Do Environmental Regulations Affect the Decision to Export?*

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Abstract

This paper investigates how a common form of environmental regulation – air quality standards – affect exporters. We develop a simple theoretical model to show how the design of these standards causes: (i) some firms to stop exporting, and (ii) a reduction in the export volumes of affected continuing exporters. We exploit quasi-experimental variation resulting from the design of Canadian air quality standards to test these predictions empirically. Our estimates confirm the predictions of our model: we find that for the most affected manufacturers, regulation reduced export volumes by 36% and increased the likelihood plants exit exporting by 5%.

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1 Introduction

Exporters often take an outsized role in popular debates over the effects of environmental regulation due to concerns over how these policies affect the ability of domestic firms to compete globally. The underlying intuition is quite simple: environmental regulations raise costs for domestic producers, making it more difficult for them to compete in foreign markets with firms who do not face similar policies. Yet, despite the popular appeal of this intuition amongst both policymakers and the public at large, there is surprisingly little evidence of how environmental regulations affect individual exporters.[1]

The purpose of this paper is to address this issue. To do so, we ask how a commonly used form of environmental regulation – air quality standards – have affected the export participation decisions and export volumes of manufacturing plants. Our analysis proceeds in two steps. First, we develop a simple general equilibrium model to obtain a set of predictions as to how air quality standards affect exporters. Second, we exploit quasi-experimental variation created by a major revision to Canadian air quality regulation - the implementation of the Canada Wide Standards for Particulate Matter and Ozone (CWS) - to test these predictions using data from Canadian manufacturing plants over the period 2004-2010.[2]

While debates over the effects of environmental regulation have encompassed many different policies, our choice to focus on air quality standards is motivated by their legislative importance around the world. Air quality standards have been employed in many countries; for example, both the US and Europe have used air quality standards to address air pollution (via the Clean Air Act Amendments and EU Clean Air Directives, respectively) that are very similar in design to the CWS. Moreover, these policies have had a significant effect on environmental quality; they explain close to 40% of the reduction in the emission intensity of the manufacturing sector (Najjar and Cherniwchan, 2017).

Although air quality standards have had a large effect on pollution, it is not immediately obvious how they will affect exporting. This is due to the fact that air quality standards are not imposed uniformly across all firms, unlike many other common forms of environmental policy. Instead, the typical air quality standard requires regulated firms to either: (i) adopt "leading technologies" that lower the emission intensity of production, or (ii) face a regulatory sanction, such as a fine or production quota.[3] This means that the effects of air quality

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[1] Although there is little work examining the effects of environmental regulations on individual exporters, there is a large literature studying the effects of environmental regulations on aggregate trade flows. For overviews of this work, see Copeland and Taylor (2004), Copeland (2011), or Cherniwchan et al. (2017).

[2] In what follows, we use terms firm and plant interchangeably. We do this as most of the plants in our sample are single plant firms. We examine whether the presence of multi-plant firms affects our main results in our empirical analysis, and find they do not affect our main conclusions.

[3] Most air quality standards feature this type of two-part regulation. For example, the design of the

standards on exporting will depend on how firms choose to comply with regulation, making the effects of the policy difficult to predict ex-ante.

To confront this problem, we develop a simple two-sector general equilibrium model of a small open economy in which the exporting and regulatory compliance decisions of polluting firms are determined endogenously. Our model has three key features. First, it allows for polluting firms to select into exporting on the basis of their productivity, as in the workhorse trade model of Melitz (2003). Second, it allows for polluting firms to reduce their emission intensity via the adoption of a more efficient production technology.[4] Third, we assume domestic firms are regulated via constraints similar to those imposed under a typical air quality standard: these firms must either adopt cleaner technologies or pay a pollution tax.

This framework delivers three main results. First, it predicts that, on average, air quality standards will lower export revenues from continuing exporters. Second, it predicts that air quality regulation will cause some firms to exit exporting. That is, regulation should produce a change in both the intensive- and extensive-margin of exporting. The first two predictions are a straightforward result of the fact that, on average, air quality standards raise production costs. The model's third prediction is that both these intensive- and extensive-margin effects of air quality standards will be concentrated among the smallest exporters. This pattern arises because of the specific design of policy. Given that these regulations have an implicit two-part structure, only large and relatively productive firms find it profit-maximizing to comply with regulation by adopting cleaner technologies. The remaining relatively small and low productivity firms instead face higher production costs as a result of incurring a penalty for not upgrading (the pollution tax). This cost increase makes it more difficult for relatively small exporters to compete internationally, causing some to exit exporting, and a reduction in export revenues for those small continuing exporters, for which exporting remains profitable.[5]

We test these predictions empirically using a unique longitudinal dataset that contains information on both the pollution emissions and production decisions of Canadian manufacturing plants over the period 2004-2010. In addition to containing information on the value of exports, this dataset contains information on plant pollution emissions, which allows us to

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US Clean Air Act requires regulated establishments to adopt state-of-the-art abatement technologies, and imposes fines on those that fail to do so (Greenstone, 2002). European standards have a similar design; EU Directive 2010/75/EU requires firms to adopt the best available techniques, and imposes penalties on those that fail to do so (European Parliament, 2010).

[4] We make this assumption for consistency with the design of air quality standards; as we noted above, these regulations typically use "leading" technologies as a benchmark for policy, a point we return to below.

[5] It is also worth noting that our model also predicts air quality standards will cause exporter revenues to fall by more than domestic revenues, as domestic price levels adjust in response to policy. While this is not a core result, as we discuss further below, we also test this prediction prediction empirically as a further means to validate the model.

determine which plants in each industry were subject to regulation. This makes it possible for us to identify the effects of air quality standards on exports from individual plants.

The empirical challenge we face is in credibly identifying the effects of air quality standards given the possibility of confounding factors, such as industry-specific demand shocks. To address this issue we exploit variation in regulatory stringency created by the design of the CWS. The CWS established thresholds for the ambient concentration of $\mathrm{PM}_{2.5}$ to ensure a minimum level of air quality; regions where ambient $\mathrm{PM}_{2.5}$ concentrations exceeded the minimum threshold in a given year were subject to more stringent regulation than others. These features created variation in regulation across time and regions. Moreover, by law, the CWS targeted plants in industries that were viewed as a primary cause of poor air quality, creating variation in regulation across industries.[6] Hence, to identify the causal effects of the CWS on exporting, we utilize a triple-difference research design that exploits variation in regulatory stringency across time, region and industry. This approach allows us to flexibly control for other factors that would otherwise confound the effects of the CWS.

Using this approach, we find robust evidence that the CWS affected exporters in a manner consistent with the predictions of our model.[7] Our baseline estimates suggest that the CWS had a large effect on export volumes; we find that the CWS caused export revenues from the average continuing exporter to fall by just under 22%. The CWS appears to have a much smaller effect on exit from exporting; our baseline estimates suggest that the CWS increased the likelihood of exiting the export market by just over 1%, although this effect is not statistically significant at conventional levels.

While these results suggest that air quality standards primarily affect continuing exporters, the results of our model suggest that these estimates may mask potentially important heterogeneity created by the design of policy. As noted above, our model predicts that the effects of air quality standards will be concentrated among the smallest exporting plants. To test this prediction empirically, we allow the estimated effects of the CWS to differ across plants on the basis of their initial size. The results are as expected; we find that for plants in the bottom quartile of the plant-size distribution, the CWS reduced the likelihood of exporting by 5% and export volumes by 36%. These findings suggest that the effects of environmental regulation on exporters depend explicitly on the design of policy.

Altogether, our findings contribute to four distinct literatures. First is the large body of

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[6] For further details on the design and implementation of the CWS, see Section 3.2.

[7] We show that our baseline results are robust to a number of factors, including controlling for the effects of ozone regulations enacted under the CWS, controlling for foreign ownership, restricting our sample to exclude any plants that do not sell domestically, including lagged dependent variables to account for the presence of sunk costs, and accounting for differences across single and multi-plant firms. We also show that our results are not simply capturing the effects of a systematic relationship between a regions air quality and the export decisions of the region's manufacturing plants.

research examining the effects of environmental regulation on international trade. Much of this work has focused on aggregate trade flows (e.g. Ederington et al. (2005); Levinson and Taylor (2008); Kellenberg (2009); Bustos (2011); Aichele and Felbermayr (2015); Millimet and Roy (2016)). Our work contributes to this literature by providing evidence of the microfoundations underlying these aggregate responses to regulation.[8] In so doing, we show that changes in aggregate trade flows may be due to both extensive-margin changes in the set of firms that export, and intensive-margin changes in export volumes from continuing exporters. However, our findings also suggest that the relative magnitude of these margins will depend on both the design of policy and the extent of heterogeneity across firms.[9]

The second literature our research contributes to is the large body of work examining the effects of air quality regulations. At present most of this research has focused on domestic outcomes, such as output (e.g. Greenstone (2002)), entry and exit (e.g. Henderson (1996); Becker and Henderson (2000); List et al. (2003)), productivity (e.g. Berman and Bui (2001b); Greenstone et al. (2012)), employment (e.g. Berman and Bui (2001a); Walker (2013)), pollution (e.g. Greenstone (2003); Gibson (2016)), and pollution intensity (e.g. Najjar and Cherniwchan (2017)). By focusing on international outcomes, our work is most closely related to that of Hanna (2010), who examines how air quality standards imposed under the Clean Air Act affected the foreign direct investment decisions of US multinational firms.[10] Our work builds on that of Hanna by examining another aspect of firm participation in global markets: exporting.

Our work also contributes to a burgeoning literature studying environmental regulations and pollution in general equilibrium models featuring firm heterogeneity. To date, much of this work has focused on closed economies (e.g. Konishi and Tarui (2015); Tombe and Winter (2015); Anoulies (2017); Najjar and Cherniwchan (2017); Andersen (2018)). By developing a model to study the effects of environmental regulations in an open economy, our work is more closely related to that of Shapiro and Walker (2018) and Kreickemeier and Richter (2018), who each examine the effects of emissions taxes that are applied uniformly across

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[8] By focusing on the microfoundations underpinning how environmental regulations affect trade flows, our work is also related to Hering and Poncet (2014) and Shi and Xu (2018), who study the effects of environmental regulations on Chinese exporters. However, both Hering and Poncet, and Shi and Xu study the effects of regulation on aggregate measures of trade rather than individual exporters.

[9] Our results also contribute to a related literature examining the micro-foundations of the relationship between international trade and the environment. To date the majority of these studies have focused on how international trade affects environmental outcomes at individual manufacturing plants (e.g. Martin (2012), Cherniwchan (2017)). Our work contributes to this line of research by providing evidence of how environmental regulations affect manufacturing plants' participation in international trade.

[10] Other recent work examining the effects of environmental policy on foreign direct investment includes that of Chung (2014) and Cai et al. (2016). For an overview of the literature examining how environmental regulations affect FDI see Cole et al. (2017).

firms. We depart from these papers by instead examining the two-part regulatory structure that underpins commonly used air quality standards.

Finally, our work contributes to a large literature studying the determinants of exporting. This literature has examined various factors that affect exporting, including exporter characteristics (Bernard et al., 1995; Bernard and Jensen, 1999), sunk costs (Roberts and Tybout, 1997), financial constraints (Greenaway et al., 2007; Manova et al., 2015), and experimentation (Albornoz et al., 2012), amongst other factors. We build on this earlier work by showing how environmental regulations affect export decisions.

The remainder of this paper proceeds as follows. Section 2 presents our model. Section 3 discusses our data. Section 4 discusses our research design and presents our baseline empirical specification. Section 5 presents our results. Section 6 concludes.

2 A Model of Air Quality Standards and Exporting

We begin our analysis by developing a simple general equilibrium model of a small open economy in which the domestic government regulates pollution using the two-part regulatory approach implicit in many air quality standards. As we discussed above, our motivation for doing so stems from the fact that with this type of regulatory design, firms are able to respond endogenously; each firm will choose the method of compliance (technological upgrading or incurring regulatory penalties) that it finds to be profit maximizing, making the effects of air quality standards difficult to predict ex-ante. We use our model to derive several empirical predictions as to the effects of air quality standards on exporters. Below, we outline the core features of the model and highlight its key empirical predictions. For the sake of brevity, we relegate many details of the model's solution and the relevant derivations to the appendix.

2.1 Setup

We consider a small open economy populated with L identical agents, each endowed with a single unit of labor. Labor is supplied inelastically, and is used as an input to produce in two active sectors. One sector produces homogeneous goods, while the other sector produces differentiated goods. The production of differentiated goods creates pollution as a byproduct; this harms domestic consumers, lowering their utility.

Given that the economy is small and open, domestic agents are able to consume both domestically produced and imported goods. As such, domestic agents spend all available income, I, to maximize their utility, given by:

$$U = \alpha \ln \left[\int_{v \in \Omega} q(v)^{\rho} dv + \int_{v' \in \Omega_m} q(v')^{\rho} dv' \right]^{1/\rho} + [1-\alpha] \ln q_0 - h(Z), \tag{1}$$

where $0 < \alpha < 1$ and $0 < \rho < 1$. $q(v)$ and $q_m(v')$ denote the consumption of domestic and foreign varieties of differentiated goods, respectively, while Ω and Ω_m denote the sets of all available domestic and imported varieties. The elasticity of substitution between differentiated goods is given by $\sigma = 1/[1-\rho]$. The consumption of the homogeneous good is denoted q_0. Finally, $h(Z)$ denotes the damage from aggregate pollution Z. We assume that consumers ignore the effects of pollution when making their consumption decisions.

With this setup, the demand for domestic and imported differentiated goods by domestic agents are given by:

$$q(v) = p(v)^{-\sigma} P^{\sigma-1} E_D \quad \text{and} \quad q_m(v') = p_m(v')^{-\sigma} P^{\sigma-1} E_D, \tag{2}$$

where $p(v)$ and $p_m(v')$ denote the prices of domestically produced variety v and imported variety v', respectively, $E_D = \alpha I$ denotes total expenditure on differentiated goods, and P is the price index given by:

$$P = \left[\int_{v \in \Omega} p(v)^{1-\sigma} dv + \int_{v' \in \Omega_m} p_m(v')^{1-\sigma} dv' \right]^{\frac{1}{1-\sigma}}. \tag{3}$$

Similarly, domestic demand for the homogeneous good is given by $q_0 = E_0/p_0$, where $E_0 = [1-\alpha]I$ and p_0 are total expenditure on, and the price of, the homogeneous good, respectively.

To complete the demand side of the model, we need to account for foreign demand of both domestically produced differentiated and homogeneous goods. To do so, we adopt an approach similar to that of Demidova and Rodríguez-Clare (2009) and assume that these demands depend on exogenous parameters. Specifically, we assume foreign demand for differentiated goods is given by:

$$q_x(v) = p_x(v)^{-\sigma} A_D, \tag{4}$$

where $p_x(v)$ is the export price of a domestically produced variety, and A_D is exogenously given. Similarly, we assume foreign demand for the homogeneous good is given by $q_0' = A_0/p_0$, where A_0 is exogenously given.[11]

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[11] In what follows, we assume that the magnitudes of A_D and A_0 are sufficient to ensure diversified production in both economies.

The domestic homogeneous goods sector is perfectly competitive. The production of a unit of the homogeneous good requires a single unit of labor, and its production creates no pollution. For convenience, in what follows, we let the homogeneous good be the numeraire, meaning that domestic wages are equal to one.

The domestic differentiated goods sector is characterized by monopolistic competition and free entry, meaning each firm produces a unique variety of differentiated good. Entry requires firms to pay a fixed entry cost, denoted f_ϵ. Upon entering, each firm draws a productivity φ from a known pareto distribution, denoted by $G(\varphi) = 1 - \varphi^{-k}$.

After entering, firms observe their draw of φ and decide whether or not to exit the market. If they do not exit, they are faced with two additional decisions. First, firms must decide whether to retrofit their production technology that lowers their pollution emissions. We assume that upon entry, firms are endowed with a "dirty" production technology that has a labor requirement of $f + q/\varphi$ to produce q units of output and a pollution-labor ratio of $z(\varphi)/l(\varphi) = \kappa$. This means that the pollution emitted by firm with productivity level φ using the dirty technology is $z(\varphi) = \kappa/\varphi$. Firms are able abate pollution by adopting a retrofitted "clean" technology that has a pollution-labor ratio of $z_r(\varphi)/l_r(\varphi) = \kappa/\gamma$, where $\gamma > 1$. For a firm with productivity level φ, retrofitting results in pollution emissions of the level $z_r(\varphi) = \kappa/\gamma\varphi$. Adopting this retrofit technology requires firms to pay an additional fixed cost of f_r.

The second decision faced by firms if they do not exit is whether they should sell to the domestic market or to both the domestic and foreign market. Following Melitz (2003), we assume that exporting to the foreign market requires firms to incur an additional fixed cost, denoted by f_x.

It is worth noting that in what follows, we assume $f < f_x < f_r$. We assume $f < f_x$ to be consistent with the empirical observation that not all firms export; as we show below, this assumption ensures that only a subset of firms select into exporting. We assume $f_x < f_r$ to be consistent with the available empirical evidence relevant to our empirical setting; estimates of the fixed cost of exporting range between approximately \$325,000 and \$400,000 (Das et al., 2007), whereas the fixed cost associated with installing abatement equipment exceeds \$640,000 (Becker, 2005).[12]

After making their technological adoption and export market entry decisions, firms produce output to maximize profit. In each period, firms face an exogenous probability of exit, denoted by δ.

To complete the supply side of the model, we need to account for foreign supply of homogeneous and differentiated goods. For simplicity, we assume that the market structures

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[12] All figures reported in 1988 US dollars.

and production technologies of the foreign homogeneous and differentiated goods sectors are the same as in the domestic economy, and that the fixed costs, productivity distribution, and exit probability associated with the foreign differentiated goods sector are also the same as in the domestic economy. However, for tractability, we denote the fixed cost foreign firms must pay to enter the domestic market by f_m.

2.2 The No-Regulation Equilibrium

Our interest is in understanding the effects of air quality standards on the export decisions of domestic firms in the differentiated goods sector. Hence, we start by examining these decisions in the "no-regulation" equilibrium (denoted with a superscript *no*), in which the domestic government does not regulate pollution emissions. Other details of the no-regulation equilibrium, such as the supply decisions of foreign firms and the relevant equilibrium conditions, are given in the appendix.

Given our assumption on preferences, domestic firms in the differentiated goods sector set a constant markup over marginal costs. Hence, in the absence of regulation, a firm with productivity φ charges $p^{no}(\varphi) = 1/[\rho\varphi]$ in the domestic market and $p_x^{no}(\varphi) = 1/[\rho\varphi]$ in the export market, regardless of its technology choice. This means for a domestic firm with productivity φ, revenues from selling in the domestic market ($r^{no}(\varphi)$) and the export market ($r_x^{no}(\varphi)$) are given by:

$$r^{no}(\varphi) = E_D[\rho P^{no}]^{\sigma-1}\varphi^{\sigma-1} \tag{5}$$

$$r_x^{no}(\varphi) = A_D[\rho]^{\sigma-1}\varphi^{\sigma-1}. \tag{6}$$

It follows that the profits for a firm with productivity φ from selling in the domestic market using the dirty ($\pi^{no}(\varphi)$) and retrofit ($\pi_r^{no}(\varphi)$) technologies are given by:

$$\pi^{no}(\varphi) = \frac{r^{no}(\varphi)}{\sigma} - f, \tag{7}$$

$$\pi_r^{no}(\varphi) = \frac{r^{no}(\varphi)}{\sigma} - [f + f_r], \tag{8}$$

and the profits from selling in the domestic market and exporting using the dirty ($\pi_x^{no}(\varphi)$) and retrofit ($\pi_{x,r}^{no}(\varphi)$) technologies are given by:

$$\pi_x^{no}(\varphi) = \frac{r^{no}(\varphi) + r_x^{no}(\varphi)}{\sigma} - [f + f_x], \tag{9}$$

$$\pi_{x,r}^{no}(\varphi) = \frac{r^{no}(\varphi) + r_x^{no}(\varphi)}{\sigma} - [f + f_r + f_x]. \tag{10}$$

After receiving their productivity draw, firms choose between the dirty and retrofitted technology, and which markets to serve to maximize profits. These choices are depicted in Figure 1, which displays the profit functions associated with each firm choice as a function of productivity.

As the figure shows, a firm's profit maximizing choice will depend on its productivity level, φ. Let

$$\varphi_{\epsilon}^{no} = \left[\frac{\sigma f}{E_D}\right]^{\frac{1}{\sigma-1}} \left[\frac{1}{\rho P^{no}}\right] \tag{11}$$

denote the productivity cutoff such that a firm is just indifferent between exiting and entering the market using the dirty technology, and let

$$\varphi_{x}^{no} = \left[\frac{\sigma f_x}{A_D}\right]^{\frac{1}{\sigma-1}} \left[\frac{1}{\rho}\right] \tag{12}$$

denote the productivity cutoff such that a firm is just indifferent between exporting and only serving the domestic market using the dirty technology. Then any firm that receives a productivity draw such that $\varphi < \varphi_{\epsilon}^{no}$ will exit, and any firm that receives a productivity draw such that $\varphi_{x}^{no} \leq \varphi$ will export using the dirty technology. Similarly, any firm that receives a productivity draw such that $\varphi \in [\varphi_{\epsilon}^{no}, \varphi_{x}^{no})$ will adopt the dirty technology and only serve the domestic market.

As Figure 1 also shows, no firm chooses to adopt the retrofit technology to lower their emissions in the absence of regulation. This is due to the fact that, in the absence of regulation, reducing pollution necessarily raises costs for the firm. Hence, it is profit maximizing for no firm to adopt the retrofit technology in the absence of regulation.

2.3 The Effects of Air Quality Standards on Exporting

Having determined the choices of differentiated domestic firms in the absence of regulation, we now consider the effects of the domestic government regulating domestic pollution emissions using a two-part regulatory rule similar to those implicit in commonly used air quality standards. Given our interest in obtaining empirical predictions as to the effects of these regulations on domestic firms in the differentiated goods sector, below we again focus on our discussion on these firms; other details are again relegated to the appendix.

The two-part regulation (*reg*) imposed by the domestic government requires firms to either adopt a clean, low emission-intensity production technology, or pay a pollution charge

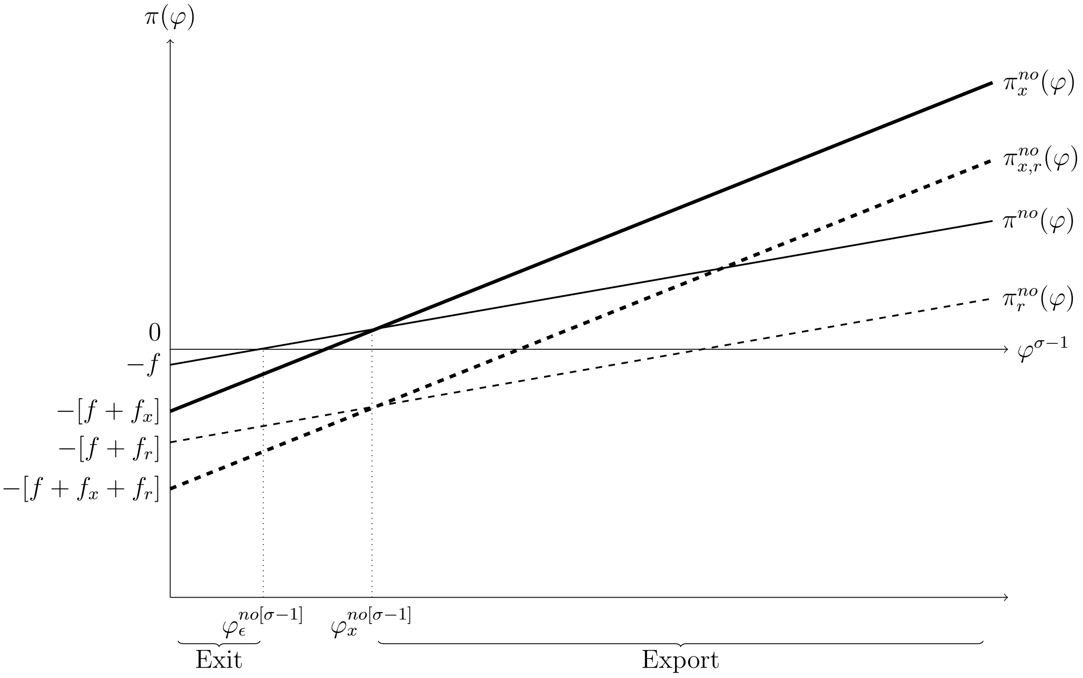

Figure 1: Export and Abatement Choice Without Environmental Regulation

τ, that is levied on each unit of pollution emitted.[13] Given that no firm unilaterally chooses to adopt the retrofit technology in the absence of regulation, this means that all firms now face a choice of how to comply with regulation: adopt the retrofit production technology that has a lower emission intensity, or pay $\tau z(\varphi)$.

Adopting the retrofit technology requires firms to incur the additional fixed cost f_r, but leaves marginal costs unchanged. As such, a firm with productivity φ that chooses adoption will charge $p_r^{reg}(\varphi) = p^{no}(\varphi) = 1/[\rho\varphi]$ in either market, so the revenues from selling domestically and in the export market are given by:

$$r_r^{reg}(\varphi) = E_D[\rho P^{reg}]^{\sigma-1}\varphi^{\sigma-1} \tag{13}$$

$$r_{x,r}^{reg}(\varphi) = A_D[\rho]^{\sigma-1}\varphi^{\sigma-1} \tag{14}$$

and

$$\pi_r^{reg}(\varphi) = \frac{r_r^{reg}(\varphi)}{\sigma} - [f+f_r], \tag{15}$$

$$\pi_{x,r}^{reg}(\varphi) = \frac{r_r^{reg}(\varphi) + r_{x,r}^{reg}(\varphi)}{\sigma} - [f+f_r+f_x] \tag{16}$$

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[13] To be consistent with the design of air quality standards used in practice, we assume that any revenues collected from the pollution charge are spent outside the model.

are the profits from serving the domestic market and both the domestic and foreign markets using the retrofit production technology, respectively.

Choosing to use the dirty technology necessarily increases marginal costs due to the pollution charge; with constant mark-ups, output prices must increase as well. As a result, a firm with productivity φ that chooses to use the dirty production technology will charge a price $p^{reg}(\varphi) = [1 + \tau\kappa]/\rho\varphi$ in either market, so revenues from selling domestically and exporting are given by:

$$r^{reg}(\varphi) = \frac{E_D \left[P^{reg}\rho\right]^{\sigma-1} \varphi^{\sigma-1}}{\left[1 + \tau\kappa\right]^{\sigma-1}} \tag{17}$$

$$r_x^{reg}(\varphi) = \frac{A_D \left[\rho\right]^{\sigma-1} \varphi^{\sigma-1}}{\left[1 + \tau\kappa\right]^{\sigma-1}} \tag{18}$$

and profits from selling in the domestic market and both domestically and abroad are given by:

$$\pi^{reg}(\varphi) = \frac{r^{reg}(\varphi)}{\sigma} - f \tag{19}$$

$$\pi_x^{reg}(\varphi) = \frac{r^{reg}(\varphi) + r_x^{reg}(\varphi)}{\sigma} - [f + f_x]. \tag{20}$$

Clearly, complying with regulation reduces a firm's profitability regardless of whether it chooses to retrofit or use the dirty technology. However, the profit maximizing choice will depend on the firm's productivity draw.

This can be seen in Figure 2, which illustrates the partial equilibrium effects of environmental regulation holding the domestic price index associated with the differentiated goods sector (P) fixed.[14] As the figure shows, the imposition of the pollution charge τ makes producing with the dirty production technology less profitable at any level of productivity. This means that it is now profitable for some firms to adopt the retrofit technology, as the increase in fixed costs associated with doing so is smaller than the increase in variable costs that arise from utilizing the dirty technology. Letting $T(\tau) = \left[\frac{[1+\tau]^{\sigma-1}-1}{[1+\tau]^{\sigma-1}}\right] > 0$, then

$$\varphi_r^{reg} = \left[\left[\frac{\rho^{\sigma-1}}{\sigma}\right]\left[\frac{f_r}{T(\tau)}\right]\left[E_D P^{reg(\sigma-1)} + A_D\right]\right]^{\frac{1}{\sigma-1}} \tag{21}$$

denotes the productivity cutoff such that firms are indifferent between using the retrofit and

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[14] For expositional simplicity, we do not plot profits associated with using the retrofitted technology to serve the domestic market only; given our assumptions on the relative magnitudes of fixed costs, firms never choose to adopt the retrofit technology without exporting.

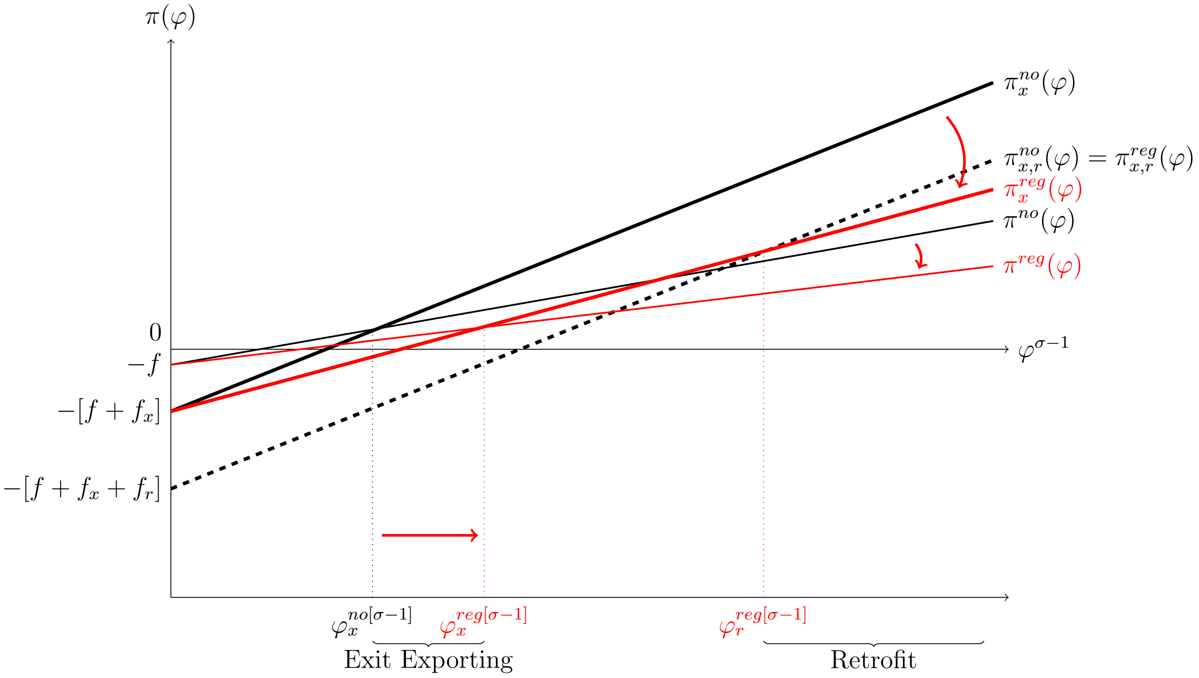

Figure 2: Export and Abatement Choice With Environmental Regulation

dirty technologies.[15] Then firms with $\varphi \in [\varphi_r^{reg}, \infty)$ choose to adopt the retrofit technology in response to regulation.

Figure 2 also shows that some firms exit the export market in response to regulation. This is due to the increase in costs created by regulation; these increased environmental costs mean that some firms are no longer able to afford to pay f_x, meaning it is now profit maximizing for these firms to exit exporting. Let

$$\varphi_x^{reg} = \left[\frac{\sigma f_x}{A_D}\right]^{\frac{1}{\sigma-1}} \left[\frac{1+\tau}{\rho}\right]. \tag{22}$$

denote the productivity such that firms are indifferent between exporting and only serving the domestic market using the dirty technology when regulated. Then, relatively low-productivity exporters – that is, exporters with $\varphi \in [\varphi_x^{no}, \varphi_x^{reg})$ – exit the market in response to regulation.

While Figure 2 is useful for developing intuition as to how firms endogenously respond to the imposition of an air quality standard, our ultimate interest is obtaining a set of empirical predictions as to the effects of this type of regulation on export volumes and participation

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[15] This requires imposing parameter restrictions such that $\varphi_r^{reg} > \varphi_x^{reg}$. The parameter restriction required for this to be a valid equilibrium is $f_r > T(\tau)\left[[1+\tau]^{\sigma-1} f \left[\frac{\varphi_x^{reg}}{\varphi_\epsilon^{reg}}\right]^{\sigma-1} + \frac{\rho^{\sigma-1} A_D}{\sigma}\right]$

in exporting. As such, we now turn to consider the effects of regulation while allowing all prices to adjust.

We begin by examining the effects of regulation on the export volumes of continuing exporters.

Proposition 1. *Regulation causes a reduction in average export revenues from continuing exporters.*

Proof. To prove Proposition 1, note that the average export revenues of domestic differentiated goods firms absent regulation are given by:

$$\begin{aligned}\bar{r}_x^{no} &= \int_{\varphi_x^{no}} r_x^{no}(\varphi)g(\varphi)d\varphi \\ &= \left[\frac{k}{\eta}\right]\left[\frac{\rho^{\sigma-1}A_D}{\varphi_x^{no^{\eta}}}\right],\end{aligned} \tag{23}$$

where $\eta = k - [\sigma - 1] > 0$. Similarly, average export revenues under regulation are given by

$$\begin{aligned}\bar{r}_x^{reg} &= \int_{\varphi_x^{reg}}^{\varphi_r^{reg}} r_x^{reg}(\varphi)g(\varphi)d\varphi + \int_{\varphi_r^{reg}} r_{x,r}^{reg}(\varphi)g(\varphi)d\varphi \\ &= \left[\frac{k}{\eta}\right]\left[\rho^{\sigma-1}A_D\right]\left[\left[\frac{1}{\varphi_x^{reg^{\eta}}}\right] - T(\tau)\left[\frac{1}{\varphi_x^{reg^{\eta}}} - \frac{1}{\varphi_r^{reg^{\eta}}}\right]\right],\end{aligned} \tag{24}$$

where the second equality follows from $r_x^{reg} = r_{x,r}^{reg} - T(\tau)r_{x,r}^{reg}$.

Now, consider the set of firms that continue exporting following regulation (those with productivity $\varphi \geq \varphi_x^{reg}$). Average export revenues in the absence of regulation for these continuing exporters are given by

$$\begin{aligned}\bar{r}_x^{no,cont} &= \int_{\varphi_x^{reg}} r_x^{no}(\varphi)g(\varphi)d\varphi \\ &= \left[\frac{k}{\eta}\right]\left[\frac{\rho^{\sigma-1}A_D}{\varphi_x^{reg^{\eta}}}\right],\end{aligned} \tag{25}$$

Subtracting Equation (25) from Equation (24) gives the following expression for the change in average export revenues due to regulation for continuing exporters

$$\bar{r}_x^{reg} - \bar{r}_x^{no,cont} = -\left[\frac{k}{\eta}\right]\left[\rho^{\sigma-1}A_D T(\tau)\right]\left[\frac{1}{\varphi_x^{reg^{\eta}}} - \frac{1}{\varphi_r^{reg^{\eta}}}\right]. \tag{26}$$

By construction, $\varphi_r^{reg} > \varphi_x^{reg}$, which means Equation (26) is negative. □

Proposition 1 shows air quality standards affect international trade along the intensive margin. By raising production costs, this type of regulation causes a firm's optimal size in the foreign market to shrink. Thus, on average, regulation reduces export revenues from the domestic firms that continue to export.

Next, we turn to examine the heterogeneity underlying this intensive-margin effect.

Proposition 2. *The reduction in average export revenues caused by regulation is driven by firms who are relatively small exporters prior to regulation.*

Proof. Due to the retrofitting fixed cost, only relatively large, productive domestic firms choose to retrofit in response to regulation. Domestic firms that draw a productivity level below φ_r^{reg} choose not to retrofit, while those that draw a productivity level above this cut-off choose to retrofit. Comparing export revenues for a firm with productivity draw φ yields

$$\frac{r_x^{reg}(\varphi)}{r_x^{no}(\varphi)} = \begin{cases} 1 & \varphi \geq \varphi_r^{reg} \\ \left[\frac{1}{1+\tau}\right]^{\sigma-1} & \varphi_x^{reg} \geq \varphi > \varphi_r^{reg}, \end{cases}$$

which means export revenues fall due to regulation only for the least productive surviving exporters (those with $\varphi \in [\varphi_x^{reg}, \varphi_r^{reg})$). As firm revenues are monotonically increasing in the productivity draw, these firms must have had the smallest export volumes prior to regulation of all domestic exporters that continue exporting following regulation. □

Proposition 2 shows that the intensive margin effect will be driven by relatively small exporters. This result is a product of the design of policy. While all firms are less profitable following regulation, only those firms that choose to use the dirty technology experience a increase in their variable costs. This leads to the differential effect on export revenue; firms that employ the dirty technology raise their prices following regulation while firms that retrofit do not. As a result, dirty-technology firms are less competitive in the foreign market, and their export sales fall.

Our next step is to examine the effects of regulation on the extensive margin. As we discussed above in the context of Figure 2, regulation causes a shift in the productivity cutoff for which it is profitable to export. Thus, we have the following proposition.

Proposition 3. *Regulation causes some domestic producers to leave the export market.*

Proof. Proving Proposition 3 requires showing that the domestic export cut-off increases following regulation. This is straightforward, as the export cut-off with regulation, Equation (22), is clearly larger than the cut-off absent regulation, Equation (12). To make this explicit, note that dividing the export cut-off under regulation by the export cut-off without regulation gives

$$\frac{\varphi_x^{reg}}{\varphi_x^{no}} = 1 + \tau > 0. \tag{27}$$

□

Proposition 3 shows that regulation generates an extensive margin response by causing firms that have productivity $\varphi \in [\varphi_x^{no}, \varphi_x^{reg})$ to leave the export market. Thus, regulation shrinks the measure of domestic firms that enter the domestic market and choose to produce for the foreign market. This occurs because regulation makes production more costly, and domestic firms cannot pass this cost increase onto foreign consumers.

As, by definition, the marginal exporter is the least productive active exporter in the industry, Proposition 3 leads to a straightforward corollary on the extensive margin effects of regulation.

Corollary 1. *The domestic firms that leave the export market in response to regulation are the smallest exporters in the domestic market prior to regulation.*

Proof. Corollary 1 follows from Proposition 3. Any firm with a productivity draw in the interval $[\varphi_x^{no}, \varphi_x^{reg})$ would export absent regulation, but would not export when the domestic economy is regulated. As $\frac{\partial \pi_x^{no}(\varphi)}{\partial \varphi} > 0$, these firms must be the least productive, and thus smallest, exporters absent regulation. □

It is worth noting that a policy that does not differentially regulate firms, such as a uniform pollution tax, would also produce heterogeneity in the extensive-margin effects of regulation in our setup. Any regulation that raises production costs for the marginal exporter will cause firms to exit exporting as long as cost pass-through to the foreign market is not complete. In contrast, a uniform policy will not produce the stark heterogeneity in the intensive-margin effects of regulation on trade that are created by an air quality standard.

Our final step is to examine the differential effects of regulation on revenues from the domestic and foreign markets.

Proposition 4. *For a domestic producer that exports with- and without-regulation, regulation reduces export revenues more than domestic revenues if the retrofitting fixed-cost, f_r is sufficiently large.*

Proof. See the Online Appendix. □

Proposition 4 shows that regulation has a larger effect on the export revenues than domestic revenues of continuing exporters. The underlying intuition is quite straightforward.

Environmental regulation acts as a relative cost shock for domestic firms because it is enacted unilaterally; this makes it more difficult for domestic firms to compete with foreign firms both at home and abroad. However, the presence of fixed export costs mean that the composition of firms that a domestic firm is competing with differs across the domestic and foreign markets. The domestic market is primarily comprised of domestic firms that are also affected by policy, whereas the foreign market is not. As a result, the cost shock created by domestic environmental regulation has a larger effect on demand for domestic products in the foreign market, leading to a proportionally larger reduction in export revenues.

In the empirical analysis that follows, we test these empirical predictions by examining the effect of a change in Canadian environmental policy on the export volumes and export participation decisions of Canadian manufacturing plants. Our test of Proposition 1 comes from examining regulation's effect on the export volumes of affected plants. Our test of Proposition 2 comes from examining how regulation's effect on export volumes varies across the plant size distribution.[16] We test Proposition 3 and Corollary 1 by estimating the effect of regulation on plant exit from the export market, and examining whether this effect varies across the plant size distribution. Finally, we test Proposition 4 by estimating the effect regulation on plant revenue, and comparing this estimate to our estimate of the effects of regulation on export volumes.

3 Data and Measurement

Our goal in this paper is to determine the effect of air quality standards on the export decisions of Canadian manufacturing plants. To do so, we utilize a unique micro dataset that contains information on both the pollution emissions and export decisions of Canadian manufacturing plants over the period 2004-2010. This dataset was created by linking the data from the National Pollution Release Inventory (NPRI), a publicly available dataset containing information on the pollution emissions of Canadian manufacturing facilities, with confidential data on plant characteristics from the Annual Survey of Manufacturers (ASM).[17] Together, these data sources allow us to create a longitudinal dataset containing information on the export decisions of plants that emit fine-scale particulate matter ($PM_{2.5}$), a pollutant regulated in Canada over our period of study as part of the suite of of environmental

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[16] As we discuss further below, we use plant size as a proxy for productivity levels because we are unable to construct and estimate of TFP using our data.

[17] These data were linked by Statistics Canada. For further details on the data and its construction, see Najjar and Cherniwchan (2017).

regulations called the Canada-Wide Standards.[18]

3.1 Descriptive Statistics

In order to understand how air quality standards affect a plant's participation in international markets, we examine three outcomes: plant export sales, the likelihood of exiting the export market, and total plant sales. Together, these variables allow us to test the core propositions from our model.

Summary statistics for total sales, total exports, and the probability of exporting are reported in Table 1. Column (1) of the table reports statistics for our main dataset, which comprises an unbalanced panel of manufacturing plants that emit $PM_{2.5}$ pollution. The summary statistics in column (1) are weighted to account for possible sample bias created by the procedure used to link the NPRI and ASM.[19] For comparison, column (2) of the table reports summary statistics for the entire sample of plants in the ASM. Although we do not use the full ASM dataset in our analysis, we present these statistics to highlight the difference between our sample of polluters and the average Canadian manufacturing facility.

The descriptive statistics reported in Table 1 suggest that, on average, the manufacturing plants that emit $PM_{2.5}$ are substantially larger, are much more likely to export, and export more than the average plant in the Canadian manufacturing sector. This is potentially driven both by reporting requirements for the NPRI, as plants typically only report to the NPRI database if they have at least ten employees, and structural differences between polluters and non-polluters. While we cannot disentangle the two sources of these differences, it is worth noting that the NPRI requires any plant that operates a boiler or generator on-site to report their $PM_{2.5}$ emissions, regardless of their number of employees. As many industrial $PM_{2.5}$ emitters use an on-site boiler or generator, it is unlikely that the employment threshold is the main cause of the differences reported in Table 1.

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[18] While we do not explicitly analyze the pollution data in our empirical work, having this linked data is valuable for two reasons. First, Environment and Climate Change Canada does not maintain a list of historically regulated facilities. Restricting our analysis to known $PM_{2.5}$ emitters ensures we are examining facilities that were likely regulated. Second, restricting our sample to plants that emit $PM_{2.5}$ also ensures we have a valid control group.

[19] In brief, this potential bias occurs because linkage success is correlated with plant size. If the effect of treatment varies by plant size, then relying on the un-weighted data will produce biased results. For details on this issue, and a formal discussion on how weighting corrects this bias, see the online appendix to Najjar and Cherniwchan (2017).

Table 1: Summary Statistics

	$PM_{2.5}$ (1)	Full ASM (2)
Sales (\$1 mill.)	194.62	11.12
	(890.55)	(123.56)
Exports (\$1 mill.)	97.88	6.661
	(709.67)	(89.74)
Pr(Export)	0.76	0.36
	(0.43)	(0.48)
N	6501	309541

Notes: Table reports averages and standard deviations of key variables examined in the main analysis. Each column reports the summary statistics for a different sample. Column (1) is the sample of plants that emit $PM_{2.5}$ and column (2) reports plant characteristics for the entire manufacturing sector. Statistics in column (1) are weighted to account for potential sample bias induced by the match of the NPRI and ASM. All monetary values are reported in 2007 Canadian dollars.

3.2 Canadian Environmental Regulations

We supplement the data from the NPRI-ASM dataset with data from Najjar and Cherniwchan (2017) on whether each plant faced regulation under the Canada-Wide Standards for Particulate Matter and Ozone (CWS).[20] The CWS was a major revision to Canadian environmental policy that occurred in the year 2000 as a result of an agreement between the federal government of Canada and the provinces. The policy was intended to improve air quality across the country by creating air quality standards for fine-scale particulate matter ($PM_{2.5}$) and ground-level ozone (O_3) that applied to each major town or city in Canada.[21] These standards required each CMA to meet an air quality target; those cities with poor ambient air quality were required to adopt stringent environmental regulations, while the remaining CMAs had to ensure that their air quality did not deteriorate. In addition, the CWS designated a set of "targeted" industries that were to be the focus of regulation given that they were viewed as key determinants of poor air quality.[22] Thus, the CWS created variation in regulatory stringency across time, regions, and industries. In Section 4 we discuss

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[20] The Canada-Wide Standards for Particulate Matter and Ozone were two of the many environmental standards enacted under the Canada-Wide Standard system. Canada-Wide Standards were created for benzene, mercury, and dioxins and furans, among others.

[21] Under the terms of the agreement, an urban area's status as a major town or city was determined using Statistics Canada's definitions of Census Agglomeration (CA) or Census Metropolitan Area (CMA). For convenience, we use the terms CMA and city to refer to both CAs and CMAs.

[22] The targeted industries were pulp and paper, lumber and wood product manufacturing, electric power generation, iron and steel manufacturing, base metal smelting, and the concrete and asphalt industries (Canadian Council of Ministers of the Environment, 2000).

how we use this variation to identify the effects of environmental regulation.

While the CWS was a federal policy, the regulation of individual plants was overseen by the various provincial environment ministries. These authorities regulated plants that were in targeted industries and violating regions through the annual provincial operation permitting systems. These systems, in effect, provide plants with the authority to operate in a given jurisdiction. Permitting authorities can impose detailed requirements on a plant's operations, including mandating the adoption of certain production techniques and imposing production constraints (Angle, 2014). As part of this system, regulated plants had to either show they were operating using clean production processes, or face a production constraint (Najjar and Cherniwchan, 2017).[23]

The variation in environmental regulation created by the CWS is shown in Figure 3, which depicts which CMAs were forced to adopt more stringent environmental regulations to address ambient $PM_{2.5}$ and O_3 problems at least once over the period 2000-2010. In the figure, CMAs that adopted more stringent environmental regulations due to ambient pollution concentrations exceeding the relevant air quality standard are depicted in red, orange and yellow. The red CMAs were required to adopt more stringent policy under both the $PM_{2.5}$ and O_3 standards, while the orange and yellow CMAs were only required to adopt more stringent policy under the $PM_{2.5}$ standard or the O_3 standard, respectively. CMAs depicted in green were not required to adopt more stringent policy under either standard.

As the figure shows, the CWS created substantial variation in environmental regulation across CMAs. Of the 149 CMAs in our sample, 23% adopted new regulations under only the $PM_{2.5}$ standard, 26% adopted new regulations under only the O_3 standard, and 11% adopted new regulations under both standards. We exploit this variation, and the fact that the CWS targeted a subset of industries, to identify the effects of environmental regulation on the export decisions of Canadian manufacturing plants.

4 Research Design

To determine the effects of environmental regulation on the export decisions of Canadian manufacturing plants, we adopt the research design we developed in our previous work studying the effects of the CWS on the clean-up of the Canadian manufacturing sector

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[23] This is a common approach to implementing air quality standards. In the US, the National Ambient Air Quality Standards imposed under the Clean Air Act require plants in relatively polluted counties and polluting industries to adopt clean processes, and penalizes those that fail to do so (Greenstone, 2002). In Europe, the EU Industrial Emissions Directive requires the adoption of clean production techniques by facilities in polluted regions, and directs member states to impose penalties on non-complying plants (European Parliament, 2010).

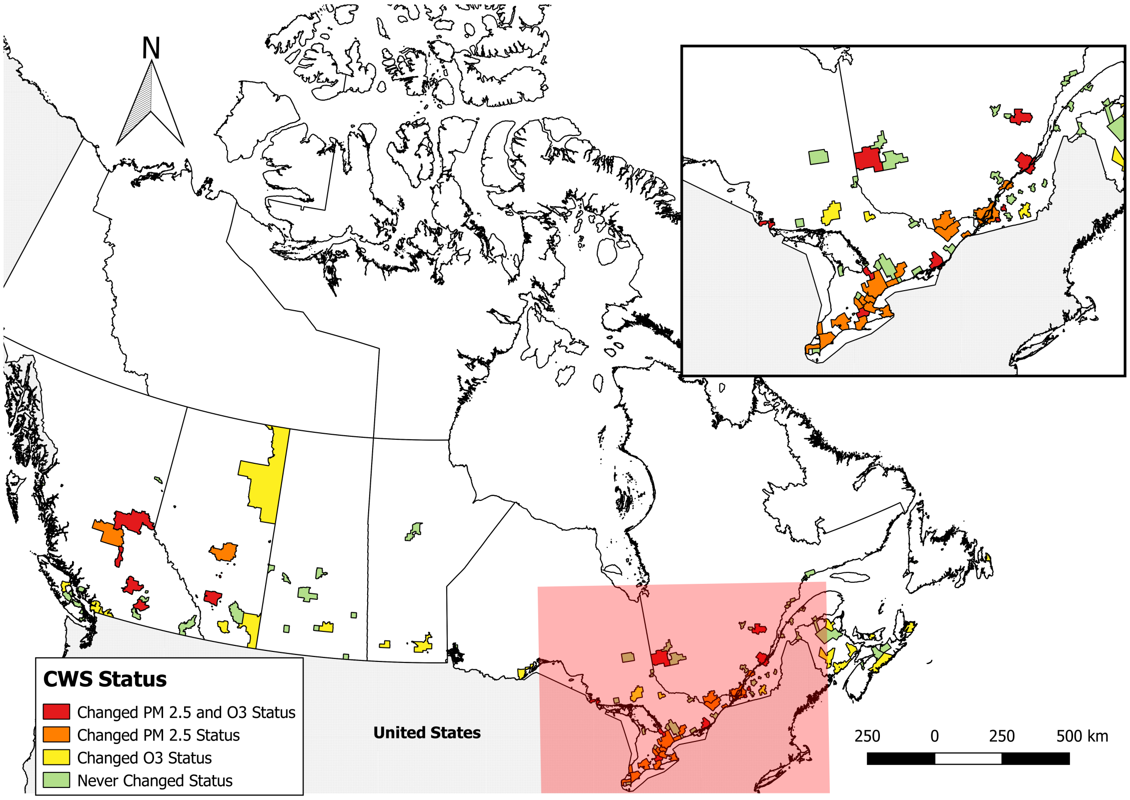

Figure 3: Regulatory Status Changes under the CWS

Notes: Figure depicts $PM_{2.5}$ and O_3 standard status changes for each CMA from 2000 to 2010. Red CMAs changed status under both the $PM_{2.5}$ and O_3 standards. Orange CMAs only changed status for the $PM_{2.5}$ standard. Yellow CMAs only changed status for the O_3 standard. Green CMAs didn't change status under either standard. The mainland United States is shown in light gray. Part of the northern Canadian Territories are trimmed for scale. The inset shows detail on the most densely populated area of Canada, colored in light red on the main map. *Source:* Najjar and Cherniwchan (2017).

(Najjar and Cherniwchan, 2017). As such, we exploit the variation in regulation created by the design and implementation of the CWS. As shown in Figure 3, ambient air quality changes led to variation in the environmental regulations faced by different CMAs over time. Moreover, these regulations targeted a subset of industries in the manufacturing sector, meaning that the regulations varied across industries as well. We use these three sources of variation – across industries, regions, and time – in a triple-difference research design to isolate the causal effects of the $PM_{2.5}$ standard on the export decisions of affected plants.[24]

Our approach starts by exploiting the variation in $PM_{2.5}$ regulation over time. To that end, our research design compares the average outcomes from plants in targeted industries located in regulated CMAs (the plants "treated" by $PM_{2.5}$ regulation) while regulated to their

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[24] As we noted in Section 3, while the CWS regulated both $PM_{2.5}$ and O_3 pre-cursors, we primarily focus on the $PM_{2.5}$ standard for our analysis.

outcomes while unregulated.[25] This comparison allows us to control for any unobserved time-invariant plant, industry, or CMA-specific heterogeneity that would otherwise confound the effects of regulation. For example, this addresses any permanent differences between treated and non-treated plants.[26]

We then exploit the variation in regulation across industries, by comparing the average outcomes from plants in targeted industries to the average outcomes from plants in non-targeted industries located in the same CMA in the same year. This allows us to control for any unobserved time-varying CMA specific heterogeneity, such as localized recessions, that might affect the decision to export. This comparison also allows us to control for any provincial or local policy changes that might affect manufacturing production costs, provided they are not levied specifically against targeted industries. As corporate income taxes vary across provinces and over time, and would potentially affect export decisions, this is an important feature of our research design.[27]

We next exploit the variation in regulation across regions, by comparing average outcomes for plants in the same industry in the same year across violating and non-violating CMAs. That is, we take all plants in a particular industry and year, and compare the average outcomes across CMAs that violate the $PM_{2.5}$ standard at some point in time to the average outcomes across CMAs that never violate the standard. This allows us to control for any time-varying industry heterogeneity, such as foreign demand shocks, that would otherwise confound identification.[28]

Finally, our approach compares the average outcomes of treated plants to the average outcomes of plants in non-targeted industries located in CMAs that did not experience a change in $PM_{2.5}$ regulation. These plants serve as a counterfactual that allow us to capture the effects of any unobserved aggregate shocks, such as changes in technology or exchange rate fluctuations, common across all facilities in the country.

The credibility of this research design rests on the exogeneity of treatment. As we discuss in Najjar and Cherniwchan (2017), there are two reasons to believe that treatment is exogenous. First, the CWS air quality standards were set federally, meaning that they are unrelated to local tastes, characteristics and economic conditions. Second, ambient pollution levels in a CMA do not necessarily reflect local economic activity due to the fact that particulate matter can be transported long distances via wind patterns. A plant in a targeted

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[25] That is, we take plants in targeted industries and regions that violate the $PM_{2.5}$ standard at some point in time, and compare their outcomes while their region is in violation with their outcomes while their region is in compliance.

[26] We accomplish this by including a plant fixed effect in our regressions.

[27] We accomplish this by including a CMA-by-year fixed effect in our regressions.

[28] We accomplish this by including an industry-by-year fixed effect in our regressions.

industry is treated if its region's air quality exceeds the strict, federally set threshold. As air pollution emitted can be transported over long distances due to prevailing winds, and there are many sources of $\mathrm{PM}_{2.5}$ pollution that will affect the air quality of a given CMA, it would be very challenging for a individual plant to intentionally manipulate their region's treatment status. These facts suggest that treatment is exogenous.

Although we believe this identifying assumption is likely satisfied in our context, we nevertheless present the results of a key robustness exercise aimed at assessing this concern following our main analysis. In this exercise, we use the strict threshold nature of the CWS to ensure our results are not simply capturing a relationship between a region's air quality and export decisions of the plants therein, as would exist if plants could manipulate their treatment status. We accomplish this by testing for structural breaks between targeted and non-targeted industries in regions with air quality below the threshold, and find no evidence consistent with a failure of our key identifying assumption.

4.1 Empirical Specification

We implement our research design by estimating several variants of the following equation:

$$y_{pijt} = \beta T_{ijt}^{PM_{2.5}} + \rho_p + \mu_{jt} + \lambda_{it} + \epsilon_{pijt} \tag{28}$$

where y_{pijt} is the outcome of interest (either an indicator of export status, the natural log of total shipments, or the natural log of export sales) at plant p, in industry i, located in CMA j, at time t. $T_{ijt}^{PM_{2.5}}$ is a treatment indicator for the particulate matter standard implemented under the CWS. This indicator takes the value one for plants that are in industries targeted by the CWS for years in which their CMA exceeds the $\mathrm{PM}_{2.5}$ standard's threshold. The ρ_p are plant fixed effects that capture any time-invariant plant specific heterogeneity. The μ_{jt} are CMA×year fixed effects that capture any time-varying region specific heterogeneity, such as localized recessions. The λ_{it} are industry×year fixed effects that capture time-varying industry heterogeneity, such as demand shocks. Finally, ϵ_{pijt} captures idiosyncratic changes in outcomes across plants.

The coefficient of interest in Equation (28) is β. This coefficient capture the average percentage difference in outcomes across plants that were affected by the $\mathrm{PM}_{2.5}$ standard relative to those that were not, and is identified from within-plant comparisons over time. These comparisons will identify the causal effect of environmental regulations if there are no other factors aside from the CWS particulate matter standard driving differences in outcomes across treated and non-treated plants. As we discuss above, we believe this to be true in this context.

While Equation (28) will produce estimates of the average effect of the CWS particulate matter standard, our model predicts that the effects of regulation will differ across plants on the basis of their productivity level. Given that the ASM does not include information on plant capital stocks, making it impossible to calculate TFP measures using standard methods, we assess this heterogeneity on the basis of plant size.[29] For this, we adopt the approach first used by Bustos (2011) to study the differential effects of trade liberalization across plants on the basis of their initial size. Specifically, we estimate:

$$y_{pijt} = \sum_{q=1}^{4} \beta_{Q_q} \left[T_{ijt}^{PM_{2.5}} \times Q_q \right] + \rho_p + \mu_{jt} + \lambda_{it} + \epsilon_{pijt} \tag{29}$$

where Q_q is an indicator variable equal to one if plant p is in plant size quartile q, β_{Q_q} is the effect of the CWS particulate matter standard on plants in size quartile q, and all other variables are defined as in Equation (28).[30]

In both specifications, we cluster standard errors by industry-CMA to address heteroskedasticity introduced by our research design (Bertrand et al., 2004). As our analysis relies on matching two datasets, we also weight each observation by the inverse of the match probability to address any potential bias introduced by the matching procedure.[31]

5 Results

In what follows we use the variation in regulatory exposure created by the CWS to test our model's predictions regarding the effects of air quality standards on exporters. We start by examining regulation's effect on export revenues from continuing exporters, before turning to examine its effect on the decision to exit from exporting. We then examine the effects of the CWS on total revenues from continuing exporters. Finally, we present results from three key robustness checks.

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[29] Recall that in our model, there is a one-to-one mapping between plant productivity and size.

[30] We use two approaches to construct Q_q, depending on the analysis sample. In our samples that are restricted to continuing exporters that export in all years, we define plant size as the natural log of export sales in the first year the plant enters the data and split the plant size distribution for continuing exporters into quartiles. In our sample that includes all plants, we define plant size as the natural log of total revenues in the first year the plant enters the data and split the plant size distribution for all plants into quartiles.

[31] Full details on the match procedure are available in the online appendix to Najjar and Cherniwchan (2017). In short, our data is created by matching plants across two datasets. As the match probability is correlated with firm-size, which is itself potentially correlated with treatment, there is a potential match-induced sample bias. We correct for this bias by weighting observations by the inverse of the (estimated) match probability.

5.1 Export Revenue

Recall that Proposition 1 predicts air quality standards should cause a reduction in average export revenues from domestic firms that continue to export following regulation. We begin our empirical analysis by directly testing this prediction, and examine the effects of the CWS particulate matter regulations on plant export revenues. So as not to conflate intensive-margin with extensive-margin changes, here we restrict our analysis to continuing exporters who sell in foreign markets in each year of our sample.

These results are reported in Table 2. The table reports estimates from five separate regressions; in all cases, the dependent variable is the natural log of export revenues, and each regression is weighted to correct for potential sample bias induced by the procedure used to match the NPRI to the ASM. Throughout, standard errors clustered by industry-CMA are reported in parentheses. The first four specifications reported in columns (1) to (4) are based on equation (28). As such, the estimated coefficient reports the average effect of the particulate matter standard on affected plants. Our baseline estimate, reported in column (1), includes plant, industry-year and CMA-year fixed effects. Columns (2) through (4) present evidence of the robustness of PM regulation's effect on export revenues. Column (2) adds an indicator of whether industry i in CMA j was also regulated under the CWS O_3 standard in year t. Column (3) adds an indicator of whether plant p was owned by a foreign parent at time t. Finally, Column (4) restricts the sample to exclude the set of plants that only export and do not sell domestically.

The last specification, reported in column (5), is based on equation (29) and reports the estimated effects of the particulate matter standard by initial plant-size quartile. While the results in columns (1) to (4) are intended to test Proposition 1, the results in column (5) assess whether changes in production costs were uniformly distributed across the firm-size distribution. That is, column (5) is our test of Proposition 2.

The estimates reported in columns (1)-(4) of Table 2 show the CWS led to a significant reduction in export revenues from affected plants. For example, the estimate reported in column (1) indicates that the the CWS particulate matter standard is associated with a 21.9% reduction in export revenue from affected manufacturing plants. In addition to being statistically significant, this effect is also economically meaningful; given that the average plant in our sample had export revenues of close to \$98 million CAD, this estimate implies that the CWS particulate matter reduced the export revenues of the average plant by just over \$21 million CAD. Our preferred estimate, reported in column (2), shows that this effect is robust to controlling for the effects of the other regulation imposed under the CWS. Adding an indicator of treatment status under the CWS O_3 regulations appears to have no effect on either the point estimate or standard error, suggesting that our estimates of the effect of

Table 2: Environmental Regulations and Export Revenue from Continuing Exporters

	(1)	(2)	(3)	(4)	(5)
$PM_{2.5}$ Std.	-0.219^b	-0.219^b	-0.219^b	-0.242^b	
	(0.055)	(0.056)	(0.056)	(0.056)	
$PM_{2.5}$ Std.×Q1					-0.356^a
					(0.117)
$PM_{2.5}$ Std.×Q2					-0.189
					(0.161)
$PM_{2.5}$ Std.×Q3					-0.150
					(0.133)
$PM_{2.5}$ Std.×Q4					-0.170
					(0.140)
O_3 Std.		X	X	X	X
Foreign Owner			X		
Rest. Sample				X	
R^2	0.288	0.289	0.289	0.297	0.289
Obs.	4093	4093	4093	3807	4093

Notes: Table reports estimates of the effects of the CWS on the natural log of export revenues for plants that are continuing exporters. All regressions include plant, industry-year and CMA-year fixed effects, and are weighted by the inverse of the match probability to control for potential match-induced sample bias. Column (3) includes an indicator of whether the plant is owned by a foreign company. Column (4) restricts the sample to exclude plants that only sell abroad. Column (5) reports estimates of the effects of the CWS by firm size. In all cases, standard errors are clustered by CMA-industry. ^{c}, ^{b}, and ^{a} denote significance at the 10%, 5%, and 1% level, respectively.

the $PM_{2.5}$ standard are not capturing the effects of other CWS regulations.

Columns (3) and (4) provide further evidence that the CWS particulate matter standard negatively affected manufacturing plant export revenues. One concern with our preferred estimate is that it is not just capturing the effects of CWS regulation, but also the effects of foreign ownership, which is time-varying. For example, foreign owners may be able to help offset the effects of a negative shock such as the CWS, in ways not possible for domestically owned plants, by exploiting unique knowledge of their home markets. This type of activity would lead to a downward bias in our estimates if firms respond to regulation by selling regulated plants to foreign companies. The estimate reported in column (3) shows that our preferred estimate is robust to accounting for this explanation; including an indicator of whether a plant is owned by a foreign entity has no discernible effect.

A final concern with our preferred estimate is that it may be driven by plants that do not sell domestically. While our theoretical framework considers the case where plants either only sell domestically or sell both domestically and export, over 5% of our sample is comprised of plants that do not sell in the Canadian market. In principle, the CWS could have a larger effect on the export revenues of these plants because they are potentially at the largest disadvantage when they are regulated. Unlike plants that sell domestically and potentially compete with other plants that are regulated under the CWS, plants that do not sell in the domestic market only compete with foreign plants that are unaffected by the CWS. As a result, our baseline estimates could be simply capturing the effects of the CWS on this set of plants. However, as the estimate reported in column (4) shows, restricting our sample to exclude the set of plants that only sell abroad has little effect on our results. Overall, we conclude there is strong evidence in favour of Proposition 1.

The estimates reported in column (5) suggest that the reduction in export revenue is most pronounced among the smallest exporting plants, and is consistent with Proposition 2. The estimate reported in row three indicates that the CWS particulate matter standard reduced the export revenue of plants in the lowest size quartile by 35.6%. The remaining estimates in column (5) also show a negative effect on export revenues, however, these are not significant at conventional levels.

5.2 Exit Out Of Exporting

Next, we test Proposition 3 and examine the effects of the CWS on the likelihood a plant exits the export market. Given regulation appears to be costly enough to induce a reduction in export revenues, then our model suggests that some plants should stop exporting all together. To test this prediction, we turn to examine our full sample of plants, which includes both exporting and non-exporting plants.

For this exercise, we estimate a linear probability model of the effects of the CWS particulate matter regulations on an indicator of whether a plant exits out of exporting. We label a plant as an "exiter" from exporting in year t if it reported export revenues in year $t-1$, but had no export revenues (but was still in operation) in year t.[32,33]

The results of this exercise are presented in Table 3. We again report estimates from five specifications. The first four, reported in columns (1)-(4) respectively, are based on equation (28), and report the average effect of particulate matter regulation on export status at affected plants. The fifth specification, reported in column (5), is based on equation (29), and reports the effects of the regulation by initial plant-size quartile. This serves as a test of Corollary 1. Here, plant size is measured as a plant's total revenue in the base year, as we include both exporters and non-exporters in the sample. Again, column (1) includes plant, industry-year and CMA-year fixed effects only, while column (2) adds an indicator of

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[32] For other papers that adopt this approach to defining exit, see Berman et al. (2012) or Fatum et al. (2018).

[33] We also examined the CWS' effect on entry into exporting, adopting an analogous specification. We find no evidence that the CWS affected export entry. These estimates are available upon request.

Table 3: Environmental Regulations and Export Exit

	(1)	(2)	(3)	(4)	(5)
$PM_{2.5}$ Standard	0.012	0.012	0.011	0.012	
	(0.017)	(0.016)	(0.016)	(0.017)	
$PM_{2.5}$ Std.×Q1					0.051^{b}
					(0.021)
$PM_{2.5}$ Std.×Q2					-0.025
					(0.029)
$PM_{2.5}$ Std.×Q3					-0.004
					(0.035)
$PM_{2.5}$ Std.×Q4					-0.014
					(0.025)
O_3 Standard		X	X	X	X
Foreign Ownership			X		
Restricted Sample				X	
R^2	0.117	0.117	0.126	0.118	0.131
Observations	6501	6501	6501	6149	6501

Notes: Table reports estimates of the effects of the CWS on an indicator of plant export exit. All regressions include plant, industry-year and CMA-year fixed effects, and are weighted by the inverse of the match probability to control for potential match-induced sample bias. Column (3) includes an indicator of whether the plant is owned by a foreign company. Column (4) restricts the sample to exclude plants that only sell abroad. Column (5) reports estimates of the effects of the CWS by firm size. In all cases, standard errors are clustered by CMA-industry. ^{c}, ^{b}, and ^{a} denote significance at the 10%, 5%, and 1% level, respectively.

whether the plant was regulated under the CWS O_3 standard in a given year, column (3) adds an indicator of foreign ownership and column (4) restricts the sample to exclude the set of plants that only export and do not sell domestically.[34]

The estimates reported in the first four columns of Table 3 provide inconclusive evidence of the CWS' effect on the likelihood of exiting exporting. For example, our baseline estimate, reported in column (1), shows that the CWS increased the likelihood of a plant exiting the export market by just over 1%. Not only is this effect economically small, it is statistically insignificant. This is still true when we control for O_3 regulation, allow for differences in foreign ownership, or restrict our sample to exclude foreign exporters. Thus, the average effects of the CWS on exit from exporting appear to be both muted and imprecise.

The estimates reported in column (5), however, suggest that the average effects of regulation mask substantial heterogeneity in how plants respond to regulation. Specifically, the estimates reported in column (5) show a 5% increase in the likelihood of export exit for plants in the first quartile of the plant-size distribution as a result of the CWS. This

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[34] All regressions are weighted to correct for potential sample bias induced by the procedure used to match the NPRI to the ASM. Standard errors clustered by industry-CMA are reported in parentheses.

result is consistent with our model's prediction that the smallest exporting firms will exit the export market in response to regulation. The intuition behind this heterogeneity, as our model highlights, is that the marginal exporter should be relatively small. Thus, if regulation increases production costs, the plants that exit the export market should be the smallest exporters.

5.3 Domestic vs. Foreign Revenue

Finally, we examine Proposition 4, which predicts air quality standards should cause a larger reduction in export revenues than domestic revenues for continuing exporters. This happens because domestic prices should adjust in response to regulation, while foreign prices should be constrained. To that end, we report estimates of the CWS' effect on total plant revenues for continuing exporters (the same sample of plants included in Table 2), and compare these to our estimates in Table 2.

These results are presented in Table 4, which reports estimates from five separate regressions. In each case, the dependent variable is the natural log of total revenue, and each regression is weighted to correct for potential sample bias induced by the procedure used to match the NPRI to the ASM. The regressions reported in each column correspond to the same columns in Table 2 and Table 2. As such, column (1)-(4) report estimates based on equation (28). Column (1) only includes plant, industry-year and CMA-year fixed effects, while column (2) adds an indicator of whether the plant was regulated under the CWS O_3 standard in a given year, column (3) adds an indicator of foreign ownership, and column (4) again restricts the sample to exclude the set of plants that only export and do not sell domestically. Finally, column (5) reports estimates from a specification based on equation (29) and reports the estimated effects of the particulate matter standard by initial plant-size quartile, where plant size is based on export revenues. While we have no formal proposition that maps into this specification, the model suggests that any reduction in total revenues should be largest for the smallest exporters. We present these results to examine this intuition.

The estimates reported in row one of columns (1)-(4) in Table 4 show that the CWS caused a considerable reduction in total plant revenue from continuing exporters. For example, our preferred estimate, in column (2), shows an average reduction of just under 11%. In addition, this result appears to be robust to our alternative sample restrictions (columns (3) and (4)). Moreover, as is expected, the results in column (5) show that the reduction in total revenues is most pronounced among the smallest exporters.[35]

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[35] In addition, we find similar results if we expand our sample to all operating plants. Our preferred specification (which corresponds to column (2)) yields a point estimate of -0.108 with a standard error of 0.050.

Table 4: Environmental Regulations and Revenue from Continuing Exporters

	(1)	(2)	(3)	(4)	(5)
$PM_{2.5}$ Std.	-0.107^c	-0.107^c	-0.107^c	-0.106^c	
	(0.055)	(0.056)	(0.056)	(0.056)	
$PM_{2.5}$ Std.×Q1					-0.183^b
					(0.084)
$PM_{2.5}$ Std.×Q2					-0.115
					(0.140)
$PM_{2.5}$ Std.×Q3					-0.041
					(0.065)
$PM_{2.5}$ Std.×Q4					-0.090
					(0.071)
O_3 Std.		X	X	X	X
Foreign Owner			X		
Rest. Sample				X	
R^2	0.322	0.322	0.323	0.316	0.323
Obs.	4093	4093	4093	3807	4093

Notes: Table reports estimates of the effects of the CWS on the natural log of plant revenues for plants that are continuing exporters. All regressions include plant, industry-year and CMA-year fixed effects, and are weighted by the inverse of the match probability to control for potential match-induced sample bias. Column (3) includes an indicator of whether the plant is owned by a foreign company. Column (4) restricts the sample to exclude plants that only sell abroad. Column (5) reports estimates of the effects of the CWS by firm size. In all cases, standard errors are clustered by CMA-industry. ^{c}, ^{b}, and ^{a} denote significance at the 10%, 5%, and 1% level, respectively.

Note that the magnitude of our preferred point estimate is effectively half of that reported in column (2) of Table 2.[36] As average exports are approximately half of a plant's total revenue in our sample, this suggest that the majority of the reduction in revenues from exporters comes from sales in foreign markets.

The evidence presented in Table 4 is consistent with Proposition 4; the CWS had a much larger effect on plant export revenue than plant total revenue for continuing exporters. In addition, the effects of regulation are most pronounced in the lowest plant-size quartile, which is consistent with the model's intuition.

5.4 Robustness

We conclude our empirical analysis by presenting the results of several additional robustness tests. We first present a test that probes the validity of our research design. Next, we enrich our empirical specification to account for the dynamic nature of a firm's trade decisions.

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[36] A one sided test comparing the coefficient in column (2) of Table 2 to that in column (2) of Table 4 produces a p-value of 0.076.

Finally, we account for the potential affect differences in firm ownership structure may have on our results.

In the first test, we estimate a version of Equation (28) in which we allow the effect of CWS particulate matter regulation to vary by CMA air quality. As CWS particulate matter regulation employs a strict cut-off design, we should only observe a significant difference between plants in targeted and non-targeted industries in CMAs that violate the particulate matter standard. In contrast, there should be no meaningful difference across industries in CMAs below the standard's threshold, as these CMAs were not subject to regulation.

We test for this break by estimating the following flexible triple-difference regression

$$Y_{pict} = \sum_b \beta^b_{PM}[K_i \times I(\underline{A^{PM}_b} \leq a^{PM}_{ct} < \overline{A^{PM}_b})] + \rho_p + \mu_{ct} + \lambda_{it} + \epsilon_{pict}. \tag{30}$$

In Equation (30), b indexes air quality bin numbers, K_i selects all industries targeted by the CWS, a^{PM}_{ct} is the $\text{PM}_{2.5}$ air quality measured in CMA c in year t, $\underline{A^{PM}_b}$ is the air quality lower bound for bin b, $\overline{A^{PM}_b}$ is the air quality upper bound for bin b, and $I(\underline{A^{PM}_b} \leq a^{PM}_c < \overline{A^{PM}_b})$ is an indicator for all CMA-years with air quality that corresponds to bin b. Equation (30) also includes a full set of plant (ρ_p), CMA-by-year (μ_{ct}), and industry-by-year (λ_{it}) fixed effects. The coefficients of interest, β^b_{PM}, give the effects of the $\text{PM}_{2.5}$ standard in air quality bin b. These are identified from changes in air quality over time that moves CMAs across bins. In estimating Equation (30), the bin with the cleanest air quality (below 23 $\mu g/m^3$) is the excluded category.[37]

As the $\text{PM}_{2.5}$ standard's threshold was set at 30 $\mu g/m^3$, there should be no meaningful pattern in the differences between targeted and non-targeted industries below this level. Most importantly, if we find a consistently positive difference among these clean regions, this would suggest our estimates may be capturing something else besides the effects of the CWS. We also note that the CWS treated nearly violating regions (those with $\text{PM}_{2.5}$ between 27 and 30 $\mu g/m^3$) as "warning regions." Although there were no regulatory changes required by the CWS in these regions, there is a concern that regions may have implemented voluntary efforts to control pollution. If doing so increased production costs among plants in targeted industries, this would lead to a downward bias in our results. The results from Equation (30) also serve as a test for this issue.

We estimate Equation (30) for our three main dependent variables: an indicator for plant export exit (see Section 5.2 for details), the natural log of plant export revenues for continuing exporters, and the natural log of total plant revenue for continuing exporters. The results

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[37] All regressions are weighted to correct for potential sample bias induced by the procedure used to match the NPRI to the ASM. Standard errors clustered by industry-CMA are reported in parentheses.

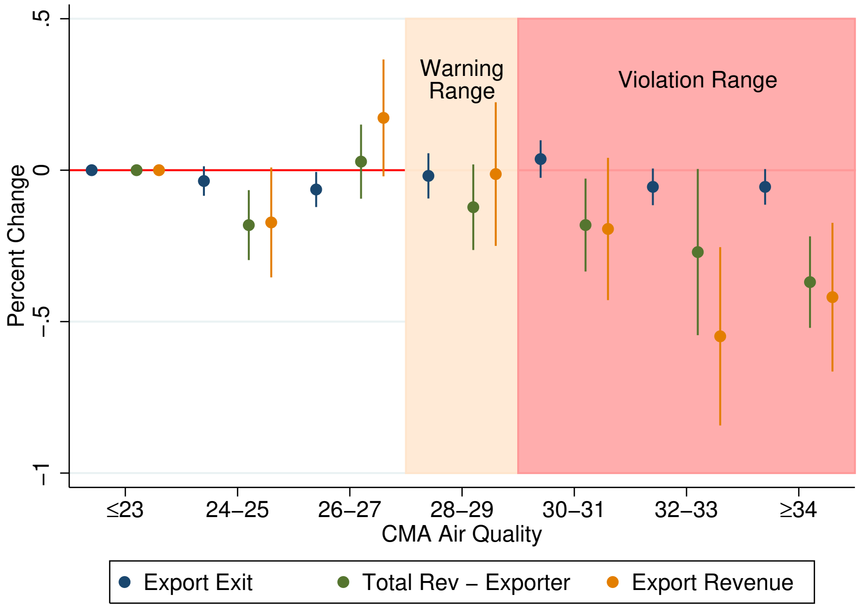

Figure 4: The Effect of CWS Regulation by CMA Air Quality

Notes: Figure displays estimates from a flexible DDD estimation of the $PM_{2.5}$ standard's effect on plants, allowing allowing the effects of regulation to vary by CMA air quality. Results from three different regressions are shown, each with a different dependent variable (an indicator for plant exit from exporting, the natural logarithm of plant sales for continuing exporters and the natural logarithm of plant export sales for continuing exporters). Dots reflect the point estimates for each CMA air quality bin, while the dashed line displays the associated 95% confidence interval. These coefficients are measured relative to the excluded group (air quality below 23 $\mu g/m^3$). All regressions include plant, industry-year, and CMA-year fixed effects, and are weighted by the inverse of the NPRI-ASM match probability to control for potential sample bias. Standard errors are clustered by industry-CMA.

of all three of these regressions are shown jointly in Figure 4. This figure presents the β^b_{PM} coefficients with 95% confidence intervals from each regression, ordered by CMA air quality level. We label coefficients for regions violating the CWS particulate matter standard as being in "Violation Range," and those close to violation as being in "Warning Range."

The results in Figure 4 lend confidence to our research design. The coefficient estimates for the clean regions show no meaningful pattern. Some coefficients are negative, while others are positive, and all are relatively small in magnitude. For regions in the warning range, the coefficient estimates are small and not statistically different from zero, suggesting our main estimates are not biased downwards because of voluntary regulation in these regions. Lastly, for the regions that violate the CWS, there is a negative and statistically significant difference in total revenue and export revenue for plants in targeted industries relative to those in non-targeted industries.

Table 5: The Effect of CWS Regulation - Controlling for Sunk Costs

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable:	ln(Export Rev.)		Pr(Export Exit)		ln(Total Rev.)	
$PM_{2.5}$ Std.	-0.158	-0.157	0.060^b	0.061^b	-0.082^c	-0.083^c
	(0.108)	(0.108)	(0.030)	(0.030)	(0.047)	(0.047)
Lagged Dependent Variable	0.242^a	0.239^a	-0.089^b	-0.087^b	0.231^c	0.237^c
	(0.090)	(0.089)	(0.036)	(0.029)	(0.127)	(0.126)
O_3 Std.	X	X	X	X	X	X
AR1	-3.952	-3.952	-8.864	-9.405	-2.563	-2.571
AR2	1.474	1.461	0.305	0.292	1.274	1.289
Obs.	2367	2367	3694	3694	2367	2367

Notes: Table reports Arellano-Bond estimates of the effects of the CWS, allowing for lagged dependent variables and using either one- or two-lags as instruments. Three different dependent variables are considered: the natural log of export revenues for plants that are continuing exporters, an indicator for export-exit for all plants, and the natural log of total revenues for continuing exporters. All regressions include plant, industry-year and CMA-year fixed effects, and are weighted by the inverse of the match probability to control for potential match-induced sample bias. In all cases, standard errors are clustered by CMA-industry. ^{c}, ^{b}, and ^{a} denote significance at the 10%, 5%, and 1% level, respectively.

One remaining concern with our main estimates is the possibility that the estimating equation is miss-specified because we have failed to account for persistence in firm decisions due to sunk costs. This is a particularly important consideration in our context because previous work studying export behaviour has emphasized the role of sunk costs in determining the export decisions of plants (i.e. Roberts and Tybout (1997) or Bernard and Jensen (2004)). As such, we adapt the approach taken by Bernard and Jensen (2004) to add a lagged dependent variable to our main estimating equation, Equation (28). Given that estimating these specifications with a fixed effects estimator would yield inconsistent estimates, we follow the approach of Arellano and Bond (1991) and adopt a GMM procedure with either one or two lags as instruments.

In Table 5 we present these estimates for our three main dependent variables: export revenues for continuing exporters (columns (1) and (2)), export exit (columns (3) and (4)), and total revenues for continuing exporters (columns (5) and (6)). Each specification includes plant, industry-year, and CMA-year fixed effects, and an indicator for O_3 regulation. Each regression is also weighted to correct for potential match-induced sample bias.

The estimated coefficients reported in columns (1) and (2) of Table 5 are consistent with our main results, as they show the CWS had a negative effect on export revenues. These estimates, however, are imprecisely estimated and not statistically significant at conventional levels. The loss of precision, relative to the estimates in Table 2, is likely owing to the considerable reduction in sample size from this restriction.[38]

The results in columns (3) and (4) show that allowing for the possibility of sunk costs in exporting results in a significant and relatively large effect of regulation on export exit. The coefficients in row one of columns (3) and (4) show the CWS particulate matter standard increased export exit by approximately 6%. As export status has been shown to be highly dependent on past plant outcomes (Roberts and Tybout, 1997), it is perhaps not surprising that our results are sensitive to this control.

Finally, the results in columns (5) and (6) are also consistent with our main results. The CWS caused a significant reduction in total revenues from continuing exporters. Moreover, the point estimates in columns (5) and (6) are approximately half of those reported in columns (1) and (2), suggesting the reduction in revenues was largely driven by export markets.[39]

In our final robustness test, we examine whether differences in firm ownership structure affect our results. Approximately 50% of the plants in our data are owned by multi-plant firms. As multi-plant firms may have resources at their disposal not available to single-plant firms, regulation may have different effects on plants based on their firm's structure. While the presence of multi-plant firms does not necessarily pose an identification problem, understanding these potential differences is important for understanding the mechanisms driving our results.[40]

We address this issue by estimating a version of Equation (28) in which we allow the effect of regulation to differ for plants owned by mutli- and single-plant firms.[41] The results of this exercise are shown in Table 6. In Table 6, we report estimates for our three core dependent variables. In each column, the first row shows the effect of the CWS particulate matter standard, the second row shows the differential effect of the particulate matter standard for multi-plant firms, and the third row shows the effect of a plant switching in or out of multi-plant ownership.[42]

The results of this exercise show that among plants owned by single-plant firms, CWS particulate matter regulation caused a significant increase in export exit, and a significant reduction in both total revenues and export revenues for continuing exporters. However,

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[38] In addition, lagged export revenue is positively associated with current export revenues in both specifications.

[39] Note that this difference is not statistically significant, likely owing to the considerable reduction in sample size.

[40] Note that the presence of multi-plant firms only causes a potential identification problem if the treatment of one plant alters the potential outcomes of another plant owned by the same firm.

[41] For this exercise we use the firm ownership information in the ASM.

[42] All regressions are weighted to correct for potential sample bias induced by the procedure used to match the NPRI to the ASM. Standard errors clustered by industry-CMA are reported in parentheses.

Table 6: The Effect of CWS Regulation - Multi-Plant Firms

	(1)	(2)	(3)
Dependent Variable:	ln(Export Rev.)	Pr(Export Exit)	ln(Total Rev.)
$PM_{2.5}$ Std.	-0.271^a	0.060^a	-0.165^b
	(0.102)	(0.020)	(0.065)
$PM_{2.5}$ Std. x Multi-Plant	0.091	-0.065^a	0.103
	(0.092)	(0.022)	(0.070)
Multi-Plant	0.051	-0.007	0.052
	(0.085)	(0.017)	(0.051)
R^2	0.945	0.288	0.968
N	3948	6418	3948

Notes: Table reports estimates of the effects of the CWS on plants allowing treatment to vary by the number of plants owned by the plant's parent firm. Results from three different regressions are shown, each with a different dependent variable (the natural logarithm of plant sales for continuing exporters, an indicator for plant exit from exporting, and the natural logarithm of plant export sales for continuing exporters). The first row reports the effects of the $PM_{2.5}$ standard. The second row reports the effects of the $PM_{2.5}$ standard interacted with the multi-plant firm indicator. The final row shows the coefficient on the multi-plant firm indicator. All regressions include plant, industry-year and CMA-year fixed effects. Standard errors are clustered by CMA-industry. ^{c}, ^{b}, and ^{a} denote significance at the 10%, 5%, and 1% level, respectively.

these effects are considerably muted for plants owned by multi-plant firms. For these firms, there is essentially no change in export exit. There also appears to be a smaller reduction in total revenues and export revenues for continuing exporters, although this difference is not significant at conventional levels.

These results yield two important implications. First, if one is concerned about the potential bias caused by the presence of plants owned by multi-plant firms, focusing solely on single plant firms leads our core results unchanged: CWS particulate matter regulation reduced export volumes from continuing exporters and led plants to exit the export market. Second, the effect on exports appears to be much smaller for plants owned by multi-plant firms. This suggests that the resources available to these plants may allow them to comply with regulation at a lower cost, thus reducing regulation's effect on their ability to compete internationally.

6 Conclusion

Debates on environmental policy have long hinged on the concern that stringent policy may impede a domestic producer's ability to compete globally (Jaffe et al., 1995). Consequently, exporters are often heavily featured in policy discussions. Yet, despite their prominence in these debates, little is known about how environmental policy affects individual exporters.

In this paper we ask how air quality standards, a common form of environmental regulation, affect manufacturing facilities' export participation decisions and export volumes. We address this question by developing a general equilibrium trade model and testing predictions from that model using quasi-experimental variation in regulatory stringency.

In our model, heterogeneous firms compete via monopolistic competition and decide whether to participate in foreign markets. In addition, domestic firms are regulated via constraints similar to those often imposed by air quality standards: these firms must either adopt cleaner technologies or pay a pollution tax.

The model yields three main predictions. First, air quality standards reduce export revenues for continuing exporters, thus affecting trade via the intensive margin. Second, they affect trade via the extensive margin by causing some firms to leave the export market. Finally, due to both the fixed costs of exporting and the design of regulation, these intensive and extensive margin effects are most pronounced among the smallest exporters.

Next, we test the model's predictions using confidential Canadian microdata. With this data, we examine how a major Canadian environmental policy affected the export patterns of Canadian manufacturing plants over the period 2004-2010. This policy, called the Canada Wide Standards for Particulate Matter (CWS), implemented regional air quality standards in every major town or city of Canada. In addition, the CWS explicitly targeted plants in a select group of industries. Thus, the CWS created variation in regulatory stringency across industries, regions, and time, which we exploit using a triple-difference research design.

We find the CWS had a large effect on continuing exporters, causing a 22% reduction in export volumes for these plants. The policy, however, had a much smaller effect on the extensive margin, increasing the probability a plant exits the export market by just over 1%, on average. As our model predicts, however, the effects of regulation varied considerably across the plant-size distribution. Among plants in the smallest quartile of the plant-size distribution, regulation increased the probability of exit by 5% and export volumes by 36%.

Our results suggest that concerns over the effects of environmental regulation amongst regulated – and even potentially regulated – exporters may well be justified. However, our results also suggest that the effects of environmental regulations on exporters depend explicitly on how these policies are designed. Alternative policies used to address pollution, such as taxes or emission intensity standards, may have very different effects on exporters, particularly along the intensive margin.

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A Theory

A.1 Closing the Model

Absent regulation, the model is characterized by domestic productivity cut-offs for production and exporting (φ_ϵ^{no} and φ_x^{no}), the measure of domestic entrants, the domestic price index, the foreign production and importing cut-offs, the measure of foreign entrants, and the foreign price index. Under regulation, the model also requires solving for the domestic retrofitting cut-off (φ_r^{reg}). It is worth noting that due to the freely-traded, homogeneous outside good and competitive labor markets, all domestic firm-level outcomes (including production and technology choices, and average revenues) are independent of the measure of entrants in both countries, and the foreign production and importing cut-offs. In addition, all domestic firm-level outcomes and the domestic price index can be characterized as a function of the domestic exit cut-off.

A.1.1 Equilibrium in Domestic Differentiated Goods

To solve for all domestic outcomes of interest requires using the domestic free entry condition. This condition under regulatory regime j is $\bar{\pi}^j = \delta f_\epsilon$, where δ is the probability of an exogenous exit, f_ϵ is the fixed cost of entry, and $\bar{\pi}^j$ is the average profits earned by a domestic firm. We first describe this condition absent regulation.

Absent regulation, average profits are given by

$$\begin{aligned}\bar{\pi}^{no} &= \int_{\varphi_\epsilon^{no}} \frac{r^{no}(\varphi)}{\sigma} g(\varphi) d\varphi + \int_{\varphi_x^{no}} \frac{r_x^{no}(\varphi)}{\sigma} g(\varphi) d\varphi - \left[1 - G(\varphi_\epsilon^{no})\right] f - \left[1 - G(\varphi_x^{no})\right] f_x \\ &= \left[\frac{\sigma - 1}{\eta}\right] \left[\frac{f}{\varphi_\epsilon^{no}} + \frac{\rho^k}{f_x^{\frac{\eta}{\sigma-1}}} \left[\frac{A_D}{\sigma}\right]^{\frac{k}{\sigma-1}}\right],\end{aligned} \tag{31}$$

where the second equality follows from $\frac{r^{no}(\varphi)}{\sigma} = f\left[\frac{\varphi}{\varphi_\epsilon^{no}}\right]^{\sigma-1}$ and $\frac{r_x^{no}(\varphi)}{\sigma} = f_x\left[\frac{\varphi}{\varphi_x^{no}}\right]^{\sigma-1}$. Substituting Equation (31) into the domestic free entry condition yields the solution to φ_ϵ^{no}, which characterizes all domestic firm-level outcomes.

To characterize domestic firm-level outcomes under regulation, note that average profits are given by

$$\begin{aligned}\bar{\pi}^{reg} = & \int_{\varphi_\epsilon^{reg}} \frac{r^{reg}(\varphi)}{\sigma} g(\varphi)d\varphi + \left[[1+\tau]^{\sigma-1}-1\right]\int_{\varphi_r^{reg}} \frac{r_r^{reg}(\varphi)}{\sigma} g(\varphi)d\varphi \\ & + \int_{\varphi_x^{reg}} \frac{r_x^{reg}(\varphi)}{\sigma}g(\varphi)d\varphi + \left[[1+\tau]^{\sigma-1}-1\right]\int_{\varphi_r^{reg}}\frac{r_{x,r}^{reg}(\varphi)}{\sigma}g(\varphi)d\varphi \\ & - \left[1-G(\varphi_\epsilon^{reg})\right]f - \left[1-G(\varphi_x^{reg})\right]f_x - \left[1-G(\varphi_r^{reg})\right]f_r.\end{aligned}$$

Using $\frac{r^{reg}(\varphi)}{\sigma} = f\left[\frac{\varphi}{\varphi_\epsilon^{reg}}\right]^{\sigma-1}$ and $\frac{r_r^{reg}(\varphi)}{\sigma} = f_x\left[\frac{\varphi}{\varphi_x^{reg}}\right]^{\sigma-1}$ simplifies this to

$$\bar{\pi}^{reg} = \left[\frac{\sigma-1}{\eta}\right]\left[\frac{f}{\varphi_\epsilon^{reg^k}} + \frac{f_x}{\varphi_x^{reg^k}} + \left[[1+\tau]^{\sigma-1}\right]\left[\frac{f}{\varphi_\epsilon^{reg^{\sigma-1}}} + \frac{f_x}{\varphi_x^{reg^{\sigma-1}}}\right]\frac{1}{\varphi_r^{reg^\eta}}\right] - \frac{f_r}{\varphi_r^{reg^k}}.$$

In addition, the retrofitting cut-off can be expressed as

$$\left[[1+\tau]^{\sigma-1}-1\right]\left[\frac{f}{\varphi_\epsilon^{reg^{\sigma-1}}} + \frac{f_x}{\varphi_x^{reg^{\sigma-1}}}\right]\varphi_r^{reg^{\sigma-1}} = f_r.$$

Incorporating this further simplifies $\bar{\pi}^{reg}$ to

$$\bar{\pi}^{reg} = \left[\frac{\sigma-1}{\eta}\right]\left[\frac{f}{\varphi_\epsilon^{reg^k}} + \frac{f_x}{\varphi_x^{reg^k}} + \frac{f_r}{\varphi_r^{reg^k}}\right]. \tag{32}$$

Substituting Equation (32) into the domestic free entry condition yields the following expression

$$\frac{f_r}{\varphi_r^{reg^k}} = \frac{\eta\delta f_\epsilon}{\sigma-1} - \frac{f}{\varphi_\epsilon^{reg^k}} - \frac{f_x}{\varphi_x^{reg^k}}. \tag{33}$$

In addition, a slight transformation of the equation that defines the retrofitting cut-off (Equation 14 in the main text) yields

$$\frac{f_r}{\varphi_r^{reg^k}} = \left[[1+\tau]^k-1\right]^{\frac{k}{\sigma-1}}\left[\frac{f}{\varphi_\epsilon^{reg^{\sigma-1}}} + \frac{f_x}{\varphi_x^{reg^{\sigma-1}}}\right]^{\frac{k}{\sigma-1}}\frac{1}{f_r^{\frac{\eta}{\sigma-1}}}. \tag{34}$$

As $\varphi_x^{reg} = \left[\frac{\sigma f_x}{A_D}\right]^{\frac{1}{\sigma-1}}\left[\frac{1+\tau}{\rho}\right]$, Equation (33) and Equation (34) define a two-equation system, the solution to which yields expressions for φ_r^{reg} and φ_ϵ^{reg}, which can then be used to characterize the firm-level domestic outcomes. Note that both Equation (33) and Equation (34) are continuous functions of $\frac{f_r}{\varphi_r^{reg^k}}$ and φ_ϵ^{reg}. In addition, Equation (33) is monotonically increasing

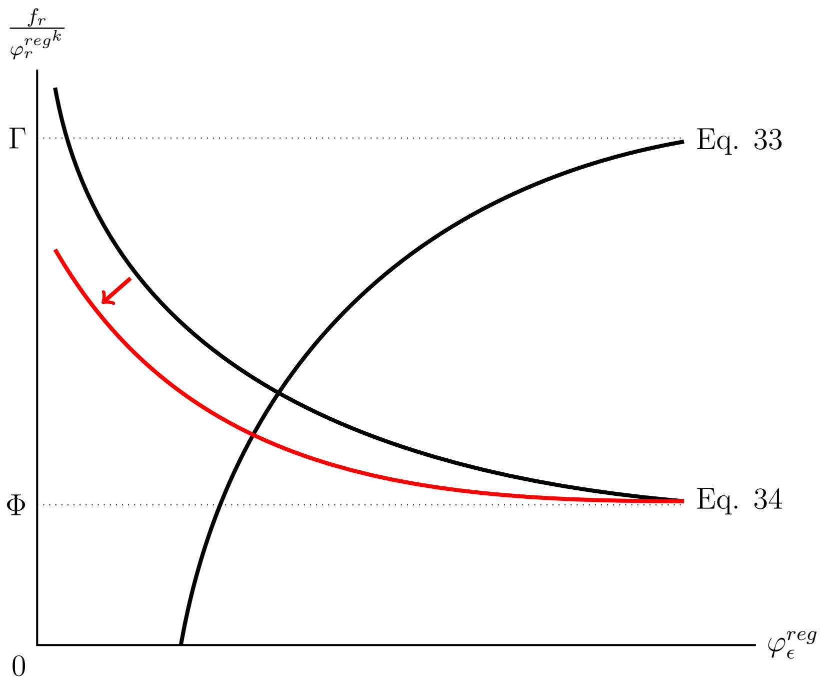

Figure 5: Implicit Solution to φ_r^{reg} and φ_ϵ^{reg}

in φ_ϵ^{reg}, while Equation (34) is monotonically decreasing in φ_ϵ^{reg}. Thus, a unique equilibrium exists for the system.

A graphical representation of the system is shown in Figure 5, where the vertical axis shows $\frac{f_r}{\varphi_r^{reg^k}}$ and the horizontal axis shows φ_ϵ^{reg}, and both equations are labelled.[43] Notice that increasing f_r causes Equation (34) to flatten, but does not affect Equation (33). This shows a useful comparative static result to which we will refer again shortly: $\frac{\partial [f_r/\varphi_r^{reg^k}]}{\partial f_r} < 0$.

A.1.2 Equilibrium in International Differentiated Goods

To characterize firm outcomes in the foreign differentiated goods sector requires solving for the foreign exit cut-off and the import cut-off. The zero profit condition for foreign producers is analogous to the domestic zero profit condition. This yields the following foreign exit cut-off under domestic regulatory regime j

$$\varphi_{\epsilon,A}^{j} = \left[\frac{\sigma f}{E_A}\right]^{\frac{1}{\sigma-1}} \left[\frac{1}{\rho P_A^j}\right], \tag{35}$$

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[43] In addition, to simplify the figure, we let $\Gamma = \frac{\eta \delta f_\epsilon}{\sigma-1} - \frac{f_x}{\varphi_x^{reg^k}}$ and $\Phi = \left[[1+\tau]^k - 1\right]^{\frac{k}{\sigma-1}} \left[\frac{f_x^{\frac{k}{\sigma-1}}}{\varphi_x^{reg^k}}\right] \frac{1}{f_r^{\frac{\eta}{\sigma-1}}}$.

where $E_A = \alpha I_A$ and I_A is foreign income. Any foreign firm that draws a productivity level below $\varphi^j_{\epsilon,A}$ would choose to exit the market, while all remaining firms produce.

A foreign firm indifferent between exporting to the domestic economy (which we call importing) must earn zero profit as an importer. As there are no variable trade costs, importer profits when the domestic government uses regulatory regime j are given by $\pi^A_m = \frac{E_A[\rho P^j]^{\sigma-1}}{\sigma} - f_m$. Thus, the indifferent importer is characterized by the following productivity level under domestic regulatory regime j

$$\begin{aligned}\varphi^{A^j}_m &= \left[\frac{\sigma f_m}{E_D}\right]^{\frac{1}{\sigma-1}} \left[\frac{1}{\rho P^j}\right] \\ &= \begin{cases} \left[\frac{f_m}{f}\right]^{\frac{1}{\sigma-1}} \varphi^j_\epsilon \text{ if } j = no, \\ \left[\frac{f_m}{f}\right]^{\frac{1}{\sigma-1}} \left[\frac{\varphi^j_\epsilon}{1+\tau\kappa}\right] \text{ if } j = reg. \end{cases}\end{aligned} \tag{36}$$

As the second equality shows, the import cut-off is a function of the domestic exit cut-off.

Clearly, the foreign production cut-off depends on the foreign price index. This price index can be solved from the foreign free entry condition. Under domestic regulatory regime j, the foreign free entry condition is $\bar{\pi}^j_A = \delta f_\epsilon$, where δ is the probability of an exogenous exit, f_ϵ is the fixed cost of entry, and $\bar{\pi}^j_A$ is the average profits earned by a foreign firm. It is straightforward to show that $\bar{\pi}^j_A$ is a function of both the foreign and domestic exit cut-offs.

A.1.3 Measures of Entrants

The measure of entrants in the domestic and foreign differentiated goods sectors can be solved for using the price index definitions, the free entry conditions, and the exit cut-offs. Note that the domestic price index under regulatory regime j, is given by

$$P^{j^{1-\sigma}} = M^j_{H,H} \int_{\varphi^j_\epsilon} p^{j^{1-\sigma}}(\varphi) \frac{d\varphi}{1-G(\varphi)} + M^j_{A,H} \int_{\varphi^j_m} p^{j^{1-\sigma}}_m(\varphi) \frac{d\varphi}{1-G(\varphi)}, \tag{37}$$

where $M^j_{H,H}$ is the measure of domestic firms that sell in the domestic market, $M_{A,H}$ is the measure of foreign firms that sell in the domestic market, $p^j(\varphi)$ is the price charged in the domestic market by a domestic firm, and $p^j_m(\varphi)$ is the price charged in the domestic market by a foreign firm. Equation (37) can be rewritten as

$$P^{j^{1-\sigma}} = M^j_{E,H} \int_{\varphi^j_\epsilon} p^{j^{1-\sigma}}(\varphi) d\varphi + M^j_{E,A} \int_{\varphi^j_m} p^{j^{1-\sigma}}_m(\varphi) d\varphi, \tag{38}$$

where $M_{E,H}^{j}$ is the measure of entrants to the domestic market and $M_{E,A}^{j}$ is the measure of entrants to the foreign market.

Given our assumption of a small open economy, the foreign price index is given by

$$P_A^{j^{1-\sigma}} = M_{A,A}^{j} \int_{\varphi_{\epsilon,A}^{j}} p_A^{j^{1-\sigma}}(\varphi) \frac{d\varphi}{1-G(\varphi)}, \tag{39}$$

where $M_{A,A}^{j}$ is the measure of foreign firms that sell in the foreign market. This expression can be rewritten as

$$P_A^{j^{1-\sigma}} = M_{E,A}^{j} \int_{\varphi_{\epsilon,A}^{j}} p_A^{j^{1-\sigma}}(\varphi) d\varphi. \tag{40}$$

Note that the zero profit conditions with the exit cut-offs yield alternative expressions for the price indices. Thus, combining Equation (38) and Equation (40) with these alternative price index equations can be used to solve for the measure of entrants to the domestic and foreign markets.

A.1.4 Domestic Labor Market Clearing

The domestic labor market clears where domestic labor supply, L, equals domestic labor demand. Domestic labor demand comes from two sources: the homogeneous goods sector and the differentiated goods sector.

To determine labor demand from the domestic homogenous goods sector, note that this market clears where total domestic and foreign demand equals total domestic supply. Given this good is the numeraire and the assumed linear production structure, total labor demand from this sector is given by $E_0 + A_0$. Labor demand for this sector is the same with and without regulation.

Differentiated good labor demand is given by the measure of domestic entrants multiplied by the average labor demand from domestic differentiated goods producers. This accounts for both fixed and variable labor demand. Given the assumed production function, in regulatory regime j variable labor demand for domestic production from a firm that produces using the dirty technology is $\rho r^{j}(\varphi)$, while export labor demand is $\rho r_x^{j}(\varphi)$. Similar expressions exist for a retrofit firm's labor demand. Accordingly, average labor demand without regulation is given by

$$\begin{aligned} \bar{l}^{no} &= \int_{\varphi_\epsilon^{no}} \left[f + \rho r^{no}(\varphi)\right] g(\varphi) d\varphi + \int_{\varphi_x^{no}} \left[f_x + \rho r_x^{no}(\varphi)\right] g(\varphi) d\varphi \\ &= \rho \bar{r}^{no} + \rho \bar{r}_x^{no} + \left[1 - G(\varphi_\epsilon^{no})\right] f + \left[1 - G(\varphi_x^{no})\right] f_x. \end{aligned} \tag{41}$$

Using the definitions of average revenues and the productivity distribution, this reduces to

$$\bar{l}^{no} = \rho^{\sigma}\left[\frac{\kappa}{\eta}\right]\left[\frac{E_D P^{no^{\sigma-1}}}{\varphi_{\epsilon}^{no^{\eta}}} + \frac{A_D}{\varphi_x^{no^{\eta}}}\right] + \frac{f}{\varphi_{\epsilon}^{no^{k}}} + \frac{f_x}{\varphi_x^{no^{k}}} \tag{42}$$

Similarly, average labor demand with regulation is

$$\begin{aligned} \bar{l}^{reg} &= \rho\bar{r}^{reg} + \rho\bar{r}_x^{reg} + \left[1 - G(\varphi_{\epsilon}^{reg})\right] f + \left[1 - G(\varphi_x^{reg})\right] f_x + \left[1 - G(\varphi_r^{reg})\right] f_r \\ &= \rho^{\sigma}\left[\frac{\kappa}{\eta}\right] E_D \left[\frac{1}{\varphi_{\epsilon}^{reg^{\eta}}} - T(\tau)\left[\frac{1}{\varphi_{\epsilon}^{reg^{\eta}}} - \frac{1}{\varphi_r^{reg^{\eta}}}\right]\right] \\ &+ \rho^{\sigma}\left[\frac{\kappa}{\eta}\right] A_D \left[\frac{1}{\varphi_x^{reg^{\eta}}} - T(\tau)\left[\frac{1}{\varphi_x^{reg^{\eta}}} - \frac{1}{\varphi_r^{reg^{\eta}}}\right]\right] + \frac{f}{\varphi_{\epsilon}^{reg^{k}}} + \frac{f_x}{\varphi_x^{reg^{k}}} + \frac{f_r}{\varphi_r^{reg^{k}}}, \end{aligned} \tag{43}$$

where the second equality follows from $r^{reg} = r_r^{reg} - T(\tau)r_r^{reg}$ and $r_x^{reg} = r_{x,r}^{reg} - T(\tau)r_{x,r}^{reg}$.

Given these expressions, domestic labor market clearing in regulatory regime j occurs where

$$L = M_{E,H}^{j}\bar{l}^{j} + E_0 + A_0. \tag{44}$$

A.1.5 Foreign Labor Market Clearing

Finally, the foreign labor market clears where foreign labor supply (L_A) equals foreign labor demand.

Labor demand from the foreign differentiated goods sector is the measure of foreign entrants multiplied by the average labor demanded by foreign differentiated goods producers. Following a similar derivation as for the domestic case, average foreign differentiated labor demand under domestic regulatory regime j is

$$\bar{l}_A^{j} = \rho\bar{r}^{A^j} + \rho\bar{r}_m^{A^j} + \left[1 - G(\varphi_{\epsilon,A}^{j})\right] f + \left[1 - G(\varphi_m^{A^j})\right] f_m, \tag{45}$$

where $\bar{r}^{A^j}$ is the average revenue earned by foreign producers from selling in the foreign market and $\bar{r}_m^{A^j}$ is the average revenue earned by foreign producers from selling in the domestic market. Substituting in the expressions $\bar{r}^{A^j} = \left[\frac{\kappa}{\eta}\right]\frac{\rho^{\sigma-1}E_A}{\varphi_{\epsilon,A}^{j^{\eta}}}$ and $\bar{r}_m^{A^j} = \frac{\sigma f_m}{E_D}\left[\frac{E_A}{\varphi_m^{A^j}}\right]$ gives average labor demand as

$$\bar{l}_A^{j} = \rho^{\sigma}\frac{\kappa}{\eta}\frac{E_A}{\varphi_{\epsilon,A}^{j^{\eta}}} + \rho\frac{\sigma f_m}{E_D}\frac{E_A}{\varphi_m^{A^j}} + \frac{f}{\varphi_{\epsilon,A}^{j^{\kappa}}} + \frac{f_m}{\varphi_m^{A^{j^{k}}}}. \tag{46}$$

Similar to the domestic case, labor demand from the foreign homogeneous goods sector is given by $E_0^A + A_0^A$, where E_0^A and A_0^A are the expenditures on foreign homogeneous goods by foreign and domestic consumers, respectively.

Given these expressions, foreign labor market clearing in regulatory regime j occurs where

$$L_A = M^j_{E,A}\bar{l}^j_A + E^A_0 + A^A_0. \tag{47}$$

A.2 Proof of Proposition 4

Before proving Proposition 4 from the main text, we first present the following useful lemma.

Lemma 1. *Regulation causes a rise in the domestic price index if the fixed cost of retrofitting, f_r, is sufficiently large.*

Proof. To solve for the domestic price index absent regulation, note that substituting Equation (31) into the domestic free entry condition absent regulation and using the expression for the exit cut-off, φ^{no}_{ϵ}, and the exporting cut-off, φ^{reg}_{x}, gives the following expression for the Home price index absent regulation

$$P^{no^k} = \left[\frac{\eta}{\sigma-1}\right]\left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right]\left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\delta f_{\epsilon}\right] - \left[\frac{f}{f_x}\right]^{\frac{\eta}{\sigma-1}}\left[\frac{A_D}{E_D}\right]^{\frac{k}{\sigma-1}} \tag{48}$$

To solve for the domestic price index under regulation, substitute Equation (32) into the domestic free entry condition under regulation and use the expressions for the exit cut-off, φ^{reg}_{ϵ}, and the exporting cut-off, φ^{reg}_{x}, to get

$$\begin{aligned} P^{reg^k} = [1+\tau]^k\left[\frac{\eta}{\sigma-1}\right]\left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right]\left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\delta f_{\epsilon}\right] - \left[\frac{f}{f_x}\right]^{\frac{\eta}{\sigma-1}}\left[\frac{A_D}{E_D}\right]^{\frac{k}{\sigma-1}} \\ - [1+\tau]^k\left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right]\left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\frac{f_r}{\varphi_r^{reg^k}}\right]. \end{aligned} \tag{49}$$

Now, subtracting Equation (48) from Equation (49) and rearranging gives

$$P^{reg^k} - P^{no^k} = \left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right]\left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\right]\left[\left[[1+\tau]^k - 1\right]\left[\frac{\eta\delta f_{\epsilon}}{\sigma-1}\right] - [1+\tau]^k\frac{f_r}{\varphi_r^{reg^k}}\right]. \tag{50}$$

Clearly, $P^{reg^k} - P^{no^k}$, and thus $P^{reg} - P^{no}$, is positive if and only if

$$\left[\frac{[1+\tau]^k - 1}{[1+\tau]^k}\right]\left[\frac{\eta\delta f_{\epsilon}}{\sigma-1}\right] > \frac{f_r}{\varphi_r^{reg^k}}. \tag{51}$$

From the solution to φ_r^{reg} defined in Appendix A.1, $\frac{\partial[f_r/{\varphi_r^{reg}}^k]}{\partial f_r} < 0$. This implies there is a threshold in the size of f_r above which Equation (51) is satisfied, and CWS-style regulation must increase the domestic price index. $\square$

We now turn to our proof of Proposition 4 from the main text. Note that export revenues only fall for continuing domestic exporters who have a productivity draw $\varphi \in [\varphi_x^{reg}, \varphi_r^{reg})$. Thus, it suffices to show that export sales fall more than domestic sales for these firms.

Consider such a firm with productivity level φ. Relative domestic revenues with- and without-regulation are given by

$$\frac{r^{reg}(\varphi)}{r^{no}(\varphi)} = \left[\frac{P^{reg}}{P^{no}}\right]^{\sigma-1} \left[\frac{1}{1+\tau}\right]^{\sigma-1}, \tag{52}$$

and relative export revenues are given by

$$\frac{r_x^{reg}(\varphi)}{r_x^{no}(\varphi)} = \left[\frac{1}{1+\tau}\right]^{\sigma-1}. \tag{53}$$

Clearly, the reduction in export revenues is greater than the reduction in domestic revenues for this firm if and only if $P^{reg} > P^{no}$. By Lemma 1, this condition holds when f_r is sufficiently large.