. Note that the relative demand for m_{it} and n_{it} are not a function of output (or z_{it}), given our assumption of constant marginal costs. If technology differences are not Hick's neutral then productivity differences cause input demand to vary across firms and time.[23] As such, input demand will contain information on firm productivity levels, $\omega_{it} = \omega(k_{it}, m_{it}, n_{it}, d_{it-1})$, and we can write the domestic revenue function in (14) as

$$\begin{aligned}\ln r_{it}^D &= \rho_0 + \sum_{t=1}^{T} \rho_t D_t + (\eta_D+1)(\beta_k \ln k_{it} - \omega_{it}) + u_{it} \\ &= \rho_0 + \sum_{t=1}^{T} \rho_t D_t + f(k_{it}, m_{it}, n_{it}, d_{it-1}) + v_{it} \end{aligned} \tag{15}$$

where ρ_0 is a constant, D_t is a set of year dummies and we approximate $f(\cdot)$ by a fourth order polynomial of its arguments. The essence of the above method is that the function $f(\cdot)$ captures the combined effects of exporting, abatement, capital and productivity on domestic revenue. We denote the fitted value of the $f(\cdot)$ function as $\hat{\varphi}_{it}$. According to our model the estimate of $\hat{\varphi_{it}}$ captures $(\eta_D+1)(\beta_k \ln k_{it} - \omega_{it})$ which is a function of capital and productivity. We first estimate (15) by OLS, recover an estimate of the composite term, $\hat{\varphi}_{it}$ and construct a productivity series for each firm. Specifically, inserting φ_{it} into (4) we write the estimating equation

$$\hat{\varphi}_{it} = \beta_k^* \ln k_{it} - \alpha_0^* + \alpha_1(\hat{\varphi}_{it-1} - \beta_k^* \ln k_{it-1}) - \alpha_2^* d_{it-1} - \alpha_3^* e_{it-1} - \alpha_4^* d_{it-1} e_{it-1} + \xi_{it}^* \tag{16}$$

where the asterisk indicates that the coefficients are scaled by (η_D+1). Equation (16) is estimated by

[23] Numerous studies find that technical change is not Hick's neutral. See Jorgenson, Gollop, and Fraumeni (1987) for an example.

non-linear least squares and the parameters are retrieved given η_D.[24]

Dynamic Parameters

The remaining parameters of the model can be estimated using the discrete decisions for exporting and abatement. Given the first-stage parameter estimates we construct a firm-level productivity series, $\omega_i \equiv (\omega_{i1},...,\omega_{iT})$ and in combination with the observed firm-level series of exporting $e_i \equiv (e_{i1},...,e_{iT})$, export revenues $r_i^X \equiv (r_{i1}^X,...,r_{iT}^X)$, and firm-level abatement $d_i \equiv (d_{i1},...,d_{iT})$ we can write the i^{th} firm's contribution to the likelihood function as

$$P(e_i,d_i,r_i^X|\omega_i,k_i,\Phi) = P(e_i,d_i|\omega_i,k_i,\Phi,z_i^+)h(z_i^+|d_i^-) \tag{17}$$

where z_i^+ is the time series of export market shocks for firm i in years in which it exports and $d_i^- \equiv (d_{i0},...,d_{iT-1})$ is the sequence of lagged abatement decisions. Equation (17) expresses the joint probability of discrete export and abatement decisions, conditional on export market shocks and the marginal distribution of z. Note that in this case the marginal distribution of z varies across firms with different abatement histories. Given the estimated parameters of the export shock process we can simulate exports shocks, construct the density $h(z_i^+|d_i^-)$, and evaluate the likelihood function.[25]

The model allows us to express the probabilities of exporting or abatement as functions of the value functions and sunk and fixed cost parameters. Specifically, assuming that the sunk and fixed costs are *iid* draws from a known distribution, the joint probabilities of exporting and abatement can be written as the product of the choice probabilities for d_{it} and e_{it} in each year, conditional on s_{it}. The probability of exporting can be written as:

$$P(e_{it}=1|s_{it}) = P(e_{it-1}\gamma_{it}^F + (1-e_{it-1})\gamma_{it}^S \leq \pi_{it}^X + V_{it}^E - V_{it}^D) \tag{18}$$

Intuitively, the sunk and fixed costs are identified from differential entry and exit behavior across similar firms with different export histories.

[24]Standard errors are computed by bootstrapping over equations (13),(15), and (16).

[25]The Supplemental Appendix describes how we simulate the density of endogenous export shocks conditional on a firm's observable abatement history.

Similarly, the probability of abatement can be calculated as:

$$\begin{aligned} P(d_{it}=1|s_{it}) &= P(d_{it-1}\gamma_{it}^{A}+(1-d_{it-1})\gamma_{it}^{S}\leq \\ &\qquad \delta E_t V_{it+1}(s_{it}|e_{it},d_{it}=1)-\delta E_t V_{it+1}(s_{it}|e_{it},d_{it}=0)) \end{aligned} \tag{19}$$

The probability of abatement depends on the *current* export decision due to the model's timing assumption requiring export decisions to be made ahead of abatement decisions.[26]

The probabilities depend on sunk and fixed cost parameters, export and abatement histories, and the expected value functions, $E_t V_{it+1}$, V_{it}^{D} and V_{it}^{E}. For a given set of parameters we employ a Bayesian Monte Carlo Markov Chain (MCMC) estimator to characterize the posterior distribution of the sunk and fixed cost parameters. We assume that all fixed and sunk costs are drawn from separate, independent exponential distributions. The estimated sunk and fixed costs we estimate should then be interpreted as the the means of those distributions.[27]

Data

We estimate the model using firm-level data from Indonesia between 1994-1997, collected annually by the Central Bureau of Statistics, *Budan Pusat Statistik* (BPS). The survey covers the population of manufacturing firms in Indonesia with at least 20 employees. The data capture the formal manufacturing sector and record detailed firm-level information on domestic and export revenues, capital, intermediate inputs, energy and expenditures on environmental abatement. Data on revenues, investment and inputs are combined with detailed wholesale price indices to deflate price changes over time.[28] We abstract from the firm's initial (domestic) entry decision and focus on the set of continuing firms. Initially, we study the period between 1994-1996 due to the potential concern that the 1997-1998 Asian crisis may affect the results. However, as documented in the Supplemental Appendix, including this year leads to similar estimates in both industries.

Table 1 describes size differences across firms measured by average sales in the saw mill (ISIC 3311) and wood furniture (ISIC 3321) industries.[29] Overall, we follow 583 saw mill producers and 460 wood

[26] In the first year of the data we do not observe d_{it-1}. To deal with this initial conditions problem we model the initial decisions using probit equations in the first year (Heckman, 1981).

[27] Due to the small estimated change in Φ_X over time we also constrain it to be constant below.

[28] Price deflators are constructed as closely as possible to Blalock and Gertler (2004) and include separate deflators (1) output and domestic intermediates, (2) capital, (3) energy, (4) imported intermediates and (5) export sales. Further details can be found in the Supplemental Appendix.

[29] Throughout our paper we focus exclusively on domestically-owned firms where less than 10 percent of equity is held by

Table 1: Average Sales

	Saw Mills			Wood Furniture		
	Non-Exporters	Exporters		Non-Exporters	Exporters	
	Average Domestic Sales	Average Domestic Sales	Average Export Sales	Average Domestic Sales	Average Domestic Sales	Average Export Sales
1994	19,267	23,913	140,742	3,702	6,352	13,147
1995	18,159	28,657	115,485	3,616	7,304	11,717
1996	12,207	27,884	142,923	3,933	6,616	14,588

Table 2: Average Sales Across Abatement Status 1994-1996

	Non-Exporters		Exporters	
	Non-Abate	Abate	Non-Abate	Abate
Saw Mills	16,113	9,629	91,028	127,401
Wood Furniture	3,369	4,029	13,305	16,352

Notes: Abatement expenditures are measured in thousands of 1983 Indonesian rupiahs.

furniture producers who operate continuously between 1994 and 1996.[30] In both industries, exporters report larger average sales than non-exporters which is indicative of the superior productivity enjoyed by firms who self-select into export markets. It is worth noting, however, that the distribution of sales is highly skewed in each industry; the average level of domestic sales among domestic non-exporters is approximately 7.6 and 4.7 times the size of the median level of domestic sales in the saw mill and wood furniture industries, respectively. The distributions of domestic and export sales among exporters are similarly skewed. Table 1 also documents important size differences across industries. The average saw mill producer earns 3-5 times more domestic revenue than the average furniture producer, while the average saw mill exporter earns 10-11 times more export revenue than the average furniture exporter.

While it is well known that exporting is relatively uncommon among manufacturing firms there are few estimates of abatement rates in developing nations. Define an abating firm as one that invests a positive amount in environmental abatement in the current year.[31] Overall, 20 and 11 percent of producers in the saw mill and wood furniture industry reported positive abatement expenditures during this period.

Table 2 presents the average sales across export and abatement status. Notably, among non-exporting firms that abate in the saw mills industry, average sales at home are 40 percent *smaller* on average than firms which do not abate. This pattern is reversed among exporting firms; among exporters total sales are

foreign investors. Using this definition, 94 percent of firms in the Indonesian manufacturing industry are domestically-owned during this period.

[30] Summary statistics for the comparable 1994-1997 sample are reported in the Supplemental Appendix.

[31] Given the short time dimension of the panel data and the small number of firms which choose to abate estimating a model with a continuous abatement choice variable is practically very difficult in this context. The small number of observations severely restricts our ability to identify the firm's abatement policy rule. We do, however, test this restriction and find that using a continuous measure of abatement has little impact on the estimated demand parameters. See the Supplemental Appendix for details.

Table 3: Abatement and Export Behaviour

	Saw Mills			Wood Furniture		
	Abt. Rate	Abt. Expend.	Obs.	Abt. Rate	Abt. Expend.	Obs.
Exporter	22.74	119.04	1148	15.52	56.36	1218
Non-Exporter	15.62	26.38	1934	9.58	6.47	1827
	Exp. Rate	Exp. Rev.	Obs.	Exp. Rate	Exp. Rev.	Obs.
Abater	46.36	106,263.10	563	51.92	14,712.77	364
Non-Abater	35.21	77,196.40	2519	38.38	10,972.06	2681

Notes: Abatement expenditures are measured in thousands of 1983 Indonesian rupiahs.

40 percent *higher* among abating firms. The difference across abating and non-abating firm is indicative of the impact abatement may have on export sales in particular. In the wood furniture industry this pattern is not nearly as stark. Abating firms tend to generate sales which are 20 percent higher than non-abaters among non-exporting firms and 23 percent higher among exporting firms.

The top panel of Table 3 documents differences in abatement behavior across exporting and non-exporting firms in Indonesia. Columns 1 and 4 present the percentage of exporting and non-exporting firms which incur abatement expenditures in the saw mills and wood furniture industries. We observe that exporting firms are always more likely to engage in abatement than their non-exporting counterparts by 6 to 7 percent. Similarly, columns 2 and 5 present the average annual abatement expenditures across exporting and non-exporting firms, conditional on the firms having incurred some positive abatement expense. On average exporters spent 350 to 770 percent more on abatement than non-exporters over the same period. Across industries, abatement expenditures tend to be higher in the saw mills industry than in the wood furniture industry, capturing the size difference across industries. The average abatement expenditure (among those who abate) in the saw mill and wood furniture industries were respectively, 69 and 32 thousand 1983 Indonesian rupiahs, and these represent approximately 2 percent of the median firm's total revenue in each industry. Even though abatement is captured by a binary variable in our model it is worth noting that we do allow for abatement cost heterogeneity by drawing fixed and sunk costs from exponential distributions. The bottom panel of Table 3 documents the export rate and the average size of export revenues across abatement status. Similarly, we find that firms who choose to abate are more likely to export and, among those who export, they tend to have much higher export sales.

Finally, Table 4 reports the transitions in and out of exporting and abatement across all four possible combinations these variables could have taken in the preceding year. Only 10 percent of firms abate and export in the saw mills industry, while only 5 percent of firms are simultaneously engaged in both activities in the wood furniture industry. Export status is very persistent in the saw mill and wood furniture industries

Table 4: Annual Transition Rates for Continuing Plants

Saw Mills

	Status in $t+1$			
Status in t	Neither	only Exp.	only Abt.	Both
All Firms	0.566	0.231	0.105	0.098
Neither	0.857	0.069	0.063	0.012
only Exp.	0.112	0.729	0.000	0.155
only Abt.	0.344	0.156	0.547	0.094
Both	0.059	0.314	0.098	0.529

Wood Furniture

	Status in $t+1$			
Status in t	Neither	only Exp.	only Abt.	Both
All Firms	0.682	0.209	0.065	0.045
Neither	0.901	0.054	0.041	0.005
only Exp.	0.167	0.790	0.016	0.027
only Abt.	0.375	0.063	0.469	0.094
Both	0.000	0.200	0.029	0.771

where exporters respectively receive 81 and 85 percent of revenues from export sales on average. Firms engaged in either activity are much more likely to begin the other activity than are firms that are not engaged in either activity. Moreover, the persistence in each state is suggestive of potential sunk costs associated with each behavior.

The above tables suggest the potential interdependence of the export and abatement decisions. However, if both exporting and abatement are costly we might expect that only the most productive firms are able to engage in either activity. Any correlation across activities may be spurious and offer no real indication of an important interaction at the firm-level. Moreover, if there is a causal relationship between abatement and exporting, the simple correlations offer little indication on the mechanism through which exporting affects the decision to abate or vice-versa. For example, if exporting encourages firms to improve firm-level productivity, then we might expect that exporting encourages the adoption of costly abatement technology. Similarly, abatement may introduce new highly productive technology to the firm and improve productivity to the point where firms are willing to enter export markets. Most importantly, if abatement influences export growth separately from changes in productivity the above correlations provide little evidence of the differential return to abatement in different markets. We quantify and disentangle these various effects below.[32]

Empirical Results

Elasticity of Demand, Cost and Productivity Evolution

The first-stage parameter estimates are reported in Table 5.[33] The point estimate of the domestic market elasticity in the saw mill and wood furniture industries are -5.5 and -7.4, respectively, which implies mark-ups of 32 and 16 percent. Export market demand is estimated to be less elastic in both industries with an estimated elasticity parameter of -2.5 in either case and an implied mark-up of 67 percent.

[32]The Supplemental Appendix provides further reduced form evidence. It is omitted here for brevity.

[33]Estimates based on the 1994-1997 sample are presented in the Supplemental Appendix.

Table 5: First Stage Parameter Estimates

	Saw Mills		Wood Furniture	
$1+1/\eta_D$	0.817	(0.025)	0.864	(0.170)
$1+1/\eta_X$	0.598	(0.032)	0.600	(0.043)
β_k	-0.028	(0.011)	-0.005	(0.013)
α_0	0.245	(0.067)	0.053	(0.099)
α_1	0.863	(0.028)	0.901	(0.033)
α_2	-0.029	(0.018)	0.011	(0.031)
α_3	0.040	(0.018)	0.024	(0.048)
α_4	0.036	(0.025)	-0.023	(0.047)
Obs.	1329		1731	

Notes: Bootstrap standard errors are in parentheses.

The coefficient on the log of capital stock is negative in each industry (though only significantly in the saw mills industry) and implies that firms with larger capital stocks have lower marginal costs. The parameter α_1 captures the effect of lagged productivity on current productivity and implies a strong linear relationship between the two variables. The coefficients α_2 and α_3 measure the impact of past abatement and export experience on future productivity. In both industries α_2 is estimated to be insignificantly different from zero, implying that firms which abate witness almost identical productivity evolution to those that do not. In contrast, there appear to be small, but positive and significant learning-by-exporting effects in the saw mill industry. The estimated parameter implies that manufacturing firms in the saw mill industry can expect productivity to improve by an extra 4.0 percent, in years subsequent to exporting. The parameter α_4 captures the interaction between export experience and abatement and is also insignificantly different from zero in both industries. Overall, our first stage results present little evidence for any impact of abatement on productivity. However, they may also indicate that any increases in domestic demand from abatement are offset by increases in marginal cost.

Dynamic Estimates

Table 6 reports the means and standard deviations of the posterior distributions for all parameters in both industries. The first set of estimates apply to the dynamic process on export demand and indicate that abatement has a positive impact on future export demand growth in both the saw mill and wood furniture industries. In the saw mills industry, the parameter γ_2 implies that firms which abate expect export demand to grow 1.4 percent faster than similar firms who do not while in the wood furniture industry abating firms anticipate that export demand will grow 6 percent faster.

The difference in magnitude across wood products is striking and can be interpreted in a number of ways. First, our estimates may reflect the fact that wood furniture is closer to a finished product than

Table 6: Dynamic Parameter Estimates

	Saw Mills		Wood Furniture	
γ_0(Export Shock Intercept)	0.004	(0.002)	0.202	(0.049)
γ_1(Export Shock AR process)	0.975	(0.002)	0.795	(0.022)
γ_2(Abatement effect on Export)	0.014	(0.002)	0.060	(0.010)
γ^A(Abatement FC)	19.598	(0.953)	0.027	(0.006)
γ^D(Abatement SC)	113.485	(1.946)	2.194	(0.719)
γ^F(Export FC)	24.301	(0.490)	0.069	(0.006)
γ^S(Export SC)	164.770	(4.954)	20.578	(0.405)
Φ_X (Export Rev Intercept)	7.851	(0.093)	8.615	(0.071)
σ_μ(Export Shock Std Dev)	0.973	(0.037)	1.304	(0.060)
Obs.	1154		886	

Notes: Standard deviations are in parentheses.

the plywood and other basic lumber products produced by saw mills. As argued by Arora and Cason (1996) firms which are closer to final consumers tend to be much more sensitive to their environmental performance. Second, our estimates may simply reflect the fact that most products from the saw mills industry are more common, easier to smuggle, and more difficult to credibly tie to unsustainable harvesting practices. This evidence stands in contrast to the finding that abatement had little effect on productivity and domestic revenues. Moreover, it suggests that the interaction between trade and abatement may leave substantial room for policy intervention.

The parameter γ_0 captures the growth in export demand over time. It is estimated to be positive in the wood furniture industry, but close to zero in the saw mills industry. This is consistent with evidence at the aggregate level which suggests that the volume of Indonesian plywood exports peaked in 1993, while the exports of other timber products have demonstrated consistent increases over the period (Brann, 2002). Finally, the parameter γ_1 is the autocorrelation parameter in the export demand process and indicates that export demand tends to be a highly persistent process across industries and that decisions to abate may have a long-lived impact on export sales.

The reported values of the fixed and sunk cost parameters, γ^A, γ^D, γ^F and γ^S, capture the mean of the exponential distributions for abatement fixed costs, abatement sunk costs, export fixed costs and export sunk costs, respectively.[34] The sunk costs parameters are estimated to be much larger than the fixed cost parameters, though the difference is greatest for exporting. This implies that for each activity the sunk cost distribution will have more mass concentrated in the high cost values. Thus, for the same marginal benefit, a firm will be more likely to continue exporting or abating than to begin exporting or abating.[35]

[34]They are measured in millions of 1983 Indonesian rupiahs.

[35]Note as argued in Eaton et al. (2009) export sunk costs may be capturing longer-run entry dynamics associated with building a customer base abroad.

The reported parameters are the mean values of the distribution of fixed and sunk cost draws. Below we show that the incurred costs by most firms are much smaller.

Model Performance

We simulate the model in order to assess its predictive ability relative to observed empirical patterns. We compute patterns of abatement and export choice, transition patterns between choices and productivity trajectories to compare the simulated patterns with those observed in the data. Specifically, we take the

Table 7: Predicted Abatement, Exporting and Productivity in 1996

	Abatement Rate		Export Rate		Productivity	
	Saw Mills	Wood Furn	Saw Mill	Wood Furn	Saw Mill	Wood Furn
Actual Data	0.204	0.111	0.329	0.263	3.175	0.876
Predicted	0.198	0.079	0.312	0.244	3.153	0.851

initial year status $(\omega_{i1}, z_{i1}, d_{i1}, e_{i1}, k_i)$ of all firms in our data as given and simulate the next 3 year's export demand shocks z_{it}, abatement costs γ^A, γ^I and export costs γ^F, γ^S. Solving the firm's dynamic problem we compute the optimal export and abatement decisions year-by-year. For each firm, we repeat the simulation exercise 100 times and report the average of these simulations.

Table 7 reports the mean abatement rate, export market participation rate and productivity level in both the data and in the model. The model matches the empirical predictions very closely in both industries, though it slightly underpredicts abatement in the wood furniture industry. Table 8 reports the actual and predicted transition rates for the saw mill and wood furniture industries. In both industries the model is successful in matching the broad patterns in the empirical transition matrix, though it does slightly underpredict (overpredict) the persistence in export status and abatement status in the saw mills (wood furniture) industry.

Determinants of Abatement and Exporting

In this section we isolate the roles that export and abatement history play across the distribution of firms on the subsequent export or abatement decisions. The left panel of Table 9 reports the marginal benefit to abatement across export status (columns) and productivity levels (rows). The right panel of Table 9 provides a similar decomposition for exporting across productivity and abatement. We observe that in both industries the marginal benefit to exporting always large and strongly increasing in productivity.

The left panel of Table 9 indicates that the marginal benefit to abatement is positive, large and increas-

Table 8: Actual and Predicted Transition Rates

Saw Mills

Data	Status in $t+1$			
Status in t	Neither	only Exp.	only Abt.	Both
Neither	0.857	0.069	0.063	0.012
only Exp.	0.112	0.729	0.000	0.155
only Abt.	0.344	0.156	0.547	0.094
Both	0.059	0.314	0.098	0.529
Model	**Status in $t+1$**			
Status in t	Neither	only Exp.	only Abt.	Both
Neither	0.841	0.070	0.070	0.020
only Exp.	0.306	0.514	0.026	0.096
only Abt.	0.437	0.025	0.442	0.154
Both	0.091	0.145	0.084	0.680

Wood Furniture

Data	Status in $t+1$			
Status in t	Neither	only Exp.	only Abt.	Both
Neither	0.901	0.054	0.041	0.005
only Exp.	0.167	0.790	0.016	0.027
only Abt.	0.375	0.063	0.469	0.094
Both	0.000	0.200	0.029	0.771
Model	**Status in $t+1$**			
Status in t	Neither	only Exp.	only Abt.	Both
Neither	0.949	0.034	0.013	0.003
only Exp.	0.039	0.914	0.000	0.047
only Abt.	0.311	0.001	0.612	0.077
Both	0.012	0.071	0.002	0.915

ing in productivity for exporting firms in both industries. In contrast, the marginal benefit to abatement is decreasing and negative among non-exporting firms in the saw mills industry. This difference occurs because non-exporting firms do not reap any immediate benefit from abatement, but are required to incur start-up costs associated with this activity. Moreover, our first-stage point estimates implied that abatement had small, but negative effects on productivity growth. Among saw mill producers who are likely to export in the future, Table 9 suggests that it is often optimal to wait until entering the export market before starting to abate. To this extent, the estimated model suggests that barriers to trade may also hinder abatement.

Table 9: Marginal Benefit of Abatement and Exporting (Millions of Rupiahs)

Marginal Benefit of Abatement

Saw Mills			Wood Furniture		
ω_t	$e_t = 1$	$e_t = 0$	ω_t	$e_t = 1$	$e_t = 0$
2.78	333.0	-134.4	0.38	0.19	0.11
3.55	733.2	-1033.1	0.69	0.20	0.11
4.31	628.9	-894.9	1.00	0.21	0.12
5.08	1426.2	-2502.7	1.31	0.22	0.14
5.84	7704.0	-16614.6	1.62	0.24	0.15

Marginal Benefit of Exporting

Saw Mills			Wood Furniture		
ω_t	$d_{t-1} = 1$	$d_{t-1} = 0$	ω_t	$d_{t-1} = 1$	$d_{t-1} = 0$
2.78	6502.9	6494.0	0.38	2.52	2.45
3.55	20789.7	20771.1	0.69	3.15	3.08
4.31	56888.7	56850.5	1.00	4.12	4.06
5.08	176184.0	176119.5	1.31	5.62	5.56
5.84	574346.2	574265.5	1.62	7.93	7.87

In the wood furniture industry we observe the opposite pattern: the marginal value of abatement is always positive and increasing in productivity, though we note that the marginal benefit is relatively small. The explanation for this result is two-fold. First, this result is picking up the fact that the average producer in the wood furniture industry is much smaller than the average producer in the saw mills industry. Second, we estimated that non-exporting, abating firms tend to experience somewhat faster productivity growth than those that do not abate in the wood furniture industry. As such, abatement has value even to firms that are unlikely to begin exporting. Furthermore, there is a much larger immediate impact from abatement on export growth for wood furniture producers relative to their counterparts in the saw mills industry.[36].

Table 10: Incurred Fixed and Sunk Abatement/Export Costs

Saw Mills					Wood Furniture				
	$d_{t-1}=1$	$d_{t-1}=0$	$d_{t-1}=1$	$d_{t-1}=0$		$d_{t-1}=1$	$d_{t-1}=0$	$d_{t-1}=1$	$d_{t-1}=0$
ω_t	$e_{t-1}=1$	$e_{t-1}=1$	$e_{t-1}=0$	$e_{t-1}=0$	ω_t	$e_{t-1}=1$	$e_{t-1}=1$	$e_{t-1}=0$	$e_{t-1}=0$
2.78	9.9/14.8	38.3/12.7	13.1/ 71.1	62.3/ 56.5	0.38	0.02/0.06	0.09/0.06	0.01/1.17	0.05/1.14
3.55	10.6/17.6	41.5/17.3	17.5/ 66.0	81.4/ 65.0	0.69	0.02/0.06	0.09/0.06	0.01/1.43	0.05/1.39
4.31	13.5/23.9	47.3/23.8	17.7/ 99.3	95.7/ 96.7	1.00	0.02/0.06	0.10/0.06	0.01/1.78	0.06/1.75
5.08	18.9/24.3	68.5/24.3	19.6/158.2	113.4/157.1	1.31	0.02/0.06	0.10/0.06	0.01/2.25	0.06/2.23
5.84	19.2/24.3	90.2/24.3	19.6/163.8	113.4/163.7	1.62	0.02/0.06	0.11/0.06	0.01/2.82	0.07/2.80

Table 10 reports the average abatement and exporting fixed and sunk costs for each combination of export and abatement history across productivity levels. These values correspond to predicted costs *incurred* by firms with different export and abatement histories. For instance, given a productivity level of say 4.31 in the saw mills industry, the average fixed cost of abatement and exporting incurred by firms that have previous exporting and abatement experience is 13.5 and 23.9 million Indonesian Rupiahs, respectively. Similarly, for the same productivity level and no past experience in either activity, the sunk cost of abatement and exporting is 95.7 and 96.7 million, respectively. Fixed and sunk costs of both activities increase with productivity but more so for exporting than abating.

In the wood furniture industry we observe relatively little difference in the fixed costs abatement across the distribution of productivity. Together with the observation that sunk abatement costs are proportionally much larger than fixed abatement costs, these results suggest that abatement behavior in the wood furniture industry is largely driven by the sunk abatement costs. This is arguably reasonable for two reasons. First, saw mills tend to be much bigger operations, which require greater year-to-year abatement expenditures. Saw mills are more heavily involved in timber harvesting (cutting), forest-licensing and replanting and, as such, incur larger costs each year to meet certification requirements. In contrast, wood furniture producers are more likely to specialize in production of particular types of wood and do not always harvest timber themselves. In this case certification would require that they purchase materials from a certified source (Synnott, 2005). Auditing and administrative costs are likely to account for a larger percentage of abatement costs in the wood furniture industry.

Policy Experiments

In this section we consider three distinct policy experiments. The first two experiments consider the impact of trade liberalization and abatement subsidies, respectively, on future exporting and abatement.

[36]Setting the estimated first stage coefficients governing the productivity effects of abatement and export experience to zero, $\alpha_2=\alpha_3=\alpha_4=0$, reveals a pattern which suggests that the marginal benefit to abatement is positive but also always increasing in productivity for both non-exporters and exporters in both industries

The last experiment considers the implications of tighter environmental export restrictions imposed by countries which import Indonesian products. The experiments actual capture policies which have been considered in the Indonesian context. In each case we simulate the model for 10 years after changing a policy-influenced parameter. We assume throughout that Indonesia is a small country relative to the rest of the world and that any general equilibrium effects from changes in policy are small.

Trade Liberalization

In the first experiment we increase in the size of the foreign market by 20 percent which, in this context, may be interpreted as a reduction in variable trade costs.[37] The top panel of Table 11 presents the change in the proportion of firms which choose to abate relative to the baseline model after 1, 2, 5 and 10 years in the first 4 columns. The increase in the size of the export market has a positive impact on abatement. Across industries the proportion of firms who endogenously choose to abate rate increases by 7.5-8.6 percent in the first year and is 15.0 to 33.2 percentage points higher after 10 years.

Table 11: Trade Liberalization

Export Demand	Endogenous, $\gamma_2 > 0$				Exogenous, $\gamma_2 = 0$			
Years after 1996	1	2	5	10	1	2	5	10
	Change in the Proportion of Abating Firms							
Saw Mills	8.6	12.9	15.2	15.0	1.1	1.1	1.4	1.2
Wood Furniture	7.5	12.3	22.3	33.2	0	0	0	0
	Change in the Proportion of Exporting Firms							
Saw Mills	1.6	2.3	3.3	3.8	0.3	0.7	0.6	0.8
Wood Furniture	5.2	8.8	15.5	22.2	5.6	9.3	16.2	22.3

This experiment highlights the importance of the complementarity between exporting and abatement *on the export market*. In other words, the above results are not driven by productivity dynamics but rather the complementarity of export demand and abatement. To demonstrate this point we resimulate the model under the baseline specification and after trade liberalization with the additional restriction that $\gamma_2 = 0$ before and after the change in policy. This amounts to assuming that the only impact of abatement on the transition of the state variables occur through productivity. We observe that in either case trade liberalization has a very small impact on abatement rates. After 10 years the change in policy has increased the proportion of abating firms by 1.2 percentage points in the saw mills industry and has had no effect in the wood furniture industry.

The bottom panel of Table 11 presents the same information for the response of exporting to trade

[37] We assume that tariffs are embedded in the effective size of the foreign market. Alternatively, we may interpret this experiment as capturing the impact of growing demand for wood products from emerging markets. It is expected that demand for wood products from emerging market countries such as China will grow substantially in the coming decades (FWI/GFW, 2002).

liberalization. In either industry we observe moderate increases in export participation over time. In the saw mills industry, the proportion of exporters rises by 1.6 percentage points in the first year and is 3.8 percentage points higher than the baseline level after 10 years. Similarly, the proportion of wood furniture exporters rises by 5.2 percentage points in the first year and is over 22 percentage points higher 10 years after the change in policy.

Note, however, a similar pattern is found when we consider an exogenous export demand process where $\gamma_2 = 0$. This is not surprising since increasing the size of the export market should induce firms to export regardless of any complementarity with abatement decisions. What is more surprising is that we observe a slightly stronger rise in exporting in the wood furniture industry after the change in policy with exogenous rather endogenous export demand. There are two reasons for the effect. The primary reason for this result is the effect (not shown Table 13) that the exogenous export demand has on baseline export rates. In particular, baseline export rates are 1 percent lower in the first year under exogenous demand and 3 percent lower after 10 years (relative to baseline endogenous demand model). In the the wood furniture industry the change in policy is large enough to draw in almost the same set of firms into exporting regardless of the export abatement complementarity. A secondary reason for the difference in dynamics is due to the complementarity between exporting and abatement. Exporting firms which have previously abated tend to have slower productivity growth (given our first stage estimates) in the endogenous export demand model than firms which export alone. By discouraging abatement the exogenous export demand model has the effect of encouraging greater exporting through slightly stronger productivity growth.

Abatement Subsidies

The second policy experiment we consider is lowering the fixed abatement costs by 20 percent in each industry.[38] We interpret this experiment as broadly capturing the impact of firm-level subsidies to practice sustainable production. Currently, the Indonesian government along with numerous foreign governments and non-governmental agencies are actively engaged in subsidizing sustainable timber management in Indonesia.[39]

The top panel of Table 12 documents the difference in abatement participation due to the change in policy. A 20 percent reduction in the fixed cost of abatement has a moderate, positive impact on abatement

[38] In the saw mills industry this amounts to a reduction in the fixed abatement costs of 3.9 million 1983 Indonesian Rupiahs. In the wood furniture industry the fixed abatement parameter is reduced by 5.4 thousand 1983 Indonesian Rupiahs. The reduction in the cost parameter in the wood furniture industry is smaller since the estimated fixed cost parameter is smaller.

[39] Examples include (funding source in brackets): Tree Seed Source Development Project (Nordic Development Fund (NDF) / Nordic Development Bank (NDB)), Indonesian Forest Seed Project (Danida Forest Seed Centre), Overseas Economic Cooperation Fund Project (Japan), and the Japan International Forestry Promotion and Cooperation Center Project (JIFPRO).

rates. In the saw mills industry abatement rates increase by 3.4 percentage points in the first year and are 5.4 percentage points higher than the baseline model after 10 years. The impact of abatement subsidies is similar in the wood furniture industry even though the immediate return to abatement is larger. We observe that the model predicts that over the 10 year period abatement increases by 6.8 percentage points relative to the baseline model.

Table 12: Abatement Subsidies

Export Demand	Endogenous, $\gamma_2 > 0$				Exogenous, $\gamma_2 = 0$			
Years after 1996	1	2	5	10	1	2	5	10
	Change in the Proportion of Abating Firms							
Saw Mills	3.4	4.5	5.4	5.4	1.0	1.3	1.0	0.5
Wood Furniture	2.6	3.5	4.7	6.8	0.1	0	0	0
	Change in the Proportion of Exporting Firms							
Saw Mills	0.5	0.5	0.5	1.1	0.8	1.0	1.0	1.0
Wood Furniture	0.5	0.5	0.8	1.3	0.1	0.1	0.4	0.5

The bottom panel of Table 12 presents the impact of abatement subsidies on export participation in both industries. We observe that in either industry the subsidies have a small initial impact on exporting and, even after 10 years, the export rates are still only 1 percent higher than the baseline model. These results, in conjunction with the result in the top panel, are driven by the fact that new uptake in abatement is largely coming from existing exporters in this case. Given the large sunk and fixed costs associated with exporting, the abatement subsidies are not sufficient enough to get non-exporting firms to start abatement until they have entered export markets.

The last four columns of Table 12 report the results for the model with exogenous export demand. They indicate that the observed changes in abatement are again driven by the complementarity of exporting and abatement on the export market. We note that ignoring the differential returns across markets we would not otherwise be able to distinguish the group of firms most affected by the policy change (exporters).

Import Restrictions

In the last policy experiment, we constrain export markets in such a fashion that firms which did not abate in the previous year are completely cut off from export markets. The idea we are trying to capture is one where importing nations strictly reject uncertified products for import. Importantly, the cost of abatement to producers does not change throughout this experiment. Although this policy is extreme we note that this type of policy has been proposed as a potential mechanism to combat unsustainably harvested wood in developing countries (Brack et al., 2002). Further this experiment allows us quantify the full impact of export participation on abatement rates over time.

Table 13: Import Restrictions

Export Demand	Endogenous, $\gamma_2 > 0$				Exogenous, $\gamma_2 = 0$			
Years after 1996	1	2	5	10	1	2	5	10
	Change in the Proportion of Abating Firms							
Saw Mills	14.7	18.8	19.7	17.3	10.9	12.4	12.8	12.7
Wood Furniture	10.6	17.9	31.6	43.2	11.5	13.6	20.9	29.1
	Change in the Proportion of Exporting Firms							
Saw Mills	-23.2	-18.1	-8.9	-5.2	-26.8	-25.7	-22.4	19.1
Wood Furniture	-20.0	-20.5	-22.2	-20.3	-20.6	-21.4	-24.8	-28.4

The first column of Table 13 demonstrates that abatement increases substantially relative to the baseline model in the first year. By the tenth year proportion of firms abating has risen by 17 percentage points in the saw mills industry and by 43 percentage points in the wood furniture industry, relative to baseline. This also suggests that using the export markets as a means to encourage abatement may be an effective policy tool, though we caution that the export market is very large in both industries studied here.

The last four columns of Table 13 present the same estimates for the exogenous export demand model. In both industries we note that the increase in abatement relative to baseline is only slightly smaller than that in the endogenous demand model in the first year. This suggests that closing export markets to environmentally damaging goods may be an effective abatement policy tool *even if there is no differential effect of abatement on export demand growth*. Beyond the initial impact the two models differ more substantially. By the tenth year abatement gains in the exogenous demand model are 4.6 and 14.1 percentage points smaller than the model with endogenous export demand.[40]

The bottom panel of Table 13 presents the impact of import restrictions on export participation. In contrast to the previous policy experiments where encouraging trade (abatement) increased the incentive to abate (export) over time, in this case encouraging abatement through import restrictions harms exporting. In both industries export participation rate is reduced by at least 20 percentage points in the first year. This is not surprising since only a small fraction of exporting firms initially abate and so most incumbent exporters are forced to exit export markets. In the saw mills industry we observe a strong return to exporting in the subsequent years. Ten years after the policy change the export participation rate is only 5 percentage points lower than the baseline rate. In the wood furniture industry export participation grows much more slowly.

The last four columns of the bottom panel present the results for the exogenous export demand model

[40]Due to the difference in baseline rates we can interpret the estimated differences between the two models as capturing the lower bound of the complementarity between exporting and abatement.

in both industries. In the saw mills industry we observe an even larger fall in initial export participation and a slower increase afterwards. In the wood furniture industry the results are even more stark; exporting falls sharply after the implementation of the policy and *continues to fall* in each subsequent year. This result presents a very different picture of the impact of this policy relative to the endogenous export demand model. Exporting falls because fixed and sunk export costs are now effectively the sum of the respective export and abatement costs. As such, many exporters incur higher annual expenditures to stay in export markets and over time many firms no longer find exporting profitable. Once exporters have left the market re-entry is also deterred by higher effective sunk export costs. In the endogenous export demand model higher sunk and fixed costs are offset by a larger export market.

Conclusions

This paper presents and estimates a dynamic model of heterogenous firm which endogenously choose to make environmental investments and export. The model is estimated using a panel of Indonesian timber producers. Counterfactual policy experiments are employed to assess the impact of changing environmental or trade policy on firm-level export and abatement decisions.

The model is able to broadly match environmental investment and exporting behavior among Indonesian timber producers. The model captures the differential export behavior across firms which abate and those that do not. It emphasizes that accounting for the interaction between firm-level abatement and export decisions is essential to recovering accurate estimates of the impact of changes in trade or environmental policy on either outcome over time. The empirical estimates of the model's parameters suggest firm-level environmental investment may increase export demand growth by 1.4 to 6 percent across timber industries.

The counterfactual experiments imply that import restrictions in destination markets can have a large impact on exporting and environmental investment. Over ten years we estimate that closing export markets to non-abating firms would increase abatement rates by 18 and 43 percentage points in the saw mills and wood furniture industries, but cause export participation rates to fall by 5 and 20 percentage points, respectively. In this sense our model confirms that environmental restrictions in destination markets can act as trade barriers and suggests that these barriers may be an effective tool in encouraging firm-level abatement. The experiments confirm that ignoring the differential returns to the same activity on different markets can potentially lead to misleading policy conclusions.

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Appendix

Supplemental Appendix for “Environmental Investment and Export Dynamics”

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This document is the Supplemental Appendix for the paper “Environmental Investment and Export Dynamics.” The following sections provide (A) a description of major export markets for Indonesian timber products, (B) a historical timeline of corporate timber purchasing policies in export markets, (C) a description of the data construction, (D) a detailed data description and all summary statistics which were omitted from the main text, (E) a description of basic abatement and exporting patterns, (F) reduced-form evidence of the impact abatement has on firm-level energy, materials and capital intensity, (G) robustness checks of the main estimates, (H) a detailed description of the computation method used to obtain the dynamic estimates (I) additional results for the dynamic parameter estimates and (J) a simple model used to provide intuition behind our counterfactual experiments.

Indonesian Timber Industry Exports

It is well known that Indonesian’s success in the timber industry has been tied to a rich endowment of dense forests. Table 17 describes the destinations of Indonesian exports in the wood and cork industries (ISIC code 331) and the wood furniture and fixtures industry (ISIC code 332).[41] We observe that in each industry Japan, Europe and the United States are all important export markets for Indonesian producers. Although these statistics provide support for the hypothesis in the main text they may largely underestimate the percentage of timber products destined for these markets. The World Wildlife Fund (WWF, 2008) notes that Indonesian timber products are often shipped to intermediary countries such as Hong Kong or Singapore only to be reexported. Even more importantly Indonesian wood products produced from illegally harvested wood are often smuggled out of the country. For example, the WWF (2008) reports that Indonesia is the second largest exporter of illegally harvested timber products to Europe in

[41] While these definitions are not an exact match to the industrial classification used in the paper, they are reasonably close since the saw mills industry (3311) and wood furniture industry (3321) are the largest sub-industry in classifications (331) and (332), respectively.

the world (behind Russia) and up to 40 of European wood imports are from illegally harvested wood.[42] Obidzinski et al (2006) argue as much as 25 percent of illegally harvested Indonesian wood during this period may have been smuggled out of the country and are not counted in official statistics. Remarkably, Obidzinski et al (2006) further note that this practice has been curtailed since the year 2000 and that international scrutiny and pressure has played a key role in reducing illegal harvesting and smuggling.

Table SA1: Percentage of Indonesian Exports by Country Destinations

	Wood & Cork	Wood Furniture
Japan	34	31
Europe	11	25
USA	9	21
South Korea	9	3
Hong Kong	6	1
Singapore	2	4
Australia	1	4

The share of exports by destination is computed using data from the UN Commodity Trade Statistics Database.

Corporate Timber Purchasing Policies

In the section we provide documentation for a number of timber purchasing policies which were enacted during our sample period among firms which are global purchasers of tropical timber products. This list is not intended to be exhaustive; there were many of these policies enacted in many different countries during our sample period. Unfortunately, there is no complete source that documents all such policies. Instead, we chose to focus on only those firms with international profiles for whom we could find ready information on their timber purchasing history.

Tables SA2-SA6 document the timber purchasing policy in over 40 large international firms during our sample period. We include information for these firms beyond the sample period to document their continuing commitment to international environmental issues in timber markets. Similarly, Table SA7 documents the founding date of national timber-purchasing groups dedicated to only purchasing timber products from environmentally certified producers. Again, we document that numerous groups were founded before or during our sample period and many more were founded in the years that followed our

[42] Specifically, among the products included in the saw mill industry, WWF estimates that approximately 25 percent of European plywood imports and 40 percent of European profiled wood imports are from illegally harvested wood. Similarly, between 10 to 15 percent of European wood imports of wood furniture and finished wood products are produced from illegally harvested wood.

sample period. We also document the year the buying group joined the Global Forest and Trade Network (GFTN), a global timber purchasing group administered by the World Wildlife Fund (WWF). While national timber purchasing groups differed in policy before joining the GFTN, the firms and countries joined to the GFTN follow similar purchasing guidelines. These guidelines include independent certification requirements, such as FSC certification. Details can be found on the website: http://gftn.panda.org/ along with a list of the hundreds of corporations committed to following GFTN purchasing policies. The information contained in these tables was compiled from Kupfer (1993), Viana (1996), Hansen (1998), Owens (1998), Fletcher and Hansen (1999), Greenpeace International (1999), Howard and Rainey (2000), IKEA (2004), World Wildlife Fund (2006), GFTN (2011) and the corporate web sites for *B&Q*, *Carrefour*, *Home Depot* and *Walmart*.

Table SA7: A History of National Timber Purchasing Groups

Country	First Launched Buyer's Group	Joined GFTN	Country*	First Launched Buyer's Group	Joined GFTN
United Kingdom	1991	1999	Japan	1999	—
Belgium	1994	1999	Brazil	2000	2000
Netherlands	1992	1999	Russia[c]	2000	2000
France	1995	1999	Malaysia	2004	2004
Ireland	1995	2000	Cameroon	2005	2005
Switzerland	1995	1999	China	2005	2005
Austria	1995	1999	Indonesia	2005	2005
Germany	1995	1999	Romania	2005	2005
Spain	1995	1999	Bolivia	2006	2006
Sweden	1995	1999	Peru	2006	2006
North America[a]	1995	1999	Vietnam	2006	2006
Denmark	1998	1999	Republic of Congo	2007	2007
Finland	1998	1999	Portugal	2008	2008
Norway	1998	1999	India	2009	2009
Australia[b]	1999	2006	Lao PDR	2009	2009
Italy	1999	—			

Notes: (a) United States and Canada. (b) GFTN date is estimated based on the year the first available member in that country joined GFTN. (c) In Russia, this is a producer group rather than a consumer group. (*) GFTN is also has groups operating in Ghana, Belize, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua, Panama and Puerto Rico. We were not able to determine the earliest date at which these groups began operating and excluded them from the table for this reason.

Table SA2: Corporate Timber Purchasing Policies

Retailer/Firm	Core/Related Product	Year	Policy	Countries of Operation
Assi Doman	Logging/Timber Products	1990s	Ceases logging ancient forests and purchasing products from such forests.	Sweden
B&Q[a,b]	DIY/Garden Furniture	early 1990s	Adopts a coded basis for wood purchases to track sources and sustainability of harvesting.	United Kingdom, China, Ireland
		1991	Founds British Forest and Trade Network	
		1993	Helps found FSC certification and begins reducing wood purchases from non-FSC certified sources.	
		2011	Eliminates all non-FSC certified wood from	
		global supply chain.		
Bridgman	Furniture	1991	Founds British Forest and Trade Network	
Bouwfonds[c]	Property Development	early 1990s	Begins phasing out tropical timber without FSC certification.	Netherlands
Carrefour	Hypermarkets	1997	Begins phasing out unsustainably harvested wood from its supply chain.	France, Argentina, Azerbaijan, Bahrain, Belgium, Brazil, Bulgaria China, Colombia, Dominican Republic, Egypt, Greece, Indonesia, Iran, Italy, Japan, Jordan, Kuwait, Malaysia, Monaco, Morocco, Oman, Pakistan, Poland, Portugal, Qatar, Romania, Saudi Arabia Singapore, Slovenia, Spain, Syria, Taiwan, Thailand, Tunisia, Turkey, United Arab Emirates.
		1998	Works with WWF towards achieving FSC certification.	
		2006	Discontinues selling furniture made from teak wood.	
		2007	Discontinues selling furniture made from keruing.	

Notes: (a) Members of the British Forest and Trade Network commit to standard independent certification (later FSC, 1995), phasing out of wood products from non-certified (later non-FSC) forests, phasing-in of (later FSC) certified products, bi-annual published progress reports. (b) In 1999 the British Forest and Trade Network joins other national buying agencies to form the Global Forest and Trade Network (GFTN). The GFTN presently operates in over 30 countries and has over 300 companies as members. (c) Along with project development giant Bouwfonds 72 additional Dutch project developers and 180 additional Dutch builders signed similar letters of intent signed by Dutch throughout the early 1990s.

Table SA3: Corporate Timber Purchasing Policies

Retailer/Firm	Core/Related Product	Year	Policy	Countries of Operation
Carillion plc	Construction	1997	Joins British Forest and Trade Network	United Kingdom
Chindwell Company Ltd	Timber Products/Furniture	1992	Joins British Forest and Trade Network	United Kingdom
Cinnabar	Set Construction	1993	Reduces use of tropical timber in set construction.	United States
Clarks Wood Company	Hardwood Importer	1992	Joins British Forest and Trade Network	United Kingdom
David Craig Ltd	Garden Furniture	1991	Founds British Forest and Trade Network	United Kingdom
ENSO/Stora-Enso	Timber Products/Pulp	1990s	Ceases logging ancient forests and purchasing products from such forests.	Sweden
Finewood	Doors	1991	Founds British Forest and Trade Network	United Kingdom
Focus	DIY/Garden Furniture	1992	Joins British Forest and Trade Network	United Kingdom
FW Mason and Sons	Timber Products	1991	Founds British Forest and Trade Network	United Kingdom
Graefe	Veneered Marquetry	1991	Founds British Forest and Trade Network	United Kingdom
Habitat	Furniture	1991	Founds British Forest and Trade Network	United Kingdom
Hollywood Center Studios	Film Prod./Set Construction	1990	Ceases using tropical wood in set construction	United States

Table SA4: Corporate Timber Purchasing Policies

Retailer/Firm	Core/Related Product	Year	Policy	Countries of Operation
Homebase Ltd	DIY/Garden Furniture	1995	Joins British Forest and Trade Network	United Kingdom
Home Depot	DIY/Garden Furniture	1990	Forms working environmental group to study deforestation and other environmental issues.	United States, Canada Mexico, China
		1993	Founding member of the Forest Stewardship Council.	
		1995	Dramatically reduces wood purchases without FSC certification.	
		1999, 2002	Further reductions in wood purchases without FSC certification.	
IKEA	Furniture Retailer	1992	Commits to only using wood from responsibly-managed forests that replant and maintain biological diversity.	Sweden, Norway, Denmark, Switzerland, Germany, Germany, Australia, Hong Kong, Canada, Austria, Singapore, Netherlands, Spain, Iceland, France, Saudi Arabia, Belgium, Kuwait, United States, United Kingdom, Italy, Hungary, Poland, Taiwan Czech Republic, Slovakia United Arab Emirates, Finland, Malaysia
Intergamma (Gamma and Karwei)	DIY/Garden Furniture	1993	Begins phasing out wood products sourced without FSC certification.	Netherlands, Belgium United States
J Sainbury plc	Supermarkets/Furniture	1991	Founds British Forest and Trade Network	United Kingdom
Lexington	Set Construction	1993	Reduces use of tropical timber in set construction.	United States

Table SA5: Corporate Timber Purchasing Policies

Retailer/Firm	Core/Related Product	Year	Policy	Countries of Operation
Magnet Ltd	Kitchen Cabinets	1991	Founds British Forest and Trade Network	United Kingdom
M&N Norman	Timber Products	1991	Founds British Forest and Trade Network	United Kingdom
MCA/Universal	Film Prod./Set Construction	1993	Reduces use of tropical timber in set construction.	United States
Meyer International	Timber Product Importing	1998	Commits to only purchasing FSC certified products.	United Kingdom
MFI	Furniture	1991	Founds British Forest and Trade Network	United Kingdom
Moore's Furniture Group	Furniture	1998	Joins British Forest and Trade Network	United Kingdom
OBI	DIY/Garden Furniture	1993	Ceases selling wood without FSC certification.	Germany, Italy, Austria, Czech Republic, Hungary
Otto-Versand	Mail Order Products	1990s	Begins reducing use of tropical timber in its product range.	Germany
Paramount Pictures	Film Prod./Set Construction	1993	Reduces use of tropical timber in set construction.	United States
Praktiker	DIY	1993	Ceases selling wood without FSC certification.	Germany, Greece, Luxembourg
Praxis	DIY	1990s	Gradually phases out wood products sourced without FSC certification.	Netherlands
Premium Timber Products	Timber Products	1991	Founds British Forest and Trade Network	United Kingdom

Table SA6: Corporate Timber Purchasing Policies

Retailer/Firm	Core/Related Product	Year	Policy	Countries of Operation
Richard Burbidge Ltd	Stairs, Decking	1991	Founds British Forest and Trade Network	United Kingdom
Saint-Gobain Bldg Dist	Building Materials	1998	Joins British Forest and Trade Network	United Kingdom
SCA	Timber Products/Pulp	1990s	Ceases logging ancient forests and purchasing products from such forests.	Sweden
Shadbolt International	Doors	1992	Joins British Forest and Trade Network	United Kingdom
Sony Pictures Studios	Film Prod./Set Construction	1993	Reduces use of tropical timber in set construction.	United States
Texas Homecare	DIY	1991	Founds British Forest and Trade Network	United Kingdom
Twentieth Century Fox	Film Prod./Set Construction	1993	Reduces use of tropical timber in set construction.	United States
Walmart	Dept Store/Garden Furniture	1993 2008	Limited introduction of “Ecostore” outlets which only sell products made with sustainably produced lumber. Begins reducing unsustainably harvested wood from its supply chain. Aims to eliminate such wood by 2013.	United States, Brazil, Canada, Chile, China, Argentina, India, Costa Rica, El Salvador, Guatemala, Honduras, Hong Kong, Japan, Mexico, Nicaragua, Pakistan, Puerto Rico, United Kingdom.
Walt Disney Pictures	Film Prod./Set Construction	1993	Reduces use of tropical timber in set construction.	United States
Warner Bros.	Film Prod./Set Construction	1993	Reduces use of tropical timber in set construction.	United States

Data Construction

The primary source of data is the Indonesian manufacturing census between 1994 and 1997. We focus on these years due to the fact that these are the only years the abatement expenditure data is collected. Collected annually by the Central Bureau of Statistics, *Budan Pusat Statistik* (BPS), the survey covers the population of manufacturing plants in Indonesia with at least 20 employees. The data capture the formal manufacturing sector and record detailed plant-level information on over 100 variables covering industrial classification (5-digit ISIC), revenues, intermediate inputs, labour, capital, energy, wages, trade behavior and foreign ownership. Nominal values of total sales, capital and inputs are converted to the real values using the manufacturing output, input, and export price deflators at the industry level.[43] In order to focus on the domestic industry, we drop all plants where more than 10 percent of equity is held by foreign investors.

Data Description

In this section we report summary statistics for the variables used in our study, either in the main text or the supplemental appendix. Table SA8 contains a list of the variables under study and a very brief set of sample moments for the entire manufacturing sector and both industries we study in particular. For brevity, we first report statistics for the 1994-1996 time period. Differences in the 1994-1997 sample described below.[44]

1994-1997 Sample Summary Statistics

In this section we present summary statistics for the 1994-1997 sample. Tables SA9-SA12 are analogous to Tables 1-4 in the main text. In general, the all tables are very similar to those in the main text with only one exception in Table SA9. As such, we largely refer the reader to the main text for a longer discussion of the features of the data.

In Table SA9 we observe that average domestic sales increase in both industries. This is largely due to changing composition of exporting and non-exporting firms. The Asian crisis reaches Indonesia in the fall of 1997. Because of this many previous exporters choose to stop exporting in 1997 and focus on domestic markets. This has two effects. First, since exporting firms are generally larger and more productive than

[43] Price deflators are constructed as closely as possible to Blalock and Gertler (2004). A concordance table between the industry price deflators and the 5-digit industrial classification was provided by BPS Indonesia.

[44] We do not report a table analogous to Table SA8 for the 1994-1997 since the sample moments are very similar to that of Table SA8 for each variable.

Table SA8: Variable Description

	All Industries			Saw Mills			Wood Furniture		
Variable	Obs.	Mean	Std. dev.	Obs.	Mean	Std. dev.	Obs.	Mean	Std. dev.
Domestic Sales	52370	7073	74681	3082	15247	109574	3120	2973	11011
Export Sales	8098	45742	185212	1148	83805	206226	1236	11441	21589
Export Share	8098	0.687	0.332	1148	0.806	0.243	1236	0.853	0.231
Exporter Status	52370	0.155	0.362	3082	0.372	0.484	3120	0.396	0.489
Capital Stock	52370	14930	231124	3082	23023	157982	3120	5562	111555
Fuel	52370	987	12520	3082	1502	5715	3120	107	717
Electricity	52370	662	6248	3082	570	2533	3120	135	532
Intermediate Materials	52370	15062	94463	3082	24586	100160	3120	3829	12811
Total Number of Employees	52370	167	748	3082	268	637	3120	122	232
Total Wage Bill	52370	2128	12656	3082	3236	9229	3120	1059	2627
Environmental Expenditures	7399	80	458	563	69	248	371	33	334
Abatement Status	52370	0.141	0.348	3082	0.183	0.386	3120	0.119	0.324
Abatement per Worker	52370	0.036	0.349	3082	0.043	0.326	3120	0.018	0.283
Fuel per Worker	52370	3	11	3082	4	7	3120	0.763	2
Electricity per Worker	52370	2	16	3082	2	3	3120	0.649	1
Materials per Worker	52370	57	193	3082	60	154	3120	27	66

Notes: Figures are reported in thousands of Indonesian Rupiahs. Export sales and export share are only reported for firms with positive export sales. Environmental expenditures are only reported for firms with positive abatement expenditures.

non-exporting firms when former exporters choose to stop exporting they increase the average size of a non-exporting firm. Second, smaller exporters, though still larger than domestic firms, were those most likely to stop exporting. As such, the group of remaining exporters are on average larger than before.

Despite the similarity in the two samples, the change in export behaviour in 1997 was a potential cause for concern. Because of this we focus on the 1994-1996 in the main text. However, when we repeat the estimation exercise including 1997 we find almost identical parameter estimates. These results are reported below.

Table SA9: Average Sales, 1994-1997

	Saw Mills				Wood Furniture		
	Non-Exporters	Exporters			Non-Exporters	Exporters	
	Average Domestic Sales	Average Domestic Sales	Average Export Sales		Average Domestic Sales	Average Domestic Sales	Average Export Sales
1994	20,770	27,504	161,527	1994	3,599	7,122	13,181
1995	20,317	31,811	127,487	1995	3,450	8,109	12,629
1996	13,907	32,176	165,744	1996	3,693	6,999	15,820
1997	31,872	53,664	157,296	1997	5,483	13,593	18,303

Table SA10: Average Sales Across Abatement Status 1994-1997

	Non-Exporters		Exporters	
	Non-Abate	Abate	Non-Abate	Abate
Saw Mills	22,956	17,772	173,141	223,716
Wood Furniture	3,943	5,814	18,838	20,395

Notes: Abatement expenditures are measured in thousands of 1983 Indonesian rupiahs.

Table SA11: Abatement and Export Behaviour, 1994-1997

Abatement Rates and Expenditures

Industry	Saw Mills			Wood Furniture			All		
	Rate	Expend.	Obs.	Rate	Expend.	Obs.	Rate	Expend.	Obs.
Exporter	28.26	225.71	559	16.15	16.35	322	20.52	218.82	10171
Non-Exporter	16.53	41.05	1337	9.21	7.44	1162	13.33	50.31	60423

Export Rates and Revenues

Industry	Saw Mills			Wood Furniture			All		
	Rate	Revenues	Obs.	Rate	Revenues	Obs.	Rate	Revenues	Obs.
Abater	41.69	183,196.00	379	32.70	15,839.40	159	20.58	71,029.81	10140
Non-Abater	26.43	140,619.70	1517	20.38	12,388.23	1325	13.37	39,612.86	60454

Notes: Abatement expenditures are measured in thousands of 1983 Indonesian rupiahs.

Table SA12: Annual Transition Rates for Continuing Plants, 1994-1997

Saw Mills

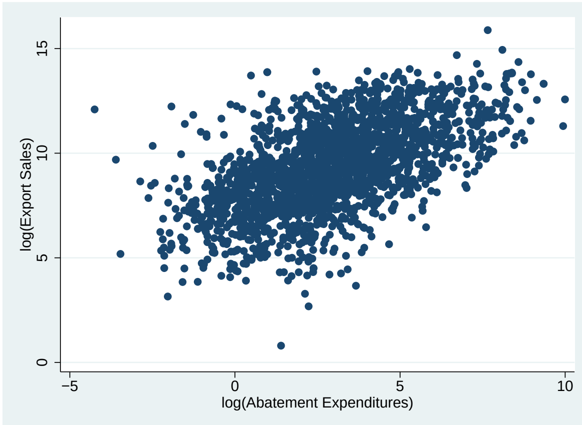
	Status in $t+1$			
Status in t	Neither	only Exp.	only Abt.	Both
All Firms	0.594	0.202	0.119	0.086
Neither	0.888	0.043	0.059	0.099
only Exp.	0.199	0.661	0.028	0.113
only Abt.	0.306	0.006	0.612	0.076
Both	0.101	0.271	0.124	0.504

Wood Furniture

	Status in $t+1$			
Status in t	Neither	only Exp.	only Abt.	Both
All Firms	0.717	0.174	0.074	0.035
Neither	0.913	0.037	0.046	0.004
only Exp.	0.293	0.660	0.026	0.022
only Abt.	0.413	0.053	0.453	0.080
Both	0.109	0.196	0.152	0.544

Exporting and Abatement Correlation

Below we examine the raw correlation between exporting and abatement. Figure SA1 plots the relationship between export sales and abatement expenditures at the firm-level in Indonesia over the 1994-1996 period. We observe a strong positive correlation between these variables. However, this result is not necessarily indicative of a causal relationship between exporting and environmental abatement; it is likely that both are related to firm size and/or firm efficiency. In fact, as shown in Figure SA2, we observe a very similar relationship between domestic sales and environmental expenditure, suggesting that large, productive plants may be more likely to engage in such activities. In particular, Pargal and Wheeler (1996) suggest that environmental abuses are more easily observable among larger plants (which employ more workers) in the Indonesian context. This may in turn increase the incentive to abate.



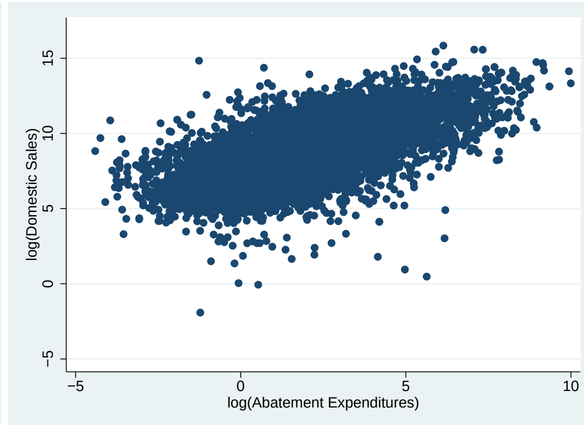


Figure SA1: Export Sales and Abate. Exp.

Figure SA2: Domestic Sales and Abate. Exp.

In order to provide some very basic evidence which controls for firm-size in a fairly unconditional manner we plot firm-level export-intensity against abatement-intensity in Figure SA3. In this figure, we normalize both export sales and abatement expenditures by domestic sales. Bernard, Eaton, Jensen and Kortum (2003) suggest that domestic sales are a reasonable proxy for both firm size (and productivity) since they compare firm-level performance on the same market. In this figure we continue to see a strong positive relationship between exporting and abatement. In particular, our figure shows that among firms which engage in these activities, firms which invest in abatement activities more intensively are more likely to have relatively large export sales. It is important to note that these figures do not contain any causal evidence and ignore the fact that few firms choose to engage in either activity. However, they are suggestive of a distinct relationship between firm-level abatement activities and export performance.

Abatement, Investment and Energy Intensity

In the main text we outlined that there is little reason to believe that environmental expenditures may be directed towards changing the production process to reduce the impact of industrial production on emissions or energy use. While we cannot directly observe the exact nature of firm-level expenditures on abatement, we can check if abatement has any significant impact on energy use, intermediate demand or capital stock. As noted by Cole and Elliott (2003) capital stock is strongly correlated to air and water pollutants. If we find that capital stock or energy usage falls in response to abatement we may be concerned that abatement in the wood products industry is directed towards air or water pollution abatement rather than deforestation.

To examine this possibility we consider the following reduced form specification for the indirect im-

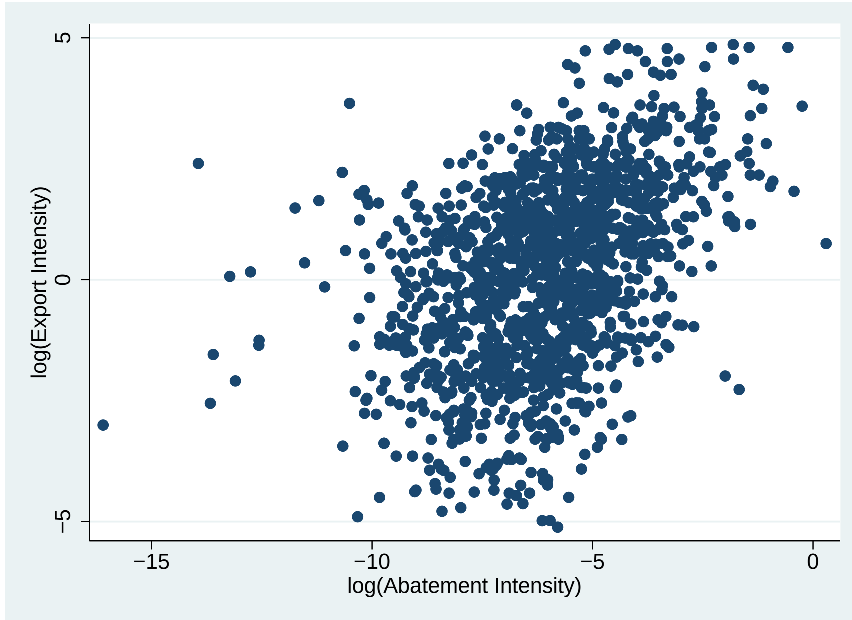


Figure SA3: Export Intensity and Abatement Intensity

pact of expenditures on energy use:

$$\Delta f_{it} = \Delta d_{it}\alpha + \Delta Z_{it}\beta + \zeta_{it}$$

where f_{it} is the logarithm of the firm's energy/input choice, d_{it} is the firm's decision to abate or not and the matrix Z_{it} contains a number of control variables including firm-specific productivity, the logarithm of firm-specific capital and year dummies. Note firm-specific productivity is measured using Olley-Pakes (1996) control-function methods (detailed in Section G of the Supplemental Appendix). The results for the saw mills and wood furniture industries are presented in Tables SA13 and SA14. We expect that if changes in abatement behavior reduce energy use we should observe a negative coefficient on the firm-level change in abatement status, α.

Tables SA13 and SA14 document the impact of abatement on four firm-level inputs: fuel, electricity, intermediate materials, and capital stock in the saw mill and wood furniture industries. In all the regressions it appears that input use, regardless of type, is almost entirely driven by firm-level productivity. More productive firms will, on average, have greater sales and as such demand greater amounts of inputs. The results also indicate that there are important differences across firms of different sizes, larger plants (with larger capital stocks) use less energy, conditional on productivity. This may reflect economies of scale. Surprisingly the coefficient on abatement status, either in the current period or in the previous year,

Table SA13: Energy Use and Abatement in the Saw Mill Industry

Dependent Variable	Fuel				Electricity			
Change in Abatement Status (Δd_t)	-0.141	-0.149			0.070	0.063		
	(0.092)	(0.093)			(0.131)	(0.131)		
Lagged Change in Abatement Status			0.109	0.108			0.016	0.014
			(0.106)	(0.106)			(0.150)	(0.151)
Change in Export Status (Δe_t)		0.062				0.385		
		(0.210)				(0.301)		
Lagged Change in Export Status				-0.095				0.054
				(0.114)				(0.160)
$\Delta(d_t \times e_t)$		0.052				-0.159		
		(0.125)				(0.178)		
Change in Total Factor Productivity	2.751	2.766	2.771	2.780	2.905	2.916	2.903	2.891
	(0.270)	(0.270)	(0.271)	(0.271)	(0.397)	(0.399)	(0.397)	(0.399)
Change in Capital Stock	-0.338	-0.341	-0.339	-0.341	-0.335	-0.338	-0.333	-0.331
	(0.053)	(0.053)	(0.053)	(0.053)	(0.076)	(0.076)	(0.076)	(0.076)
Observations	566				322			

Dependent Variable	Inter. Inputs				Capital			
Change in Abatement Status (Δd_t)	-0.044	-0.046			0.002	-0.006		
	(0.033)	(0.033)			(0.073)	(0.073)		
Lagged Change in Abatement Status			0.179	0.179			0.083	0.083
			(0.037)	(0.037)			(0.083)	(0.083)
Change in Export Status (Δe_t)		0.077				0.069		
		(0.075)				(0.166)		
Lagged Change in Export Status				0.034				-0.067
				(0.040)				(0.083)
$\Delta(d_t \times e_t)$		-0.044				0.028		
		(0.045)				(0.099)		
Change in Total Factor Productivity	5.186	5.185	5.219	5.216	3.928	3.928	3.928	3.937
	(0.096)	(0.096)	(0.094)	(0.094)	(0.133)	(0.133)	(0.133)	(0.134)
Change in Capital Stock	-0.675	-0.675	-0.679	-0.678				
	(0.019)	(0.019)	(0.019)	(0.019)				
Observations	577				577			

Notes: Standard errors are in parentheses.

Table SA14: Energy Use and Abatement in the Wood Furniture Industry

Dependent Variable	Fuel				Electricity			
Change in Abatement Status (Δd_t)	0.107	0.100			-0.095	-0.102		
	(0.130)	(0.130)			(0.161)	(0.162)		
Lagged Change in Abatement Status			0.132	0.134			-0.081	-0.074
			(0.128)	(0.128)			(0.159)	(0.159)
Change in Export Status (Δe_t)		-0.051				0.102		
		(0.205)				(0.256)		
Lagged Change in Export Status				0.073				0.191
				(0.122)				(0.153)
$\Delta(d_t \times e_t)$		-0.043				-0.172		
		(0.128)				(0.160)		
Change in Total Factor Productivity	4.116	4.165	4.140	4.164	4.059	4.119	4.037	4.074
	(0.821)	(0.824)	(0.821)	(0.823)	(0.976)	(0.978)	(0.977)	(0.976)
Change in Capital Stock	-0.093	-0.092	-0.095	-0.094	-0.093	-0.089	-0.093	-0.087
	(0.043)	(0.043)	(0.043)	(0.043)	(0.052)	(0.052)	(0.052)	(0.052)
Observations	420				398			

Dependent Variable	Inter. Inputs				Capital			
Change in Abatement Status (Δd_t)	-0.029	-0.029			-0.111	-0.119		
	(0.056)	(0.056)			(0.146)	(0.147)		
Lagged Change in Abatement Status			0.107	0.109			0.002	-0.003
			(0.053)	(0.054)			(0.142)	(0.142)
Change in Export Status (Δe_t)		0.023				-0.214		
		(0.089)				(0.233)		
Lagged Change in Export Status				0.047				-0.159
				(0.053)				(0.139)
$\Delta(d_t \times e_t)$		-0.038				0.173		
		(0.056)				(0.146)		
Change in Total Factor Productivity	14.024	14.04	14.041	14.056	12.099	12.021	12.101	12.022
	(0.350)	(0.351)	(0.348)	(0.349)	(0.714)	(0.718)	(0.714)	(0.718)
Change in Capital Stock	-0.448	-0.447	-0.448	-0.447				
	(0.018)	(0.018)	(0.018)	(0.018)				
Observations	443				443			

Notes: Standard errors are in parentheses.

Table SA15: Energy Intensity and Abatement in the Saw Mill Industry

Dependent Variable	Fuel/Worker				Elec./Worker			
Change in Abatement Status (Δd_t)	-0.084	-0.093			0.073	0.063		
	(0.092)	(0.092)			(0.134)	(0.134)		
Lagged Change in Abatement Status			0.065	0.063			0.073	0.074
			(0.105)	(0.105)			(0.154)	(0.154)
Change in Export Status (Δe_t)		0.038				0.273		
		(0.208)				(0.308)		
Lagged Change in Export Status				-0.136				-0.045
				(0.114)				(0.164)
$\Delta(d_t \times e_t)$		0.088				-0.058		
		(0.124)				(0.182)		
Change in Total Factor Productivity	2.286	2.305	2.298	2.310	2.341	2.372	2.345	2.355
	(0.269)	(0.269)	(0.269)	(0.270)	(0.406)	(0.408)	(0.406)	(0.408)
Change in Capital Stock	-0.304	-0.308	-0.305	-0.307	-0.279	-0.286	-0.277	-0.279
	(0.053)	(0.053)	(0.053)	(0.053)	(0.078)	(0.078)	(0.078)	(0.078)
Observations	566				322			

Dependent Variable	Inter. Inputs/Worker				Capital/Worker			
Change in Abatement Status (Δd_t)	0.013	0.010			0.059	0.050		
	(0.041)	(0.042)			(0.081)	(0.081)		
Lagged Change in Abatement Status			0.139	0.139			0.047	0.046
			(0.047)	(0.047)			(0.092)	(0.092)
Change in Export Status (Δe_t)		0.054				0.048		
		(0.094)				(0.183)		
Lagged Change in Export Status				-0.007			-0.111	
				(0.051)			(0.010)	
$\Delta(d_t \times e_t)$		-0.009				0.064		
		(0.056)				(0.109)		
Change in Total Factor Productivity	4.702	4.705	4.727	4.728	3.586	3.587	3.590	3.593
	(0.120)	(0.120)	(0.119)	(0.119)	(0.147)	(0.147)	(0.148)	(0.148)
Change in Capital Stock	-0.639	-0.640	-0.642	-0.642				
	(0.024)	(0.024)	(0.024)	(0.024)				
Observations	577				577			

Notes: Standard errors are in parentheses.

Table SA16: Energy Intensity and Abatement in the Wood Furniture Industry

Dependent Variable	Fuel/Worker				Elec./Worker			
Change in Abatement Status (Δd_t)	0.094	0.085			-0.111	-0.121		
	(0.134)	(0.135)			(0.168)	(0.169)		
Lagged Change in Abatement Status			0.050	0.053			-0.164	-0.155
			(0.132)	(0.132)			(0.166)	(0.166)
Change in Export Status (Δe_t)		-0.073				0.084		
		(0.212)				(0.267)		
Lagged Change in Export Status				0.110				0.224
				(0.126)				(0.160)
$\Delta(d_t \times e_t)$		-0.068				-0.197		
		(0.132)				(0.167)		
Change in Total Factor Productivity	3.342	3.415	3.356	3.392	3.066	3.146	3.023	3.067
	(0.850)	(0.852)	(0.851)	(0.852)	(1.02)	(1.021)	(1.02)	(1.019)
Change in Capital Stock	-0.118	-0.116	-0.120	-0.118	-0.105	-0.101	-0.106	-0.10
	(0.045)	(0.045)	(0.045)	(0.045)	(0.054)	(0.054)	(0.054)	(0.054)
Observations	420				398			
Dependent Variable	Inter. Inputs/Worker				Capital/Worker			
Change in Abatement Status (Δd_t)	-0.034	-0.037			-0.114	-0.125		
	(0.064)	(0.064)			(0.149)	(0.150)		
Lagged Change in Abatement Status			0.030	0.139			-0.075	-0.079
			(0.062)	(0.047)			(0.145)	(0.145)
Change in Export Status (Δe_t)		0.001				-0.232		
		(0.102)				(0.237)		
Lagged Change in Export Status				-0.007			-0.121	
				(0.051)			(0.142)	
$\Delta(d_t \times e_t)$		-.062				0.148		
		(0.064)				(0.149)		
Change in Total Factor Productivity	13.074	13.112	13.077	13.102	10.915	10.867	10.908	10.845
	(0.403)	(0.404)	(0.403)	(0.403)	(0.729)	(0.734)	(0.730)	(0.734)
Change in Capital Stock	-0.468	-0.466	-0.467	-0.466				
	(0.021)	(0.021)	(0.021)	(0.021)				
Observations	443				443			

Notes: Standard errors are in parentheses.

are always insignificant with one exception in both industries. In the third and fourth columns of Tables SA13 and SA14 the coefficient on abatement status implies a statistically significant impact of abatement on intermediate input use. However, the coefficient takes the wrong sign indicating that abating firms tend to use more intermediate inputs relative to similar non-abating firms. Similarly, the insignificant impact of abatement on capital stock in Tables SA13 and SA14 suggest that firm-level abatement does not have a strong influence on the capital stock of firms in the saw mill and wood furniture industries. As such, we find no evidence that abatement is strongly correlated with (air or water) emissions-related variables in these industries. Moreover, our assumption that there is little variation in firm-level capital stock over time in Section 3 of the main text appears quite plausible.[45]

The results, however, may be contaminated by the fact that firms which choose to adopt abatement technology tend to be larger and, as such, demand more inputs. We repeat the experiment using the log of input intensity, measured as fuel, electricity, intermediate inputs, and capital per worker, in place of the logarithm of the level variables. The results are reported in Tables SA15 and SA16. Again, we find that changes in input intensity are largely driven by firm-specific productivity changes where more productive firms still demand higher amounts of inputs even after controlling for firm size. Consistent with the results in the previous tables, we find no evidence that abatement causes any significant reduction in input-intensity across all input groups. In fact, the results for exporting are also very similar; export status has little impact on energy use once we control for productivity.

Overall, these results would suggest that if firms are reducing their environmental impact through their abatement choices it is not greatly affecting these margins. While this does not imply that abatement choices are not improving local environmental quality,[46] it is consistent with observation that firms in the wood products sector are largely concerned with mitigating deforestation rather than other environmental concerns. Furthermore, our evidence is consistent with that in Pargal and Wheeler (1996) which suggests that local pollution in the Indonesian timber industry is relatively small.

Robustness Checks: Control-Function Estimation

Below we describe a three-step, reduced-form method which measures both productivity and export demand and estimates the impact of firm-level abatement decisions on their evolution over time. While this method is consistent with the structural estimates provided in the main text it uses a more flexible (but

[45] We have also examined the correlation with the level of abatement expenditure and have found similar results.

[46] Pargal and Wheeler (1996) find that larger firms in more easily observable parts of Indonesia were more likely to create less water pollution, a dimension we cannot observe in our data.

less efficient) method to identify the dynamic process on export demand. The first two steps are identical to those presented in the main text, while the third step extends the standard control function method to examine the evolution of export demand.

As in the main text we assume that each firm's marginal cost, c_{it} is constant with respect to total output and equal across domestic and export markets. Setting marginal revenue equal to marginal cost in each market we can write total variable cost, tvc_{it}, as a combination of domestic and export revenue weighted by their respective elasticities:

$$\begin{aligned} tvc_{it} &= q_{it}^D c_{it} + q_{it}^X c_{it} \\ &= r_{it}^D \left(1 + \frac{1}{\eta_D}\right) + r_{it}^X \left(1 + \frac{1}{\eta_X}\right) + \varepsilon_{it} \end{aligned} \tag{20}$$

where the error term ε_{it} captures measurement error in total variable cost. Estimating equation (20) by OLS we retrieve the estimates of η_D, and η_X and turn next to estimating the parameters of the productivity process. Note that these elasticity estimates will be used to rescale productivity and export demand estimates. While the elasticity estimates will affect the magnitude of abatement on productivity and export demand shocks, they will not affect the sign or significance of such estimates. For instance, recall that the domestic revenue function in the main text is written as

$$\ln r_{it}^D = (\eta_D + 1)\ln\left(\frac{\eta_D}{\eta_D + 1}\right) + \ln \Phi_t^D + (\eta_D + 1)(\beta_0 + \beta_k \ln k_{it} + \beta_w \ln w_t - \omega_{it}) + u_{it}. \tag{21}$$

The composite error includes both unobserved *iid*, u_{it} component and plant-specific, time varying productivity, ω_{it}, rescaled by the domestic elasticity estimate, η_D: $-(\eta_D + 1)\omega_{it} + u_{it}$. As in Olley and Pakes (1996) we pursue a strategy where we will rewrite unobserved productivity as an approximation of a non-parametric function of observables that are correlated with it. Under certain regularity conditions observed material and electricity demand, m_{it} and n_{it}, are invertible so that we can write productivity as an unknown function of the input choices

$$\omega_{it} = \omega_t(k_{it}, m_{it}, n_{it}, d_{it-1}).$$

Letting a constant capture the intercept term we can rewrite the domestic revenue function in (21) as

$$\ln r_{it}^D = \rho_0 + D_t \rho_t + f(k_{it}, m_{it}, n_{it}, d_{it-1}) + v_{it} \tag{22}$$

where D_t is a matrix of year dummies, and $f(\cdot)$ is a fourth order polynomial of its arguments. The essence of the above method is that the approximated non-parametric function $f(\cdot)$ captures the combined effects of exporting, abatement, capital and productivity on domestic revenue.

We denote the fitted value of the $f(\cdot)$ function as $\hat{\phi}_{it}$. According to our model the estimate of $\hat{\varphi}_{it}$ captures $(\eta_D+1)(\beta_k \ln k_{it} - \omega_{it})$ which is a function of capital and productivity. We first estimate (22) by OLS and recover an estimate of the composite term, $\hat{\phi}_{it}$. Following Olley and Pakes (1996), Doraszelski and Jaumandreu (2008) and Aw, Roberts and Xu (2011) we construct a productivity series for each firm. Inserting φ_{it} into the first order Markov process for productivity

$$\begin{aligned}\omega_{it} &= g(\omega_{it-1}, d_{it-1}, e_{it-1}) + \xi_{it} \\ &= \alpha_0 + \alpha_1\omega_{it-1} + \alpha_2 d_{it-1} + \alpha_3 e_{it-1} + \alpha_4 d_{it-1}e_{it-1} + \xi_{it}\end{aligned}$$

we write the estimating equation

$$\hat{\phi}_{it} = \beta_k^* \ln k_{it} - \alpha_0^* + \alpha_1(\hat{\phi}_{it-1} - \beta_k^* \ln k_{it-1}) - \alpha_2^* d_{it-1} - \alpha_3^* e_{it-1} - \alpha_4^* d_{it-1}e_{it-1} + \xi_{it}$$

where the asterisk indicates that the coefficients are scaled by (η_D+1). This equation can be estimated by non-linear least squares where all of the right-hand side variables are predetermined to the innovations in productivity and the parameters can be retrieved for a given value of η_D. In particular, the productivity innovations ξ_{it} are orthogonal to all information available at time $t-1$ and can be used to construct the orthogonality conditions. In fact, for each candidate parameter vector $\alpha' = (\beta_k', \alpha_0', \alpha_1', \alpha_2', \alpha_3', \alpha_4')$, we may construct an estimate for the residual as:[47]

$$\hat{\xi_{it}}(\alpha') = \hat{\phi}_{it} - \beta_k' k_{it} - \hat{E}[\omega_{it}|\omega_{i,t-1}, d_{i,t-1}, e_{i,t-1}]. \tag{23}$$

This completes the second step.

We use a similar procedure to capture the impact of abatement on the evolution of the export demand process. The logic behind applying the Olley-Pakes (1996) methodology to export demand is a straightforward extension of that from the productivity literature. Conditional on abatement, capital and firm-level productivity, if export demand shocks are (a) uncorrelated with domestic market outcomes and (b) cause firms to change their choice of intermediate materials over time, then there remains some variation in input demand that contains information regarding export-specific shocks.

[47] Because we are only including continuing plants, we ignore the issue of endogenous attrition as in Olley and Pakes (1996).

However, we only observe export revenues for firms that choose to enter the export market. This potentially creates a severe selection issue since only firms with sufficiently high export demand shocks will choose to enter export markets. In order to account for this possibility we follow the suggestion in Olley and Pakes (1996) and estimate a first stage selection equation for the probability of exporting as a function of firm-level productivity, capital and previous export and abatement decisions.

The model suggests that the decision to export may be correlated with the decision to abate. As such, the proposed model suggests that a single equation probit would ignore potential information in current abatement decisions. In order to exploit the correlation across current abatement and export decisions we estimate a bivariate probit where we jointly estimate the decision to export and the decision to abate.[48] Define the threshold value of ξ_{it} that induces a plant to export at t by $\bar{\xi}_{it}$ and let $S_{it} = (\omega_{i,t}, d_{i,t-1}, e_{i,t-1})$. Since a plant exports if $\xi_{it} \geq \bar{\xi}_{it}$, the export probabilities are given by

$$Pr\{e_{it} = 1 | \bar{\xi}_{it}, S_{it}\} = \frac{Pr\{e_{it} = 1, d_{it} = 1 | \bar{\xi}_{it}, S_{it}\}}{Pr\{d_{it} = 1 | e_{it} = 1, \bar{\xi}_{it}, S_{it}\}} = 1 - F(\bar{\xi}_{it}) \equiv \theta_{it}. \tag{24}$$

By inverting (24), we may obtain $\bar{\xi}_{it}$ as a function of θ_{it} and write this inverse function as $\bar{\xi}_{it} = \bar{\xi}^{*}(\theta_{it})$.

We then estimate the empirical export revenue function as

$$\ln r_{it}^{X} = \Gamma_0 + D_t \Gamma_t + F(k_{it}, \omega_{it}, n_{it}, m_{it}, d_{it-1}) + H(\hat{\theta}_{it}) + \nu_{it} \tag{25}$$

where F and H are fourth order polynomials in their respective arguments.

We denote the fitted value of the $F(\cdot)$ function as $\hat{\psi}_{it}$. According to our model the estimate of $\hat{\psi}_{it}$ captures $(\eta_X + 1)(\beta_k \ln k_{it} - \omega_{it}) + z_{it}$ which is a function of capital, productivity and the export demand shock for exporting firms. We first estimate (25) by OLS and recover an estimate of the composite term, $\hat{\psi}_{it}$. Given the estimates $\hat{\psi}_{it}$, $\hat{\omega}_{it}$, $\hat{\eta}_X$, and $\hat{\beta}_k$ we can recover a firm-specific export demand, $\hat{z}_{it}$, whenever the firm chooses to export. This estimate captures the remaining variation in export sales which is not explained by firm-level differences in total productivity or capital stock (or size), but is related to firm-level choices of electricity or materials.

Our aim is to provide some reduced-form evidence for the effects we discuss in the main text. Unfortunately, the data requirements are more rigorous in this context since the last step of the estimation requires that in order for the firm to be included in a dynamic regression of export demand it must have exported for at least 2 consecutive years. In our short panel, this proves to be a strongly binding con-

[48] Our later results were insensitive to using a single-equation probit.

straint since there are few exporters in any given year. As such, we aggregate the industry data in order to perform this experiment. Specifically, we consider the wood products sector as a whole at the 2-digit industry level (ISIC code 33) instead of 4-digit industries presented in the main text, saw mills (ISIC code 3311) and wood furniture industry (ISIC code 3321). Where possible we will note differences between the aggregated and disaggregated industries.

Given the estimated series of productivity and export demand we can examine the firm-level variation in these variables with export and abatement behavior. We first examine how firm-level productivity varies across firms with different abatement and export histories. In particular, we consider the following specification for current productivity

$$\omega_{it} = \alpha_0 + \alpha_1 \omega_{it-1} + \alpha_2 d_{it-1} + \alpha_3 e_{it-1} + \alpha_4 d_{it-1} e_{it-1} + \xi_{it}$$

This equation is identical to equation (7) in the main text. Estimates of the coefficients for the wood products industry are reported in Table SA17. Standard errors are computed using the bootstrap.

Consistent with the results reported in the main text of the paper, we find little evidence that abatement has any effect on productivity growth. The first column of Table SA17 suggests that there is no evidence that previous abatement improves productivity at the firm-level. As in the main text, there is some evidence that previous export experience can have a positive effect on firm-level productivity growth. The interaction between previous export and previous abatement experience is also again insignificant. For robustness, we also examine firm-level differences across current export and abatement decisions in column 2 of Table SA17. It is important to note that the estimates may not necessarily reflect a causal relationship between abatement and/or exporting and productivity since the current values are not treated as state variables in the above procedure.[49] Examining current instead of lagged abatement and export decisions has almost no impact on all of the estimated coefficients. The one exception would be the coefficient on current exporting which doubles in magnitude. To further test our results we drop the lagged productivity and add firm-level fixed effects to the regression. Columns 3 and 4 report the results from these regressions. We again find no evidence that abatement has any effect on productivity.

A potential concern with these results is that our discrete measure of abatement may not do a good job of capturing the variation in abatement activity across firms. To test this concern we replace the discrete measure of abatement with a continuous measure in above algorithm and repeat the above estimation

[49]To the extent that the lagged values may be treated as instruments for the current firm decisions we might expect that the productivity estimates are still estimated reasonably precisely.

Table SA17: Productivity, Abatement and Exporting

Industry	All Wood Products							
	d_t discrete				d_t continuous			
ω_{t-1}	0.888	0.861			0.867	0.856		
	(0.020)	(0.016)			(0.015)	(0.017)		
d_{t-1}	-0.002		-0.019		0.005		-0.002	
	(0.011)		(0.023)		(0.008)		(0.011)	
e_{t-1}	0.029		-0.003		0.049		-0.003	
	(0.011)		(0.025)		(0.012)		(0.027)	
$d_{t-1}e_{t-1}$	0.009		-0.020		0.005		-0.006	
	(0.018)		(0.029)		(0.008)		(0.011)	
d_t		-0.009		-0.018		0.003		0.0001
		(0.017)		(0.026)		(0.008)		(0.012)
e_t		0.060		-0.003		0.060		0.006
		(0.013)		(0.023)		(0.012)		(0.021)
d_te_t		0.040		-0.020		0.013		0.005
		(0.023)		(0.030)		(0.008)		(0.011)
Fixed Effects	No	No	Yes	Yes	No	No	Yes	Yes
Obs.	1233							

Notes: Two hundred bootstrap samples are used to compute standard errors (in parentheses). Similar results for the disaggregated industries can be found in the main text.

procedure. Specifically, we replace the binary variable d_t with

$$d_t = \log(1 + \text{total abatement expenditures in year } t).$$

The results are reported in the last four columns of Table SA17. Remarkably, the coefficients are very similar to those estimated using the binary variable. We find that even when using the continuous abatement variable there is no evidence that abatement expenditures have any impact on firm productivity.

Table SA18 documents the estimated coefficients in the reduced-form bivariate probit for abatement (columns 1, 3 and 5) and exporting (columns 2, 4 and 6) for all wood products industries (columns 1 and 2), saw mills (columns 3 and 4) and wood furniture (columns 5 and 6) individually.[50] In all three cases we observe that previous abatement (exporting) experience strongly encourages future abatement (exporting). More interestingly we further observe that past abatement experience significantly increases the probability of future export in all three cases, though it is important to note that this effect is only marginally significant in the saw mills industry (the associated p-value is 0.07). Similarly, previous export experience appears to always positively impact future abatement decisions though this effect is not strongly significant in any case. This may suggest that firms wait to invest in abatement until they have entered export markets.[51]

Firm-level productivity is also a strong predictor of abatement and export decisions with the exception of column (5), the abatement decision in the wood furniture industry. There are a number of explanations

[50] In Table SA18 d_{it} is always treated as binary variable.

[51] This interpretation is consistent with the timing assumption in the main text.

Table SA18: Bivariate Probit for Abatement and Exporting

Industry	All Wood Products		Saw Mills		Wood Furniture	
Dependent Variable	d_{it}	e_{it}	d_{it}	e_{it}	d_{it}	e_{it}
d_{t-1}	1.865	0.242	1.799	0.255	2.045	0.522
	(0.080)	(0.098)	(0.106)	(0.138)	(0.153)	(0.186)
e_{t-1}	0.128	2.152	0.097	1.924	0.175	2.379
	(0.088)	(0.077)	(0.131)	(0.120)	(0.157)	(0.134)
ω_t	0.273	0.895	0.200	1.233	-0.030	1.669
	(0.084)	(0.084)	(0.109)	(0.122)	(0.332)	(0.289)
ρ	0.049		0.163		0.037	
Obs.	2466		1157		895	

Notes: Standard errors are in parentheses.

for the result that productivity has little impact on abatement decisions in this industry. The results in the main text suggest that the sunk costs of abatement in the wood furniture industry are much larger than the fixed costs of maintaining abatement activities. This may suggest that while beginning abatement (potentially of rare tropical forests) is particularly costly, the smaller degree harvesting in this industry is less costly to sustainably maintain. As such, once firms have begun abatement their previous abatement experience is the primary driver of future abatement activities. Alternatively, since we use domestic revenues to estimate productivity, this result may simply reflect that there is little firm-level benefit, either in terms of productivity or profitability, from abatement among domestic firms in the wood furniture industry. To the extent that our simple specification does not capture the return to abatement on export markets, the coefficients of abatement or exporting may be biased. Nonetheless, the results on previous abatement and export history along with the correlation parameter between abatement and export decisions, ρ, are suggestive that we may expect these decisions to be interrelated.

The third equation we report is the dynamic process on export demand. Specifically, we write the estimating equation as

$$\hat{z}_{it} = \gamma_0 + \gamma_1 \hat{z}_{it-1} + \gamma_2 d_{it-1} + J(\tilde{\theta}_{it}) + \mu_{it}$$

where $J(\tilde{\theta_{it}})$ is a fourth order polynomial in the predicted probability of exporting in two consecutive years, $\tilde{\theta}$, to again control for selection into export markets. The results for the estimation of this equation are presented in Table SA19.

The results are broadly consistent with those reported in the main text of the paper. In the first column we omit the lagged export demand term, z_{t-1}, and estimate that lagged abatement increases export demand by 19.5 percent. This estimate statistically significant and much larger than the estimated coefficient in the main text. In the second column we repeat this exercise with z_{t-1} and the coefficient on abatement falls to 6.2 percent in the wood products industry. We emphasize that this result is very close to parameter estimates reported in the main text, but recognize that this coefficient is no longer significant here. The lack of significance is not surprising as we have few observations on which we can estimate the export demand process since our panel is relatively short, few firms export in two consecutive years and export sales are highly persistent. A primary advantage of using the Bayesian MCMC methods described in the main text is that we are able to exploit all of variation in export sales in the data. Similar results are found in columns 3 and 4 when we use current abatement status in place of lagged abatement status. In this case we again observe a coefficient which is very close to that reported in the main text, except it is statistically significant at conventional levels of confidence. It is encouraging that the estimated coefficients are similar to that returned by the Bayesian MCMC method implemented in the main text even though the industry under consideration are not an exact match to those in the main text and the available variation to the identify the coefficients is much more restricted.

In the final four columns we again test whether using a continuous measure of abatement alters our results. We again generally find abatement has a positive, statistically significant impact on export demand in each case, though it is only marginally significant in column 6. While the estimated coefficients are somewhat smaller than those estimated using the discrete variable, they imply similar total effects for the median abater and are all well within the range estimated across industries in the main text.[52]

Table SA19: Export Demand and Abatement

Industry	All Wood Products							
	d_t discrete				d_t continuous			
z_{t-1}		0.695		0.691		0.717		0.720
		(0.069)		(0.073)		(0.069)		(0.076)
d_{t-1}	0.195	0.062			0.088	0.023		0.027
	(0.098)	(0.052)			(0.031)	(0.013)		(0.013)
d_t			0.214	0.106			0.086	
			(0.097)	(0.043)			(0.032)	
Obs.	286							

Notes: Two hundred bootstrap samples are used to compute standard errors.

Estimation Methodology

In this section we provide detailed information regarding the estimation of the dynamic parameters. The following subsection discuss the computation of the firm's dynamic problem, the assumptions on the prior

[52]Among abating firm the median value for the continuous variable d_t is approximately 2.

distributions of each parameter, the construction of the marginal density of export shocks and a description of how to simulate endogenously determined, partially observed export demand shocks.

Computation of the Firm's Dynamic Problem

We need to solve each firm's dynamic optimization problem in order to compute the conditional choice probabilities for exporting , $P(e_{it}|z_{it},k_{it},\omega_{it},\Phi_X,e_{it-1},d_{it-1})$, and abatement, $P(d_{it}|z_{it},k_{it},\omega_{it},\Phi_X,e_{it-1},d_{it-1})$. For a state vector $s=(z,\omega,e_{-1},d_{-1},k,\phi_X)$ we use equations (6)-(9) in the main text and the following algorithm to calculate the value functions for each firm.

1. Guess the value of the initial value function $V^0(s)$.

2. Calculate the expected value

$$EV^0=\int_{z'}\int_{\omega'}(z',\omega',e,k,\Phi_X)dF(\omega'|\omega,d,e)dF(z'|z,d)$$

   where we calculate $F(\omega'|\omega,d,e)$ and $F(z'|z,d)$ are calculated according to equations (4) and (5), respectively.

3. Using EV^0 we calculate V_t^{E0} and V_t^{D0} using equations (7) and (8):

$$\begin{aligned}V^{E0}(d_{-1}) \quad = \quad & P[\delta EV^0(e=1,d=1)-\delta EV^0(e=1,d=0)>d_{-1}\gamma^A+(1-d_{-1})\gamma^D]\cdot\\ & (EV^0(e=1,d=1)-d_{-1}E(\gamma^A|\cdot)-(1-d_{-1})E(\gamma^D|\cdot))+\\ & P[\delta EV^0(e=1,d=1)-\delta EV^0(e=1,d=0)\le d_{-1}\gamma^A+(1-d_{-1})\gamma^D]\cdot\\ & EV^0(e=1,d=0)\end{aligned}$$

   and

$$\begin{aligned}V^{D0}(d_{-1}) \quad = \quad & P[\delta EV^0(e=0,d=1)-\delta EV^0(e=0,d=0)>d_{-1}\gamma^A+(1-d_{-1})\gamma^D]\cdot\\ & (EV^0(e=0,d=1)-d_{-1}E(\gamma^A|\cdot)-(1-d_{-1})E(\gamma^D|\cdot))+\\ & P[\delta EV^0(e=0,d=1)-\delta EV^0(e=0,d=0)\le d_{-1}\gamma^A+(1-d_{-1})\gamma^D]\cdot\\ & EV^0(e=0,d=0)\end{aligned}$$

4. Using our calculations in step (3) we construct the value function $V^1(z,\omega,e_{-1},d_{-1},k,\Phi_X)$ using

equation (9) as:

$$
\begin{aligned}
&V^1(z,\omega,e_{-1},d_{-1},k,\Phi_X) = \\
&\quad \pi^D(z,\omega,k) + P[\pi^X(z,\omega,k,\Phi_X) + V^{E0}(d_{-1}) - V^{D0}(d_{-1}) > e_{-1}\gamma^F + (1-e_{-1})\gamma_S] \cdot \\
&\quad (\pi^X(z,\omega,k,\Phi_X) + V^{E0}(d_{-1}) - V^{D0}(d_{-1}) - e_{-1}E(\gamma^F|\cdot) - (1-e_{-1})E(\gamma_S|\cdot)) \\
&\quad P[\pi^X(z,\omega,k,\Phi_X) + V^{E0}(d_{-1}) - V^{D0}(d_{-1}) \leq e_{-1}\gamma^F + (1-e_{-1})\gamma_S] \cdot V^{D0}(d_{-1})
\end{aligned}
$$

5. We then repeat steps (2)-(4) until convergence, $V^{j+1} - V^j < \varepsilon$.

We adopt Rust's (1997) method to discretize the state space since it is very large in this case. We fix the grid values for k with 8 categories and select $N = 100$ low-discrepancy points for ω and z: $(\omega_1, z_1), \ldots, (\omega_n, z_n), \ldots, (\omega_N, z_N)$. On each grid point we solve the firm's dynamic problem as described above for the value function $\hat{V}$. We can then calculate EV using the discrete Markov operator:

$$
\begin{aligned}
EV &= \int_{z'}\int_{\omega'} V^0(z',\omega',e,k,\Phi_X)dF(\omega'|\omega,d,e)dF(z'|z,d) \\
&= \frac{1}{N}\sum_{n=1}^{N}\hat{V}(z_n,\omega_n,e,d,k,\Phi_X)p^N(z_n,\omega_n|z,\omega,e,d)
\end{aligned}
$$

where $p^N(z_n,\omega_n|z,\omega,e,d) = \frac{p(z_n|z)p(\omega_n|\omega,e,d)}{\sum_{n=1}^{N} p(z_n|z)p(\omega_n|\omega,e,d)}$.

Details of Bayesian MCMC Estimation

The set of dynamic parameters we estimate in the second stage are $\Theta = (\gamma^A, \gamma^D, \gamma^F, \gamma^S, \gamma_0, \gamma_1, \gamma_2, \sigma_z, \Phi_X, \theta^d, \theta^e)$ where θ^d and θ^e are, respectively, the parameters for the probit equations for the initial conditions of abatement and exporting. Our sampling algorithm follows Das, Roberts and Tybout (2007) and Aw, Roberts and Xu (2011) closely and we adopt their priors where possible. In general, the priors we adopt are very diffuse; the means of all fixed and sunk cost distributions are assumed to have priors that follow a $N(0,1000)$ distribution while the prior for the revenue intercept and the prior for the effect of abatement on export demand are also set to follow a $N(0,1000)$ distribution. The autoregressive coefficient in export demand is set to follow a $U[-1,1]$ distribution while the log σ_z distribution is set to follow a $N(0,10)$ distribution as in the above citations.

Constructing $h(z_i^+|d_i^-)$

Here we follow Das, Roberts and Tybout (2007) closely, but extend their exercise to account for the history of abatement on the firm's current export demand. Define the set of uncensored export demand shocks for firm i as

$$\begin{aligned} z_i^+ &= \Big\{z_{it}^+ = \ln r_{it}^X - (\eta_X+1)\ln\left(\frac{\eta_X}{\eta_X+1}\right) - \ln\Phi_t^X - (\eta_X+1)(\beta_0+\beta_k\ln k_{it}+\beta_w\ln w_t \\ &\quad -\omega_{it}); r_{it}^X > 0\Big\} \end{aligned}$$

Let v_{it}^+ be the demeaned autoregressive export demand process $v_{it}^+ \equiv = z_{it}^+ - (\gamma_0+\gamma_2 d_{it-1})(1-\gamma_1)^{-1}$ conditional on d_{it-1} and let d_i^- represent the set of previous export decisions $d_i^- \equiv \{d_{i,-1},....,d_{i,T-1}\}$. To derive the density function of the uncensored export demand shocks we assume that the z_{it} process is in long-run equilibrium. The transition density of z_{it} then implies that $z_{it}^+|d_{it-1} \sim N((\gamma_0+\gamma_2 d_{it-1})(1-\gamma_1)^{-1}, \sigma_\mu^2(1-\gamma_1^2)^{-1})$ and $h(z_i^+|d_i^-) = N((\gamma_0+\gamma_2 d_{it-1})(1-\gamma_1)^{-1}, \Sigma_{zz})$ where the diagonal elements of Σ_{zz} are determined by $E[v_{it}^2] = \sigma_\mu^2(1-\gamma_1^2)^{-1}$ and the off-diagonal elements are $E[v_{it}v_{it-k}] = \gamma_1^{|k|}\sigma_\mu^2(1-\gamma_1^2)^{-1}\ \forall\ k \neq 0$. Note that the key difference here is that the mean of distribution of export demand shocks varies across the distribution of heterogeneous firms with different abatement histories.

Simulating z_{i1}^T

To simulate the entire vector of export demand shocks z we first consider the vector of export shocks for firm i from year 1 to T as an $T\times 1$ vector $z_{i1}^T = (z_{i1},...,z_{iT})$. The set of uncensored export demand shocks z_i^+ is expressed as a $q_i \times 1$ vector where $q_i = \sum_{t=1}^T e_{it}$. Exploiting the fact that $\mu_{it} \sim N(0,\sigma_\mu^2)$ we can write $z_{i1}^T|z_i^+, d_i^- \sim N(\Gamma_0\iota + \Gamma_1 v_i^+ + \Gamma_2 d_i^-, \Sigma_{zz} - \Sigma_{zz^+}\Sigma_{z^+z^+}^{-1}\Sigma_{zz^+}')$ where $\Sigma_{zz} = E[v_{i1}^T v_{i1}^{T\prime}]$, $\Sigma_{zz^+} = E[v_{i1}^T v_i^{+\prime}]$ and $\Gamma_1 = \Sigma_{zz^+}\Sigma_{z^+z^+}$. The elements of these matrices are determined by $E(v_{it}v_{it+s}') = \gamma_1^{|k|}\sigma_\mu^2(1-\gamma_1^2)^{-1}$. The matrices Γ_0 and Γ_2 are $T\times T$ lower triangular matrices where the elements are given by $(\gamma_0(1-\gamma_1^2))(\sigma_\mu^2(1-\gamma_1))^{-1}\Sigma_{zz}^l$ in the first case and $(\gamma_2(1-\gamma_1^2))(\sigma_\mu^2(1-\gamma_1))^{-1}\Sigma_{zz}^l$ in the second and Σ_{zz}^l is the lower triangle of Σ_{zz}.

A number of these expressions merit comment. First, as in Das, Roberts and Tybout (2007) the dimension and composition of the Σ_{zz^+} and $\Sigma_{z^+z^+}$ matrices vary across firms with different export participation patterns. Because the z_{it} are serially correlated we exploit information in each year that the firm exports to calculate $E[z_{i1}^T|d_i^-, v_i^+]$. Moreover, because z_{it} is stationary the weight placed on v_{it} is highest in year t and declines monotonically with $|s|$. Second, a key difference here is that we also use the entire history of abatement decisions to simulate export profit shocks for both exporting and non-exporting firms. However, unlike the demeaned export profit shocks v_{it}, abatement decisions in year t do not reveal any additional information about the level previous (or current) export demand once we have accounted for its impact on the mean of the distribution of z_{it}. For this reason Γ_0 and Γ_2 are lower triangular.

The distributions above allow us to write the vector of export demand shock components as

$$z_{i0}^T = \begin{cases} \Gamma_0 \iota + \Gamma_1 v_i^+ + \Gamma_2 d_i^- + \Gamma_3 \eta_i & \text{if } q > 0 \\ \Gamma_0 \iota + \Gamma_2 d_i^- + \Gamma_3 \eta_i & \text{if } q = 0 \end{cases} \tag{26}$$

where $\Gamma_3 \Gamma_3' = \Sigma_{zz} - \Sigma_{zz^+} \Sigma_{z^+z^+}^{-1} \Sigma_{zz^+}'$ and η_i is a $T \times 1$ vector of independent and identically distributed standard normal random variable. Note that $\Gamma_3 \Gamma_3'$ has rank $T - q_i$ reflecting that Γ_3 has q_i zero columns and only $T - q_i$ elements of η_i actually have an impact in determining z_{i0}^T. In contrast, Γ_2 impacts the estimate of z_{it} in each year for each firm regardless of export status. This function allows us to simulate $P(e_i, d_i, r_i^X | \omega_i, k_i, \Phi) = P(e_i, d_i | \omega_i, k_i, \Phi, z_i^+) h(z_i^+ | d_i)$ which appears in equation (20) in the main text. Specifically, we draw a set of S η_i vectors and use (26) to evaluate $P(e_i, d_i | \omega_i, k_i, \Phi, z_i^+) h(z_i^+ | d_i^-)$ at each η_i and averaging over the S outcomes.

Estimates from the 1994-1997 sample

Below we present first and second stage estimates, analogous to those presented in the text, for the longer 1994-1997 sample. The advantage of the this sample is that with an additional year's worth of data we are able to better the dynamic processes on productivity and export demand. The disadvantage of this sample is that it is unclear how much the Asian crisis affected abatement and export behavior in 1997.

Nonetheless, we repeat the full estimation procedure detailed in the main text on the full 1994-1997 sample. We find that estimates in both stages of the estimation routine are very close to the results found using the 1994-1996 sample. The results are presented in Tables SA20-SA21. We refer the reader to the main text for further discussion of the individual parameters.[53]

[53] We have also estimated the model on other manufacturing industries unrelated to forestry. Given that these results shed little insight on the issue of deforestation we have not chosen not to include them here. However, they are available on request.

Table 14: First Stage Parameter Estimates, 1994-1997

	Saw Mills		Wood Furniture	
$1+1/\eta_D$	0.734	(0.053)	0.810	(0.149)
$1+1/\eta_X$	0.616	(0.031)	0.707	(0.067)
β_k	-0.041	(0.015)	-0.005	(0.011)
α_0	0.212	(0.076)	0.094	(0.112)
α_1	0.900	(0.019)	0.908	(0.023)
α_2	-0.023	(0.026)	0.001	(0.023)
α_3	0.086	(0.034)	0.030	(0.037)
α_4	0.026	(0.035)	-0.011	(0.032)
Obs.	1407		1075	

Notes: Bootstrap standard errors are in parentheses.

Table 15: Dynamic Parameter Estimates, 1994-1997

	Saw Mills		Wood Furniture	
γ_0(Export Shock Intercept)	0.059	(0.013)	0.329	(0.114)
γ_1(Export Shock AR process)	0.932	(0.008)	0.699	(0.038)
γ_2(Abatement effect on Export)	0.034	(0.005)	0.040	(0.004)
γ^A(Abatement FC)	16.355	(1.185)	0.003	(0.001)
γ^D(Abatement SC)	94.072	(1.736)	0.040	(0.020)
γ^F(Export FC)	19.734	(1.757)	0.064	(0.004)
γ^S(Export SC)	166.960	(1.418)	19.826	(1.076)
Φ_X (Export Rev Intercept)	8.000	(0.152)	6.098	(0.214)
σ_μ(Export Shock Std Dev)	1.407	(0.022)	1.199	(0.024)
Obs.	1407		1075	

Notes: Standard deviations are in parentheses.

A Simple Model of Abatement and Exporting

In the section we describe a simple, static model of exporting and abatement. In order to provide intuition for the firm-level decisions in the spirit of Melitz (2003) we simplify the model described in Section 2 of the main text using the following assumptions:

- Firm-level productivity is constant over time and invariant to exporting decisions.
- All firms face the export demand shock z^n which is constant over time.
- Define $\tilde{z}^n \equiv \exp\{z^n\}$. If a firm chooses to abate its export demand shock increases to $\tilde{z}^a = \beta\tilde{z}^n$ where $\beta > 1$ in the current period. Any benefit from abatement on the export market lasts only 1 period.
- Firms pay the same fixed cost of exporting, γ^F, and there are no sunk export costs.
- Firms that choose to abate also incur a fixed abatement cost, γ^A. There are no sunk abatement costs.
- Capital and input prices are normalized to 1 and β_0 is normalized to 0 in equation (5) from the main text.
- Firms expect that the size of the export market, Φ^X, is constant over time.

Using the above restrictions and equation (5) from the main text we can write the profit from exporting for a non-abating firm as

$$\pi^X = \rho\Phi^X\tilde{\omega}\tilde{z}^n - \gamma^F,$$

while for the abating firm export profit can be written as

$$\pi^{XA} = \rho\Phi^X\tilde{\omega}\tilde{z}^a - \gamma^F - \gamma^A$$

where $\rho = (\eta_X/(\eta_X+1))^{\eta_X+1}$ and $\tilde{\omega} = \exp\{-\omega(\eta_X+1)\}$ is an index of productivity.

Suppose that the marginal exporter chooses not to abate. In this case, we can derive the threshold productivity for exporting, $\tilde{\omega}^X$, without abatement by setting the profit from exporting to zero

$$\pi^X = 0 \Rightarrow \tilde{\omega}^X = \frac{\gamma^F}{\rho\Phi^X\tilde{z}^n}.$$

Similarly, we can determine the threshold for productivity for exporting and abatement in this case by comparing the two current export profit levels across abatement status

$$\pi^X = \pi^{XA} \Rightarrow \tilde{\omega}^{XA} = \frac{\gamma^A}{\beta\rho\Phi^X \bar{z}^n}$$

Examining these two conditions it is evident that there is no reason to expect that the threshold for abatement and exporting to necessarily be above the threshold for exporting alone. In fact, we will have the threshold ordering $\tilde{\omega}^{XA} < \tilde{\omega}^X$ only when $\gamma^F(\beta - 1) > \gamma^A$.[54] These conditions imply that it is more likely that the marginal exporter will also optimally choose to abate when β is large and γ^A is relatively small. Allowing z^n to vary across firms it is straightforward to further demonstrate that among firms with a large export market (large z^n) the marginal exporter will also choose to abate, while the marginal exporter will not necessarily choose to abate among firms with a relatively small export market (small z^n).

In order to capture the differential effects of policy change across firms and industries we focus on two cases below. In scenario 1 (sc 1), $\tilde{\omega}^{XA} > \tilde{\omega}^X$ we predict that some firms will choose to export but not abate. This case is likely for firms with smaller export markets (small z^n) and in industries where the export gain from abatement is small (β is small), the fixed abatement cost is large (γ^A is large) and the fixed export cost is small (γ^X is small). This case is depicted in Figure SA4. In scenario 2 (sc 2), $\tilde{\omega}^{XA} < \tilde{\omega}^X$ we predict that all firms which choose to export will also abate. This case is likely for firms with large export markets and in industries where the export gain from abatement is large, the fixed abatement cost is small and the fixed export cost is large. We demonstrate this case in Figure SA5.

In what follows, we now consider the effect of the three policy experiments discussed in the main text. Throughout we continue to consider the partial equilibrium effects of the changes in policy. First, we analyze the impact of trade liberalization which we interpret as an increase in the effective size of the export market, Φ^X. The change in trade policy increases the export profits for both abaters and non-abaters without influencing fixed costs. This results in an upward rotation in the slope of both profit functions in Figure SA6 where π^X moves up to $\pi^{X\prime}$ and π^{XA} to $\pi^{XA\prime}$. Note that the profit function rotates further inward because $\beta > 1$ and the trade liberalization is particularly beneficial for firms which abate. For a sufficiently large increase in the size of the export market this change in policy could shift the threshold for exporting and abatement below the threshold for exporting alone (scenario 2).

[54] If all exporting firms abate the productivity of the marginal exporter (and abater) can be found where $\pi^{XA} = 0$ which implies $\tilde{\omega}^{XA} = \frac{\gamma^F + \gamma^A}{\rho\Phi^X \bar{z}^n \beta}$.

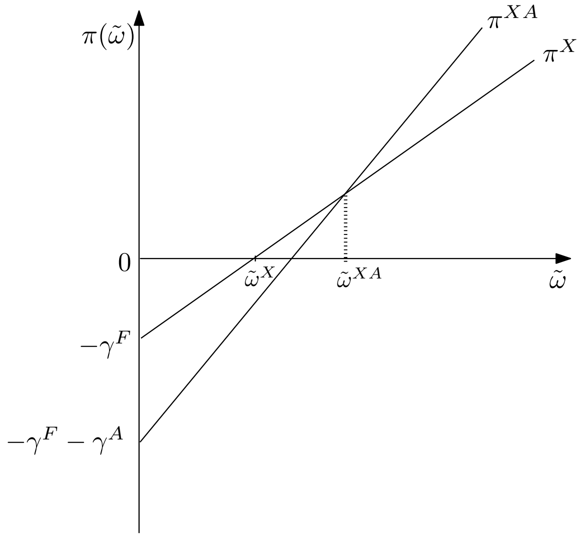


Figure SA4: Export Profits (sc 1)

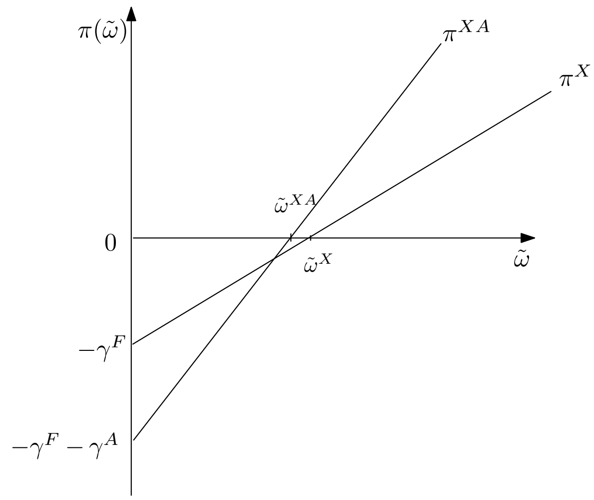


Figure SA5: Export Profits (sc 2)

The productivity threshold for exporting drops from $\tilde{\omega}^{X}$ to $\tilde{\omega}^{X\prime}$ while that for both exporting and abating is lowered from $\tilde{\omega}^{XA}$ to $\tilde{\omega}^{XA\prime}$. As a result of the change in trade policy, less productive firms who were not able to export can now do so. Likewise, some exporting firms which were not previously abating now find it profitable to export and abate. Hence, firms with productivity between $\tilde{\omega}^{X\prime}$ and $\tilde{\omega}^{X}$ enter the export market and firms which have productivity between $\omega^{XA\prime}$ and ω^{XA} begin abating and exporting.

In Figure SA7 we present the effect of the same policy change on firms in scenario 2. Again we observe an inward rotation of the export profit functions, where the rotation is largest for the profit function for abating firms. In this case the simple model implies that trade liberalization will reinforce the fact that threshold for abatement and exporting is below the threshold for exporting alone. Among the firms that are induced to begin exporting because of the change in policy they will also all begin abating.

The second policy experiment we consider is abatement subsidies which we interpret as a decrease in the fixed cost of abatement. The fixed cost of abating and exporting is lower as γ^{A} decreases to $\gamma^{A\prime}$. In Figures SA8 and SA9 this is represented by a parallel leftward shift of the profit function, π^{XA}, to $\pi^{XA\prime}$. The profit line for exporting alone is unaffected. In Figure SA8, the cutoff productivity for exporting and abating decreases to $\omega^{XA\prime}$. A number of exporting firms with productivity less than the previous cutoff, ω^{XA}, now find it profitable to abate. Since the productivity threshold for firms that only export is the same, the proportion of firms that only export shrinks with an abatement subsidy. Again if the subsidy is large enough the export profit function π^{XA} could shift far enough to the left such that the productivity threshold for abating and exporting is now lower than that for exporting only (scenario 2). In Figure

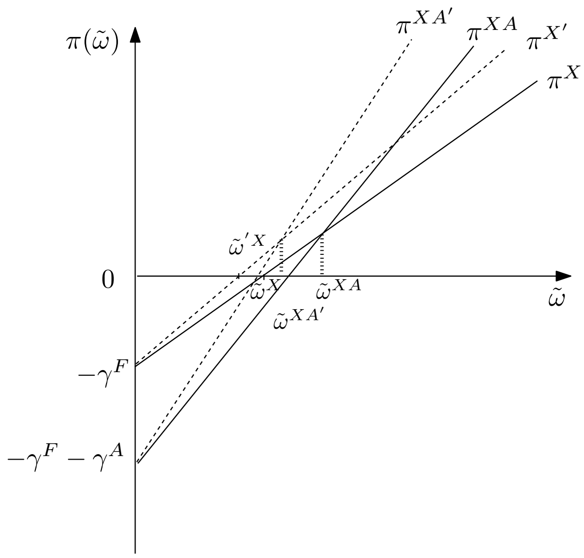


Figure SA6: Trade Liberalization (sc 1)

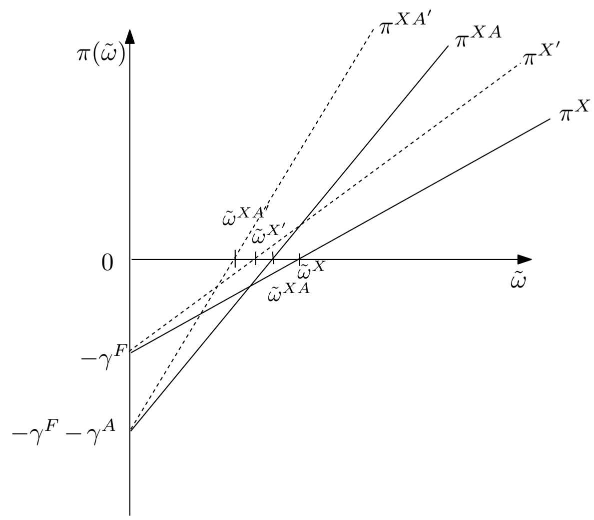


Figure SA7: Trade Liberalization (sc 2)

SA9 the abatement subsidy will increase both the number of firms which abate and the number of firms which export since all exporting firms optimally choose to abate. In this scenario, the export threshold is a function of the abatement fixed cost directly and, as such, sensitive to the changes in environmental policy.

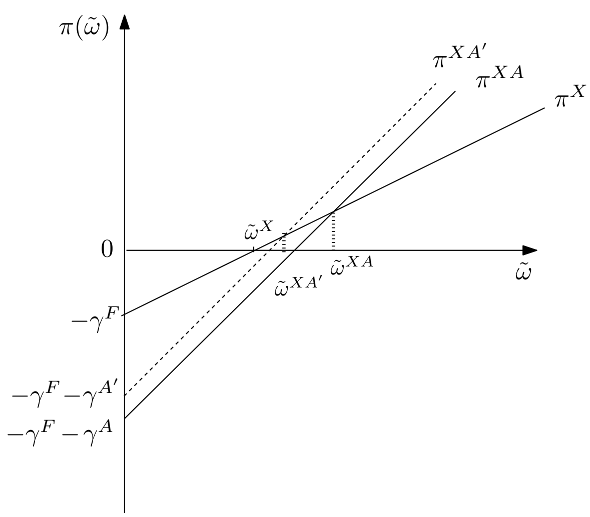


Figure SA8: Abatement Subsidies (sc 1)

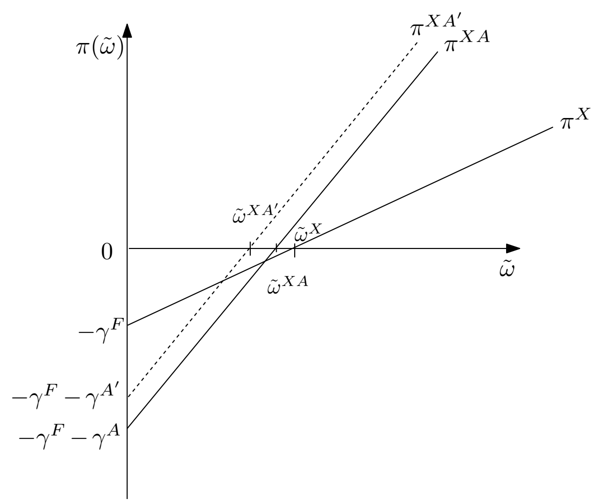


Figure SA9: Abatement Subsidies (sc 2)

In the last policy experiment we constrain export markets to firms which abate. The policy change forces firms with productivity between ω^X and $\omega^{XA\prime}$ in Figure SA10 out of the export market, lowering the fraction of firms that decide only to export. Firms that have productivity levels between $\omega^{XA\prime}$ and ω^{XA} that otherwise would only export begin abating as a result of the import restriction. In scenario 2, depicted

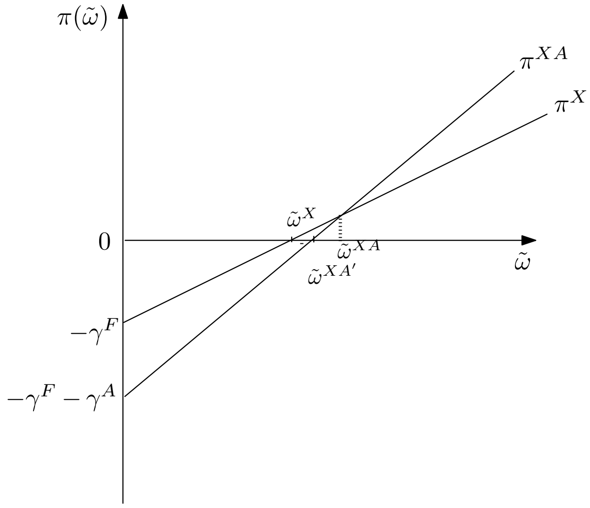


Figure SA10: Import Restrictions (sc 1)

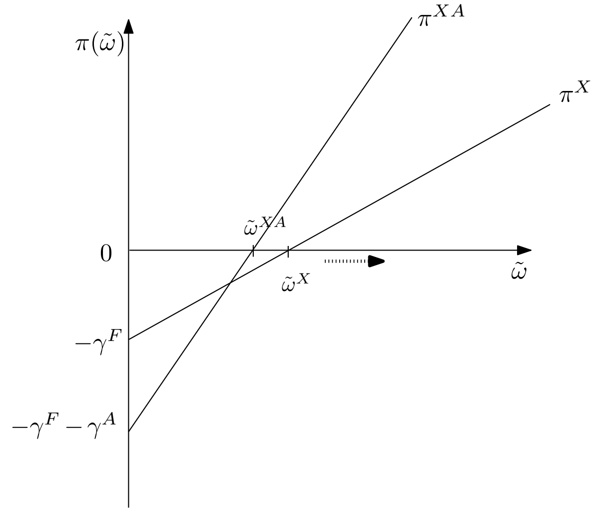


Figure SA11: Import Restrictions (sc 2)

in Figure SA11, the change in policy has no effect on firm-level abatement or export decisions.

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Chapter II

Cross-Border Pollution Externalities and Trade Agreements

Introduction

This paper investigates the impact of the absence of an international environmental agreement on trade negotiations. Specifically, the paper focuses on the implication of a cross-border pollution externality for non-cooperative environmental policies and cooperative trade taxes. In the case of no cross-border pollution, the efficient outcome is free trade and a pollution tax that is equal to the marginal cost of domestic pollution as in Limao (2005). With transboundary pollution, the efficient trade policy outcome includes free trade and pollution taxes take into account the cost of polluting trading partners as well.[55] These first-best policy outcomes obtain irrespective of whether policy choices are made strategically or simultaneously. Focusing on the case of cross-border pollution, I find that choosing trade and environmental policies strategically matters for efficiency in the absence of an environmental agreement. The model in this paper shows that the efficient outcome can be supported when trade cooperation occurs after unilateral pollution taxes are set. Thus, without an environmental agreement, countries can exploit the timing of trade negotiations to achieve efficiency.

To obtain my results, I analyze a two-stage game of trade and environmental policy choices between national governments. In the first stage, each government sets a level of pollution tax. The pollution tax can only be applied to domestic output.[56] In the second stage, governments negotiate the level of trade taxes that maximizes joint welfare. In this paper, governments care only about the welfare of their residents where no consideration is given to political motivations. The equilibrium from this game is efficient as discussed above. However, when governments cooperate over trade policy in the first stage and unilaterally set pollution taxes in the second stage, the resulting pollution taxes are inefficiently low. The framework in this paper provides an alternate mechanism through which efficiency may be reached in the absence of an environmental agreement. It also allows for an in-depth analysis of the strategic interaction between trade policy choices and the pollution spill over effect.

The relationship between trade agreements and environmental policies has already received significant attention in the literature. Bagwell and Staiger (2001) investigate how domestic standards should be

[55]The efficiency result is obtained by cooperating over both trade and environmental policies.

[56]Governments typically do not have judicial power to tax pollution in other countries. However, given the strategic nature of the policy game, the level of pollution tax set in one country may influence pollution indirectly in another country. Also, the focus here is on production-related pollution where no consideration is given to pollution externalities related to consumption.

handled in the WTO in light of their associated trade effects while Ferrara, Missios, and Yildiz (2009) emphasize the impact of tariff regimes on the outcome of environmental agreements and on welfare. Basically, key papers have either abstracted from nonpecuniary international externalities as in Bagwell and Staiger (2001) or have focused on enforcement of agreements such as Limao (2005) and Ederington (2002).[57] Other papers have examined the impact of strategic interaction between governments on the motives for linking trade and environmental policy or keeping them separate.[58] None of these papers, however, consider the impact of the timing of trade negotiations when pollution from production crosses borders and when countries cannot coordinate their environmental policies. Also, these previous studies say nothing about the use of trade policy to pursue environmental goals *especially when* countries are constrained by trade agreements.[59]

In this paper I show that there exists a unique choice of unilateral first-stage pollution taxes such that free trade is the outcome of negotiations in the second-stage. The selection of any other pollution tax level introduces barriers to trade in the cooperation stage with the aim of addressing the cross-border pollution externality issue. The first-stage pollution taxes that result in efficient trade policies are equivalent to the first-best, efficient pollution taxes. The findings in this paper suggest that an environmental agreement may not be required as countries could strategically choose policies that achieve global efficiency with just a trade agreement. Furthermore, with regards to the pollution spill over effect, the results in this paper ought to provide some insight on the impact of environmentally conscious trade policies. From a policy perspective, it addresses the question of whether Article XX of the GATT is justified when taking into account cross-border pollution externalities.[60]

The paper proceeds as follows. In Section 2 the basic model is set up. In Section 3 the efficient solution is solved for under the assumption that a trade and environmental agreement can be reached. Section 4 models a game of trade and environmental policy choice between countries, characterizing

[57]Limao (2005) considers cross-border externalities but in the context of self-enforcing agreements. Staiger and Sykes (2009) take into account a negative consumption externality that does not cross international borders. Ederington (2002) analyzes a model where the government maximizes social welfare and the pollution externality has no cross-border effects.

[58]See Copeland (1990) who examines strategic interactions with negotiable (tariffs) and non-negotiable (subsidies) trade barriers but does not consider transnational production or consumption externalities. Furthermore, he assumes the trade policy game is cooperative in the first stage but non-cooperative in the second stage. Other examples include Ludema and Wooton (1994), Copeland (2000), and Horn (2006).

[59]In a model that has a negative production externality only affecting the importing country, Ludema and Wooton (1994) show that the equilibrium tariff is higher in the importing country due to the externality. However, in their model, they do not consider the implications of strategically timing trade negotiations. Also there is no scope for domestic policy analysis in their study since home production generates no externality.

[60]Article XX may be viewed as a contingent contract that restricts governments' use of domestic policy to extract gains from trading partners while also taking into account environmental concerns. The particular nature of these contracts and the constraints that the WTO can incorporate into agreements to limit ex-post WTO violations is also of interest but is outside the scope of this paper.

a non-cooperative equilibrium. In Section 5, I consider policy choices when the pollution tax is set first followed by coordination over tariffs and examine the reverse timing of trade negotiations as well. Section 6 concludes.

The Model

Consider an economy with two countries, Home and Foreign, two non-numeraire manufacturing goods, x and y, and one numeraire good denoted by n. The government in each country sets the level of trade taxes, τ and τ^* respectively, and the pollution tax level, t and t^* respectively for each manufacturing good in its country.[61] Preferences of the representative consumer in both countries are given by $U = c_n + \sum_{i=1}^{2} u(c_i)$ where c_i is consumption of good i, for $i = \{x, y\}$. Assume $u(c_i) = c_i - \frac{c_i^2}{2}$ so that Home's demand function for good i is $d(p_i) = 1 - p_i$. Home's consumer surplus associated with good i is then $CS(p_i) = u(d(p_i)) - p_i d(p_i)$. Foreign demand functions and consumer surplus are symmetrically defined in terms of the foreign prices, p_x^* and p_y^*. I assume that n is sufficiently abundant in each country such that it is always consumed in positive amounts by all agents and the marginal utility of income is fixed at one. As such, the partial-equilibrium analysis of the non-numeraire sectors, x and y is comparable to a general-equilibrium trade model since consumption of the additional numeraire good occurs quasi-linearly. Trade in the numeraire good is then determined by the overall trade balance condition.

Each good is produced in both Home and Foreign. Production functions are assumed to be of the form $S_x = (L_x)^{1/2}$ and $S_y = (2L_y)^{1/2}$ for Home and $S_x^* = (2L_x^*)^{1/2}$ and $S_y^* = (L_y^*)^{1/2}$ for Foreign, where $L_i(L_i^*)$ is the labor used in the production of good i in Home (Foreign). Home is more productive in sector y than in sector x and vice-versa for Foreign. So, Home exports good y and imports good x while Foreign exports good x and imports good y. Given perfectly competitive markets, Home's supply functions are represented by the increasing functions $S_x(q_x)$ and $S_y(q_y)$ and Foreign's by $S_x^*(q_x^*)$ and $S_y^*(q_y^*)$ where $q_i(q_i^*)$ is the producer price of good $i = \{x, y\}$ in Home (Foreign). The supply functions for goods x and y are: $S_x(q_x) = q_x/2$, $S_y(q_y) = q_y$, $S_x^*(q_x^*) = q_x^*$, and $S_y^*(q_y^*) = q_y^*/2$. The related domestic and foreign profit functions are given by $\Pi_x(q_x) = q_x^2/4$, $\Pi_y(q_y) = q_y^2/2$, $\Pi_x^*(q_x^*) = q_x^{*2}/2$, and $\Pi_y^*(q_y^*) = q_y^{*2}/4$.

Production of good x emits pollution in both Home and Foreign.[62] The total pollution damage to Home is $z(q, q^*) = S(q) + \delta S^*(q^*)$ and to Foreign is $z^*(q, q^*) = S^*(q^*) + \delta S(q)$ where $0 \leq \delta \leq 1$ captures the geographical scope or range of the externality. As such, δ may be interpreted as the fraction of foreign pollution that affects the domestic country and equals zero if pollution is purely local or one if pollution is

[61] Home country variables are denoted without a * while variables for the foreign country have * attached to them.

[62] The focus here is on production-related pollution where no consideration is given to pollution externalities related to consumption.

perfectly transboundary.[63] The cost of this externality is given by the function $\phi(z(q,q^*))$ which I assume is twice differentiable and convex, and $\phi(0) = 0$. The cost function takes the form $\phi(z(q,q^*)) = \alpha \cdot z(q,q^*)^2$ at home and $\phi^*(z^*(q,q^*)) = \alpha \cdot z^*(q,q^*)^2$ in Foreign. Good y production does not generate externalities, so $\alpha_y = 0$ in both Home and Foreign. The nonnegative weight, $\alpha \in [0,1]$, reflects valuation of the externality in each country. The parameter α may also indicate the strength of domestic environmental lobbies. Note that in this paper I assume α is the same in both countries.[64]

Let τ_x and t_x denote Home's specific import tariff and pollution tax in sector x. Likewise, t_x^* and τ_x^* denote Foreign's pollution tax and Foreign's specific export tax on good x. The net trade tax for good x is defined as $r_x \equiv \tau_x + \tau_x^*$. If trade and pollution taxes are not prohibitive, home's consumer and producer price for good x are given by $p_x = p_x^w + \tau_x$ and $q_x = p_x^w + \tau_x - t_x$ respectively where p_x^w is the world price of good x. Foreign's local consumer and producer prices can be expressed as $p_x^* = p_x^w - \tau_x^*$ and $q_x^* = p_x^w - \tau_x^* - t_x^*$ correspondingly. Market prices for good y are defined in a similar fashion for both countries.[65] The international market-clearing condition for good i is $D(p_i) + D^*(p_i^*) = S(q_i) + S^*(q_i^*)$. Upon determination of tariffs and pollution taxes, the arbitrage condition for good x is $p_x = p_x^* + \tau_x + \tau_x^*$ for consumer prices and $q_x = q_x^* + \tau_x + \tau_x^* - t_x + t_x^*$ for producer prices. In sector y, the arbitrage condition is $p_y = p_y^* - \tau_y - \tau_y^*$ for consumer prices and $q_y = q_y^* - \tau_y - \tau_y^*$ for producer prices. This yields market-clearing world prices, $\tilde{p}_x^w = p_x^w(\tau_x, t_x, \tau_x^*, t_x^*)$, $\tilde{p}_y(\tilde{p_y^w}, \tau_y)$, and local prices for good x and y in Home: $\tilde{p}_x(\tilde{p_x^w}, \tau_x)$, $\tilde{q}_x(\tilde{p_x^w}, \tau_x, t_x)$, $\tilde{q}_y(\tilde{p_y^w}, \tau_y, t_y)$, and $\tilde{p}_y^w = p_y^w(\tau_y^*, t_y^*, \tau_y, t_y)$.[66] Similarly, equilibrium consumer and producer prices for good x in Foreign are $\tilde{p}_x^*(p_x^w, \tau_x^*)$ and $\tilde{q}_x^*(p_x^w, \tau_x^*, t_x^*)$ and for good y are $\tilde{p}_y^*(p_y^w, \tau_y^*)$ and $\tilde{q}_y^*(p_y^w, \tau_y^*, t_y^*)$.

Total Home welfare is the sum of welfare in both sectors and is defined as $W \equiv W_x + W_y$. Similarly, total Foreign welfare is $W^* \equiv W_x^* + W_y^*$. Furthermore, welfare in each sector is measured as the sum of consumer surplus and producer surplus, plus trade and domestic policy revenue, less environmental damage costs.[67] The government's objective is to maximize total welfare where welfare in each sector is:

$$W_i \equiv \int_{p_i}^{1} D(p_i)dp_i + \int_{0}^{q_i} S(q_i)dq_i + \tau_i M_i(p_i, q_i) + t_i S(q_i) - \phi_i(z(q_i, q_i^*)); i = \{x, y\}$$

For good x, this could be written as:

[63] I assume here that the spill over effect is the same in Home and Foreign. It should also be noted that the degree to which pollution crosses borders is completely independent of the amount of trade. One can think of δ as being determined solely by geographical and chemical factors.

[64] Also notice that the only asymmetry present in this model is in the comparative advantage of Home and Foreign.

[65] Given that production of good y does not emit pollution, the pollution tax is set to zero in that industry and the only policy instrument available is a trade tax.

[66] Note that the market-clearing local prices depend on trade policy through the net trade tax, r.

[67] Alternatively, the externality could be included in the consumer's utility function but given the structure of the model and the additive separability of the welfare function, this is equivalent to the exposition done here.

$$W_x(p_x^w, p_x, q_x, q_x^*) \equiv \int_{\tilde{p}_x}^{1} D(p_x)dp_x + \int_0^{\tilde{q}_x} S(q_x)dq_x + (p_x - p_x^w)M_x(p_x, q_x) + (p_x - q_x)S(p_x) - \phi_x(z(q_x, q_x^*))$$

where Home's excess demand for good i is $M_i \equiv D(p_i) - S(q_i)$ and Foreign's excess supply is similarly defined. Since prices are determined by tariffs and pollution taxes, government welfare is ultimately a function of the policy instruments.

To highlight the effect of the cross-border pollution externality on strategic behavior vis-a-vis trade and environmental policies, we focus our analysis on the polluting sector, x. Recall that this is Home's import sector and Foreign's export sector.[68] The world and local price functions take the following form:

$$p^w = [4 + 2t^* - 3\tau + t + 4\tau^*]/7$$

$$p = [4 + 2t^* + 4\tau + t + 4\tau^*]/7$$

$$p^* = [4 + 2t^* - 3\tau + t - 3\tau^*]/7$$

$$q = [4 + 2t^* + 4\tau - 6t + 4\tau^*]/7$$

$$q^* = [4 - 5t^* - 3\tau + t - 3\tau^*]/7$$

The monotonicity of the demand and supply functions gives world prices that are decreasing in the import tariff and increasing in export and pollution taxes. Basically, tariffs depress imports, leading to lower world prices and taxes lower world supply, resulting in higher world prices. Import tariffs raise domestic prices for consumers and producers as the traded good becomes more expensive in the domestic market. Alternatively, export taxes reduce domestic consumer and producer prices. The reason is that world prices are now higher as a result of the export tax and all else equal given the arbitrage condition, prices in the exporting country fall. Pollution taxes raise domestic consumer prices but lower producer prices for the simple fact that the direct pollution tax effect dominates the rise in world prices. Lastly, to ensure positive trade volume, I assume that trade taxes are not too large such that trade is prohibited.

[68] We drop the subscript, x, from now on.

Efficiency

In this section, I define a plan as efficient if it implies the largest possible surplus for division between the two countries.[69] The planner's problem is to choose trade and environmental policies that maximize joint welfare, which is given by:

$$J(p,q,p^*,q^*) = W(p^w,p,q,q^*) + W^*(p^w,p^*,q^*,p,q) \tag{1}$$

First, note that joint welfare is independent of world prices due to the market clearing condition that Home good x imports are exactly Foreign's exports of good x. Basically, world price changes that occur when local prices are fixed merely result in income redistribution across countries. Hence, local prices alone matter for efficiency here and since local prices only depend on net trade barriers given pollution taxes, joint welfare is also fully determined by net tariffs. Totally differentiating the joint welfare function, we get:

$$dJ = (\tau+\tau^*)dM + (t-\hat{t})dS + (t^*-\hat{t}^*)dS^* \tag{2}$$

where $\hat{t} = \phi' z - \delta \phi^{*'} z$ and $\hat{t}^* = \phi^{*'}_{z^*} - \delta \phi'_{z^*}$ may be defined as the marginal costs of global pollution. Also, $\phi'(\phi^{*'})$ is the derivative of Home's (Foreign's) pollution externality cost with respect to Home's (Foreign's) total pollution damage. It is easy to see that if taxes are set efficiently and prices equalize across countries, the expression in (2) becomes zero.

Proposition 1. *The efficient trade policy outcome is $r^E = \tau^E + \tau^{*E} = 0$. The efficient pollution tax is $t^E = \hat{t}(\delta,\alpha)$ for home and $t^{*E} = \hat{t}^*(\delta,\alpha)$ for foreign. The efficient pollution taxes consider the marginal costs of global pollution.*

This proposition establishes that, even in the presence of a cross-border pollution externality, trade policies are efficient. Intuitively, because the efficient pollution tax takes into account global pollution, the only motive governments have for trade protection is to influence the terms-of-trade at the expense of

[69] This is equivalent to the policy outcome from reciprocal trade and environmental agreements in the context of the present model. See Bagwell and Staiger (2001) and Maggi and Rodriguez-Clare (1998; 2007).

trading partners. However, the efficient plan takes away this terms-of-trade externality motive given that the planner maximizes joint welfare. Thus, the efficient trade outcome obtains.[70]

The following discussion of the conditionally efficient tariffs highlights the impact of the cross-border pollution externality in this analysis. Solving the maximization problem described above, when pollution taxes are set first and trade taxes are chosen in the second stage, the net trade tax, $r^E(t,t^*)$, is obtained as a function of pollution taxes.[71] In the benchmark case of no cross-border pollution, that is when $\delta = 0$, the trade policy choice simplifies to:

$$r^E(t,t^*,0) = \frac{16\alpha + (14+18\alpha)t - (21+34\alpha)t^*}{42+26\alpha} \tag{3}$$

Alternatively, when $\delta = 1$, that is when all of one country's pollution affects the other country, trade policy is given by:

$$r^E(t,t^*,1) = \frac{24\alpha + (14-8\alpha)t - (21+16\alpha)t^*}{42+4\alpha} \tag{4}$$

Assuming pollution taxes are set to zero in (3) and (4), notice that the net trade tax with perfect trans-boundary pollution is greater than that with no cross-border pollution. In general, however, the relationship between (3) and (4) will depend on the pollution taxes obtained from the first stage. In any case, for values of δ between zero and one, the net trade tax conditional on pollution taxes, $r^E(t,t^*)$, will lie somewhere between (3) and (4). Furthermore, from the two benchmark cases, it is clear that the cooperative trade tax, $r^E(t,t^*)$, is increasing in Home's pollution tax and decreasing in Foreign's pollution tax level for $0 \leq \delta \leq 1$ and $0 \leq \alpha \leq 1$. The intuition is that when Home raises its pollution tax, production shifts to Foreign, increasing pollution in both Home and Foreign. Thus, the level of trade protection rises to indirectly lower Foreign's pollution. Similarly, if Foreign decreases it's pollution tax, then trade protection rises to curb Foreign pollution.

With an environmental agreement in the first stage of the game, the choice of t and t^* maximizes (1) where the pollution externality is fully internalized and the pollution taxes chosen are equal to the marginal cost of polluting in both Home and Foreign. The efficient pollution taxes are:

[70] The efficient policy outcomes are the same irrespective of the timing of negotiations.

[71] Due to ease of exposition, the net tariffs are described in full in the appendix. Note that it is the net trade taxes that are unique not individual tariffs.

$$t^E = \hat{t}(\delta,\alpha) = \frac{[4\alpha(1+\delta(4+\delta)+2\alpha(-1+\delta^2)^2)]}{[7+8\alpha(2+\delta(-1+2\delta)+\alpha(-1+\delta^2)^2)]} \tag{5}$$

and

$$t^{*E} = \hat{t}^*(\delta,\alpha) = \frac{[8\alpha(1+\delta+\delta^2+\alpha(-1+\delta^2)^2)]}{[7+8\alpha(2+\delta(-1+2\delta)+\alpha(-1+\delta^2)^2)]} \tag{6}$$

From the expression in (2), notice that the two last terms are equal to zero given the efficient choices of t and t^*. Thus for efficiency, consumer prices must be the same in both Home and Foreign, suggesting that trade policies must be efficient. In effect, plugging (5) and (6) into the net trade tax, $r^E(t,t^*)$, gives the efficient trade policy outcome, that is, $r^E = \tau^E + \tau^{*E} = 0$.

Noncooperative Policy Choices

In this section I consider the static policy game and characterize the Nash trade and environmental policies.

Noncooperative Policy Choices With Pollution Taxes Set in the First-Stage

Without any international agreement, in Stage 1 of the game, the two governments noncooperatively and simultaneously choose levels of pollution taxes to maximize national welfare. Then in Stage 2 the governments, having observed the levels of pollution tax, choose tariff levels τ and τ^* respectively. I solve for an equilibrium in pollution and trade taxes using backwards induction. Nash equilibrium tariff choices in the second stage are defined as a set of policies $(\tau^N(t,t^*), \tau^{*N}(t,t^*))$, which satisfy the first-order conditions for Home and Foreign's maximization problem. To highlight the factors that influence policy choices, as in (2), I totally differentiate Home and Foreign's welfare functions:

$$dW = -Mdp^w + (p-p^w)dM + (t-\phi')dS - \delta\phi' dS^* \tag{7}$$

$$dW^* = M^*dp^w - (p^*-p^w)dM^* + (t^*-\phi^{*'})dS^* - \delta\phi^{*'} dS \tag{8}$$

From (7) and (8), observe that there are four key effects of tariff choices: the impact of tariffs on world prices (*terms of trade effect*), the impact of tariffs on local consumer prices (*volume-of-trade effect*) , the impact of tariffs on local producer prices (*domestic producer price effect*), and the impact of tariffs on foreign producer prices (*foreign pollution externality effect*). The domestic producer price effect can be further disentangled into two component effects: a *tax revenue effect* and a *domestic pollution externality effect*. The first two effects, the terms of trade and volume-of-trade effects, and the tax revenue effect, are typical in the trade literature.[72] This paper highlights two additional effects: the *domestic pollution externality effect* and the *foreign pollution externality effect*. A country can reallocate surplus from its trading partner to itself through the terms-of-trade effect associated with world price movements. Furthermore, changes in trade policies affect welfare through changes in local consumer prices that alter the volume of trade, which is the volume-of-trade effect. Trade policies also influence local producer prices, which affect domestic production, impacting domestic policy revenue and consequently welfare. The domestic (foreign) pollution externality effect refers to the ability of trade policy to alter the local (foreign) producer price and therefore the equilibrium domestic (foreign) supply levels and the amount of pollution damage incurred holding the volume of trade fixed. Changes in pollution emissions in turn affect welfare.

If Home sets its production tax equal to the marginal cost of the domestic externality and consumer prices are the same as world prices, the pollution externality effect originating from Home and the volume-of-trade effect disappear as shown in (7). However, the Home government still has an incentive to restrict trade because it can use trade policy to influence welfare through the terms-of-trade effect (Mdp^w) and the foreign pollution externality effect $(\phi' dS^*)$ illustrated in (7). It is clear that the first term in (7) which represents the terms-of-trade effect is positive when Home's tariff changes as gains in welfare occur through a lower world price of the good that Home imports. With a lower world price comes less foreign supply which reduces the pollution externality from Foreign, also improving Home's welfare. The terms-of-trade and foreign externality effects seem to reinforce each other in this case. Similar intuition holds for the Foreign country as well. If Foreign fully internalizes its domestic pollution and the volume of trade is constant, from (8) we see that Foreign's terms-of-trade is higher when trade taxes increase, which has a positive effect on welfare. The higher resulting world price makes Home producers want to supply more, increasing the cross-border pollution effect which negatively impacts Foreign's welfare. Hence, it could be the case that in Foreign the negative cross-border externality effect exactly offsets the positive

[72] See Bagwell and Staiger (1999) who also consider a political-economy effect. I abstract from political economy effects in this model in order to emphasize the effect of the pollution externality in the simplest model possible. Future research will analyze the impact of political lobbies in a similar model.

terms-of-trade effect in which case Foreign would have no need to restrict trade.

Within the context of the model, the four effects in (7) and (8) are:

$$dW = 3M(p,q) - 6\tau + 2t + \alpha(6\delta - 4)\{S(q) + \delta S^*(q^*)\} \tag{9}$$

$$dW^* = 4M^*(p^*,q^*) - 6\tau^* - 3t^* - \alpha(4\delta - 6)\{S^*(q^*) + \delta^* S(q)\} \tag{10}$$

The first term in (9) corresponds to $-Mdp^w$ in (7), which represents the terms-of-trade effect and reflects the effect of a slight increase of Home's tariff on imports and tariff revenue due to the lowering of the world price. As stated above, this represents a redistribution of surplus from foreign exporters to the domestic country and lowers the cost to the domestic government of offering further protection to its import-competing producers. The second term, 6τ, captures the volume-of-trade effect and reflects the efficiency cost to the domestic country when it raises its import tariff slightly. Import volume decreases as a result of the implied higher local consumer prices. The last terms in (9) correspond to $(t-\phi')dS - \delta\phi' dS^*$ in (7) and represent the combined domestic and foreign producer price effect of a small increase in the domestic import tariff, τ. The term, $2t + \alpha(6\delta - 4)S(q)$, measures the net effect on producer surplus, domestic tax revenue, and pollution damage of exchanging a fixed $S(q)$ units of domestically produced good x at a higher producer price. All else equal, Home's domestic and foreign pollution externality effects, $\alpha(6\delta - 4)S(q)$ and $\alpha(6\delta - 4)\delta S^*(q^*)$, increase domestic welfare with a higher import tariff when $\delta > 2/3$. The point here is that an increase in Home's import tariff lowers Foreign supply and raises domestic production due to higher prices. This diminishes the fraction of Foreign pollution that spills over to Home (welfare improving) but also augments pollution from domestic production (welfare decreasing). Thus,the net effect on welfare is positive, holding all other factors constant, if the proportion of Foreign pollution that affects home is greater than 2/3. If Home pollutes significantly more than Foreign does in Home and $\delta < 2/3$, then both pollution externality effects will cause a higher import tariff to lower Home's welfare. A similar interpretation applies to (4) with a few exceptions. First, a small increase in the export tax raises the world price of good x, reallocating surplus from Home to Foreign, thus improving Foreign's terms of trade. Second, higher export taxes lower producer prices in Foreign, resulting in a lower equilibrium supply level that hurts Foreign welfare through lower tax revenue. Third, the pollution externality effect on Foreign welfare is positive as long as $\delta^* < 3/2$. When Foreign increases its export tax, domestic supply and consequently domestic pollution decreases. However, Home's production increases which results in a larger pollution spill-over to Foreign. In sum, Foreign benefits from an export tax when its domestic pollution damage is greater than the spill-over from Home as the gain from lower internal pollution is greater than the decrease in welfare from the pollution originating from abroad.

Let $\tau^{BR}(\tau^*, t, t^*)$ and $\tau^{*BR}(\tau, t, t^*)$ indicate Home's import tariff and Foreign's export tax best-response functions. Considering the benchmark cases from the previous section, I find that in the event of no cross-border pollution ($\delta = 0$), the best-response functions for Home and Foreign are:

$$\tau^{BR}(\tau^*, t^*, t, 0) = \frac{(3-8\alpha)-(18+8\alpha)\tau^*-(9+4\alpha)t^*+(20+12\alpha)t}{(60+8\alpha)} \tag{11}$$

$$\tau^{*BR}(\tau, t, t^*, 0) = \frac{(4+24\alpha)-(24+18\alpha)\tau-(33+30\alpha)t^*+(8+6\alpha)t}{(66+18\alpha)} \tag{12}$$

In the second benchmark case of full pollution spill over effects, that is when $\delta = 1$, Home and Foreign's best-response functions are given by:

$$\tau^{BR}(\tau^*, t^*, t, 1) = \frac{(3+12\alpha)-(18+2\alpha)\tau^*-(9+8\alpha)t^*+(20-4\alpha)t}{(60+2\alpha)} \tag{13}$$

$$\tau^{*BR}(\tau, t, t^*, 1) = \frac{(4+12\alpha)-(24+2\alpha)\tau-(33+8\alpha)t^*+(8-4\alpha)t}{(66+2\alpha)} \tag{14}$$

For all applicable values of α, note that both Home and Foreign's reaction curves are downward sloping with respect to the other country's trade tax level. The intuition behind the downward sloping reaction curves is that when Foreign's export tax increases, Foreign production decreases, raising the world price of good x. Consumer prices rise and Home experiences a fall in imports as a result. The decline of Home's imports weakens the terms-of-trade benefit associated with a higher import tariff. Although the production externality gain increases when the import tariff is raised in terms of less pollution being emitted, Home's downward sloping best-response tariff function implies that this effect is secondary to the terms-of-trade effect.

Furthermore, under the assumption that pollution taxes are set to zero in both countries, note that when Foreign sets an export tax, Home's best-response function with $\delta = 1$ is greater than its reaction function with no transboundary pollution ($\delta = 0$). This suggests that Home responds to a pollution spillover by raising its import tariff level.[73] In contrast, Foreign's best-response function is lower with transboundary pollution than without when Home sets a positive import tariff, suggesting that Foreign reacts to Home's pollution spillover by reducing its export tax. The trade policy best response functions will fall somewhere between the two benchmark cases for values of $\delta \in [0, 1]$. In sum, the Nash trade taxes chosen by Home and Foreign reflect the cross-border nature of the production externality through the δ parameter.

Figure 1: Noncooperative Best-Response Curves

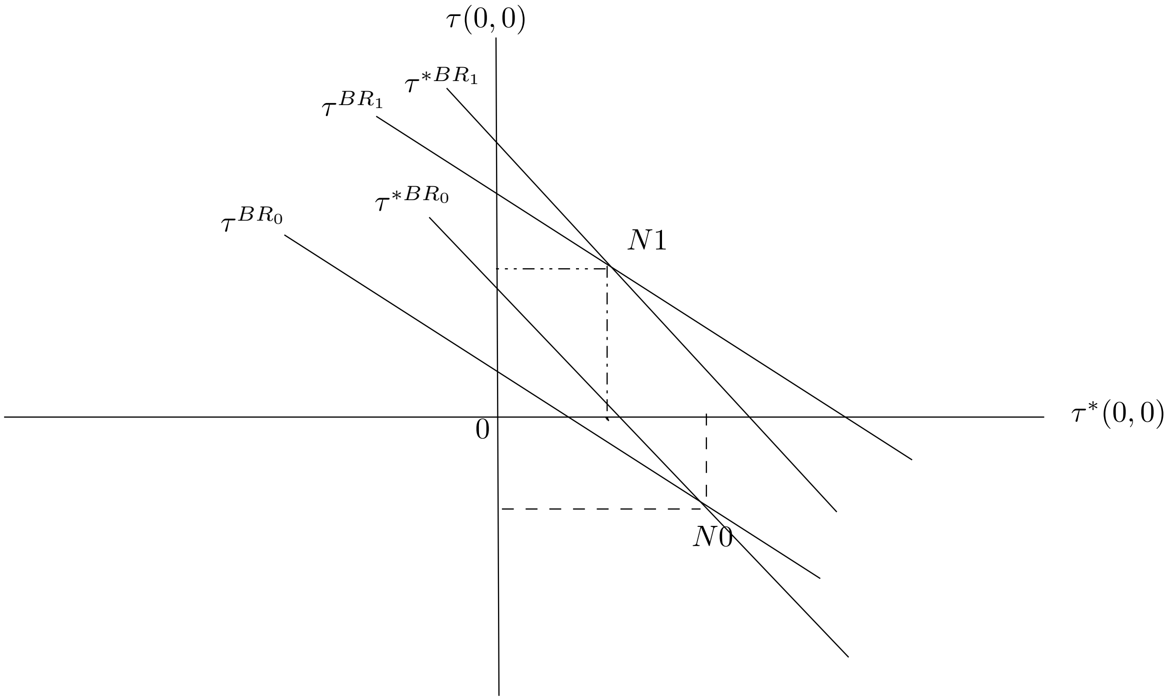

Figure 1 highlights the Nash best-response curves for Home and Foreign in the two benchmark cases where the pollution taxes in both countries are zero.[74] The point N0 reflects the equilibrium with no cross-border pollution while N1 is the equilibrium point when pollution is perfectly transboundary. Figure 1 suggests that Home imposes a negative Nash import tariff while Foreign sets a positive Nash export tax when $\delta = 0$. For an average valuation of the externality ($\alpha = 0.5$), Home responds to an increase in Foreign's export taxes by lowering it's import tariff where it essentially becomes an import subsidy.[75]

[73]Ludema and Wooton (1994) obtain this result as well in a model with trade policy but no domestic policy instrument available and a cross-border pollution externality.

[74]In this example, $\alpha = 0.5$.

[75]Again, production taxes are set to zero here. This is just for ease of exposition. In the appendix I describe the full Nash

Intuitively, with no cross-border pollution, Home would like Foreign to produce more, hence the subsidy. However, when pollution perfectly crosses borders, Foreign production now hurts Home where Home now responds to Foreign's trade policy by setting a positive import tariff. Given that Foreign is the exporter of the polluting good, the government's best-response is still to set a positive export tax to reduce domestic production and pollution. This follows from the previous discussion comparing (11) to (13) and (12) to (14). Moving from zero to perfect pollution spill over, Home's best-response tariff increases from an import subsidy to an import tariff when pollution taxes are set to zero as illustrated in Figure 1. However, it is important to keep in mind that the level of pollution taxes will be positive in which case best-responses and equilibrium policies will differ from what is highlighted in Figure 1.

From the best-response functions I obtain Home and Foreign's Nash trade tariffs given pollution taxes.[76] Combining both trade taxes, I compare them to those in (3) and (4). With no cross-border pollution in the non-cooperative game, I obtain:

$$r^N(t,t^*,0) = \frac{(7+16\alpha)+(28+18\alpha)t-(42+34\alpha)t^*}{84+26\alpha} \tag{15}$$

The other benchmark case of perfect transboundary pollution is given by:

$$r^N(t,t^*,1) = \frac{(7+24\alpha)+(28-8\alpha)t-(42+16\alpha)t^*}{84+4\alpha} \tag{16}$$

It is clear from (15) and (16) that given pollution taxes, Nash trade taxes are higher when pollution is perfectly transboundary than in the event of no cross-border pollution. Furthermore, assuming pollution taxes are set to zero, the Nash trade taxes in (15) and (16) may be greater or less than the cooperative trade taxes in (3) and (4) depending on the values of α. In general, the relationship between Home and Foreign's Nash trade tax levels and the pollution taxes depend on the parameter values of the model, δ and α.[77] Home's Nash tariff increases in its pollution tax for all possible parameter values, that is $\delta \in [0,1]$ and $\alpha \in [0,1]$. A rise in Home's pollution tax lowers domestic supply of good x. This allows Foreign producers to supply more of the good. Since Home is only concerned about domestic welfare, holding

equilibrium when environmental policy is chosen in the first stage and trade policy in the second stage.

[76] Full expressions for the trade tariffs are presented in the appendix.

[77] Under the condition that trade is not prohibitive, a positive trade volume occurs at the Nash tariff if for production taxes t and t^*, $r^N < (1-3t^*+2t)/6$, which then implies that $-21+7\alpha[5+4t+\delta^2(5+4t-9t^*)-9t^*+12\delta(-t+t^*)] < 0$. Hereafter, given the domestic and foreign production tax level, we assume the conditions for non-prohibitive trade are satisfied.

everything else constant, it raises unilateral tariffs for two reasons. First, the desire to protect its import-competing industry causes Home's government to increase its Nash import tariff in order to mitigate Home producers' loss due to higher pollution taxes at Home. Second, the foreign pollution externality rises due to higher Foreign production. As a result, the Home government raises its import tariff level to put downward pressure on Foreign production of the imported good, thereby reducing the negative externality.[78] In contrast, Foreign's Nash trade tax is decreasing in its pollution tax level. The government in Foreign lowers its Nash export taxes in response to a rise in Foreign pollution taxes to favor its exporting sector and to restrict the pollution externality from the other country's production.

Now consider the first stage of the game. Given the Nash tariffs described above, both Home and Foreign unilaterally choose production taxes to maximize their respective welfare. Solving their respective first-order conditions, the Nash production taxes[79] can be expressed as a function of the model's parameters, δ and α:

$$t^N = t^N(\delta, \alpha) \text{ and } t^{*N} = t^{*N}(\delta, \alpha) \tag{17}$$

when $\delta = 0$, Nash pollution taxes simplify to:

$$t^N = \frac{\alpha(-1674 - 2904\alpha - 852\alpha^2 - 72\alpha^3)}{(-2646 - 6048\alpha - 4182\alpha^2 - 960\alpha^3 - 72\alpha^4)}$$

$$t^{*N} = \frac{\alpha(-5589/2 - 3294\alpha - 888\alpha^2 - 72\alpha^3)}{(-2646 - 6048\alpha - 4182\alpha^2 - 960\alpha^3 - 72\alpha^4)}$$

When Home and Foreign set both policies simultaneously, Ederington (2002) and Limao (2002) show that pollution taxes chosen unilaterally are efficient and reflect the marginal cost of domestic pollution in the noncooperative policy game. To compare this result with the model in this paper, the Nash pollution taxes when policy choices are made simultaneously are:

$$t^N(\delta = 0) = \frac{\alpha(26 + 38\alpha)}{42 + 83\alpha + 38\alpha^2}$$

$$t^{*N}(\delta = 0) = \frac{\alpha(45 + 38\alpha)}{42 + 83\alpha + 38\alpha^2}$$

It is straightforward to verify that Home's (Foreign's) pollution tax in the absence of a cross-border

[78] Note that without a pollution tax, Home's import tariff may be used to reduce domestic pollution.

[79] See appendix for exact expression of Home and Foreign production taxes.

pollution externality when both policies are chosen simultaneously is less (greater) than in the two-stage policy game. This suggests that given no pollution spillover effect, Home (Foreign) is overtaxing (undertaxing) domestic production relative to the efficient level in the two-stage game.

When $\delta = 1$, the Nash pollution taxes are given by:

$$t^N = \frac{\alpha(-4500 - 114\alpha)}{(-2646 - 4662\alpha - 108\alpha^2)}$$

$$t^{*N} = \frac{\alpha(-4509 - 99\alpha)}{(-2646 - 4662\alpha - 108\alpha^2)}$$

Holding α constant, Home's production tax increases with δ. This is as a result of the fact that Home's welfare is negatively affected by pollution irrespective of the source. Home increases its production tax to improve its environmental quality where Foreign essentially shifts some of its cost of polluting to Home. Similarly, Foreign's pollution tax increases with δ where the intuition from Home applies here as well. This is confirmed when analyzing (17) in light of the two benchmark cases. I find that Home and Foreign's pollution taxes are less with no cross-border pollution than they are with perfectly transboundary pollution, reflecting concern about pollution regardless of the source.

Furthermore, I find that given δ, Home and Foreign pollution taxes increase with α. Basically, the more heavily Home (Foreign) weighs the pollution externality, the more Home's (Foreign's) government will raise its pollution tax in an effort to limit the increasingly negative impact of the externality on domestic welfare.

When a country places zero valuation on the pollution externality, that is when $\alpha = 0$, pollution taxes chosen unilaterally are efficient in the noncooperative policy game where Home and Foreign set both policies simultaneously since there is no externality to correct. However, the desire to use trade policy to manipulate the terms-of-trade is still present for both governments and countries enter into a trade agreement to correct this terms-of-trade externality. The optimal cooperative trade policy in the simultaneous move game where either $\alpha = 0$ or $\delta = 0$ is efficient.

When each country is able to choose trade and environmental policies strategically though, it is no longer obvious that unilateral production taxes are efficient even with a trade agreement. The reason being that both governments anticipate that they will be constrained by tariffs in the second stage. As such, their choice of domestic policy in the first stage potentially reflects this.[80]

Plugging the pollution taxes from (17) back into the tariffs obtained conditional on environmental

[80]When we consider cooperative policies in the next section, we will explore the issue of domestic policy substituting for trade policy and vice-versa.

policy choices gives the optimal Home and Foreign Nash tariffs[81], as a function of δ and α:

$$\tau^N = \tau^N(\delta,\alpha) \text{ and } \tau^{*N} = \tau^{*N}(\delta,\alpha) \tag{18}$$

To make these tariffs comparable to the tariffs in the efficiency section, I use the net tariff level, $r^N = \tau^N + \tau^{*N}$ and again refer to the two benchmark cases. In the case of no spill over effect, the net trade tax is given by:

$$\begin{aligned} r^N(t,t^*,0) &= \tau^N(t,t^*) + \tau^{*N}(t,t^*) \\ &= \frac{(147+67\alpha+12\alpha^2)}{4(441+12\alpha^4+1008\alpha+697\alpha^2+160\alpha^3)} \end{aligned} \tag{19}$$

The second benchmark case of $\delta = 1$ is given by:

$$\begin{aligned} r^N(t,t^*,1) &= \tau^N(t,t^*) + \tau^{*N}(t,t^*) \\ &= \frac{(147+253\alpha+16\alpha^2)}{12(147+259\alpha+6\alpha^2)} \end{aligned} \tag{20}$$

The most important point to note here is that the optimal unilateral trade policy is *not* efficient. Furthermore, from (19) and (20), notice that the net level of trade protection is higher with perfect cross-border pollution than when pollution is purely local. Essentially, the relationship between the Nash import tariff chosen by Home and δ given α is positive for one key reason: as Foreign's pollution increasingly crosses over Home's borders, Home's welfare is affected negatively which prompts the Home government to raise its import tariff in an effort to curb Foreign production and consequently Foreign pollution. In contrast, Foreign's export tax decreases with the spill over pollution from Home. The reason for this is that if Home increasingly pollutes into Foreign, Foreign's welfare is negatively impacted and Foreign lowers its export tax to raise Foreign supply. This reduces Home's production and as such Home's pollution. The fact that the net trade taxes in (19) and (20) are higher with cross-border pollution than without implies that Home's import tariff is larger in magnitude than Foreign's export tax. Nevertheless, both Home and Foreign unilaterally use trade policy to try and address the pollution externality.

[81] Again, see appendix for full expression of Nash trade taxes for Home and Foreign.

While Figure 1 highlights the Nash tariffs with no pollution taxes where Home's choice of an import subsidy depends on the pollution spill over effect, it is of interest to determine whether the Home and Foreign trade taxes in (18) have similar signs for the applicable range of parameters, that is $\delta \in [0,1]$ and $\alpha \in [0,1]$. I find Home's Nash import tariff to be positive within the range of parameter values. Without cross-border pollution effects (i.e. when $\delta = 0$), Home's government finds a slight positive import tariff desirable, implying that the terms-of-trade benefit outweighs the volume-of-trade cost due to a reduction in import volume. Considering the foreign pollution externality effect provides an added rational for imposing a positive import tariff as this lowers Foreign production and reduces the amount of pollution that spills over to Home. However, the domestic pollution externality reduces the appeal of a higher import tariff as domestic supply goes up, raising the local pollution emissions level. Determining the sign of Foreign's Nash export tax is more ambiguous as for some range of parameter values, the export tax is positive and for others it is negative which is in essence an export subsidy. Although when there are no pollution externality effects, Foreign's government finds a slight export tax desirable indicating that the terms-of-trade benefit exceeds the cost of reduced trade volume. Including the local pollution externality effect raises the attractiveness of an export tax because there is less local production, thus less pollution. In contrast, a higher Foreign export tax raises Home's supply of the good, which poses an extra pollution externality cost to Foreign that lowers the appeal of an export tax. In any case, the Nash tariffs in (18) are not efficient.

Lastly, Home and Foreign's pollution taxes obtained in (17) are positive when $\delta \in [0,1]$ and $\alpha \in [0,1]$ since pollution also arises due to domestic production. Relative to the first-best scenario outlined in the previous section, I find that Home and Foreign Nash pollution taxes are also inefficient. The direction of inefficiency, that is whether the Nash pollution taxes are higher or lower than their efficient counterparts depends on the values of δ and α. Foreign's non-cooperative pollution tax, t^{*N} however, is always less than the first-best pollution tax, t^{*E} for any given parameter value, implying that Foreign is not internalizing the damage it causes Home and over-supplies relative to the efficient output level.

Proposition 2. *In the static non-cooperative tariff game:*

(2.1). There exists a unique Nash equilibrium.

(2.2). Nash trade and pollution taxes are inefficient.

(2.3). The net Nash tariffs are above their efficient levels.

(2.4). Home and Foreign pollution taxes are positive.

(2.5). Home's Nash import tariff is positive for all parameter values while the sign of Foreign's Nash export tax depends on the specific values of α *and* δ*.*

(2.6). Foreign's non-cooperative pollution tax is too low relative to the fully efficient tax level for the applicable range of parameter values. Home's Nash pollution tax relative to the efficient tax depends on the specific parameter values within that range.

In the standard case of no cross-border pollution externality, the first-stage Nash domestic policies are efficient while trade policies reflect terms-of-trade motives and are inefficient. With a cross-border pollution externality, the first-stage Nash domestic policies are inefficient. The reason for this is that each government only takes into account the effect of local pollution and ignores the additional cost imposed on the other country when pollution spills over. By setting a pollution tax that is too low in the first stage, Foreign can shift some of its costs of reducing pollution onto Home and possibly improve its terms-of-trade in the second stage. Home's choice of domestic policy in the first stage depends on the parameters of the model. Intuitively, Home could subsidize domestic production by setting a pollution tax below the efficient level if the pollution spillover to Foreign is large or if Home does not care about the environment. However, if Home's valuation of the externality is really high or the spillover effect is small, then Home might find it unilaterally optimal to overtax its domestic production relative to the efficient level.

In the second stage, without cross-border pollution effects, there exists only a terms of trade motive for trade protection. With transboundary pollution, there is an additional incentive to restrict trade as governments seek to control pollution and reduce the pollution externality indirectly using trade taxes. Given that Home imports the good and pollution crosses borders, the Home government has an incentive to reduce Foreign production (and pollution) in addition to improving its terms-of-trade. Recall that even if pollution is not transboundary in which case domestic policy would be efficient, Home still has the terms-of-trade motive for unilaterally setting an import tariff. Thus, Home's optimal Nash trade policy is to set an import tariff. In contrast, Foreign may find an export subsidy optimal if Foreign concern for the environment is low and pollution is transboundary, as the fact that some pollution spills over to Home encourages the Foreign government to boost domestic production. Alternatively, if Foreign values the environment, then an export tax may be optimal in the second stage, lowering domestic pollution in addition to offering terms-of-trade gains.

Noncooperative Policy Choices Under Reverse Sequence of Events

In this subsection, I consider the reverse timing where governments unilaterally set trade policy in the first stage and environmental policy in the second stage. To obtain the subgame-perfect equilibrium, the two-stage game is solved backwards, starting with the determination of pollution taxes.

Let $t^{BR}(\tau^*, \tau, t^*)$ and $t^{*BR}(\tau, \tau^*, t)$ indicate Home and Foreign's pollution tax best-response functions. Considering the benchmark cases as before, I find that in the event of no cross-border pollution, the best-response functions for Home and Foreign are:

$$t^{BR}(\tau^*, \tau, t^*, 0) = \frac{(-1+12\alpha)+(3+6\alpha)t^* + (20+12\alpha)\tau + (6+12\alpha)\tau^*}{(23+18\alpha)} \tag{21}$$

$$t^{*BR}(\tau, \tau^*, t, 0) = \frac{(2+40\alpha)+(4+10\alpha)t - (12+30\alpha)\tau - (33+30\alpha)\tau^*}{(41+50\alpha)} \tag{22}$$

In the second benchmark case with perfect transboundary pollution, that is when $\delta = 1$, Home and Foreign's best-response functions are given by:

$$t^{BR}(\tau^*, \tau, t^*, 1) = \frac{(-1+24\alpha)+(3-16\alpha)t^* + (20-4\alpha)\tau + (6-4\alpha)\tau^*}{(23+8\alpha)} \tag{23}$$

$$t^{*BR}(\tau, \tau^*, t, 1) = \frac{(2+48\alpha)+(4-16\alpha)t - (12+8\alpha)\tau - (33+8\alpha)\tau^*}{(41+32\alpha)} \tag{24}$$

For $\alpha \in [0,1]$, note that both Home and Foreign's reaction curves are upward sloping with respect to the other country's pollution tax level in the absence of a cross-border pollution externality. The intuition behind the upward sloping reaction curves is that when Foreign's pollution tax increases, Foreign production decreases, enabling Home to increase domestic production. However, this also raises Home's pollution, prompting Home to increase its pollution tax. With perfect transboundary pollution, the slope of the reaction curves shown above depend on the value α. In between the two benchmark cases, Home's pollution tax is downward sloping for values of $1/10(16-\sqrt{166}) < \delta \leq 1$ and $-3/(6-32\delta+10\delta^2) < \alpha \leq 1$ and is upward sloping otherwise. When the pollution spill over from Foreign to Home is large, an increase in Foreign's pollution tax that decreases Foreign's pollution allows Home to lower its pollution tax in order to spur domestic production. However, when Foreign's pollution does not affect Home as much relative to Home's own domestic pollution, then even if Foreign increases its pollution tax, Home's best-response is to raise its pollution tax as well.[82]

From the best-response functions, I obtain Home and Foreign's Nash pollution taxes given tariffs, $t^N(\tau,\tau^*)$ and $t^{*N}(\tau,\tau^*)$.[83] Home's Nash pollution tax rises with Home's import tariff for the relevant range of parameter values. An increase in Home's import tariff lowers the volume of trade for good x as Home prices are now higher, allowing Home producers to supply more to the domestic market. However, the increase in domestic production results in more pollution which is not desirable to Home. As a result, Home raises its pollution tax to curb the increased domestic pollution. Likewise, Home raises its pollution tax with a rise in Foreign's export tax since an export tax reduces Foreign supply, thereby increasing domestic production and domestic pollution. Home chooses a higher pollution tax to minimize the domestic pollution externality effect. For the Foreign country, the opposite is true where an increase in Foreign's export tax results in a decrease in Foreign's pollution tax. The reason for this is that by raising its export tax, the Foreign producer price declines which lowers Foreign supply and pollution. Foreign can afford to slightly lower its pollution tax to improve the competitiveness of its domestic producers. Similarly, Foreign's pollution tax decreases as Home raises its import tariff to facilitate production for Foreign suppliers.

Now consider the first stage of the game. Given the Nash pollution taxes described above, Home and Foreign unilaterally choose trade policies that maximize their respective welfare. Solving their respective first-order conditions, the Nash trade taxes can be expressed as a function of the model's parameters, δ and α:[84]

$$\tau^N = \tau^N(\delta,\alpha) \text{ and } \tau^{*N} = \tau^{*N}(\delta,\alpha) \tag{25}$$

Home sets a positive import tariff and Foreign sets an export tax given the range of parameter values. Without pollution externality effects, Foreign finds a slight export tax desirable highlighting the incentive

[82]The interpretation of Foreign's best-response curve is similar where the slope with respect to Home's production tax is negative for $1/3(8-\sqrt{43}) < \delta \leq 1$ and $-2/(5-16\delta+3\delta^2) < \alpha \leq 1$ and positive otherwise.

[83]The full expression for both taxes is provided in the appendix.

[84]See appendix for exact expression of Home and Foreign trade taxes.

to extract surplus from its trading partner. For the same reason Home chooses a positive import tariff even when there are no pollution spill over effects. Recall that from Proposition 1 the efficient trade policy is free trade. Thus, the Nash tariffs in (25) are not on the efficiency frontier.

Furthermore, Home's import tariff increases with the cross-border pollution effect, δ, ceteris paribus. A rise in δ prompts Home to increase its import tariff in order to reduce Foreign production and pollution. This in turn lowers the cross-border pollution externality effect at Home and improves Home's welfare through better environmental quality. Home's import tariff also increases with α since greater valuation of the pollution damage negatively impacts Home's welfare. By raising its import tariff, Home can reduce the amount of Foreign pollution that spills over. Foreign's trade protection level also rises with δ. One reason for this is that Foreign wants to reduce pollution within its borders irrespective of the source. Foreign's export tax increase in response to higher pollution spill over from Home implies that the benefits from lower pollution and increased export tax revenue outweigh the costs from loss in producer surplus and lower volume of trade. With respect to α, Foreign's trade tax increases the more it values environmental quality, which holds true for Home as well.

Using the Nash tariffs from (25), we obtain the optimal Home and Foreign Nash pollution taxes, as a function of δ and α:[85]

$$t^N = t^N(\delta, \alpha) \text{ and } t^{*N} = t^{*N}(\delta, \alpha) \tag{26}$$

Relative to the first-best policy outcome, Home and Foreign's Nash production taxes, t^N and t^{*N}, differ from the efficient pollution taxes obtained earlier where the differences are either positive on negative depending on the precise values of α and δ. With no pollution spillover, that is when $\delta = 0$, Home's (Foreign's) Nash production tax in (26) is less (greater) than under the previous sequence of events in (17). Thus, when countries are only concerned about domestic pollution, they can exploit the timing of trade and environmental policy choices to maximize their welfare. In particular, Home (Foreign) taxes domestic producers more (less) when it sets domestic policy first and trade policy second suggesting that in the reverse case it uses trade policy to address pollution concerns. Furthermore, Home's Nash pollution tax in (26) is increasing in δ and α. This is exactly what we observe in the alternate sequence of events where pollution taxes were chosen in the first stage. The rationale in both cases is to minimize Home's welfare loss from the pollution externality regardless of its source. Also, Foreign's non-cooperative pollution tax is

[85] Again, see appendix for full expression of Nash pollution taxes for Home and Foreign.

increasing in α and δ. In sum, we see that irrespective of the timing of negotiations, in the non-cooperative equilibrium, trade policy is used in an attempt to rectify the negative impact of the cross-border pollution externality. Given trade policy, domestic policy is used to correct for the increase in pollution within a country's borders that may have originated from either domestic or foreign production.

The following proposition summarizes the above findings:

Proposition 3. *In the static non-cooperative tariff game:*

(3.1). There exists a unique Nash equilibrium.

(3.2). Nash trade and pollution taxes are inefficient.

(3.3). The net Nash trade taxes are above their efficient levels.

(3.4). Home's Nash import tariff and Foreign's Nash export tax are both positive.

(3.5). Home and Foreign's pollution tax relative to their efficient levels depend on the cross-border pollution effect and valuation of the externality.

The intuition behind Proposition 3 is similar to that of Proposition 2, where choosing trade and environmental policies non-cooperatively results in inefficient outcomes. The key difference here is that since trade policy is chosen in the first stage, each country unilaterally finds it optimal to set a positive trade tax. This is due primarily to terms-of-trade considerations but also in an attempt to control pollution.[86] In the second stage, given their choice of trade policy in the previous stage, both countries then set their pollution taxes relative to the pollution spillover effect and how much they value the pollution externality.

Cooperative Trade Policy and Unilateral Pollution Taxes

If countries are able to agree on both trade and environmental policies, the efficiency results in Section 3 obtain. While countries have had been able to agree on trade policies over the years under the auspice of the GATT and WTO, talks to sign a new post-Kyoto international environmental agreement broke down at the 2009 conference in Copenhagen. This raises the question of whether efficiency can be attained in the absence of a global environmental agreement.

[86] Governments know that their choice of domestic policies in the second stage will reflect only domestic pollution concerns and will not efficiently correct for the pollution externality, prompting them to use trade policy as an indirect means of addressing the cross-border pollution externality.

In this section, I examine whether trade policy coordination alone might result in trade and environmental policies that lie on the efficiency frontier.[87] Key studies in the trade literature have demonstrated that by cooperating on trade policy, countries internalize the terms-of-trade externality, thereby escaping the terms-of-trade driven Prisoners' Dilemma.[88] This paper reveals that governments may manipulate their trade policies to correct for the pollution externality in addition to the terms of trade externality so as to enjoy efficiency gains. In addition, efficiency may be obtained through the *second-best* policies highlighted in this section. I take advantage of the specific structure of the model in order to acquire more insight into the role of the cross-border pollution externality parameter in the determination of the mutual trade policy.

Recall that in the absence of a trade agreement, both Home and Foreign will use their unilateral tariff choices to manipulate the terms-of-trade in their favor. However, in this model, this is not the only inefficiency present. Pollution emissions from production at home and abroad introduce an additional externality where negotiations over environmental policy is required to obtain full efficiency (as in Section 3). When no environmental deal can been reached, a negative production externality will likely have repercussions on trade volume and on trade policy in general.[89]

Trade Negotiations Occurring in the First Stage

Assuming no cooperation over domestic policy in the first-stage, in the previous section, I showed that Nash trade taxes are inefficient.[90] This section considers the case where countries unilaterally set pollution taxes in the first stage and negotiate an agreement on trade using the generalized Nash bargaining solution in the second stage, which leads to the efficient level of trade taxes.[91] The game is solved by backward induction beginning with the determination of tariffs given first-stage pollution taxes. Negotiated tariffs will be chosen to maximize

[87] The main premise in this section is that trade and trade policy have environmental related effects and vice-versa leading to the debate about linking trade and environmental policies. A number of studies cast doubt on the effectiveness of linkage under the auspice of the WTO, for example Bagwell and Staiger (1999, 2001), Ederington (2002), and Staiger and Sykes (2009). In general, the argument has been that the only international externality relevant to trade agreements is the terms-of-trade externality and that current WTO rules which focus on market access are well able to deal with any problems related to unilateral environmental policy choices.

[88] Examples include Bagwell and Staiger (2001), Copeland (2000), and Limao (2005). An import tariff has the effect of lowering the world price, hurting foreign exporters. Since the importing country does not bear the full cost of this policy, it chooses tariff levels that excessively restrict trade, leading to inefficient trade volumes.

[89] It is quite likely that the Nash pollution taxes from the previous section differ from the optimal unilateral pollution taxes obtained when countries can cooperate over trade policies. This will be established shortly.

[90] In a similar political economy model, Grossman and Helpman (1995) show that the bargaining game with intercountry transfers in a trade agreement has essentially the same equilibrium as when the transfer is constrained to zero.

[91] I assume that the two negotiating parties divide the surplus equally between them and the equilibrium agreement is reached immediately.

$$(W(\tau,\tau^*,t,t^*) - W^D(t,t^*))(W^*(\tau,\tau^*,t,t^*) - W^{*D}(t,t^*)) \tag{27}$$

where $W^D(t,t^*)$ is the threat point of Home and $W^{*D}(t,t^*)$ is Foreign's threat point. The threat point could be the non-cooperative Nash equilibrium in Section 4 or payoffs from previously negotiated trade agreements.[92] Assuming a zero threat point, the objective function is

$$(W(\tau,\tau^*,t,t^*))(W^*(\tau,\tau^*,t,t^*)) \tag{28}$$

The trade taxes from the Nash bargaining solution also maximize joint welfare in (1). Thus, the level of trade protection conditional on pollution taxes obtained in (28) will be as described in Section 3. From (3) and (4), I showed that the cooperative tariff, r^E, is increasing in Home's pollution tax and decreasing in Foreign's pollution tax for all parameter values. Though both governments no longer have the ability to influence the terms-of-trade because of the trade agreement, they can potentially affect the other country's level of pollution emissions indirectly given their choice of pollution taxes in the first stage. If Home raises its pollution tax to lower domestic pollution, production shifts to the Foreign country, increasing its pollution level and the portion that spills over to the Home country. Thus, a higher combined trade tax that reduces Foreign pollution is more desirable to both countries in terms of joint welfare. Likewise, both countries prefer higher combined trade taxes when Foreign lowers its first-stage pollution tax because of the desire to limit the additional pollution generated in Foreign, some of which flows into the Home country.

Now consider the choice of domestic policy. Each country chooses its pollution tax to maximize domestic welfare and knows that decisions made in the first stage will influence the outcome of trade policy in the second stage. The choice of pollution taxes maximize $W(p^w,p,q,q^*)$ for Home and $W^*(p^w,p,q,q^*)$ for Foreign given $r^E(t,t^*)$. The resulting pollution taxes for Home and Foreign from the first stage are:

$$t^A = t^A(\delta,\alpha) = \frac{[4\alpha(1+\delta(4+\delta)+2\alpha(-1+\delta^2)^2)]}{[7+8\alpha(2+\delta(-1+2\delta)+\alpha(-1+\delta^2)^2)]} \tag{29}$$

[92] The analysis that follows assumes that the threat point is zero. Hence, if both countries are unable to reach an agreement, the net gain from bargaining (over that of the non-cooperative equilibrium) is zero. In the case where the threat point is affected by the pollution tax chosen, the policy outcome may differ from the one presented in this study. This feature of the threat point will be included in the model and analyzed in future work. Also, note that the problem abstracts from bargaining power concerns.

and

$$t^{*A} = t^{*A}(\delta, \alpha) = \frac{[8\alpha(1+\delta+\delta^2+\alpha(-1+\delta^2)^2)]}{[7+8\alpha(2+\delta(-1+2\delta)+\alpha(-1+\delta^2)^2)]} \tag{30}$$

To determine whether the production taxes in (29) and (30) are efficient, we compare them to the policies obtained from an environmental agreement in (5) and (6). Notice that t^A and t^{*A} are exactly the same as t^E and t^{*E}, showing that the unilateral pollution taxes are indeed efficient. Plugging (29) and (30) into the Nash trade taxes conditional on domestic policy gives the efficient trade policy outcome, that is, $r^E = \tau^E + \tau^{*E} = 0$. The efficient trade and domestic policy results obtained here are important because they suggest that the Pareto frontier can be reached even without an environmental agreement. In particular, when countries (that are similar and large) choose pollution taxes first and negotiate trade policy second, the outcome of both policies are efficient.

Comparing the net cooperative tariff to the net Nash tariff, we have that $r^N > 0 = r^E$, again highlighting the fact that Nash tariffs are inefficient. To be clear, the Nash pollution tax choices, t^N and t^{*N}, in (17) do not result in the efficient trade policy outcome in the negotiation stage. Thus, with the bargaining procedure outlined in the present paper, $\{t^A, t^{*A}\}$ is the unique set of pollution taxes chosen non-cooperatively in the first stage that maximizes joint welfare and brings about efficient trade. If Home or Foreign selects a pollution tax level different from that in (29) or (30), then inefficient trade protection ensues in an effort to correct the pollution externality since the trade agreement nullifies any gains from manipulating the terms-of-trade.

These results can be summarized as follows.

Proposition 4. *In the two-stage policy game:*

(4.1). There exists a unique non-cooperative domestic policy pair that maximizes joint welfare and leads countries to agree on the free trade outcome.

(4.2). The unique non-cooperative domestic policy pair that leads countries to the efficient trade outcome is efficient.

(4.3). Trade policy is used to correct for the pollution externality even when countries are bound by a trade agreement.

Reverse Timing of Trade Negotiations

This subsection describes the trade policy option that maximizes welfare in both countries where Home and Foreign negotiate tariff levels in the first stage and unilaterally set their pollution taxes in the second stage.[93] Solving the game backwards, the determination of pollution taxes conditional on trade policy is exactly as in subsection 4.2 where Home and Foreign's Nash pollution taxes given tariffs are $t^N(\tau, \tau^*)$ and $t^{*N}(\tau, \tau^*)$ respectively.[94]

In the first stage of the game, the negotiated tariffs will be those that maximize equation (28) (and equation (1)). Let τ^C and τ^{*C} be the optimal trade policy with a trade agreement, we find that $\tau^C = -\tau^{*C}$.[95] Thus, the combined cooperative trade taxes, that is, the sum of Home and Foreign's trade taxes, $r^C = \tau^C + \tau^{*C} = 0$. The net cooperative tariff is exactly at the efficient net tariff level (zero joint tariffs). Comparing $r^C = \tau^C + \tau^{*C}$ to $r^N = \tau^N + \tau^{*N}$ from (25), I find the Nash trade taxes to be inefficient as $r^N > r^C$. Thus, entering into a trade agreement provides efficiency gains irrespective of the timing of negotiations.

Given the efficient trade outcome from the first-stage, the pollution taxes obtained in the second stage are defined as t^C and t^{C*}, which are functions of δ and α. Comparing t^C and t^{*C} with the first-best pollution taxes, t^E and t^{*E}, I get that $t^C < t^E$ and $t^{*C} < t^{*E}$, highlighting the fact that both Home and Foreign are not internalizing the cross-border externality and are taxing pollution below the efficient level.

Proposition 5.

(5.1). The trade policy outcome is efficient even when tariffs are negotiated first.

(5.2). Non-cooperative pollution taxes are inefficient and are too low relative to their efficient levels.

Proposition 5 establishes that domestic policy outcomes differ depending on the sequence of events. The pollution taxes obtained when negotiations over trade policy occur in the second stage lie on the Pareto frontier. In the absence of a multilateral environmental treaty, given that tariffs are negotiated before the non-cooperative domestic policy choice, trade agreements induce substitution towards domestic policy as a means of influencing the terms-of-trade relative to the reverse timing of trade negotiations. The intuition underlying Proposition 5 is that since countries are not bound by an environmental agreement in the second stage, they can shift the terms-of-trade in their favor using domestic policies that are chosen

[93] The same bargaining mechanism used in the previous subsection applies here as well.

[94] The full expression for both taxes is provided in the appendix.

[95] See appendix for exact expression of Home and Foreign trade taxes.

unilaterally after trade policies have been negotiated.

Conclusion

This paper presents a trade model where governments engage in strategic behavior with respect to trade and environmental policies. The model also features a cross-border pollution externality that links trade and environmental policy in the absence of a multilateral environmental accord. This paper considers both cases where trade agreements are negotiated in the first stage and non-cooperative pollution taxes are chosen in the second stage, and vice-versa in order to evaluate the role that the timing of negotiations plays on trade and environmental policy outcomes.

The model shows that governments are able to implement first-best environmental and trade policies when pollution taxes are set unilaterally in the first stage and bargaining over trade policy occurs in the second-stage. However, under the reverse timing, only the joint cooperative trade tax is efficient while domestic policies are below first-best levels. The inefficiency of environmental policy is driven by two key factors: the pollution spillover effect and the terms-of-trade externality. Without cross-border pollution, noncooperative domestic policies are efficient and reflect the marginal cost of domestic pollution. When pollution is transboundary and countries are bound by a trade agreement, there is an incentive for governments to use unconstrained domestic policy to improve their terms-of-trade and control pollution given that trade negotiations occur in the first stage. Alternatively, when trade negotiations occur in the second stage, countries set pollution taxes efficiently because they anticipate that with the cross-border pollution externality, negotiated trade policies will incorporate pollution spillover concerns.

In sum, the model emphasizes that without an environmental agreement, global efficiency may still be attained if countries that are similar and large enough to influence the terms-of-trade negotiate tariffs after setting domestic policy. Furthermore, governments choice of trade policy, negotiated or not, reflects concerns about the pollution externality. Where the use of environmental policy as a substitute for trade policy depends on the timing of negotiations, trade policy may be used to substitute for environmental policy regardless of when trade negotiations take place.

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Appendix

Efficiency Analytical Details

$$r^E(t,t^*) = \tau^E(t,t^*) + \tau^{*E}(t,t^*)$$

$$= \frac{[e_1] + [e_2]t + [e_3]t^*}{2[21 + 13\alpha - 24\alpha\delta + 13\alpha\delta^2]}$$

where $e_1 = [16\alpha - 8\alpha\delta + 16\alpha\delta^2]; e_2 = [14 + 18\alpha - 44\alpha\delta + 18\alpha\delta^2]; e_3 = [-21 - 34\alpha + 52\alpha\delta - 34\alpha\delta^2]$

Noncooperative Trade and Environmental Policy Analytical Details

$$\tau^N(t^*,t) == \frac{[a] + [b]t + [c]t^*}{6[42 + 13\alpha - 24\alpha\delta + 13\alpha\delta^2]}$$

where $a = (-1/6)[-9 + 67\alpha + 12\delta\alpha - 120\alpha\delta^2 - 52\alpha^2\delta + 52\alpha^2\delta^3 + 24\alpha^2 - 24\alpha^2\delta^4]; b = (-1/6)[-84 - 70\alpha + 96\delta\alpha - 14\alpha\delta^2 + 26\alpha^2\delta - 26\alpha^2\delta^3 - 12\alpha^2 + 12\alpha^2\delta^4]; c = (-1/6)[-27\alpha - 48\delta\alpha + 99\alpha\delta^2 + 26\alpha^2\delta - 26\alpha^2\delta^3 - 12\alpha^2 + 12\alpha^2\delta^4]$

$$\tau^{*N}(t,t^*) = \frac{[a^*] + [b^*]t - [c^*]t^*}{6[42 + 13\alpha - 24\alpha\delta + 13\alpha\delta^2]}$$

where $a^* = (1/6)[12 + 115\alpha - 12\delta\alpha - 72\alpha\delta^2 - 52\alpha^2\delta + 52\alpha^2\delta^3 + 24\alpha^2 - 24\alpha^2\delta^4]; b^* = (1/6)[-16\alpha - 36\delta\alpha + 40\alpha\delta^2 + 26\alpha^2\delta - 26\alpha^2\delta^3 - 12\alpha^2 + 12\alpha^2\delta^4]; c^* = (1/6)[-126 - 129\alpha + 108\delta\alpha - 3\alpha\delta^2 + 26\alpha^2\delta - 26\alpha^2\delta^3 - 12\alpha^2 + 12\alpha^2\delta^4]$

$$r^N(t,t^*) = \tau^N(t,t^*) + \tau^{*N}(t,t^*)$$

$$= \frac{[n_1^*] + [n_2^*]t + [n_3^*]t^*}{-2[42 + 13\alpha - 24\alpha\delta + 13\alpha\delta^2]}$$

where $n_1^* = [-7 - 16\alpha + 8\alpha\delta - 16\alpha\delta^2]; n_2^* = [-28 - 18\alpha + 44\alpha\delta - 18\alpha\delta^2]; n_3^* = [42 + 34\alpha - 52\alpha\delta + 34\alpha\delta^2]$

$$t^N = t^N(\delta,\alpha) = \frac{[a_1]\alpha - [a_2]\alpha^2 - [a_3]\alpha^3 + [a_4]\alpha^4]2\delta}{-5292 - [b_1]\alpha + [b_2]\alpha^2 + [b_3]\alpha^3 + [b_4]\alpha^4}$$

where $a_1 = [36(-93 + \delta(-162 + 5\delta))]; a_2 = [3(1936 + \delta(-423 + \delta(-2290 + \delta(771 + 82\delta))))]; a_3 = [3(-1 + \delta)(1 + \delta)(-568 + 3\delta(298 + \delta(-56 + 5\delta(-15 + 2\delta))))]; a_4 = [(-3 + 2\delta)(-2 + 3\delta)(-12 + 13\delta)(-1 + \delta^2)^2]; b_1 = 2[126(48 + \delta(-24 + 13\delta))]; b_2 = 2[6(-697 + \delta(678 + \delta(111 + 2\delta(-81 + 26\delta))))]; b_3 = 2[6(-1 + \delta)(1 + \delta)(160 + \delta(-302 + \delta(166 + \delta(-32 + 15\delta))))]; b_4 = 2[(-3 + 2\delta)(-2 + 3\delta)(-12 + 13\delta)(-1 + \delta^2)^2]$

$$t^{*N} = t^{*N}(\delta,\alpha) = \frac{[a_1^*]\alpha + [a_2^*]\alpha^2 + [a_3^*]\alpha^3 + [a_4^*]\alpha^4}{-5292 - [b_1]\alpha + [b_2]\alpha^2 + [b_3]\alpha^3 + [b_4]\alpha^4}$$

where $a_1^* = [-27(207+\delta(116+11\delta))]; a_2^* = [9(-732+\delta(396+\delta(575-312\delta+51\delta^2)))]; a_3^* = [2(-1+\delta)(1+\delta)(888+\delta(-1533+\delta(585+\delta(61+30\delta))))]; a_4^* = [2(-3+2\delta)(-2+3\delta)(-12+13\delta)(-1+\delta^2)^2]$

$$\tau^N = \tau^N(\delta,\alpha) = \frac{-378 - [c_1]\alpha + [c_2]\alpha^2 + [c_3]\alpha^3 + [c_4]\alpha^4}{-10584 - 2[b_1]\alpha + 2[b_2]\alpha^2 + 2[b_3]\alpha^3 + 2[b_4]\alpha^4}$$

where $c_1 = [3(55+\delta(1056+1679\delta))]; c_2 = [-36+\delta(-5424+\delta(1427+5(1248-487\delta)\delta))]; c_3 = [2(-1+\delta)\delta(1+\delta)(797+3\delta(-437+\delta(139+50\delta)))]; c_4 = [20(-1+\delta)^3\delta(1+\delta)^2(6+\delta(-13+6\delta))]$

$$\tau^{*N} = \tau^{*N}(\delta,\alpha) = \frac{-504 - [c_1^*]\alpha - [c_2^*]\alpha^2 - [c_3^*]\alpha^3 - [c_4^*]\alpha^4}{-10584 - 2[b_1]\alpha + 2[b_2]\alpha^2 + 2[b_3]\alpha^3 + 2[b_4]\alpha^4}$$

where $c_1^* = [237-3\delta(1308+1055\delta)]; c_2^* = [36+\delta(-4830+\delta(2033+(4194-1565\delta)\delta))]; c_3^* = [2(-1+\delta)\delta(1+\delta)(671+2\delta(-529+\delta(113+90\delta)))]; c_4^* = [20(-1+\delta)^3\delta(1+\delta)^2(6+\delta(-13+6\delta))]$

$$\begin{aligned} r^N(\delta,\alpha) &= \tau^N(\delta,\alpha) + \tau^{*N}(\delta,\alpha) \\ &= \frac{-441 - [n_1]\alpha + [n_2]\alpha^2 - [n_3]\alpha^3}{-5292 - [b_1]\alpha + [b_2]\alpha^2 + [b_3]\alpha^3 + [b_4]\alpha^4} \end{aligned}$$

where $n_1 = [201+18\delta(-21+52\delta)]; n_2 = [3(12+\delta(99+\delta(101+\delta(-341+145\delta))))]; n_3 = [(-1+\delta)\delta(1+\delta)(-126+\delta(253+\delta(-191+30\delta)))]$

Reverse Timing Nash Analytical Details

$$t^N(\tau,\tau^*) = \frac{[d_1] + [d_2]\tau + [d_3]\tau^*}{[-133 - 262\alpha + 104\alpha\delta - 10\alpha\delta^2 - 120\alpha^2 + 64\alpha^2\delta + 112\alpha^2\delta^2 - 64\alpha^2\delta^3 + 6\alpha^2\delta^4]}$$

where $d_1 = [5 - 82\alpha - 116\alpha\delta + 46\alpha\delta^2 - 120\alpha^2 + 64\alpha^2\delta + 112\alpha^2\delta^2 - 64\alpha^2\delta^3 + 8\alpha^2\delta^4]; d_2 = [-112 - 190\alpha + 120\alpha\delta - 22\alpha\delta^2 - 60\alpha^2 + 32\alpha^2\delta + 56\alpha^2\delta^2 - 32\alpha^2\delta^3 + 4\alpha^2\delta^4]; d_3 = [-21 - 72\alpha - 16\alpha\delta + 12\alpha\delta^2 - 60\alpha^2 + 32\alpha^2\delta + 56\alpha^2\delta^2 - 32\alpha^2\delta^3 + 4\alpha^2\delta^4]$

$$t^{*N}(\tau,\tau^*) = \frac{-([d_1^*] - [d_2^*]\tau + [d_3^*]\tau^*)}{[-133 - 262\alpha + 104\alpha\delta - 10\alpha\delta^2 - 120\alpha^2 + 64\alpha^2\delta + 112\alpha^2\delta^2 - 64\alpha^2\delta^3 + 6\alpha^2\delta^4]}$$

where $d_1^* = [-6 - 142\alpha - 52\alpha\delta + 18\alpha\delta^2 - 120\alpha^2 + 64\alpha^2\delta + 112\alpha^2\delta^2 - 64\alpha^2\delta^3 + 8\alpha^2\delta^4]; d_2^* = [28 + 94\alpha -$

$2\alpha\delta - 4\alpha\delta^2 + 60\alpha^2 - 32\alpha^2\delta - 56\alpha^2\delta^2 + 32\alpha^2\delta^3 - 4\alpha^2\delta^4]$; $d_3^* = [105 + 168\alpha - 102\alpha\delta + 14\alpha\delta^2 + 60\alpha^2 - 32\alpha^2\delta - 56\alpha^2\delta^2 + 32\alpha^2\delta^3 - 4\alpha^2\delta^4]$

$$\tau^N = \tau^N(\delta,\alpha) = \frac{-1480927 - [f_1]\alpha + [f_2]\alpha^2 + [f_3]\alpha^3 - [f_4]\alpha^4 + [f_5]\alpha^5 + [f_6]\alpha^6}{1397039x + 2[g_1]\alpha + 2[g_2]\alpha^2 + 2[g_3]\alpha^3 - 2[g_4]\alpha^4 + 2[g_5]\alpha^5}$$

where $f_1 = 2[63(70344 + 759163\delta) + 2(445877753\delta^2)]$; $f_2 = 4[(4886817 + \delta(139010595 + \delta(137321637 + \delta(-121198214 + 133339023\delta))))]$; $f_3 = 4[2(2547674 + \delta(165179974 + \delta(38849533 + \delta(-205217605 + \delta(61863467 + (6405363 - 27271668\delta)\delta)))))]$; $f_4 = 4[8(-320085 + \delta(-51195761 + \delta(20030820 + \delta(70081816 + \delta(-42552533 + \delta(-8581893 + 2\delta(5621973 + \delta(-1388977 + 113902\delta))))))))]$; $f_5 = 4[16(-1+\delta)(1 + \delta)(-31500 + \delta(-17445983 + \delta(15697947 + \delta(7918649 + \delta(-12650901 + \delta(4761131 + \delta(-607159 + \delta(-14725 + 6077\delta))))))))]$; $f_6 = 4[64(-5+\delta)(-3+\delta)\delta(-1+\delta^2)^2(103383 + \delta(-81079 + \delta(-8574 + \delta(22878 + \delta(-7129 + 729\delta)))))]$; $g_1 = x[49(65293 + 5\delta(-5352 + 3253\delta))]$; $g_2 = x[14(409441 + \delta(-318834 + \delta(154485 - 42572\delta + 4372\delta^2)))]$; $g_3 = x[4(1259075 + \delta(-1413054 + \delta(472449 + \delta(112732 + \delta(-330059 + (140834 - 16185\delta)\delta)))))]$; $g_4 = x[16(-5+\delta)(-3+\delta)(-1+\delta)(1+\delta)(9087 + \delta(-8504 + \delta(6898 + \delta(-2344 + 239\delta))))]$; $g_5 = x[128(-5+\delta)^2(-3+\delta)^2(-1+\delta)^2(1+\delta)^2(13 + \delta(-10 + 13\delta))]$; $x = [-133 + 2\alpha(-131 + (52 - 5\delta)\delta + 4\alpha(-5+\delta)(-3+\delta)(-1+\delta)(1+\delta))]$

$$\tau^{*N} = \tau^{*N}(\delta,\alpha) = \frac{-3089842 - [f_1^*]\alpha - [f_2^*]\alpha^2 - [f_3^*]\alpha^3 - [f_4^*]\alpha^4 - [f_5^*]\alpha^5 - [f_6^*]\alpha^6 - [f_7^*]\alpha^7}{1397039x + 2[g_1]\alpha + 2[g_2]\alpha^2 + 2[g_3]\alpha^3 - 2[g_4]\alpha^4 + 2[g_5]\alpha^5}$$

where $f_1^* = 2[7(1907782 + 6497948\delta + 44433158\delta^2)]$; $f_2^* = 2[2(11154358 + \delta(36851622 + \delta(70480786 + \delta(-48636417 + 14985658\delta))))]$; $f_3^* = 2[4(4479254 + \delta(69458768 + \delta(39361191 + \delta(-104350125 + \delta(27799647 + (5832161 - 20549848\delta)\delta)))))]$; $f_4^* = -2[16(-430335 + \delta(-29088333 + \delta(7250444 + \delta(42300776 + \delta(-24090901 + \delta(-4232849 + 2\delta(2886989 + \delta(-726693 + 63383\delta))))))))]$; $f_5^* = 2[32(-1+\delta)(1+\delta)(-31500 + \delta(-12445043 + \delta(10652319 + \delta(4763637 + \delta(-7891041 + \delta(2929903 + \delta(-321195 + \delta(-29425 + 5881\delta))))))))]$; $f_6^* = 2[128(-5+\delta)(-3+\delta)\delta(-1+\delta^2)^2(88683 + \delta(-70299 + \delta(3578 + \delta(12294 + \delta(-4581 + 533\delta)))))]$; $f_7^* = 2[1024(-5+\delta)^5(-3+\delta)^2\delta(-1+\delta^2)^3]$

$$t^N = t^N(\delta,\alpha) = \frac{4762359 + [h_1]\alpha + [h_2]\alpha^2 + [h_3]\alpha^3 + [h_4]\alpha^4 + [h_5]\alpha^5 + [h_6]\alpha^6 + [h_7]\alpha^7}{1397039x + 2[g_1]\alpha + 2[g_2]\alpha^2 + 2[g_3]\alpha^3 - 2[g_4]\alpha^4 + 2[g_5]\alpha^5}$$

where $h_1 = 2[-7(6809063 + 4\delta(4612534 + 1558911\delta))]$; $h_2 = 2[2(-165487950 + \delta(-239046475 + \delta(47033436 + \delta(14305470 + 6858917\delta))))]$; $h_3 = 2[4(-210491541 + \delta(-131271339 + \delta(172366140 + \delta(1471859 + 3\delta(7879516 +$

$5\delta(-1578004+269951\delta))))))]; h_4 = 2[8(-136992055+\delta(8049070+\delta(141737130+\delta(-29305416+\delta(5107910+\delta(-21808298+\delta(9653218+13\delta(-104492+5305\delta))))))))]; h_5 = 2[-32(-1+\delta)(1+\delta)(-24447630+\delta(16086653+\delta(1760855+\delta(-1295419+\delta(3060611+\delta(-4195521+\delta(1934765+\delta(-371457+257735\delta))))))))]; h_6 = 2[-128(-5+\delta)(-3+\delta)(-1+\delta^2)^2(152295+\delta(-102431+\delta(90082+\delta(-65602+\delta(21415+\delta(-3359+272\delta))))))]; h_7 = 2[3072(-5+\delta)^3(-3+\delta)^2(-1+\delta)^3(1+\delta)^3(-13+\delta(6+\delta(-13+4\delta)))]$

$$t^{*N} = t^{*N}(\delta,\alpha) = \frac{-1595881+[h_1^*]\alpha+[h_2^*]\alpha^2+[h_3^*]\alpha^3+[h_4^*]\alpha^4+[h_5^*]\alpha^5+[h_6^*]\alpha^6+[h_7^*]\alpha^7}{1397039x+2[g_1]\alpha+2[g_2]\alpha^2+2[g_3]\alpha^3-2[g_4]\alpha^4+2[g_5]\alpha^5}$$

where $h_1^* = 14[-15370864+\delta(-2163877+73183320\delta))]; h_2^* = 2[-554722186+2\delta(109911028+\delta(135471901+19\delta(-5987273+6556691\delta)))]; h_3^* = 2[-4(303377898+\delta(-283969835+\delta(-98846825+\delta(240075963+\delta(-96896015+2\delta(5007030+351709\delta))))))]; h_4^* = 2[-8(176262175+\delta(-258165886+\delta(-6284834+\delta(225843164+\delta(-151339562+\delta(16066770+\delta(13947022+\delta(-4562608+415775\delta))))))))]; h_5^* = 2[-32(-1+\delta)(1+\delta)(-28602480+\delta(56745099+\delta(-38733791+\delta(-2456173+\delta(17443481+\delta(-9789575+\delta(2438699+\delta(-281623+11787\delta))))))))]; h_6^* = 2[128(-5+\delta)(-3+\delta)(-1+\delta^2)^2(-163995+\delta(322217+\delta(-280456+\delta(92990+\delta(-2383+\delta(-4327+626\delta))))))]; h_7^* = 2[1024(-5+\delta)^3(-3+\delta)^2(-1+\delta)^3(1+\delta)^3(-39+\delta(68+\delta(-59+14\delta)))]$

Tariff Coordination and Unilateral Pollution Tax Analytical Details

$$\tau^C(\delta,\alpha) = -\tau^{*C}(\delta,\alpha) = \frac{35329+[i_1]\alpha+[i_2]\alpha^2+[i_3]\alpha^3+[i_4]\alpha^4}{1927317+[j_1]\alpha+[j_2]\alpha^2+[j_3]\alpha^3-[j_4]\alpha^4+2[j_5]\alpha^5}$$

where $i_1 = -2[659-\delta(6359+8938\delta)]; i_2 = -2[-4(-75+\delta(4534+\delta(1906+\delta(-3896+735\delta))))]; i_3 = -2[32(-1+\delta)\delta(1+\delta)(523+\delta(-209+3\delta(1+\delta)))]; i_4 = -2[64(-5+\delta)^2(-3+\delta)(-1+\delta)^2\delta(1+\delta)^2]; j_1 = 4[98(23935-9922\delta+7800\delta^2)]; j_2 = 4[7(642895+\delta(-512508+\delta(333008+\delta(-111296+12293\delta))))]; j_3 = 4[-4(-1066505+\delta(1233910+\delta(-604063+\delta(57396+\delta(269593+\delta(-131818+15695\delta))))))]; j_4 = 4[-768(-5+\delta)(-3+\delta)(-1+\delta)(1+\delta)(174+\delta(-169+\delta(158-57\delta+6\delta^2)))]; j_5 = 4[128(-5+\delta)^2(-3+\delta)^2(-1+\delta)^2(1+\delta)^2(13+\delta(-10+13\delta))]$

Chapter III

Environmental Regulation and Trade Protection: A Case Study of the U.S. Clean Air Act

Introduction

International trade theory contends that free trade is welfare improving. However, in practice, most countries maintain trade barriers across a number of goods. One argument for this is that governments use trade policy to protect domestic import-competing industries in exchange for political support.[96] Another rationale for trade barriers is that by acting strategically with respect to trade and domestic policy, countries may capture returns that would otherwise go to trading partners and gain some type of market advantage.[97] Ludema and Wooton (1994) and Soumonni (2011) further argue that some countries use trade policy to address negative environmental externalites of international trade. These explanations are by no means mutually exclusive as governments may restrict trade for political, strategic, and environmental reasons.

This paper examines whether domestic environmental regulatory policy has any bearing on tariff rates in the U.S. given the various motives for trade protection. Conventional wisdom suggests that stricter environmental regulation imposes significant additional costs and hinders the ability of U.S. firms to compete in international markets (Jaffe et al. 1995). This loss of competitiveness affects pollution-intensive industries disproportionately and may be reflected by declining exports, increasing imports, and possible relocation of these industries to areas with less stringent regulations. Previous empirical studies that examine the effects of environmental regulation on trade flows (e.g., see Tobey, 1990; Grossman and Krueger, 1995; and Low and Yeats, 1992) find little evidence that more stringent environmental regulations result in higher levels of import penetration.[98] Where these studies assume environmental regulation is exogenously determined, Ederington and Minier (2003) treat the level of environmental regulation and the level of import penetration as endogenous variables. They find that environmental policy has a much stronger impact on net import levels than previous studies reported. None of the papers referenced above has focused on the link between environmental regulation and trade policy using a U.S. environmental policy

[96] See for example Grossman and Helpman (1994), Goldberg and Maggi (1999), and Maggi and Rodriguez-Clare (2007).

[97] See for example Copeland (1990), Ludema and Wooton (1994), Copeland (2000), and Horn (2006).

[98] Again, the argument put forth is that stricter environmental laws reduce domestic firms competitiveness resulting in more imports relative to total output.

experiment.[99]

In this paper I analyze the impact of the last major change in U.S. environmental law, the Clean Air Act Amendments (CAAA) of 1990, on tariffs of 390 industries during the 1989-2002 period. There are several candidate explanations for why tariffs may respond to tighter environmental regulation as alluded to above. First, if *less footloose*, pollution-intensive industries have strong lobbies, the U.S. government has an incentive to compensate them for stricter environmental regulation by raising tariffs in those sectors, thereby reducing foreign competition in the domestic market.[100] Alternatively, it could be that the increasing demand for clean air in the U.S. prompts the government to first implement tighter environmental laws and then raise tariffs in pollution-intensive sectors to reduce both domestic and foreign air pollution. Lastly, the U.S. could potentially benefit from tightening domestic environmental policy and raising unilateral tariffs prior to major revisions of trade agreements, in this case the formation of the World Trade Organization (WTO) in 1995.[101]

This paper shows that the 1990 CAAA decreases tariffs disproportionately less in pollution-intensive industries between 1989 and 2002. This result holds in both a panel and an event-study analyses of U.S. industries with varying pollution intensities, and after having controlled for the level of imports, number of workers, and value added. Moreover, I obtain the same result when I restrict the sample to the 1989-1994 period prior to the creation of the WTO in 1995 and when I exclude Canada and Mexico from the sample due to the North American Free Trade Agreement (NAFTA) in 1994. Finally, I find the effect of the 1990 CAAA and pollution-intensity on tariffs to be strongest for pollutants that principally affect urban air and create acid rain, such as nitrogen dioxide (NO2), sulphur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM-10).[102] This may reflect political economy concerns as industries which emit relatively large amounts of these pollutants, such as the cement, petroleum and coal industries, may also have strong incentives to influence trade policy.

The 1990 Clean Air Act Amendment is interesting to study in this context for two main reasons. *First*, the CAAA policy experiment is clearly defined. The stated goal was to reduce air pollution emissions in

[99] Trefler (2004) uses the Canada-U.S. Free Trade Agreement to examine the impact of FTA-mandated tariff cuts on employment, labor productivity, import prices, and output while Manova (2008) uses equity market liberalizations to explain export behavior across 91 countries. Grossman and Krueger (1992) examine the likely environmental impacts of the North American Free Trade Agreement.

[100] Ederington, Levinson, and Minier (2005) find that industries with the largest pollution abatement costs also happen to be the least geographically mobile, or footloose.

[101] This could be as a result of the strategic nature of the policy game, as in Soumonni (2011) who finds that when noncooperative pollution taxes are chosen before entering into a trade agreement, the resulting trade and environmental policies are efficient.

[102] According to the Environmental Protection Agency (EPA), acid rain occurs when sulfur dioxide and nitrogen oxide emissions are transformed in the atmosphere and return to the earth in rain, fog or snow. Urban air pollution sources include automobile emissions, petroleum refineries, chemical plants, and combustion of fuel for transportation, utilities, and industries while acid rain occurs mostly from the burning of fossil fuels by electric utilites. http://epa.gov/oar/caa/caaa-overview.html

the United States. In addition, three major threats to the nation's environment and to the health of citizens were targeted: acid rain, urban air pollution, and toxic air emissions.[103] The 1990 CAAA's main focus was on domestic-related issues and did not explicitly include trade reform as part of the package.[104]

Second, given that the health of American residents was a major concern, enforcement of the 1990 CAAA was strictest on mobile sources of urban air pollution and acid rain where prompt compliance was mandated.[105] My study is able to capture this by using measures of pollution emissions that affect urban air pollution the most, create acid rain and also come primarily from industrial and agricultural sources: NO2, SO2, CO, and PM-10.

Using the 1990 CAAA as a policy experiment, the main objective in this paper is to determine the responsiveness of tariffs when environmental laws become more stringent. This is in contrast to Ederington and Minier (2003) who are concerned with the impact of environmental regulation on trade flows.[106] In the next section, I briefly describe the U.S. Clean Air Act Amendments of 1990. I discuss the data and provide some descriptive statistics in Section 3. Section 4 presents the empirical framework and results for the panel estimation and event study analysis. In Section 5, I explore how the impact of the 1990 CAAA and pollution-intensity on tariffs varies with simultaneous trade agreements. Endogeneity considerations are discussed in Section 6. Section 7 concludes.

US Clean Air Act Amendments of 1990

On November 15, 1990, President Bush signed a bill into law that significantly revised the Clean Air Act of 1970. Prior to the 1990 Amendments, the EPA regulated air toxics one chemical at a time.[107] This approach proved unsatisfactory as the 1990 CAAA established new regulatory programs for the control of acid rain, urban air pollution and the reduction of 187 toxic air pollutants. The new law also introduced an operating permits program to ensure compliance and enhance enforcement of the Act. The EPA was responsible for identifying categories of industrial sources of the listed air pollutants and set regulations using a technology-based or performance based approach to achieve emission reductions.[108]

[103] http://epa.gov/oar/caa/caaa-overview.html

[104] The Act contained provisions to provide additional unemployment benefits to workers laid off as a consequence of compliance with the Clean Air Act and pledged funds to continue the federal acid rain research program. http://epa.gov/oar/caa/caaa-overview.html. Furthermore, the 1990 CAAA did not seem to have been implemented as a response to shocks in the business cycle that could also influence trade policy. From the data I examine the log of GDP per capita in the U.S. over time and find that in the years leading up to the 1990 CAAA, GDP per capita was increasing in the average industry.

[105] http://epa.gov/oar/caa/caaa-overview.html

[106] This paper also differs from Ederington and Minier (2003) in that: (1) I conduct an event study of a major change in U.S. environmental regulation; (2) The panel estimation is done in light of the 1990 CAAA where the coefficient of interest reflects the impact of pollution intensity before and after the new law. Ederington and Minier (2003) use pollution abatement costs as a proxy for environmental policy.

[107] http://www.epa.gov/air/peg/toxics.html

[108] http://www.epa.gov/air/peg/toxics.html

The CAAA are divided into *titles* where the first seven involve direct regulation.[109] The remaining titles are revisions that establish a compensation, retraining, and relocation program to assist workers laid off due to compliance with the Act and provisions relating to research, development and air monitoring.[110]

A major component of the 1990 CAAA was the control of air toxins and acid deposition covered in Titles III and IV. Aside from targeting 187 toxic air pollutants, the Act also required the EPA to publish a list of source categories that emit certain levels of the listed pollutants within one year after the new law. Furthermore, the EPA had to issue standards that must be met based on best demonstrated control technology within two years of passage of the new law. Also, the 1990 CAAA included specific requirements for reducing emissions of nitrogen that had to be issued no later than mid-1992 for certain boilers. Title VI, which focuses on Stratospheric Ozone and Global Climate Protection, requires complete phaseout of Chlorofluorocarbons (CFCs) and Halons, and the 1990 CAAA banned certain chemicals listed as Class 1 chemicals within 2 years of enactment. In sum, compliance requirements and enforcement of the Act began as early as one year after it was signed into law and some industrial boilers had only two years to reduce nitrogen emissions by a precise amount. As such, I would expect to see an impact of the 1990 CAAA on tariffs roughly two to three years after the bill was signed.

Data

To analyze the impact of the 1990 Clean Air Act Amendment on tariffs, I combine U.S. manufacturing trade data by industry and U.S. pollution-intensity by sector. In this section, I describe the data used and present some empirical patterns.

U.S. Industry Tariff and Trade Data

I obtain data on duties charged and on the customs value of imports at the 4-digit SIC level from Schott's 2010 NBER U.S. Manufacturing Database for 1972 to 2005. Schott (2010) gathers Feenstra's (1996) U.S. trade data for the period 1972 to 1988, which are country by year by 4-digit, 1972-revision SIC industry and converts them to their 1987-version counterparts using concordance tables provided by Bartelsman, Becker and Gray (2000). For the period 1989 to 2005, Schott (2010) purchases 10-digit HS by country by year trade data from the U.S. Census Bureau and uses the concordances provided by Pierce and Schott (2009) to obtain their SIC equivalents. To the trade data I add 1972 to 2005 4-digit 1987-SIC total value added, value of shipments and employment data from the NBER-CES Manufacturing Industry Database

[109] A summary of the titles can be found in the appendix.
[110] http://epa.gov/oar/caa/caaa-overview.html

constructed by Becker and Gray (2009). I then summed the customs value of imports and duties paid by industry across trading partners and calculated the average tariff rate in each industry as the proportion of duties paid in total imports.[111]

U.S. Industry Pollution Intensity Data

I obtain data on pollution intensity for the manufacturing sector from the World Bank's Industrial Pollution Projection System (IPPS). Constructed in 1987, the data covers 448 sectors and fourteen different emission coefficients that include six air pollutants, two measures of water pollution, and toxic and metal releases to air, water, and land (Hettige et al. 1995).The IPPS data was assembled by matching US Census of Manufactures facility-level data to the Aerometric Information Retrieval System (AIRS) for air pollutants, the National Pollution Discharge Elimination System for water pollution and the Toxics Release Inventory (TRI) for toxic chemicals and metals (Levinson 2010).[112] Because not every facility in the Census reports to the environmental databases, the IPPS creates a lower bound coefficient of emission intensity: total reported emissions divided by total economic activity for each industry that includes all facilities even those that do not appear in both datasets. I use this lower bound pollution intensity coefficient (in metric tons) with respect to value added for each pollutant focusing on the major urban air and acid rain pollutants: NO2, SO2, CO, and PM-10. I also sum across the six air pollutants to obtain a measure of total air pollution intensity at the industry level.[113]

Summary Statistics

I examine the effect of pollution intensity and the 1990 CAAA on tariffs using industry-level data between 1989-2002. Table 1 presents the mean and standard deviation of tariffs, total pollution intensity and pollution intensity by pollutant, and the log of imports, employment, and value added. The tariff rate in the average industry is 3% with the dairy products and tobacco sector having the largest tariff rates (over 50%).[114]

The pollution-intensity variable varies slightly across pollutants with CO having the highest mean

[111]Ederington and Minier (2003) also calculate tariffs by dividing duties by import volume to give a measure of average ad valorem tariffs for each industry. The tariff data in this paper is only available from 1989 onwards.

[112]The six air pollutants in the IPPS are: carbon monoxide (CO), sulphur dioxide (SO2), nitrogen dioxide (NO2), particulate matter (PM-10), volatile organic compounds (VOC), and fine particulates (PT).

[113]Weber and Matthews (2007) in their study of pollution imports use NO, SO2, and CO2 as measures of pollution while Khan (2003) calculates the pollution content of an industry by summing total carcinogenic toxic releases from the TRI database.

[114]The U.S. Department of Agriculture (USDA) reports that tariffs on dairy products are well above the overall average agricultural tariff level and are among the highest of all commodities. Also, Gibson et al. (2001) find dairy tariffs average about 85%, only surpassed by unmanufactured tobacco at 90%.

Table 1: Summary Statistics: 1989-2002

	4-digit SIC U.S. Manufacturing Data				
Variable	Obs.	Mean	Std. dev.	Min	Max
Tariff	5552	3.313	4.240	0	100
Log of Imports	5552	2.061	1.492	-5.932	7.776
Log of Employment	6373	3.010	1.099	-0.693	6.321
Log of Value Added	6373	7.447	1.229	3.242	11.314
Total Pollution Intensity	6272	0.011	0.037	0	0.357
Carbon Monoxide	6272	0.0027	0.014	0	0.169
Sulphur Dioxide	6272	0.0026	0.011	0	0.140
Nitrogen Dioxide	6272	0.0016	0.006	0	0.052
Particulates	6272	0.0016	0.008	0	0.136
Volatile Organic Compounds	6272	0.0014	0.005	0	0.087
Fine Particulates	6272	0.0008	0.006	0	0.092

Notes: Standard deviations are in parentheses. Imports and Value Added are in millions of USD and employment is in 1000s.

and standard deviation. The two industries with the largest CO content are primary aluminium and steel springs while those with the largest NO2 emissions intensity are nitrogenous fertilizers and cement. The petroleum and coal products sector are the largest emitters of SO2.[115] When considering total pollution-intensity, I find the limestone industry to be the most pollution-intensive with 0.357 metric tons being polluted per unit of value added.

Figure 1 shows that tariff rates are decreasing in the years following the Act. In fact, the visual evidence suggests a declining trend in the level of U.S. tariffs overall and an even lower decline in tariffs after the 1994-1995 period. This is not surprising given that with NAFTA and the WTO came further rounds of trade liberalization.[116] The tariff reductions in the first five years reflect in part the U.S. free trade agreements with Israel (1985) and Canada (1989).[117]

Table 2 highlights tariff rates before and after the 1990 CAAA for two pollution-intensive industries (limestone and primary aluminium), non-polluting industries (diagnostic substances, and carpets and rugs), and one industry at the mean pollution-intensity level (creamery butter). From Table 2 notice that the tariff level in the most pollution-intensive industry, the limestone industry, rises on average in the years following the 1990 CAAA as does the industry with one of the highest tariff rates, the creamery butter industry.[118]

To get an idea of the relationship between tariffs and pollution intensity before and after the 1990 CAAA, I divide industries by total pollution intensity where sectors above the median pollution coefficient

[115] These industries also emit large amounts of NO2.

[116] NAFTA is the North American Free Trade Agreement signed between the U.S., Canada and Mexico in 1994.

[117] Bilateral liberalization of agricultural trade between the U.S. and Israel was still of concern in the 1990s as both countries were reluctant to remove barriers for agricultural products. http://www.ustr.gov/trade-agreements/free-trade-agreements/israel-fta

[118] Boilers are one of the major equipments used in the creamery butter industry and burn natural gas, coal, wood, oil, or other fuel to produce steam. http://www.epa.gov/airquality/combustion/index.html

Figure 1: Average US Tariff Rates over Time

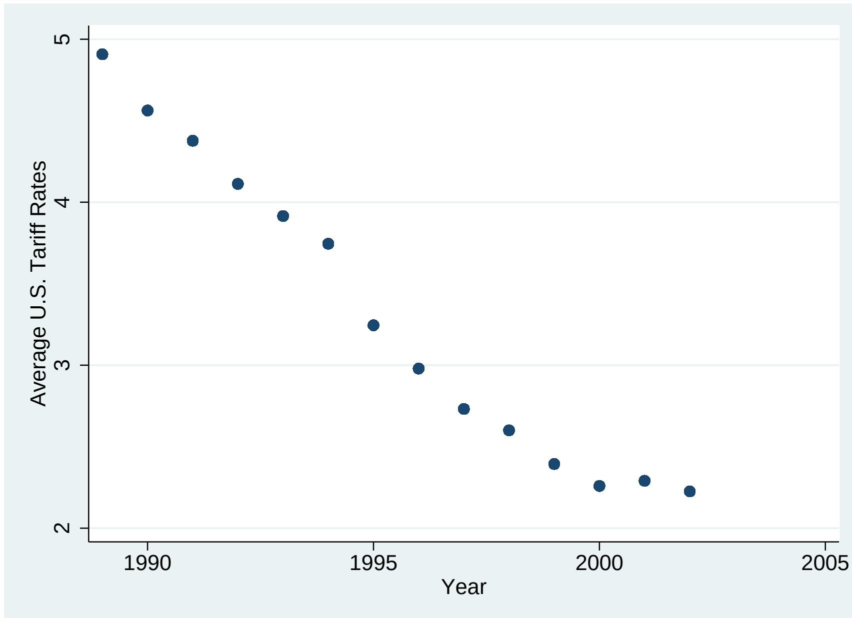

Table 2: Summary Statistics by Industry: 1989-1990 and 1991-2002

	Pre-Act Period		Post-Act Period	
Lime	0.010	(0.005)	0.146	(0.120)
Primary Aluminium	0.001	(0.0003)	0.009	(0.024)
Creamery Butter	3.650	(0.832)	13.910	(17.729)
Diagnostic Substances	5.650	(1.418)	2.140	(2.472)
Carpets and Rugs	6.436	(0.019)	4.589	(1.270)

Notes: Standard deviations are in parentheses.

Table 3: Summary Statistics by Pollution Intensity Category

	Pre-Act (1989-1990)		Post-Act (1991-1995)		Post-Act (1996-2002)	
Pollution-Intensive	3.992	(6.049)	3.140	(3.371)	1.985	(3.390)
Non Pollution-Intensive	5.487	(5.265)	4.630	(4.491)	2.860	(3.943)

Notes: Standard deviations are in parentheses.

take a value of 1 and are considered pollution-intensive while the other sectors take a value of 0 and are non-polluting. Table 3 shows the tariff rates before and after the Act for pollution-intensive and non-pollution intensive industries. It is clear that tariffs are declining over time across both groups. However, in pollution-intensive industries, tariff rates decrease more slowly relative to non-polluting sectors. To be specific, between the last two post-Act periods, tariff rates declined in non-polluting industries by about 1.77 while in pollution-intensive industries the decline was only about 1.16 percent. The same pattern is observed for the pre-Act and post-Act periods.[119] The description in Tables 2-3 suggest that import tariffs in pollution-intensive industries are higher relative to non-polluting sectors after a tightening of environmental policy. However, it could be that pollution-intensive industries already have low tariffs to begin with. Thus, we might not observe as large a decline in tariffs in those industries as we would in non-polluting industries. As such, any correlation between pollution-intensity and tariffs before and after the 1990 CAAA may be completely spurious. The goal of the two empirical estimation approaches taken in the following section is to establish a causal relationship between pollution-intensity and tariff rates in the 1989-2002 period.

Empirical Framework

The main objective of this paper is to compare tariff levels by pollution intensity at the industry level. This paper uses an estimation strategy that is in the spirit of Manova (2008) and Trefler (2004). I conduct both panel and event-study analyses of tariffs in industries with varying pollution intensities before and after the 1990 Clean Air Act Amendment.

Panel Study Empirical Specification

Following Manova (2008), I use a difference-in-difference methodology to estimate the effect of more stringent environmental regulations on trade policy across industries. The estimating equation follows

[119] It is important to point out that over the entire sample period the percentage decline in tariff rates was only about 2.68. In the Appendix, I present Table 3 by pollutant.

from the first-order conditions of the non-cooperative policy game in the theoretical model of Soumonni (2011). The base model is:

$$\tau_{it} = \alpha_0 + \alpha_1 EnvReg_t + \alpha_2 EnvReg_t \times Pollute_i + \alpha_3 Imports_{it} + \rho_i + \eta_t + \xi_{it} \tag{1}$$

where τ_{it} is the tariff rate of industry i in year t, $EnvReg_t$ is a binary variable that takes the value of 1 in the years following the November 1990 Clean Air Act Amendment and 0 otherwise, $Pollute_i$ is the pollution intensity in sector i given 1987 technology, and $Imports_{it}$ is the customs value of general imports in industry i at time t. In equation (1), the coefficient of interest is α_2 with an expected positive sign. This implies that tariff levels decrease relatively less in sectors with higher pollution intensities with stricter environmental laws .

I allow for industry and year fixed effects, and cluster errors by industry.[120] The variable $Pollute_i$ is not estimated separately because its effect is included in the industry fixed effects that also capture other industry-specific omitted characteristics. The main effect of stricter environmental laws, α_1, does not vary by industry and accounts for changes in the regulatory environment before and after the 1990 CAAA, while the time fixed effects picks up any trend in tariff rates.[121] Identification of α_2 comes from within-industry variation in pollution-intensity over time. This coefficient thus estimates how much more pollution-intensive industries are affected by tighter environmental regulations in the years following the Act relative to less pollution-intensive industries.

Panel Regression Results

The regression results from the basic model in (1) are presented in Table 4. I estimate this specification in the full panel of tariffs for 390 industries in the 1989-2002 period. The first model (I) in Table 4 shows the impact of environmental regulation on tariffs while ignoring the interaction term with industry pollution intensity while the second model (II) considers this interaction term. I find a significant negative effect of the 1990 CAAA, which suggests that in periods following more stringent environmental regulations, tariff rates in the US tend to be lower in the average industry. This may be as a result of past GATT rounds of trade negotiations that induced the U.S. to reduce tariffs on most manufactured goods imports over

[120]Results of the coefficient of interest are unchanged with or without year fixed effects and clustered standard errors.

[121]Although the 1990 Clean Air Act Amendment was a national act, stringency of the law affected industries differently depending on their production processes and enforcement occurred gradually over time for various industries. http://epa.gov/oar/caa/caaa-overview.html

Table 4: Effects of the 1990 Clean Air Act Amendment on Tariffs:Panel Study

	I		II		III	
EnvReg	-0.512	(0.254)	-2.135	(0.207)	-2.174	(0.262)
$EnvReg \times Pollute$			5.269	(1.212)	5.447	(1.249)
Log of Imports	-0.460	(0.237)	-0.395	(0.238)	-0.424	(0.243)
Log of Employment					0.361	(0.384)
Log of Value Added					0.227	(0.339)
Obs.	5552		5397		5344	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-2002.

time. However, the WTO notes that loopholes in the GATT system were heavily exploited particularly in agriculture.[122] Also, the Congressional Budget Office (CBO) points out that prior to the Uruguay Round, the U.S. maintained trade protection in the agriculture, high-technology goods, and mature industries.[123] Given that some of these industries are also pollution-intensive, interacting the environmental regulation dummy with pollution intensity might offer additional insight as to why protection increased in some industries relative to others between 1989-2002. The coefficient of interest, α_2, is positive and significant, suggesting that tariff rates fell more slowly in pollution-intensive industries following tighter air pollution control laws. More specifically, model (II) implies that for industries with pollution intensity in the 90th percentile, stricter environmental laws decrease tariff rates by about 0.11 percentage points less than in the 10th-percentile pollution-intensive industry. This effect is not trivial considering that the average tariff rate did not change by much during the entire period. Between 1989-2002, the average annual decrease in tariffs was about 0.19% per year. The results suggest that the interaction term between environmental regulation and pollution intensity accounts for approximately 3% of the variation in tariff levels. Also, the estimates presented in Table 4 hold after controlling for the customs value of imports, total employment, and total value added at the industry level as shown in the third model (III).

I proceed to estimating specification (1) using the air pollutants that predominantly affect urban air and create acid rain. Table 5 highlights the results for carbon monoxide, nitrogen dioxide, sulphur dioxide, and particulates.[124] As in Table 4, α_2, is positive and significant for all four pollutants. All else equal, given two industries with comparable employee size, value added, and imports, the industry with larger emissions of one of the four pollutants will have tariff rates decline more slowly on average. NO2 has the biggest effect where tariff rates decrease by about 0.06 percentage points less for the average NO2

[122] For details see "Understanding the WTO-The GATT years: from Havana to Marrakesh". http://www.wto.org

[123] Mature industries according to the CBO include steel, textiles, apparel, and automobiles. http://www.cbo.gov/ftpdocs/62xx/doc6202/doc09b-Entire.pdf

[124] The estimation results when all pollutants are included in (1) appear in the Appendix.

Table 5: Effects of the 1990 Clean Air Act Amendment on Tariffs By Pollutant:Panel Study

	CO		SO2		NO2		PM-10	
EnvReg	-2.132	(0.258)	-2.145	(0.259)	-2.182	(0.271)	-2.106	(0.257)
$EnvReg \times Pollute$	9.623	(3.793)	14.261	(4.856)	41.418	(10.194)	16.187	(2.842)
Log of Imports	-0.429	(0.243)	-0.426	(0.243)	-0.422	(0.244)	-0.429	(0.243)
Log of Employment	0.370	(0.384)	0.365	(0.384)	0.370	(0.386)	0.386	(0.385)
Log of Value Added	0.224	(0.340)	0.221	(0.339)	0.219	(0.341)	0.194	(0.340)
Obs.	5344		5344		5344		5344	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100*(duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-2002.

pollution-intensive industry in the years after the CAAA.[125] One potential reason for this is that the largest emitters of NO2 (agricultural chemicals, cement, petroleum refining, lime, and pulp mills industries) are those that are well-organized with potentially significant campaign contributions.[126] The government therefore has a strong incentive to raise tariff levels in those industries after setting stricter environmental laws.

The specifications in Tables 4-5 in particular exploit the differences in tariff rates across roughly 400 industries that were affected differently by the 1990 Clean Air Act Amendments. Ideally, obtaining information on the exact enforcement dates by industry and determining the particular industries that received exemptions or extensions would allow for potentially stronger identification of α_2.[127] The approach presented in this section exploits mostly the across-industry variation in pollution intensity while taking into account the differential impact of enforcement before and after the Act.[128]

In sum, the results from this panel analysis support the hypothesis that trade policies respond to changes in environmental regulations and to the 1990 Clean Air Act Amendment in particular. However, consistency of the results from (1) in Tables 4-5 and interpreting them as causal hinge on the critical assumption that imports and environmental policy reform are determined exogenously and not influenced by other factors that also have some bearing on trade policy. Given that the time-invariant data on pollution intensity was constructed in 1987 and pre-dates the 1990 CAAA, I am able to circumvent endogeneity of pollution emission concerns and treat the level of pollution-intensity as exogenously determined. I defer

[125] NO2 remains the most significant in the single regression with all pollutants included.

[126] Groups such as the National Association of Manufacturers (NAM) and the American Petroleum Institute (API) have loudly protested the EPAs decision to have greenhouse gas emissions regulated under the Clean Air Act. API members include Chevron, ConocoPhillips,Exxon Mobil, GE, Halliburton and Shell. http://www.sourcewatch.org

[127] Future work includes finding and collecting this policy information, and re-estimating equation (1) where the environmental regulation dummy would vary by industry and time.

[128] Note that I consider 1990 a pre-Act year given that the law was signed in November. As such, the implicit assumption here is that enforcement of the Act occurred as of 1991 and affected all industries equally. The event study in subsection 4.3 examines the change in tariffs for different time horizons but still under the premise that enforcement applied to all industries at the same time. The process of gathering industry-specific information on enforcement and compliance dates which would allow me to relax the latter assumption is currently underway.

other issues of endogeneity bias to Section 6 below.

Event Study Empirical Specification

In this section, I consider an alternate approach to the fixed effects panel estimation in (1). More specifically, similar to Manova (2008) and Trefler (2004), I will account for the possibility of unobserved systematic difference across industries at the time of the CAAA using an event study approach.[129] The estimates from differencing the variables in (1) before and after the change in environmental policy may still be recovered when I estimate the following specification:

$$\Delta\tau_{it} = \tau_{i1} - \tau_{i0} = \alpha_1 \Delta EnvReg_t + \alpha_2 \Delta EnvReg_t \times Pollute_i + \alpha_3 \Delta Imports_{it} + \Delta\xi_{it} \tag{2}$$

where t=1 (t=0)in the years after (before) the 1990 CAAA. Notice that the constant term, α_0, and the industry fixed effects, ρ_i, have dropped out of the regression equation, providing clean estimates of a causal impact of stricter environmental laws on tariffs. Since the environmental regulation measure used is a dummy taking the value of 1 in periods after 1990 and 0 otherwise where $\Delta EnvReg_t = EnvReg_1 - EnvReg_0 = 1 - 0 = 1$, then (2) reduces to:

$$\Delta\tau_{it} = \alpha_1 + \alpha_2 Pollute_i + \alpha_3 \Delta Imports_{it} + \Delta\xi_{it} \tag{3}$$

In specification (3), the environmental regulation dummy no longer enters the regression directly as shown above, where α_1 represents the new period intercept and captures the effect of tightening air pollution policies on tariff levels. The coefficient on pollution intensity, α_2, estimates the differential impact of the 1990 CAAA across sectors.

In this event analysis, the change in tariffs around the 1990 CAAA is the only observation for each industry. Given that 1989 is the earliest year I observe tariff data for, I first measure $\Delta\tau_{it}$ as the difference in average tariff rates between 1989 and a range of time periods. In essence, I take the difference of average tariffs for the pre-CAAA years 1989-1990 and post-CAAA years 1992-1993 which I compare with other post-CAAA years up to ten years after the Act.[130]

[129] Manova (2008) and Trefler (2004) use first-differencing, which I employ in this section as well.

[130] Recall that since the 1990 CAAA was not signed until November of that year, I consider 1990 a pre-Act year in the estimation and treat 1991 as the effective event year.

Table 6: 1990 Clean Air Act Amendment Event Study Results

	$\tau_{92,93} - \tau_{89,90}$		$\tau_{93,94} - \tau_{89,90}$		$\tau_{94,95} - \tau_{89,90}$		$\tau_{95,96} - \tau_{89,90}$	
$EnvReg \times Pollute$	2.419	(0.871)	3.366	(0.885)	3.828	(1.469)	5.177	(1.549)
$EnvReg \times PolluteCO$	5.839	(2.417)	7.777	(2.368)	6.870	(4.536)	10.074	(4.822)
$EnvReg \times PolluteSO2$	6.418	(3.622)	9.311	(3.791)	9.716	(5.332)	12.620	(5.720)
$EnvReg \times PolluteNO2$	11.688	(6.466)	16.665	(5.603)	25.317	(7.061)	32.910	(8.487)
$EnvReg \times PollutePM10$	6.902	(1.943)	9.356	(2.633)	11.986	(4.384)	15.999	(5.264)
Obs.	386		386		384		383	

	$\tau_{96,97} - \tau_{89,90}$		$\tau_{97,98} - \tau_{89,90}$		$\tau_{98,99} - \tau_{89,90}$		$\tau_{99,00} - \tau_{89,90}$	
$EnvReg \times Pollute$	6.370	(1.450)	7.278	(1.706)	7.515	(1.844)	7.087	(1.895)
$EnvReg \times PolluteCO$	12.380	(4.607)	11.424	(5.373)	10.121	(5.609)	10.036	(5.814)
$EnvReg \times PolluteSO2$	16.422	(5.769)	17.945	(6.633)	18.675	(7.135)	18.618	(7.258)
$EnvReg \times PolluteNO2$	42.508	(9.823)	62.376	(18.921)	70.623	(23.895)	58.576	(13.213)
$EnvReg \times PollutePM10$	18.736	(3.557)	23.358	(4.360)	26.395	(5.166)	25.831	(6.032)
Obs.	382		375		374		374	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level.

Event Study Results

The estimation results for all pollutants are presented in Table 6. The top panel shows the effect of the interaction between pollution intensity and the 1990 CAAA on tariffs before and after the Act through 1996 while the bottom panel considers the post-CAAA years from 1996 to 2000. I find that as early as two years after the Act, average tariff rates declined at a lower rate with total pollution intensity, suggesting a relatively rapid response of trade policy to stricter environmental regulation. All the measures of pollution intensity are positive and significant for most of the years except in 1992-1993 where NO2 and SO2 are positive but not significant at conventional levels. This is mostly as a result of Title IV of the 1990 CAAA that allows reductions of sulfur dioxide for some plants to occur in phases with slightly later deadlines than other toxic air pollutants.[131] Furthermore, as Table 6 illustrates, the coefficients seem to be growing over time. One reason for this is that part of the 1990 CAAA was to make standards and enforcement stricter over time. As such, if the more affected, pollution-intensive industries seek trade protection after an increase in the stringency of environmental laws, we might expect to see the level of trade protection rise as enforcement gets tougher or certain exceptions are phased out. As before, this effect is largest for NO2 where significant emitters of NO2 are also some of the most politically connected. There seems to be a faster decrease in tariffs in the last 3 years of Table 6 reflecting certain economic events such as Congress approved tax cuts in 1998 that perhaps reduced the need for trade protection in pollution-intensive industries as well.

[131] SO2 and NO2 pollution-intensities are highly correlated and industries with large emissions in one typically have large emissions of the other as well.

Table 7: Panel Estimation Results: 1989-1994

	CO		SO2		NO2		PM-10	
EnvReg	-0.534	(0.071)	-0.535	(0.071)	-0.543	(0.074)	-0.521	(0.072)
$EnvReg \times Pollute$	4.315	(1.861)	5.083	(2.500)	12.422	(4.557)	6.007	(2.056)
Log of Imports	-0.579	(0.209)	-0.577	(0.210)	-0.578	(0.210)	-0.580	(0.210)
Log of Employment	-0.009	(0.506)	-0.020	(0.509)	-0.015	(0.514)	0.022	(0.511)
Log of Value Added	0.768	(0.409)	0.761	(0.411)	0.760	(0.421)	0.718	(0.416)
Obs.	2318		2318		2318		2318	

	Total Pollution Intensity	
EnvReg	-0.546	(0.072)
$EnvReg \times Pollute$	2.005	(0.671)
Log of Imports	-0.577	(0.209)
Log of Employment	-0.028	(0.507)
Log of Value Added	0.776	(0.410)
Obs.	2318	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-1994.

In sum, I obtain consistent evidence of a first-order effect of the 1990 CAAA and pollution intensity on tariff levels using two different empirical strategies. The panel analysis pools all industry-year observations in the 1989-2002 period and identifies the effects of tougher environmental policies from the cross-sectional and time-series variation without taking a stance on the time it takes for the change in environmental laws to affect tariff rates. The fact that the results are qualitatively the same in both approaches provides complementary evidence on the impact of pollution intensity and tighter environmental regulations on import tariffs.

Trade Agreements and Environmental Regulation Stringency

Changes in environmental laws could potentially be part of a number of domestic policy changes that may include trade reforms. In this section, I maintain that my findings are not driven by simultaneous changes in trade policy.

Anticipation of WTO formation scheduled to occur in 1995 may have had a bearing on the change in environmental regulation, also impacting the level of tariffs. To explore this possibility, I restrict the sample period to the years preceding creation of the WTO and re-estimate specification (1) for all four pollutants.[132] I continue to find a positive and significant effect of the interaction between pollution intensity and the environmental regulation dummy on tariffs for all measures of pollution intensity. I also find that the magnitude of α_2 is considerably lower in Table 7 relative to Table 5. This may be due to

[132] This would also address other policies (monetary or fiscal) that could potentially influence both tariffs and environmental regulation and occurred after 1994. In the specification with the restricted sample, I also control for imports, value added and employment.

Table 8: Panel Estimation Results without NAFTA Trade: 1989-2002

	CO		SO2		NO2		PM-10	
EnvReg	-0.105	(0.063)	-0.118	(0.063)	-0.150	(0.069)	-0.105	(0.065)
$EnvReg \times Pollute$	6.941	(2.719)	11.983	(4.864)	36.577	(11.836)	21.846	(7.476)
Log of Imports	-0.258	(0.239)	-0.259	(0.238)	-0.260	(0.238)	-0.264	(0.239)
Log of Employment	0.089	(0.372)	0.082	(0.372)	0.085	(0.376)	0.099	(0.373)
Log of Value Added	0.141	(0.384)	0.142	(0.382)	0.143	(0.387)	0.117	(0.383)
Obs.	5333		5333		5333		5333	

	Total Pollution Intensity	
EnvReg	-0.144	(0.063)
$EnvReg \times Pollute$	5.055	(1.212)
Log of Imports	-0.262	(0.238)
Log of Employment	0.076	(0.373)
Log of Value Added	0.152	(0.383)
Obs.	5333	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-2002.

fewer data points used in estimation and/or to the fact that WTO formation presented additional motives for trade protection, biasing the estimates of α_2 in Table 5. The fact that the results still hold pre-1995 suggests that the interaction of pollution-intensity and the 1990 CAAA is not correlated with creation of the WTO or other policy changes that occurred after 1994.

The North American Free Trade Agreement implemented in 1994 could also be a source of concern for a number of reasons. First, with NAFTA came an executive order by President Clinton to conduct quantitative evaluations of the environmental effects of the proposed trade agreement, suggesting that NAFTA may have been determined endogenously with domestic environmental policy that also affected tariff rates in the United States. Second, if Canada and Mexico are not exporting a significant share of pollution-intensive goods to the U.S., then the larger decline in tariffs for non-polluting goods may just be reflecting this and not truly capturing the causal effect of the 1990 CAAA.

Given that I observe tariff data by U.S. trade partner, I control for NAFTA by excluding Canada and Mexico from the sample and I re-estimate equation (1) as before. The results in Table 8 show a positive and significant effect of pollution intensity and environmental regulation on tariffs. Thus, restricting trade to non-NAFTA partners does not seem to affect my findings.[133]

I also repeat the event-study analysis (specification (3)) excluding NAFTA trade. In particular, I examine the change in average tariff rates between the pre-Act years and three years following NAFTA.[134] As the results in Table 9 demonstrate, tariff rates decline less rapidly in the more pollution-intensive

[133]To be consistent with the WTO case, I restrict the sample period from 1989-1993 and re-estimate the model with NAFTA members. The results are similar to those presented in Table 8.

[134]Increasing the number of years after NAFTA does not significantly affect the results.

Table 9: Event Study Results without NAFTA

	$\tau_{97,98} - \tau_{89,90}$	
$EnvReg \times Pollute$	7.384	(1.422)
$EnvReg \times PolluteCO$	10.793	(3.702)
$EnvReg \times PolluteSO2$	18.030	(6.635)
$EnvReg \times PolluteNO2$	56.367	(19.622)
$EnvReg \times PollutePM10$	30.500	(8.580)
Obs.	382	

Notes: Clustered standard errors are in parentheses.

industries after environmental laws become stricter *even* in the absence of concurrent trade reforms.

Endogeneity

Endogeneity remains a serious concern in the trade and environment empirical literatures. The 1990 Clean Air Act Amendments may have been influenced by unobserved factors that could possibly determine tariffs as well. Policy makers may believe that better environmental quality improves the health of workers and consumers and leads to a stronger economy, which may also potentially impact trade policy. A few pieces of evidence suggest that, while endogeneity of the environmental regulation change cannot be unquestionably ruled out, it does not appear problematic for my results.

First, to the extent that the environmental regulation was enacted at the national level and the exact timing of the CAAA was the product of complex political processes, it may be viewed as plausibly exogenous from the perspective of individual producers. Nonetheless, if more stringent environmental laws are anticipated, tariffs may fall less slowly in more pollution-intensive industries prior to the observed date in expectation of increased costs of complying with the new regulation. Thus, the estimated impact of stricter environmental regulation would be biased downwards.

Second, reports suggest that the record heat in the summer of 1988 and the Alaskan oil spill by Exxon Valdaz in 1989 may have significantly influenced the passage of the 1990 Clean Air Act Amendments after a decade-long deadlock in clean air regulation (Bryner, 1992). These factors were by and large independent of trade policy.

Lastly, the election of George Bush as president of the U.S. in November 1988 also played a key role in tightening air pollution control laws in 1990. Bryner (1992) notes that Bush effectively used environmental issues to distance himself from the Reagan administration and gain support from the Democratic leadership who traditionally favored environmental protection. It is quite likely that the election of George Bush also had a bearing on trade policy. President Bush maintained protection for the steel industry but

Table 10: IV Panel Estimation Results: 1989-2002

	CO		SO2		NO2		PM-10	
EnvReg	-2.065	(0.295)	-2.071	(0.296)	-2.111	(0.306)	-2.03	(0.295)
$EnvReg \times Pollute$	9.267	(3.576)	13.575	(4.340)	40.234	(9.797)	15.525	(2.620)
Lagged Log of Imports	-0.491	(0.284)	-0.50	(0.285)	-0.495	(0.282)	-0.506	(0.283)
Log of Employment	0.291	(0.365)	0.359	(0.381)	0.364	(0.384)	0.380	(0.382)
Log of Value Added	0.250	(0.346)	0.250	(0.345)	0.249	(0.347)	0.225	(0.345)
Obs.	5294		5294		5294		5294	

	Total Pollution Intensity	
EnvReg	-2.097	(0.299)
$EnvReg \times Pollute$	5.212	(1.113)
Lagged Log of Imports	-0.503	(0.284)
Log of Employment	0.355	(0.381)
Log of Value Added	0.258	(0.345)
Obs.	5294	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-2002.

also pushed for the North American Free Trade Agreement. The consistent results I establish without NAFTA trade suggests that the latter case is not a major concern in my analysis. The former case of political motivation for trade protection would in any case potentially underestimate the actual impact of the interaction between pollution-intensity and the 1990 CAAA on trade policy.

There is also concern that increased imports may intensify lobbying for protection and lead to higher levels of protection (see Trefler, 1993 and Ederington and Minier, 2003). As such, I follow an approach suggested by Wooldridge (2002) and deal with the potential endogeneity of imports by using the lagged value of imports as an instrument. The idea is that once current imports have been controlled for along with unobserved, time constant factors like the ability of industries to organize, imports of other years should have no effect on tariffs during the current year.[135] However, previous imports may be correlated with unobserved organizational ability and this can be solved by using lags (Wooldridge, 2002). I estimate specification (1) by two-stage least squares (2SLS) where the in the first stage I regress imports on its lag, the environmental regulation dummy, the pollution intensity interaction with the regulation as well as time and industry fixed effects. Table 10 presents the 2SLS estimation results when the endogeneity of imports is taken into account.[136] For all pollutants in Table 10, I continue to find a positive and significant impact of pollution-intensity and environmental regulation on tariffs. I conduct the Durbin-Wu-Hausman test for endogeneity of imports. In all cases I am able to reject the null hypothesis that imports are exogenous, suggesting that the Instrumental Variable (IV) approach is more appropriate. I then test the significance of my instrument and find an F statistic above 17 for all measures of pollution intensity where an F statistic

[135]This is the strict exogeneity assumption identified in Wooldridge (2002;pg 253).

[136]Results from the first stage regression are not presented here for ease of exposition but are available upon request.

Table 11: The 1990 Clean Air Act Amendments and Footloose Industries

	Tariffs	
EnvReg	-2.184	(0.263)
$EnvReg \times Pollute$	5.504	(1.510)
$EnvReg \times TransportCosts$	0.0024	(0.024)
Log of Imports	-0.422	(0.243)
Log of Employment	0.348	(0.387)
Log of Value Added	0.233	(0.340)
Obs.	5330	

Notes: Clustered standard errors are in parentheses.

over 10 is required to suggest instruments are sufficiently strong.[137]

There may also be concern that more stringent environmental regulations might lead to the offshoring of industries that can no longer remain competitive in the United States. However, if such industries have high transport costs, they may be less sensitive to changing comparative advantage or changes in production costs relative to footloose industries and will be less likely to relocate. My hypothesis is that stricter air pollution laws will have a greater effect on tariffs in industries with high transport costs. The intuition here is that a high transport-cost industry cannot freely relocate to another country in response to tighter domestic environmental regulations and will be more likely to seek trade protection.[138] Following Ederington, Levinson, and Minier (2005), I estimate the product market transportation costs for each industry using freight costs and controlling for the distance shipped.[139] I interact the estimated transport costs with the environmental regulation dummy and include the new variable in specification (1).

The results are presented in Table 11. If the above hypothesis is correct, the interaction term will have a positive coefficient, indicating that more stringent environmental regulations will result in a slower decline of tariff rates in less footloose industries. In Table 11, the interaction term is positive but not statistically different from zero. The coefficient of the interaction between pollution-intensity and the environmental regulation dummy is still positive and significant, suggesting that tariff rates fell by less in pollution-intensive industries in the years following the 1990 CAAA even after accounting for the impact of industry immobility.

[137] Results from the significance of instrument tests appear in the Appendix. Given that I have the same number of instruments as endogenous variables, the Sargan test for the validity of the instruments cannot be applied here. As an alternate instrument, I use the difference between the first and second period lag of imports and obtain results similar to those presented in Table 7. Furthermore, the gravity model of trade states that trade between a pair of countries may be determined by country size (population) and geographical variables (physical distance, language, common border) that are plausibly exogenous from trade. Thus, I use as an alternate instrument the predicted value of a gravity trade model between the U.S. and its trading partners weighted by the industry share of total imports. The results are consistent in this case as well and presented in the Appendix.

[138] Note that if these less footloose industries are also pollution-intensive, then we might expect an even larger effect of the 1990 CAAA on tariffs.

[139] The Appendix in Ederington, Levinson, and Minier (2005) provides details. The key difference here is that I use the entire sample of exporters to the U.S. between 1989-2002.

Conclusion

This paper presents evidence that the 1990 Clean Air Act Amendment was an important determinant of tariff rates in pollution-intensive industries relative to less polluting industries in the U.S. between 1989-2002. I use the variation in pollution-intensity across industries, and show that the 1990 CAAA decreased tariffs disproportionately less in pollution-intensive sectors, particularly in those that are heavy emitters of urban air and acid rain pollutants.

My results contribute to the literature on trade and the environment in two important ways. First, I make a firm case for a causal link from pollution intensity and environmental regulation to trade barriers by exploiting the 1990 CAAA and using industry variation in pollution-intensity. Second, I find larger effects of tighter air pollution controls in industries that pollute NO2 intensively such as the cement, petroleum refining, lime, and pulp mills industries. These industries are also well organized and have groups that actively promote their interests in the political process, providing some evidence in support of political economy theories of protection. Identifying the specific motives for tariff adjustments in response to stricter air pollution laws presents scope for further research.

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Appendix

U.S. Clean Air Act Amendments of 1990

- Title I: Provisions for Attainment and Maintenance of National Ambient Air Quality Standards
  - Requires the Federal government to reduce emissions from cars, trucks, buses, consumer products, and from ships and barges.
  - Clarifies assignment of *attainment* and *non-attainment* areas.
  - Gives certain states more time to meet the air quality standard.
  - Requires states to make constant progress in reducing emissions
- Title II: Provisions Relating to Mobile Sources
  - Tighter pollution standards for emissions from automobiles and trucks as of 1994 models.
  - Reduce tailpipe emissions of hydrocarbons, carbon monoxide, and nitrogen oxides.
  - Establishes a clean fuel car pilot program in California.
  - Requires standards to become stricter over time.
- Title III: Air Toxics
  - Targets 189 toxic air pollutants of which emissions must be reduced.
  - The EPA must publish a list of source categories that emit certain levels of these pollutants within one year after the new law.
  - The EPA must issue standards that must be met based on best demonstrated control technology within two years of passage of the new law.
  - Establishes a Chemical Safety Board to investigate accidental releases of chemicals.
- Title IV: Acid Deposition Control
  - Requires a permanent 10 million ton reduction in SO2 emissions from 1980 levels.
  - Allows emission reductions in phases up to January 1, 2000.
  - Establishes tradeable emissions allowance system where each source must have sufficient allowances to cover its annual emissions or face a fine.

- Includes specific requirements for reducing emissions of nitrogen that must be issued no later than mid-1992 for certain boilers.

- Title V: Permits
  - Introduces an operating permits program.
  - Each permit is valid for period of up to 5 years.
  - Any citizen may petition EPA or the Federal court of appeals if a permit violates any aspect of the Act.
- Title VI: Stratospheric Ozone and Global Climate Protection
  - Requires complete phaseout of CFCs and halons.
  - Requires the EPA to publish a list of safe and unsafe substitutes for Class I and II chemicals and to ban the use of unsafe substitutes.
  - Requires Class I chemicals be banned within 2 years of enactment.
  - Implements ban for aerosols and non-insulating foams using Class II chemicals effective in 1994.
- Title VII: Provisions Relating to Enforcement
  - EPA may issue administrative penalty orders up to 200,000 U.S.D.
  - Criminal penalties for knowing violations are upgraded from misdemeanors to felonies.
  - Sources must certify their compliance.
  - EPA may issue administrative subpoenas for compliance data.
  - Allows citizens to seek penalties against violators.

Summary Statistics and Estimation

The summary statistics tables replicate Table 4 in the main text by pollutant. For the four main pollutants considered, I present the average tariff rate in the periods before and after the 1990 CAAA. As in Table 4, tariffs are declining over time but less so for pollution-intensive industries relative to the non-polluting industries.

I estimate the specification in (1) with all the pollutants included in the regression to determine which pollutant most strongly influences tariffs at the industry level. From Table A1, I find that NO2 is positive

Summary Statistics: NO2

	Pre-Act (1989-1990)		Post-Act (1991-1995)		Post-Act (1996-2002)	
Pollution-Intensive	3.922	(5.961)	3.088	(3.188)	1.985	(3.304)
Non Pollution-Intensive	5.550	(5.349)	4.674	(4.602)	2.856	(4.015)

Summary Statistics: SO2

	Pre-Act (1989-1990)		Post-Act (1991-1995)		Post-Act (1996-2002)	
Pollution-Intensive	4.175	(6.039)	3.297	(3.445)	2.097	(3.399)
Non Pollution-Intensive	5.343	(5.289)	4.511	(4.509)	2.768	(3.974)

Summary Statistics: CO

	Pre-Act (1989-1990)		Post-Act (1991-1995)		Post-Act (1996-2002)	
Pollution-Intensive	4.035	(6.051)	3.199	(3.416)	1.940	(2.736)
Non Pollution-Intensive	5.458	(5.264)	4.578	(4.480)	2.910	(4.430)

Summary Statistics: PM10

	Pre-Act (1989-1990)		Post-Act (1991-1995)		Post-Act (1996-2002)	
Pollution-Intensive	3.983	(6.534)	3.114	(3.358)	1.863	(2.749)
Non Pollution-Intensive	5.236	(5.047)	4.386	(4.355)	2.782	(4.171)

Notes: Standard deviations are in parentheses.

A1: Effects of the 1990 Clean Air Act Amendment on Tariffs

EnvReg	-2.433	(0.173)
$EnvReg \times PolluteNO2$	43.412	(21.162)
$EnvReg \times PolluteSO2$	-3.311	(6.853)
$EnvReg \times PolluteCO$	4.678	(3.442)
$EnvReg \times PollutePM10$	-7.839	(8.962)
$EnvReg \times PollutePT$	5.415	(10.449)
$EnvReg \times PolluteVOC$	5.610	(5.610)
Log of Imports	-0.0039	(0.006)
Log of Employment	0.396	(0.395)
Log of Value Added	0.073	(0.374)
Obs.	5324	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-2002.

Validity Tests for IV Panel Estimation Results:1989-2002

	Endogeneity (F-Stat)	Significance of IV (F-Stat)
EnvReg	0.172	102.761
$EnvReg \times PolluteNO2$	0.157	102.282
$EnvReg \times PolluteSO2$	0.155	102.622
$EnvReg \times PolluteCO$	0.117	101.557
$EnvReg \times PollutePM10$	0.170	103.684

Table 12: Gravity Model IV Panel Estimation Results: 1989-2002

	CO		SO2		NO2		PM-10	
EnvReg	-2.204	(0.765)	-2.209	(0.769)	-2.236	(0.777)	-2.175	(0.760)
$EnvReg \times Pollute$	9.809	(4.107)	14.643	(6.198)	42.013	(14.002)	16.615	(4.760)
Log of Imports	-0.319	(0.284)	-0.330	(1.077)	-0.340	(1.073)	-0.325	(1.080)
Log of Employment	0.374	(0.371)	0.368	(0.372)	0.373	(0.372)	0.390	(0.371)
Log of Value Added	0.185	(0.416)	0.188	(0.413)	0.190	(0.413)	0.156	(0.418)
Obs.	5344		5344		5344		5344	

	Total Pollution Intensity	
EnvReg	-2.216	(0.768)
$EnvReg \times Pollute$	5.521	(1.715)
Log of Imports	-0.361	(1.069)
Log of Employment	0.363	(0.371)
Log of Value Added	0.205	(0.410)
Obs.	5344	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-2002.

Table 13: Two Period Lagged Imports IV Panel Estimation Results

	CO		SO2		NO2		PM-10	
EnvReg	-2.081	(0.260)	-2.112	(0.261)	-2.141	(0.270)	-2.073	(0.256)
$EnvReg \times Pollute$	9.052	(3.896)	15.023	(5.383)	39.807	(10.012)	15.507	(2.921)
Log of Imports	-0.465	(0.281)	-0.438	(0.281)	-0.445	(0.276)	-0.442	(0.277)
Log of Employment	0.359	(0.383)	0.355	(0.383)	0.360	(0.385)	0.373	(0.384)
Log of Value Added	0.248	(0.361)	0.236	(0.360)	0.238	(0.361)	0.211	(0.361)
Obs.	5244		5244		5244		5244	

	Total Pollution Intensity	
EnvReg	-2.136	(0.263)
$EnvReg \times Pollute$	5.279	(1.304)
Log of Imports	-0.441	(0.280)
Log of Employment	0.351	(0.383)
Log of Value Added	0.244	(0.360)
Obs.	5244	

Notes: Clustered standard errors are in parentheses. The dependent variable is the average tariff level equal to $100 * (duties/customsvalueofimports)$ at the 4-digit sic industry level from 1989-2002.

and significant with tariffs increasing by about 0.07% in the average NO2 pollution-intensive industry in the years after the 1990 CAAA.