Deforestation, Foreign Demand and Export Dynamics in Indonesia

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Abstract

This paper presents a dynamic, heterogeneous firm model of investment in environmental abatement and exporting. The model highlights the interaction between firms' environmental investment and export decisions on the evolution of productivity and export demand in timber manufacturing industries. The model is structurally estimated using Indonesian timber manufacturing data that captures firm-level variation in environmental investment and export behavior. The results suggest that environmental abatement has little impact on productivity dynamics, but does encourage growth in export demand. Counterfactual experiments quantify the impact of policy change on trade and abatement decisions.

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"I want to appeal to the citizens of the whole world: look for the stamp of approval on legal wood products."

-Rashmat Witoelar, 2007
State Minister of Environment, Republic of Indonesia[1]

This paper develops a dynamic model of environmental abatement and exports with heterogeneous firms. We study 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 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 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.[2] We contribute to this literature by examining *firm-level* abatement and exporting activities in

[1]Environmental Investigation Agency (EIA), 2007.
[2]See Grossman and Krueger (1995), Antweiler et al. (2001), or Frankel and Rose (2005) for examples.

a developing country. We characterize firm-level behavior in the saw mill and wood furniture industries which are critical, resource-intensive industries in Indonesia.

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). 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.[3] 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 consumer demand in US and European markets, respectively.

Although some of the above 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

[3] 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.

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 pollution than non-exporting firms on average. He is not able, however, 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 indicate that exporting and environmental investment are closely linked within firms.

We build a dynamic structural model of exporting and abatement where these decisions endogenously influence the evolution of future productivity and export demand. 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 contains 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 minimal attention in the economics literature.[4] Third, the nature of the sustainable resource issue studied here is typical of the type of trade-off between resource depletion and

[4]Country-level studies include Ferreira (2004) and López and Galinato (2005). Likewise, firm-level studies from developing countries include Moeltner and van Kooten (2003).

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.

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 (2013). 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 to 14 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). Further, although we find weak evidence that past export experience improves productivity (often referred to as "learning-by-exporting"), our empirical exercise demonstrates that past export experience leads to stronger export demand growth.

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 (2012), we demonstrate that the entry costs associated with these activities play a key role in determining 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 18 percentage points over ten years while also increasing abatement rates by 24 percentage points. Reducing the cost of abatement by 20 percent similarly increases exports and abatement by 7 and 8 percentage points, respectively, in the same industry and time period. However, despite the observed complementarity between exporting and abatement at the firm-level, this effect may cause well intended policies may potentially lead to perverse environmental outcomes. In any case, 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.

1. Deforestation, Abatement and Trade in Indonesia

Indonesia is home to a rich endowment of natural resources, including the world's 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 a 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). By 1996 it is estimated that 2 million hectares of Indonesian forest were cleared annually in order to meet market demand for Indonesian wood products (FWI/GFW, 2002).

We are most interested in the production environment between 1994 to 1997 during which we have access to data describing firm-level abatement decisions. The success of *manufactured* Indonesian wood products in 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). Not surprisingly, export sales for Indonesian wood products are much larger than domestic sales. It is estimated that 70 percent of all wood manufactured in Indonesia is destined for export markets. We focus on the two largest industries classified at the 4-digit ISIC code level, the saw mill and wood furniture industries, where we calculate that almost 80 percent of total revenues are generated from exports sales among exporting firms. Bilateral trade data (UNCTAD) further reveal that a large majority of these shipments are destined for US, European or Japanese markets.[5]

There are three primary sources of timber for saw mill production in Indonesia: government licensed forests, typically managed by the state-owned forestry enterprise *Perum Perhutani*, community or privately-owned forests, and illegally logged timber.[6] After harvesting the raw timber Indonesian saw mill operations include the handling and transportation of logs, the drying of timber, sorting, and transformation (sawing) of logs into dimension lumber, boards, and beams. Typically these products are sold to timber producers in other industries, such as furniture manufacturers, or can be further processed in-house for domestic or export sales.

Wood furniture producers are typically less directly involved in the harvesting of trees. However, several rare woods, some of which are particularly close to extinction, are used intensively in the production of wood furniture.[7] The acquisition of raw timber accounts for 60 percent of

[5]A detailed description of the international context of certification, the timber manufacturing production process and bilateral trade relationships are reported in the online Supplemental Appendix available at https://my.vanderbilt.edu/joelrodrigue.

[6]The vast majority of timber stands are held by government forestry enterprises (Muhtaman and Prasetyo, 2006). However, illegal logging is rampant in Indonesia during our sample period. Further details can be found in the Supplemental Appendix available at https://my.vanderbilt.edu/joelrodrigue.

[7]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).

total costs in the wood furniture industry (Loebis and Schmitz, 2005). After acquiring the basic wood products from saw mill producers, wood furniture manufacturing is largely concentrated in the design and finishing of wood furniture.

Deforestation is by-far the primary environmental concern in these industries (Resosudarmo and Yusuf, 2006 and Synnott, 2005).[8] Between 1950 and 2000 it is estimated that timber production industries have accounted for a 40 percent loss in total forest coverage in Indonesia (FWI/GFW, 2002). Despite this, Indonesian manufacturers faced few binding, domestic sustainability or environmental regulations of any type during our sample period.[9]

1.1. 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). However, legislated responses were difficult to institute since Article 20 of the GATT (and later WTO agreements) obliged member countries to treat imports and domestic goods equally, regardless of the nature of production. Instead, 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*, all of which had commitments in place by 1992.[10] These policies were influential in determining the nature of timber certification which followed

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[8]Other environmental concerns in the saw mill and wood furniture industries include air pollution from adhesives or coating material, wasteful cutting and waste water/hazardous waste USAID (2011). The air pollutants were typically less of an issue in export destinations since exported products are constructed in accordance to destination market standards since these attributes will also impact the natural environment in destination markets. Hemamala et al. (1995) investigated firm-level pollution among Indonesian producers and concluded that firm-level pollutants were highly correlated with other firm-level inputs, such as capital and energy use. To double check whether environmental investment in our data was primarily directed towards deforestation in these industries, we investigated whether firm-level environmental investment had any impact on the rate at which firms use energy, intermediate materials or capital. 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. Details can be found in the Supplemental Appendix available at https://my.vanderbilt.edu/joelrodrigue.

[9]There were notable environmental programs in place by 1986 which encompassed a number of recommendations for air, water quality, hazardous waste control and deforestation, although compliance was extremely low since enforcement was essentially non-existent. See Afsah and Vincent (1997), Afsah et al. (2000) and WWF (2008) for details. Once exception is the PROPER PROKASIH program which appears to have had limited success in deterring water pollution. This program, however, was only implemented at the very end of our sample and included less than 1 percent of all Indonesian manufacturing firms at the time. Moreover, water pollution is relatively small in the timber industries Pargal and Wheeler (1996).

[10]In the 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/).

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. As documented in Table 1 by 1995 similar groups had formed in numerous European and North American countries.

Table 1: National Timber Purchasing Groups

Country	First Launched Buyer's Group	Country	First Launched Buyer's Group
United Kingdom	1991	Ireland	1995
Netherlands	1992	North America[a]	1995
Belgium	1994	Spain	1995
Austria	1995	Sweden	1995
France	1995	Switzerland	1995
Germany	1995		

Notes: This table documents the initial launch date of national certified wood product buying groups before 1998. (a) United States and Canada.

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). Timber certification bodies not only provided a mechanism by which firms could distinguish their products on export markets, but also created new costs associated with sustainable production.

1.1.1. Timber Certification and Export Markets

In contrast to inter-governmental agreements, there was significant progress on voluntary timber certification. 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).

Consumer guides and timber certification began to appear as early as 1987 (Synnott, 2005). The state-owned forestry enterprise *Perum Perhutani*, the largest owner of Indonesian forests, was the first Indonesian source of raw timber to have some forests audited and certified in 1990 (DTE, 2001). This provided saw mills and wood furniture producers with an initial source of certified timber. Similarly, by 1993 the Forest Stewardship Council (FSC) had been established as a worldwide certification body. Retailers in major export markets supported the development of the FSC and were quick to adopt these independent labels which allowed them to distinguish environmentally negligent and conscious suppliers on their store shelves.[11]

There are three 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 be 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).[12]

While certification was voluntary, numerous studies have found that voluntary certifications can have substantial impact on demand. Indonesian studies suggest that early adopters of timber certification benefitted from a substantial rise in export demand for sustainably harvested Indonesian teak furniture (Muhtaman and Prasetyo, 2006). Likewise, 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). This is consistent with the broader findings of Chen, Otsuki and Wilson (2008) which suggest that 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. In our context, we expect that certification may have a larger impact on producers of finished goods, such as wood furniture, relative to those that produce products closer to intermediate inputs, such as plywood.

1.2. Sustainability Costs

Sustainable production can be quite costly. Five typical expenditures associated with sustainable production and certification include:

[11] See the Supplemental Appendix for a timeline of standards adoption for firms such as *B&Q*, *Carrefour*, *Homebase*, *HomeDepot*, *IKEA* and *Walmart* among others. The FSC's key accomplishment was the establishment of a consistent criterion for evaluating sustainably produced timber products worldwide (Synnott, 2005).

[12] Numerous alternatives appeared shortly after 1996-1997 such as the PEFC and ISO 14001. Additionally, in 1993 the Indonesian government established the Lembaga Ekolabel Indonesia Working Group (LEI). 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 them meet international sustainability standards (Muhtaman and Prasetyo, 2006).

- changes in forest management,
- creating separate inventories of certified and non-certified products,
- tracking certified products through all previous stages of production,
- costs directly associated with the actual certification process,
- employee training.

Examples of the changes in forest management practices are obtaining legal harvesting licenses, patrolling licensed timber holdings, and the allocation of timber sources to conservation.

There are two features of this costs we emphasize for our study. First, these costs are likely to be non-trivial to firms in developing countries. Some studies suggest that certification can increase costs by 5-25 percent (Gan (2005)), which further suggests that adoption of sustainable production certification is likely to vary across heterogeneous firms. Second, all of the above costs are typically fixed in nature and are unlikely to vary directly with the scale of production. In fact, other studies confirm that these costs generally display large economies of scale (Fischer et al, 2005). We account for both of these features in our model below.

2. A Structural Model of Abatement and Exporting

We develop a structural model in the spirit of the recent 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. In fact, we prefer to emphasize the positive impact that abatement has on export demand. The model demonstrates the differential return abatement has in domestic and export markets and its impact on future, endogenous abatement and export decisions over time. This allows us to test one version of the "Porter Hypothesis": that abatement may increase firm-specific return on export markets (Porter and van der Linde, 1995).[13]

2.1. Marginal Costs, Revenues and Profits

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

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

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.[14] 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.[15]

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 decisions d_{it-1}.

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:

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

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 depend on abatement decisions through both firm-specific productivity and the export demand shock whereas abatement can only influence domestic revenues through productivity.

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. Specifically, we will rely on domestic revenue to provide information to identify firm-level productivity under the assumption that $z_{it}^j = 0$ for all i and t if $j = D$. In this case, the term ω_{it} captures

[14] 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.

[15] Previous studies of the Indonesian manufacturing sector do not report large departures from constant returns to scale in production (Amiti and Konings, 2008).

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 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 of 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.

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 described in the dynamic model below.

2.2. The Evolution of Productivity and Export Demand

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. 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 for employee training, for certification to be verified and processed and for upgraded product characteristics to be noticed in the market.[16] Likewise, the stochastic nature of our demand process accounts for the notion that increasing expenditures on abatement does not guarantee certification, or any associated increase in demand.

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

[16] As discussed above, it is important that abatement is included in the evolution of productivity, even though we don't expect that marginal costs will be affected by abatement, in order to capture any impact of abatement on domestic demand.

of productivity. If environmental management increases operation costs (e.g. maintenance costs, inventory costs, fewer resources allocated to production) we would expect that abatement would reduce firm productivity and $\alpha_2 < 0$. However, if environmental management leads to productivity improvements, we would expect $\alpha_2 > 0$.[17] 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 green production 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 model the export demand shock as a first-order Markov-process which depends on both past abatement and export decisions:

$$\begin{aligned} z_{it} &= h(z_{it-1}, d_{it-1}, e_{it-1}) + \mu_{it} \\ &= \gamma_0 + \gamma_1 z_{it-1} + \gamma_2 d_{it-1} + \gamma_3 e_{it-1} + \gamma_4 d_{it-1} e_{it-1} + \mu_{it} \end{aligned} \quad (5)$$

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. 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 measured productivity. Likewise, γ_3 tests whether previous exporters experience faster export demand growth than new exporters while γ_4 captures the complementarity or substitutability of export and abatement experience on export markets.[18]

Our structure is similar to that which has been used to study the dynamic productivity and demand in other contexts. For example, Aw Roberts and Xu (2011) consider a similar structure where productivity is a function of past investments in research and development (R&D) and exporting. In that context, they argue that any observed benefit to research and development on productivity captures improvements in production or product appeal. Our context differs in a number of important aspects. First, production costs may rise, and measured productivity fall, in response to certification and abatement. Alternatively, if abatement allows firms to learn new and improved management techniques, we may observe improvements in technical efficiency. Moreover, to the extent that abatement improves product appeal we may observe a positive impact of abatement on measured productivity since we cannot separately identify the evolution

[17] Similarly, if environmental investment increases the domestic demand it will be captured as a productivity improvement in our context.

[18] 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. Likewise, we considered an AR(2) process in place of the AR(1) process above. In either case, the coefficients on the additional variables were always very close to zero and statistically insignificant.

of productivity from changes in domestic demand. While studies predict that R&D will almost always have a positive impact on future productivity, we cannot make the same claim about abatement, *a priori*. Second, it is likely that changes in product characteristics will be received very differently by consumer in developed and developing countries. By allowing abatement to separately affect the evolution of export demand we are able to capture the differential return to abatement between the domestic and export market. Since most Indonesian timber products are destined for developed countries it is of particular interest to capture the return specific to export markets.

The export demand equation is key, but also presents a unique challenge. Suppose there are learning-by-exporting effects that are particular to the export market. Omitting these terms may result in a positive estimate of γ_2, the abatement coefficient, even if there is no actual impact of abatement on export demand simply because abatement and exporting are positively correlated. Including the export terms allows us to separately identify the abatement effect from other activities correlated with exporting. Separately identifying the abatement and exports effects in equation (5) is difficult in a reduced-form context since all firms for which we observe have positive export revenues in years t and $t-1$ (so that we have some information regarding z_t in consecutive years) must also have exported in year $t-1$ so that $d_{it} = d_{it-1} = 1$. As such we will not be able to use standard methods to separately identify γ_3 from γ_0 or γ_4 from γ_2. We discuss this at length in our empirical methodology.[19]

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.

2.3. 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.[20] The industrial analyses described above suggest that the abatement costs in the timber industries can be reasonably captured by a fixed cost structure. Similarly, the assumption of fixed and sunk export costs are common in firm-level studies of export dynamics.

[19] See the Appendix for a reduced-form example.

[20] 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.

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:

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

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

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:

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

We allow that abatement may reduce productivity and increase the cost of production. We 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 firms which expect sufficiently 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}:

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

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 the return to abatement is higher for exporters relative to non-exporters. In this case, we expect that α_4 in equation (4) or γ_2 and γ_4 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, 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.

3. 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 (2013) 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.[21]

3.1. Mark-ups and Productivity

As a first step, we recover an estimate of the mark-ups at home and abroad. Setting marginal revenue equal to marginal cost in each market we can write total variable cost, tvc_{it}, as a

[21] 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.

combination of domestic and export revenue weighted by their respective elasticities:

$$\begin{aligned} tvc_{it} &= q_{it}^D c_{it} + q_{it}^X c_{it} \\ &= r_{it}^D \left(1 + \frac{1}{\eta_D}\right) + r_{it}^X \left(1 + \frac{1}{\eta_X}\right) + \varepsilon_{it} \end{aligned} \tag{13}$$

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. Specifically, we will consider the firm-level demand for materials, m_{it}, and electricity, n_{it}, as observables which are correlated with firm-level productivity innovations. In general, input demand will be a function of both the unobserved productivity shock and the export demand shock. However, as long as productivity shocks are not strictly Hick's neutral, the relative demand for m_{it} and n_{it} will not be a function of z_{it}, but will contain information on firm-level productivity.[22] As such, we can write productivity as a function of input demand, $\omega_{it} = \omega(k_{it}, m_{it}, n_{it})$, and recast the domestic revenue function in (14) as

$$\begin{aligned} \ln r_{it}^D &= \varrho_0 + \sum_{t=1}^{T} \varrho_t D_t + (\eta_D + 1)(\beta_k \ln k_{it} - \omega_{it}) + u_{it} \\ &= \varrho_0 + \sum_{t=1}^{T} \varrho_t D_t + f(k_{it}, m_{it}, n_{it}) + v_{it} \end{aligned} \tag{15}$$

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.[23] 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

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

[23]It is possible that if we have misspecified the model, the input demand function could potentially be a direct function of abatement decisions. We have checked this possibility by re-estimating the first stage of the model while including lagged abatement decisions as additional variable in the fourth order polynomial. This additional variable had no effect on the results.

estimating equation

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

where the asterisk indicates that the coefficients are scaled by $(\eta_D + 1)$. Equation (16) is estimated by non-linear least squares and the parameters are retrieved given η_D.[24] Note that the interpretation of our results depend crucially on the fact that we use data on firm-level domestic revenues to estimate firm productivity. Our estimation strategy controls for one source of export profit heterogeneity (productivity) by exploiting differences in firm performance on the domestic market, conditional on observable input choices. While we refer to these differences as productivity differences, they capture any differences in profitability across firms on the domestic market.

3.2. Abatement Costs, Export Costs and Foreign Demand

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

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

where z_i^+ is the time series of export market shocks for firm i in years in which it exports, $d_i^- \equiv (d_{i0}, ..., d_{iT-1})$ is the sequence of lagged abatement decisions, $e_i^- \equiv (e_{i0}, ..., e_{iT-1})$ is the sequence of lagged export decisions and $de_i^- \equiv (de_{i0}, ..., de_{iT-1})$ is their interaction. 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 and export histories.

Given the parameters of the export shock process we need to simulate exports shocks conditional on past decisions, construct the density $h(z_i^+ | d_i^-, e_i^-, de_i^-)$, and evaluate the likelihood function. The key hurdle to overcome here is that while we observe export and abatement decisions in each year, we only observe information on export sales in years when the firm chooses to export. We use simulation based methods, described below, to separately identify the impact of previous export and abatement decisions on the evolution of export demand (γ_2, γ_3, γ_4) from the autoregressive coefficients (γ_0, γ_1) of export demand.

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

3.2.1. Simulating Export Shocks and Identifying Export Market Returns

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

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

Let v_{it}^+ be the demeaned autoregressive export demand process

$$v_{it}^+ \equiv= z_{it}^+ - (\gamma_0 + \gamma_2 d_{it-1} + \gamma_3 e_{it-1} + \gamma_4 d_{it-1} e_{it-1})(1-\gamma_1)^{-1}$$

conditional on d_{it-1} and e_{it-1}. The component of export demand v_{it} is key to our analysis as it captures the portion of export demand that is carried forward from the previous period. Our model requires simulating these shocks in a fashion whereby they are consistent with the model's estimated autoregressive process and the firm-specific history of export and abatement decisions.

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

$$z_{it}^+ | d_{it-1}, e_{it-1} \sim N((\gamma_0 + \gamma_2 d_{it-1} + \gamma_3 e_{it-1} + \gamma_4 d_{it-1} e_{it-1})(1-\gamma_1)^{-1}, \sigma_\mu^2 (1-\gamma_1^2)^{-1})$$

and $h(z_i^+ | d_i^-) = N((\gamma_0 + \gamma_2 d_{it-1} + \gamma_3 e_{it-1} + \gamma_4 d_{it-1} e_{it-1})(1-\gamma_1)^{-1}, \Sigma_{zz})$ 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 $E[v_{it} v_{it-k}] = \gamma_1^{|k|} \sigma_\mu^2 (1-\gamma_1^2)^{-1} \ \forall \ k \neq 0$. There are two key differences with previous work here. First, the mean of distribution of export demand shocks varies across the distribution of heterogeneous firms with different abatement and export histories. Second, the demeaned component of the export demand shock contains information on the autoregressive process of export demand separate from previous export and abatement decisions. The second component ensures that each firm's series of demand shocks is consistent with the model's autoregressive process, while second adjusts this process for each firm and year to account for the dynamic effects of exporting and abatement over time.

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

$$z_{i1}^T | z_i^+, d_i^-, e_i^-, de_i^- \sim N(\Gamma_0 \iota + \Gamma_1 v_i^+ + \Gamma_2 d_i^- + \Gamma_3 e_i^- + \Gamma_4 de_i^-, \Sigma_{zz} - \Sigma_{zz^+} \Sigma_{z^+z^+}^{-1} \Sigma_{zz^+}')$$

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 $E(v_{it}v'_{it+k}) = \gamma_1^{|k|}\sigma_\mu^2(1-\gamma_1^2)^{-1}$. The matrices Γ_j, $j = 0, 2, 3, 4$, are $T \times T$ lower triangular matrices where the elements are given by $(\gamma_j(1-\gamma_1^2))(\sigma_\mu^2(1-\gamma_1))^{-1}\Sigma_{zz}^l$ 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 $E[z_{i1}^T|d_i^-, e_i^-, de_i^-, v_i^+]$. Moreover, because z_{it} is stationary the weight placed on v_{it} is highest in year t and declines monotonically with $|s|$. Second, and unique to this paper, we use the entire history of abatement and export decisions to simulate export profit shocks for both exporting and non-exporting firms. However, unlike the demeaned export profit shocks v_{it}, abatement and export 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_j matrices, $j = 0, 2, 3, 4$, are lower triangular.

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

$$z_{i1}^T = \begin{cases} \Gamma_0\iota + \Gamma_1 v_i^+ + \Gamma_2 d_i^- + \Gamma_3 e_i^- + \Gamma_4 de_i^- + \Gamma_5\eta_i & \text{if } q > 0 \\ \Gamma_0\iota + \Gamma_2 d_i^- + \Gamma_3 e_i^- + \Gamma_4 de_i^- + \Gamma_5\eta_i & \text{if } q = 0 \end{cases} \tag{18}$$

where $\Gamma_5\Gamma_5' = \Sigma_{zz} - \Sigma_{zz^+}\Sigma_{z^+z^+}^{-1}\Sigma'_{zz^+}$ and η_i is a $T \times 1$ vector of independent and identically distributed standard normal random variable. Note that $\Gamma_5\Gamma_5'$ has rank $T - q_i$ reflecting that Γ_5 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, Γ_3, and Γ_4 impact the simulated z_{it} value in each year for each firm regardless of the firm's current export status.

Intuitively, abatement and export experience parameters γ_2, γ_3 and γ_4 are identified by comparing changes in the evolution of z_t across firms with different abatement or export histories. For example, consider two firms with identical export demand shocks in year 1, identical abatement histories, but different export histories. Suppose the first firm exports in years 1 and 3, while the second exports in all 3 years. Any difference in their export demand shocks z_t must be due to gains derived from past exporting γ_3 or random error, μ_t. Under the assumption that μ_t is normally distributed across firms and time differences in the evolution of z_t across firms identify gains from exporting specific to the export market.[25] Likewise, variation in abatement histories and z_t across firms identify γ_2 and γ_4.

It is important to note that the simulation based estimation is key to identifying the export demand parameters since we would not otherwise be able to exploit variation in data from firms

[25] This process is analogous to the learning-by-exporting hypothesis in Clerides, Lach and Tybout (1998). We might think of the process here as "learning-by-exporting-on export markets."

which do not export in consecutive years.[26] This allows us to simulate $P(e_i, d_i, r_i^X|\omega_i, k_i, \Phi) = P(e_i, d_i|\omega_i, k_i, \Phi, z_i^+)h(z_i^+|d_i^-, e_i^-, de_i^-)$. Specifically, we draw a set of S η_i vectors, use (18) to evaluate $P(e_i, d_i|\omega_i, k_i, \Phi, z_i^+)h(z_i^+|d_i^-, e_i^-, de_i^-)$ at each η_i and average over the S outcomes.[27]

3.2.2. Conditional Choice Probabilities

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:

$$P(e_{it} = 1|s_{it}) = P(e_{it-1}\gamma_{it}^F + (1 - e_{it-1})\gamma_{it}^S \leq \pi_{it}^X + V_{it}^E - V_{it}^D) \qquad (19)$$

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

Similarly, the probability of abatement can be calculated as:

$$\begin{aligned} P(d_{it} = 1|s_{it}) \quad = \quad & P(d_{it-1}\gamma_{it}^A + (1 - d_{it-1})\gamma_{it}^S \leq \\ & \delta E_t V_{it+1}(s_{it}|e_{it}, d_{it} = 1) - \delta E_t V_{it+1}(s_{it}|e_{it}, d_{it} = 0)) \end{aligned} \qquad (20)$$

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.[28]

The probabilities of exporting or abatement 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. The expected value functions can be constructed by iterating on the system of equations defined by (6), (8), (7) and (9). Solving the firm's dynamic problem in turn captures the endogenous selection of firms into exporting or abatement. We do not attempt to maximize the likelihood, but rather employ a Bayesian Monte Carlo Markov Chain (MCMC) estimator to characterize the posterior distribution of the dynamic parameters. Details regarding the algorithm used for the value-function solution and the MCMC implementation can be found in the Appendix. Last, 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.[29]

[26] See the Appendix for further discussion.

[27] In practice we set S=10.

[28] 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).

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

4. 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.[30] 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 Appendix, including this year leads to similar estimates in both industries.

The BPS manufacturing survey is intended to cover the population manufacturing firms in Indonesia. As such, the reported environmental abatement expenditures cover a wide variety of activities across numerous industries. Fortunately, because deforestation of tropical forests is a singularly important environmental issue in Indonesia, plants from the timber industries have been studied widely and in great detail and, as such, we are able to pin down the nature of these expenditures in these industries. For example, FWI/GFW (2002), Loebis and Schmitz (2005), Muhtaman and Praesayto (2006), Obidzinski et al. (2006), Yovi et al (2009) are just a small number of studies which provide detailed information for the Indonesian context.[31] Each of these studies overwhelmingly conclude that environmental activities among Indonesian timber producers are directed towards mitigating deforestation.

A limitation of our data is that we cannot determine the total expenditure incurred on each type of expense within each plant. In particular, if a firm reforms production to mitigate its impact on deforestation, but is unsuccessful in its bid to become certified we will not able to distinguish this firm from those that are successfully certified. This, potentially, has important quantitative implications. The effect will potentially bias the abatement return coefficients, γ_2 and γ_4, towards zero if firms we classify as abating do not in fact benefit from recognition in foreign markets. Despite this limitation, we document below that there remains very strong correlation between abatement expenditures and export performance.

Table 3 describes size differences across firms measured by average sales in the saw mill and wood furniture industries.[32] Overall, we follow 583 saw mill producers and 460 wood furniture

[30]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 Appendix.

[31]Many of the costs outlined here are similar to those found in similar studies in other countries. See Kaplinsky, Morris and Readman (2002) or Dunne (2000) on South Africa, Carter and Merry (1998) on the United States or Bass et al. (2001), Brack et al. (2002), Fischer et al (2005) and Gan (2009) who provide a synthesis across countries.

[32]The survey reports the primary product of each firm in the data. Using this information firms are classified

Table 2: 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	1994	3,702	6,352	13,147
1995	18,159	28,657	115,485	1995	3,616	7,304	11,717
1996	12,207	27,884	142,923	1996	3,933	6,616	14,588

Table 3: 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.

producers who operate continuously between 1994 and 1996.[33] 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. Overall, 20 and 11 percent of large, continuous producers in the saw mill and wood furniture industry reported positive abatement expenditures during this period. This does not imply that all of these producers were certified, rather only that a small percentage made any attempt at mitigating their impact on the natural environment.[34]

into the saw mills (ISIC 3311) or wood furniture (ISIC 3321) industries. Throughout our paper we focus exclusively on domestically-owned firms where less than 10 percent of equity is held by foreign investors. Using this definition, 94 percent of firms in the Indonesian manufacturing industry are domestically-owned during this period.

[33] Summary statistics for the comparable 1994-1997 sample are reported in the online Supplemental Appendix available at https://my.vanderbilt.edu/joelrodrigue.

[34] 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

Table 4: 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.

Table 4 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 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 5 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.[35] 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 less than 1 percent of the average 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

small number of observations severely restricts our ability to identify the firm's abatement policy rule. We do, however, partially test this restriction and find that using a continuous measure of abatement has little impact on a restricted set of demand parameters. See the Appendix for details. Further, Jones (2012) confirms that abatement and certification rates were relatively low during our sample period.

[35]If we normalize expenditures by total revenue we find that exporting firms spend 24 to 37 percent more on abatement than non-exporters over the same period despite being much larger.

Table 5: 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

and sunk costs from exponential distributions.[36] The bottom panel of Table 5 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 6 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 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 of 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 costly abatement. 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.

[36]Further, in the Appendix we study the impact of using a continuous abatement cost variable instead of the discrete variable.

Table 6: Mark-up and Productivity 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	(0.009)	-0.011	(0.021)
α_0	0.196	(0.050)	0.056	(0.098)
α_1	0.887	(0.017)	0.901	(0.023)
α_2	-0.0002	(0.011)	0.013	(0.031)
α_3	0.039	(0.012)	0.012	(0.024)
α_4	0.004	(0.016)	-0.006	(0.025)
Obs.	1329		1731	

Notes: Bootstrap standard errors are in parentheses.

5. Empirical Results

5.1. Mark-up and Productivity Estimates

The mark-up and productivity parameter estimates are reported in Table 7. 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.[37]

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. Although this effect is small, it represents an important source of productivity growth among exporting firms. 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 no evidence for any impact of abatement on productivity, and only weak evidence of productivity gains from pas export experience. However, they may also indicate that any increases in domestic demand from abatement are offset by increases in marginal cost.

[37]The mark-ups likely reflect differences in market structure and competition across locations. In particular, low domestic mark-ups are consistent with the finding that many domestic firms use illegally logged wood extensively.

5.2. Abatement Cost, Export Cost and Foreign Demand

Table 8 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. 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. 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.

The parameter γ_2 indicates 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 firms which abate expect export demand to grow 1.2 percent faster than similar firms who do not while in the wood furniture industry abating firms anticipate that export demand will grow 4.7 percent faster.

Similarly, past export experience is predicted to have a positive impact on export demand growth in both industries. The parameter γ_3 indicates that firms with past export experience expect export demand to grow 2.3 and 3.9 percent faster in the saw mills and wood furniture industries, respectively. Although we did not identify any significant impact of export experience on productivity in the wood furniture industry, we do observe relatively strong learning-by-exporting effects *on export markets*. Moreover, exporting firms in the saw mills industry are predicted to benefit from past export experience both in terms of productivity and export demand. The estimated coefficient γ_3 captures any effect of export experience on export demand growth *in addition to* the impact of export experience on firm-level productivity.

The last export demand parameter γ_4 captures the interaction of past export and abatement experience on export demand. We observe a striking difference across industries: in the saw mills industry γ_4 is close to zero and not strongly significant, while in the wood furniture industry we observe that γ_4 is positive, large and significant. In fact, we find that wood furniture producers with previous export and abatement experience expect export demand to grow an additional 8.9 percent faster. This evidence stands in contrast to the finding that abatement had little effect on productivity and domestic revenues.

The difference in magnitude across wood products 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 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.

To further investigate the differences across industries we study the variation in the marginal benefit to abatement across the joint distribution of productivity and demand. We find that the marginal benefit of abatement generally increases with productivity, although these ad-

Table 7: Abatement Cost, Export Cost and Foreign Demand Estimates

	Saw Mills		Wood Furniture	
γ_0(Export Shock Intercept)	0.013	(0.003)	0.173	(0.017)
γ_1(Export Shock AR process)	0.974	(0.001)	0.863	(0.011)
γ_2(Abatement effect on Export Shock)	0.012	(0.002)	0.047	(0.014)
γ_3(Export Experience effect on Export Shock)	0.023	(0.002)	0.039	(0.012)
γ_4(Export-Abatement Interaction)	0.007	(0.004)	0.089	(0.014)
γ^A(Abatement FC)	14.786	(0.301)	0.172	(0.034)
γ^D(Abatement SC)	86.355	(1.563)	38.046	(0.810)
γ^F(Export FC)	11.983	(0.987)	0.159	(0.016)
γ^S(Export SC)	173.760	(1.951)	52.790	(0.616)
Φ_X (Export Rev Intercept)	7.288	(0.084)	7.718	(0.061)
σ_μ(Export Shock Std Dev)	1.201	(0.029)	1.129	(0.050)
Obs.	1154		886	

Notes: Standard deviations are in parentheses.

ditional gains are generally small.[38] In contrast, the marginal value of abatement increases strongly across the distribution of export demand. This result is particularly striking in the wood furniture industry where the firm's output is much closer to the final consumers in export markets. Consistent with the estimates presented in Table 7, we find that the marginal benefit of abatement increases fastest with export demand among current wood furniture exporters (since $\gamma_4 > 0$), while the gains are similar across exporting and non-exporting firms in the saw mills industry (where $\gamma_4 \approx 0$).

The reported values of the fixed and sunk cost parameters, γ^A and γ^D, capture the mean of the exponential distributions for fixed and sunk abatement costs, respectively. Specifically, he average fixed abatement cost draw in the wood furniture industry is nearly 0.2 million 1983 Indonesian rupiahs, while the average fixed abatement cost draw in the saw mills industry is approximately 15 million 1983 Indonesian rupiahs. These represent 2 and 25 percent of the average annual revenue earned by a firm in the wood furniture and saw mills industries, respectively. In either industry, the average reported abatement expenditures among abating firms account for nearly 1 percent of the average firm's annual revenue. Clearly, the model estimates abatement expenditures are greater than those reported in the data. This should not be surprising, the fixed abatement costs are identified by productivity and demand differences across abating and non-abating firms. As such, they are capturing size differences across firms with different abatement status, which we have documented to be quite large. In practice, the difference between reported expenditures and estimated abatement costs can be thought of capturing the fact that numerous costly, indirect expenses must to be incurred in order to acquire certification; for example, learning about certification procedures, keeping separate firm inventories, upgrading record keeping, additional hiring and training, restructuring firm

[38] Full tables, and an extended discussion, can be found in the Appendix.

procedures and the opportunity cost associated with investing the time in achieving certification are not necessarily reported as environmental expenditures though they represent important costs that may deter firms from choosing to abate. The sunk costs parameters are estimated to be even larger than the fixed cost parameters. This implies that, for each activity, the sunk cost distribution will have more mass concentrated in the high cost values and, given the structure of the data, to be expected. The sunk cost of abatement is identified by from the difference in the probability of abating next period across firms with different status status. Thus, for the same marginal benefit, a firm will be more likely to continue abating than to begin abating.[39]

A similar pattern emerges from the fixed and sunk export cost parameters. The average fixed export cost draw n the wood furniture industry is nearly 0.2 million 1983 Indonesian rupiahs, while the average fixed abatement cost draw in the saw mills industry is approximately 11 million 1983 Indonesian rupiahs. These represent 2 and 20 percent of the average annual revenue earned by a firm in the wood furniture and saw mills industries, respectively. These costs, though large, are line with those reported in other countries and manufacturing industries.[40] Again, sunk export costs are larger than fixed export costs and capture the fact that current exporters are more likely to export next year relative to current non-exporters.

5.3. 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 initial year status $(\omega_{i1}, z_{i1}, d_{i1}, e_{i1}, k_i)$ of all firms in our data

Table 8: 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	3.115	1.174
Predicted	0.214	0.076	0.333	0.197	2.973	1.112

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 9 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

[39]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.

[40]See Das, Roberts and Tybout (2007) for example.

Table 9: 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	0.756	0.107	0.083	0.054
only Exp.	0.316	0.542	0.013	0.129
only Abt.	0.343	0.037	0.379	0.241
Both	0.140	0.178	0.032	0.650

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	0.970	0.023	0.005	0.002
only Exp.	0.201	0.775	0.000	0.023
only Abt.	0.387	0.000	0.548	0.065
Both	0.105	0.060	0.003	0.832

closely in both industries, though it slightly underpredicts abatement in the wood furniture industry. Table 10 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 the persistence in export status and abatement status in the saw mills industry.

6. Policy Experiments

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

6.1. Trade Liberalization

In the first experiment we increase the size of the foreign market by 20 percent which, in this context, may be interpreted as a reduction in variable trade costs.[41] The first 4 columns of the top panel in Table 16 presents the change in the proportion of firms which choose to abate relative to the baseline model after 1, 2, 5 and 10 years. The increase in the size of the export market has a substantial impact on abatement decisions. Across industries the proportion of firms who endogenously choose to abate increases by 4.7-6.3 percent in the first year and is 8.0 percentage points higher in the saw mills industry and 18.4 percentage points higher in the wood furniture industry after 10 years.

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

[41] 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).

Table 10: Trade Liberalization

Export Demand	Endogenous z_t, $\gamma_2, \gamma_3, \gamma_4 > 0$				No Abatement Effect $\gamma_2 = \gamma_4 = 0$				Exogenous z_t $\gamma_2 = \gamma_3 = \gamma_4 = 0$			
Years after 1996	1	2	5	10	1	2	5	10	1	2	5	10
	Change in the Proportion of Abating Firms											
Saw Mills	6.3	7.6	8.7	8.0	0.2	0.1	0.4	0.6	0.1	0.0	0.0	0.4
Wood Furniture	4.7	7.0	11.8	18.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Change in the Proportion of Exporting Firms											
Saw Mills	7.4	9.7	10.3	9.4	5.9	7.9	9.2	9.1	1.4	1.0	0.8	0.9
Wood Furniture	7.8	11.6	18.1	24.1	5.9	7.1	9.1	11.8	3.6	3.8	4.8	6.5

dynamics but rather by 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 $\gamma_2 = \gamma_4 = 0$ 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 0.6 percentage points in the saw mills industry and has had no effect in the wood furniture industry.

The bottom panel of Table 16 presents the same information for the response of exporting to trade liberalization. In either industry we observe increases in export participation over time. In the saw mills industry, the proportion of exporters rises by 7.4 percentage points in the first year and is 9.4 percentage points higher than the baseline level after 10 years. Similarly, the proportion of wood furniture exporters rises by 7.8 percentage points in the first year and is over 24.1 percentage points higher 10 years after the change in policy.

Note, however, a similar pattern is found in the saw mills industry when we consider an exogenous export demand process where $\gamma_2 = \gamma_4 = 0$. This is not surprising since increasing the size of the export market should induce firms to export regardless of any complementarity with abatement decisions. In contrast, in the wood furniture industry, where γ_2 and γ_4 are estimated to be relatively large, we observe much slower growth in exporting when we set $\gamma_2 = \gamma_4 = 0$. Ignoring the return to *abatement* on export markets leads to markedly different *export* predictions in the wood furniture industry.

Finally, we repeat the experiment under the assumption that export demand is entirely exogenous process, $\gamma_2 = \gamma_3 = \gamma_4 = 0$, as is often assumed.[42] This experiment allows us to evaluate the impact of learning-by-exporting on export markets. In this case we observe that learning-by-exporting has a large impact on predicted export rates over time. Across industries we observe that the increase in the proportion of exporting firms is 2.3-4.5 percentage points

[42]See Das, Roberts and Tybout (1997) or Aw, Roberts and Xu (2011) for examples.

higher in the initial year and 5.3-6.5 percentage points higher after 10 years. Not surprisingly, we also observe no further impact on abatement since $\gamma_2 = \gamma_4 = 0$.

6.2. Abatement Subsidies

The second policy experiment we consider is lowering the fixed abatement costs by 20 percent in each industry.[43] 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.[44]

The top panel of Table 17 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 rates. In the saw mills industry abatement rates increase by 3.1 percentage points in the first year and are 4.6 percentage points higher than the baseline model after 10 years. The immediate 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 7.5 percentage points relative to the baseline model.

Table 11: Abatement Subsidies

Export Demand	Endogenous z_t, $\gamma_2, \gamma_3, \gamma_4 > 0$				No Abatement Effect $\gamma_2 = \gamma_4 = 0$				Exogenous z_t $\gamma_2 = \gamma_3 = \gamma_4 = 0$			
Years after 1996	1	2	5	10	1	2	5	10	1	2	5	10
	Change in the Proportion of Abating Firms											
Saw Mills	3.1	3.7	4.9	4.6	0.2	0.1	0.1	0.3	0.0	-0.1	-0.3	0.0
Wood Furniture	2.9	3.9	5.6	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Change in the Proportion of Exporting Firms											
Saw Mills	0.4	0.6	1.2	1.3	-0.2	-0.5	-0.5	-0.5	-0.5	-0.9	-1.0	-0.9
Wood Furniture	3.0	4.0	5.5	7.1	0.2	0.2	0	0.2	-0.1	-0.2	-0.2	-0.5

The bottom panel of Table 17 presents the impact of abatement subsidies on export participation in both industries. In the saw mill 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.

[43] In the saw mills industry this amounts to a reduction in the fixed abatement costs of 3 million 1983 Indonesian Rupiahs. In the wood furniture industry the fixed abatement parameter is reduced by 34 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.

[44] 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).

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. We note that by 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). In contrast, the abatement subsidies increases export rates among wood furniture producers by 3 percentage points initially and 7.1 percentage points after 10 years. In the wood furniture industry the increase in abatement is driven both by current exporters and non-exporters.

Columns (5) through (8) of Table 17 report the results for the model without any abatement effect on export demand ($\gamma_2 = \gamma_4 = 0$), while columns (9) through (12) report the results for the model with exogenous export demand ($\gamma_2 = \gamma_3 = \gamma_4 = 0$). They indicate that the observed changes in abatement are again driven by the complementarity of exporting and abatement on the export market. The small changes in export rates are largely driven by productivity dynamics in both industries. Importantly, in this experiment we observe little difference in export rates between the model with no abatement effect and the model with exogenous demand. This occurs for two reasons. First, without any direct relationship between abatement and export demand, the impact of abatement on exporting through less direct channels, such as productivity, is small. A second reason for this result is the effect (not shown Table 17) that setting $\gamma_2 = \gamma_4 = 0$ the exogenous export demand has on baseline export rates. For instance, baseline export rates are 9 percent lower in the first year under $\gamma_2 = \gamma_4 = 0$ relative to the baseline endogenous demand model. As such, lower current export rates diminish potential for learning-by-exporting to have an impact on future exporting.[45]

6.3. Environmental Costs of Policy Change

Tables 10 and 11 indicate that trade liberalization or abatement will likely have a substantial impact on both firm-level abatement and exporting. However, they also present little evidence of the overall impact of policy change on environmental outcomes. For instance, even though trade liberalization encourages abatement our experiment suggests that it is quite possible that the rate of deforestation may have risen in our counterfactual experiment due to the rise in exporting. While our data do not allow us to directly measure the intensity with which abating and non-abating firms use sustainable and unsustainable sources of timber, the model's structure allows us, under mild assumptions, to characterize the implied bounds on the growth of deforestation due to policy change. First, we maintain our previous assumption that certification does not affect the firm's production function. In combination with constant returns to scale in production it implies that the growth of timber usage is proportional to output growth.

[45]Our experiments abstract from any potential entry of new firms induced by policy change. In the Indonesian context, most new entrants are small, local producers with relatively poor access to formal institutions and certification. As such, we expect that including these firms in our analysis would lower both the initial and counterfactual trade and abatement rates but have little impact on the predicted magnitudes of policy change.

Given our estimated mark-ups we compute the output growth under both the benchmark and counterfactual policies.[46]

The second assumption we need is one that characterizes the average intensity with which each type of firm uses non-sustainable sources of timber inputs in production. Since our data does not provide any such information we consider two extreme cases. In the first case, we assume that all abating firms exclusively use timber from sustainable sources and non-abating firms exclusively use timber from unsustainable sources. This is clearly a lower bound since it suggests that abating firms are using the most environmentally conscious sources in all of its production and for all the markets in which they are active. For comparison, we also consider a case where we assume that abatement has no effect on the source of timber and that all production uses unsustainable sources of timber. While this case requires that abatement status is a completely misleading signal to consumers in destination markets, it allows us to characterize the upper bound of the impact that abatement may have on production levels and, thus, the percentage increase in deforestation.

Table 12 presents the average annual increase in growth of total industry output by firms which use unsustainable sources of timber. The upper bound is effectively the total growth in industry output, while the lower bound is the growth in output from non-abating firms. The top panel of Table 12 presents results for our trade liberalization policy experiment. We observe, not surprisingly, strong output growth in both industries. The implication is that to extent that trade liberalization encourages output growth, the policy change may potentially increase the rate of deforestation accordingly. Our upper bound estimates suggest that in our two industries of interest this increase may be a high as 20-28 percent higher 10 years after the policy change.

Table 12: Percentage Growth in Annual Output Produced from Unsustainable Timber Sources

	Trade Liberalization							
	Lower Bound				Upper Bound			
Years after 1996	1	2	5	10	1	2	5	10
Saw Mills	-7.0	-9.3	0.1	0.3	8.3	13.1	24.0	28.3
Wood Furniture	-1.2	-3.6	-6.6	-14.8	4.4	2.6	6.3	20.3
	Abatement Subsidies							
	Lower Bound				Upper Bound			
Years after 1996	1	2	5	10	1	2	5	10
Saw Mills	-7.3	-9.4	-6.7	-12.2	0	0.4	0.5	0.6
Wood Furniture	-4.8	-4.1	-6.8	-8.6	0	0.5	2.3	8.3

If we instead assume that abating firms only use sustainable sources of timber, the overall environmental outcome is less clear. In the saw mills industry, we find that trade liberalization would initially cause a fall in unsustainable production due to the complementarity between exporting and abatement. The initial fall is relatively since large exporters, with large current

[46] Full details can be found in the Appendix.

export demand shocks, have the strongest current incentive to start abating. However, over time trade liberalization causes output to grow for *all* exporters regardless of abatement status. Five years after the policy, unsustainable output has reached the same level as that in the benchmark model and continues to be slightly above that of the benchmark model 10 years after the policy change. In the wood furniture industry, trade liberalization causes an initial decline in unsustainably produced output of 1.2 percent. Perhaps even more strikingly, over time trade liberalization causes even larger percentage declines in output. This is entirely due to the stronger complementarity between exporting and abatement in the wood furniture industry. Clearly, industry-specific differences play a key role in determining differential outcomes across timber manufacturing industries.

The abatement subsidy policy experiment paints a very different picture in both industries. In the saw mills and wood furniture industries we observe little or at most moderate total output growth due to the change in abatement. In the saw mills industry total annual output is only 0.6 percent higher than the benchmark model even 10 years after the change in policy. Annual output growth in the wood furniture industry, where the complementarity between exporting and abatement is stronger, is 8.3 percent. While this represents an important increase in output due to abatement subsidies it is notable that it took 10 years for the complementarity between abatement and exporting to generate a substantial increase in output growth. Moreover, when we examine the lower bound on output growth from unsustainable sources, we observe that abatement subsidies immediately reduce annual output from non-abating firms by 5-7 percent and these percentage reductions grow over time. Ten years after the policy change output growth from unsustainable production is 12 percent lower in the saw mills industry and almost 9 percent lower in the wood furniture industry. While trade liberalization encourages abatement by making exporting inherently more profitable, the abatement subsidies encourage greater export profits by encouraging firm-level abatement. Our counterfactual exercises suggest that the latter appears particularly promising for improving environmental outcomes through trade.

7. Conclusions

This paper presents a dynamic model of heterogenous firms which endogenously choose to make environmental investments and export. Our empirical methodology allows us to separately identify the return to abatement and exporting on both domestic and export markets. The model is structurally 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 unobserved export demand growth by 1 to 5 percent among non-exporting firms and 2 to 14 percent among exporting firms. In contrast, we find no appreciable impact of abatement on productivity for either exporters or non-exporters. Our estimates also reveal that past export experience encourages future export demand growth by 2 to 3 percent across industries. Past export experience has a similar, moderate impact on productivity (4 percent) in the saw mills industry, but no significant impact in the wood furniture industry.

The counterfactual experiments confirm that ignoring the differential returns to the same activity on different markets can potentially lead to misleading policy conclusions. When we increase the size of the export market by 20 percent, the experiments show that ignoring the return to abatement on export markets underestimates the increase abatement rates by 7 to 18 percentage points after 10 years. Under the same experiment we further find ignoring the return to export experience on export markets reduces export participation by 5 to 8 percentage points. However, despite the observed complementarity between exporting and abatement at the firm-level, this effect may cause well intended policies to potentially lead to perverse environmental outcomes.

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Appendix A. Corporate Timber Purchasing Policies

Table A1 lists over 40 large international firms which enacted timber purchasing policies during our sample period. 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. For brevity, we do not document the individual policy enacted by each firm here. This information can be found in our web appendix located at https://my.vanderbilt.edu/joelrodrigue. We do note that almost all of policies enacted by the firms listed below are pledges to only purchase certified or sustainably produced wood products.[47]

[47] 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 A1: Corporate Timber Purchasing Policies

Retailer/Firm	Retailer/Firm	Retailer/Firm	Retailer/Firm
Assi Doman	Focus	Magnet Ltd	Premium Timber Products
B&Q	FW Mason and Sons	M&N Norman	Richard Burbidge Ltd
Bridgman	Graefe	MCA/Universal	Saint-Gobain Bldg Dist
Bouwfonds	Habitat	Meyer International	SCA
Carrefour	Hollywood Center Studios	MFI	Shadbolt International
Carillion plc	Homebase Ltd	Moore's Furniture Group	Sony Pictures Studios
Chindwell Company Ltd	Home Depot	OBI	Texas Homecare
Cinnabar	IKEA	Otto-Versand	Twentieth Century Fox
Clarks Wood Company	Intergamma	Paramount Pictures	Walmart
David Craig Ltd	J Sainbury plc	Praktiker	Walt Disney Pictures
ENSO/Stora-Enso	Lexington	Praxis	Warner Bros.
Finewood			

Appendix B. 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.[48] In order to focus on the domestic industry, we drop all plants where more than 10 percent of equity is held by foreign investors. Table A2 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.

Appendix C. Exporting and Abatement Correlation

Below we examine the raw correlation between exporting and abatement. Figure A1 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 A2, 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

[48] 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.

Table A2: Variable Description

Variable	All Industries Obs.	All Industries Mean	All Industries Std. dev.	Saw Mills Obs.	Saw Mills Mean	Saw Mills Std. dev.	Wood Furniture Obs.	Wood Furniture Mean	Wood Furniture 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.

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.

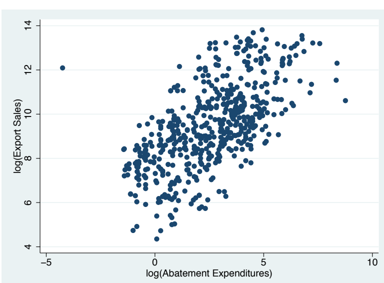

Figure A1: Export Sales and Abate. Exp.

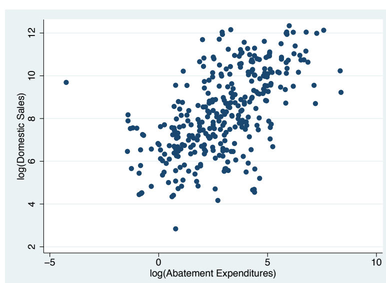

Figure A2: Domestic Sales and Abate. Exp.

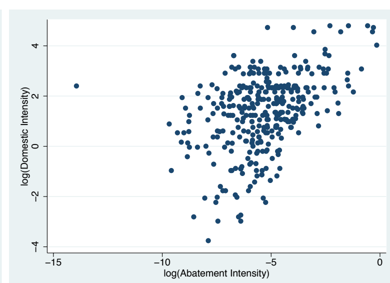

Figure A3: Export Intensity and Abatement Intensity

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 A3. 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.

Appendix D. Robustness Checks: Control-Function Estimation

Below we briefly describe a two-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 restricted and less efficient method to identify the dynamic process on export demand. There are three key advantages of this exercise: (1) it provides a robustness check on our dynamic estimates, (2) it explicitly demonstrates how our simulation-based estimation allows us to better identify the dynamic export demand process, and (3) it allows us to study the impact of using continuous measures of abatement in place of the binary measures in the main text.

Recall that in our first step we retrieve an estimate of the mark-up and the evolution of firm-level productivity as described in section 3.1 of the main text. We then develop 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 the level of intermediate materials over time, then there remains some variation in input demand that contains information regarding export-specific shocks.

However, we only observe export revenues for firms that choose to enter the export market. This potentially creates a selection issue since only firms with sufficiently high export demand shocks will choose to enter export markets. 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.[49] 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

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

export probabilities are given by

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

By inverting (D.1), 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

$$\ln r_{it}^{X}=\Gamma_0+D_t\Gamma_t+F(k_{it},\omega_{it},m_{it})+H(\hat{\theta}_{it})+\nu_{it} \tag{D.2}$$

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 (D.2) 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 productivity or capital stock, but is related to firm-level choices of materials, m_{it}.

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. This creates two difficulties. First, in our short panel, this is very demanding of the data 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 necessary we will note differences between the aggregated and disaggregated industries.

The second difficulty relates to the export demand process itself. Equation (5) in the main text defines the export demand process as

$$z_{it}=\gamma_0+\gamma_1 z_{it-1}+\gamma_2 d_{it-1}+\gamma_3 e_{it-1}+\gamma_4 d_{it-1}e_{it-1}+\mu_{it}$$

Note, however, that any firm for which we observe z_{it-1} must have exported in the previous year, so that $e_{it-1}=1$. As such, we are not able to separately identify γ_0 from γ_3 or γ_2 from γ_4. We are, however, able to separately identify these coefficients in the Bayesian Markov Chain Monte Carlo algorithm described in the main text. The reason for this is that the simulation algorithm allows to compare the distribution of export demand shocks, z_{it}, among first time exporters with different abatement histories. We can, however, identify a restricted export demand process

$$z_{it} = \tilde{\gamma}_0 + \gamma_1 z_{it-1} + \tilde{\gamma}_2 d_{it-1} + \mu_{it}$$

where $\tilde{\gamma}_0 = \gamma_0 + \gamma_3$ and $\tilde{\gamma}_2 = \gamma_2 + \gamma_4$.

Appendix D.1. Abatement and Productivity

Given the estimated series of productivity 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 A3. 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 A3 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 A3. 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.[50] Examining current instead of lagged abatement and export decisions has little impact on all of the estimated coefficients. 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 or exporting 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. For instance, it is possible that a richer environment would allow for continuous environmental investment decisions. Due to the limited panel of data to which we have access, we are unable to investigate this further in the main text. However, we do attempt to partially investigate this concern in the reduced exercise by replacing the discrete measure of abatement with a continuous measure in above

[50]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 A3: Productivity, Abatement and Exporting

Industry	All Wood Products							
	d_t discrete				d_t continuous			
ω_{t-1}	0.885	0.876			0.881	0.871		
	(0.012)	(0.012)			(0.012)	(0.013)		
d_{t-1}	0.012		-0.009		0.008		0.012	
	(0.012)		(0.027)		(0.005)		(0.006)	
e_{t-1}	0.051		-0.007		0.049		0.063	
	(0.010)		(0.029)		(0.011)		(0.012)	
$d_{t-1}e_{t-1}$	0.001		-0.009		0.002		0.003	
	(0.019)		(0.035)		(0.006)		(0.007)	
d_t		0.002		-0.010		0.001		0.011
		(0.013)		(0.019)		(0.013)		(0.007)
e_t		0.063		0.018		-0.008		0.024
		(0.013)		(0.016)		(0.028)		(0.017)
d_te_t		0.026		0.023		-0.001		-0.004
		(0.019)		(0.023)		(0.014)		(0.007)
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.

algorithm and repeating the above estimation 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 A3. 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.

Appendix D.2. Abatement and Exporting

Table A4 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.[51] 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 0.08). Similarly, previous export experience often appears to 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.[52]

[51] In Table SA4 d_{it} is always treated as binary variable.
[52] This interpretation is consistent with the timing assumption in the main text.

Table A4: 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}	1.861	0.227	1.795	0.241	2.033	0.469
	(0.080)	(0.098)	(0.106)	(0.138)	(0.154)	(0.188)
e_{t-1}	0.126	2.144	0.100	1.921	0.153	2.373
	(0.089)	(0.077)	(0.131)	(0.120)	(0.157)	(0.134)
ω_t	0.243	0.816	0.197	1.247	0.084	1.409
	(0.075)	(0.075)	(0.110)	(0.123)	(0.259)	(0.235)
ρ	0.049		0.165		0.026	
Obs.	2466		1157		895	

Notes: Standard errors are in parentheses.

Firm-level productivity is also a strong predictor of abatement and export decisions with the exceptions of columns (3) and (5) which capture the abatement decision. There are a number of explanations for the result that productivity has little impact on abatement decisions in this industry. First, because 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. Second, 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.

Appendix D.3. Abatement and Export Demand

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

$$\hat{z}_{it} = \tilde{\gamma}_0 + \gamma_1 \hat{z}_{it-1} + \tilde{\gamma}_2 d_{it-1} + J(\tilde{\theta}_{it}) + \mu_{it}$$

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 A5.

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 larger than the sum of the estimated coefficients γ_2 and γ_4 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 the sum of γ_2 and γ_4 reported in the main text, except it is statistically significant at conventional levels of confidence. It is encouraging that the estimated coefficients are consistent with those returned by the Bayesian MCMC method implemented in the main text even though the industry under consideration is 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 on the export demand process, z_{it}. We again generally find that 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.[53] We find these results encouraging and consistent with the model and findings in the main text. However, we are unable to directly test further model assumptions, such as the fixed cost nature of abatement expenditures, using our firm-level directly. In Appendix G we investigate whether abatement affects energy, electricity, materials or capital intensity as an indirect, and partial, test of this model assumption.

Table A5: Export Demand and Abatement

Industry	All Wood Products							
	d_t discrete				d_t continuous			
z_{t-1}		0.684		0.681		0.677		0.678
		(0.074)		(0.068)		(0.064)		(0.070)
d_{t-1}	0.191	0.074			0.069	0.021		
	(0.087)	(0.047)			(0.030)	(0.011)		
d_t			0.213	0.100			0.073	0.022
			(0.086)	(0.043)			(0.031)	(0.012)
Obs.	286							

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

[53]Among abating firm the median value for the continuous variable d_t is approximately 2. The p-value for the coefficient on variable d_t in column (8) of Table A5 is 0.067.

Appendix E. 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, with the exception of the learning-by-exporting on export markets parameter, γ_3, in both industries and the abatement-exporting interaction parameter, γ_4, in the wood furniture industry. Here, γ_3 is small and insignificantly different from zero while γ_4 continues to be positive and significant we note that it is substantially smaller than before. This difference likely reflects the fact that Indonesian exports fell considerably across industries during the Asian crisis. Full results are presented in Tables A6-A7. We refer the reader to the main text for further discussion of the individual parameters.

Table A6: Mark-up and Productivity Estimates

	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	-0.044	(0.015)	-0.010	(0.014)
α_0	0.237	(0.085)	0.078	(0.093)
α_1	0.894	(0.017)	0.920	(0.018)
α_2	0.002	(0.017)	0.006	(0.022)
α_3	0.086	(0.032)	0.017	(0.023)
α_4	0.006	(0.023)	-0.001	(0.026)
Obs.	1407		1075	

Notes: Bootstrap standard errors are in parentheses.

Table A7: Abatement Cost, Export Cost and Foreign Demand Estimates

	Saw Mills		Wood Furniture	
γ_0	0.008	(0.003)	0.014	(0.008)
γ_1	0.966	(0.001)	0.931	(0.007)
γ_2	0.005	(0.001)	0.023	(0.004)
γ_3	0.001	(0.003)	-0.003	(0.002)
γ_4	0.011	(0.002)	0.008	(0.004)
γ^A	15.803	(0.334)	0.083	(0.018)
γ^D	92.307	(1.101)	44.258	(0.271)
γ^F	16.159	(0.431)	0.090	(0.008)
γ^S	164.096	(1.271)	52.748	(0.235)
Φ_X	7.525	(0.060)	5.905	(0.024)
σ_μ	1.375	(0.003)	1.320	(0.006)
Obs.	1407		1075	

Notes: Standard deviations are in parentheses.

Appendix F. The Benefit of Abatement and Exporting

In this section we consider the expected gain a firm may expect should they begin abatement or exporting before any sunk or fixed costs are incurred. To this end we calculate the marginal benefit of abatement (10) and the marginal benefit of exporting (12) across the distribution of export demand and productivity. The results are based on the estimated presented in the main test and are documented in Tables A8 and A9.

Table A8 presents the marginal benefit of abatement for non-exporting firms (the top panel) and exporting firms (the bottom panel). In each industry we present the marginal benefit of abatement for twenty-five combinations of productivity and export demand shocks. The export demand shocks we present are chosen as follows. First, each time with simulate the model we save the export demand shocks capturing the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles of export demand shocks across all firms (non-exporters and exporters). We then average the each set of demand shocks across all 100 simulations and calculate the marginal benefit of abatement for the average firm in the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles of export demand distribution in our data. The productivity levels are chosen analogously; we choose the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles of empirical productivity distribution.

We observe a striking difference across the distribution of export demand and productivity. Although the marginal benefit of abatement generally increases with productivity, these additional gains are small and occasionally fall with productivity. In contrast, we observe much stronger increases in the marginal value of abatement across the distribution of export demand. This result is particularly striking in the wood furniture industry where the marginal value of abatement is nearly constant over the productivity distribution but grows strongly in export demand. Consistent with the estimates presented in Table 9, we find that the marginal benefit of abatement increases fastest with export demand among current wood furniture exporters (since $\gamma_4 > 0$), while the gains are similar across exporting and non-exporting firms in the saw mills industry (where $\gamma_4 \approx 0$). Further comparing the top and bottom panels of Table A8 it is clear that current exporters have a stronger incentive to abate. This is reasonable since current exporters are more likely to export in the future and gain from their current environmental investment.

Table A8: Marginal Benefit of Abatement (Millions of Rupiahs)

$MBA = E_tV_{t+1}(d_t = 1, e_t = 0) - E_tV_{t+1}(d_t = 0, e_t = 0)$

Saw Mills						Wood Furniture					
	z_t						z_t				
ω_t	-4.9	-3.2	-1.1	0.9	2.2	ω_t	-2.8	-1.0	0.7	1.6	2.2
2.5	2.3	3.4	9.8	23.0	35.9	0.9	0.01	0.03	0.1	0.2	0.3
2.7	2.3	3.3	10.5	22.9	36.5	1.0	0.01	0.03	0.1	0.2	0.3
3.0	2.2	3.6	11.1	22.4	39.3	1.1	0.01	0.03	0.1	0.2	0.3
3.8	2.2	4.6	10.6	23.5	46.2	1.3	0.01	0.03	0.1	0.2	0.3
4.0	2.3	4.4	10.8	24.4	45.8	1.6	0.01	0.03	0.1	0.2	0.3

$MBA = E_tV_{t+1}(d_t = 1, e_t = 1) - E_tV_{t+1}(d_t = 0, e_t = 1)$

Saw Mills						Wood Furniture					
	z_t						z_t				
ω_t	-4.9	-3.2	-1.1	0.9	2.2	ω_t	-2.8	-1.0	0.7	1.6	2.2
2.5	4.2	5.8	16.1	35.6	50.2	0.9	0.3	0.7	1.3	1.7	2.0
2.7	4.0	5.8	17.1	34.5	51.7	1.0	0.3	0.8	1.3	1.7	2.0
3.0	3.6	6.4	18.2	32.4	56.5	1.1	0.3	0.8	1.3	1.7	2.1
3.8	3.8	7.8	17.2	35.9	64.5	1.3	0.3	0.8	1.3	1.7	2.1
4.0	4.1	7.5	17.4	37.2	63.28	1.6	0.3	0.8	1.3	1.7	2.1

Table A9: Marginal Benefit of Exporting (Millions of Rupiahs)

$MBE_{it} = \pi_{it}^X + V_{it}^E(d_{it-1} = 0) - V_{it}^D(d_{it-1} = 0)$

Saw Mills						Wood Furniture					
	z_t						z_t				
ω_t	-4.9	-3.2	-1.1	0.9	2.2	ω_t	-2.8	-1.0	0.7	1.6	2.2
2.5	10.8	12.8	31.9	78.4	97.8	0.9	0.1	0.4	0.9	1.4	1.8
2.7	9.3	13.0	34.1	71.2	102.5	1.0	0.1	0.4	1.0	1.4	1.9
3.0	6.4	14.7	38.1	58.1	112.3	1.1	0.1	0.4	1.0	1.4	1.9
3.8	8.3	17.4	38.2	75.9	124.7	1.3	0.1	0.4	1.0	1.5	1.9
4.0	9.4	16.4	37.6	81.5	122.2	1.6	0.1	0.4	1.0	1.5	2.0

$MBE_{it} = \pi_{it}^X + V_{it}^E(d_{it-1} = 1) - V_{it}^D(d_{it-1} = 1)$

Saw Mills						Wood Furniture					
	z_t						z_t				
ω_t	-4.9	-3.2	-1.1	0.9	2.2	ω_t	-2.8	-1.0	0.7	1.6	2.2
2.5	11.1	13.3	34.4	85.2	105.3	0.9	0.3	0.9	2.0	2.7	3.4
2.7	9.6	13.5	37.0	77.4	110.5	1.0	0.3	0.9	2.0	2.7	3.4
3.0	6.6	15.3	41.2	63.4	121.1	1.1	0.3	0.9	2.0	2.8	3.5
3.8	8.6	18.2	41.0	82.6	133.6	1.3	0.3	0.9	2.0	2.8	3.5
4.0	9.7	17.2	40.5	88.5	130.7	1.6	0.3	0.9	2.0	2.8	3.6

Table A9 presents analogous results for the marginal benefit of exporting. While the marginal benefit of exporting is generally larger than that of abatement the pattern across the distribution of productivity, export demand and abatement history is qualitatively similar to the marginal benefit of abatement. In particular, we observe that the marginal benefit to exporting is generally increasing in productivity, past abatement decisions and export demand. However, the marginal benefit to abatement increases most strongly with the firm-level export demand shocks.

Appendix G. 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 these expenditures have any significant impact on energy use, intermediate demand or capital stock. As noted by Hemamala et al. (1995) and Cole and Elliott (2003) these inputs are 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 impact 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} captures the firm's decision to abate 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 (as described in the main text). The results for the saw mills and wood furniture industries are presented in Tables A10 and A11. 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.

Table A10: 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.

Tables A10 and A11 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. Surprisingly the coefficient on abatement status, either in the current period or in the previous year, are always insignificant with one exception in both industries. In the third and fourth columns of Tables A10 and A11 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 certifying firms tend to use more intermediate

Table A11: 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.

inputs relative to similar non-certifying firms. Similarly, the insignificant impact of abatement on capital stock in Tables A10 and A11 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 emissions-related variables in these industries.[54]

Appendix H. Details of Bayesian MCMC Estimation

The set of dynamic parameters we estimate in the second stage are $\Theta = (\gamma^A, \gamma^D, \gamma^F, \gamma^S, \gamma_0, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \sigma_\mu, \Phi_X, \theta^d, \theta^e)$ where θ^d and θ^e are, respectively, the parameters for the probit equations for the initial conditions of abatement and exporting. In general, the priors we adopt are very diffuse and we adopt the priors from Das, Roberts and Tybout (2007) and Aw, Roberts and Xu (2011) where possible. 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_μ distribution is set to follow a $N(0, 10)$ distribution as in the above citations.

Appendix I. Computation of the Firm's Dynamic Problem

In this section we provide detailed information regarding the the 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 , $P(e_{it}|\omega_{it}, z_{it}, k_i, \Phi_t, e_{it-1}, d_{it-1})$, and abatement, $P(d_{it}|\omega_{it}, z_{it}, k_i, \Phi_t, e_{it-1}, d_{it-1})$. 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 $V^0(\omega, z, k, \Phi, e_{-1}, d_{-1})$.
2. Calculate the expected value

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

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

[54]We have repeated numerous other checks using different specifications and always found the same result. These can be found at https://my.vanderbilt.edu/joelrodrigue.

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

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

and

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

4. Using our calculations in step (3) we construct the value function $V^1(z,\omega,e_{-1},d_{-1},k,\Phi)$ using equation (9) as:

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

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

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:

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

where $p^N(z_n,\omega_n|z,\omega,e,d) = \frac{p(z_n|z)p(\omega_n|\omega,e,d)}{\sum_{n=1}^{N}p(z_n|z)p(\omega_n|\omega,e,d)}$. We then use the computed values of the expected value functions directly in the construction of the conditional choice probabilities.

Appendix J. Counterfactual Details

In this section we discuss the computation of the quantity produced by each firm under the benchmark and counterfactual exercises. Equation (13) in the main text relates the firm's domestic and export revenues to total variable costs. Given constant returns to scale in production and an estimate of each firm's marginal costs we can recover the quantity produced by dividing total variable costs by marginal costs, as defined in equation (1). Our first stage estimation exercise recovers an estimate of firm-level productivity and an estimate of β_k. However, it does not provide an estimate of $\beta_0 + \beta_w w_t$ (the year-industry specific constant). To recover $\beta_0 + \beta_w w_t$ we note that using domestic and export revenues we have the following relationship

$$\beta_0 + \beta_w w_t = \frac{\ln(r_{it}^X) - \ln \Phi_t^X - z_{it}}{\eta_x + 1} - \ln\left(\frac{\eta_x}{\eta_x + 1}\right) - \beta_k k_{it} + \omega_{it}. \tag{J.1}$$

Given that all of the terms on the LHS of equation (J.1) are observable for exporting firms we can estimate the combined term $\beta_0 + \beta_w w_t$. In practice, we observe little variation in $\beta_0 + \beta_w w_t$ over our sample and restrict it to be constant over time.