

Online Appendix for Do Environmental Regulations Affect the Decision to Export?

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Appendix A Theoretical Framework: Additional Details

In this section, we provide additional details of the model presented in Section 2 of the main text.

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

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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

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

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 (A.1) 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

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

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

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

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

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

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

$$\bar{\pi}^{reg} = \left[\frac{\sigma - 1}{\eta} \right] \left[\frac{f}{\varphi_\epsilon^{reg^k}} + \frac{f_x}{\varphi_x^{reg^k}} + \frac{f_r}{\varphi_r^{reg^k}} \right].\tag{A.2}$$

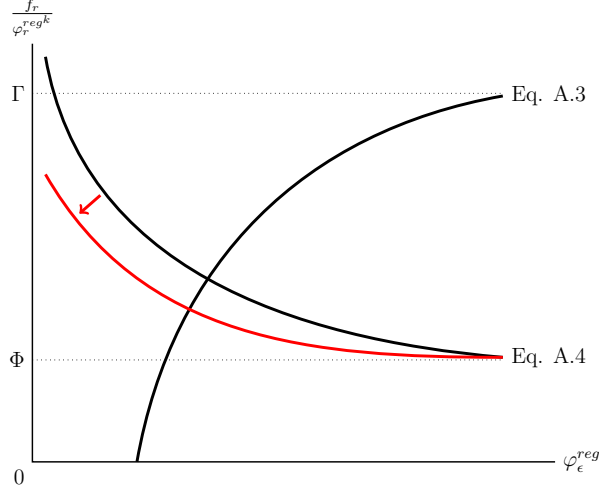


Figure 1: Implicit Solution to φ_r^{reg} and φ_ϵ^{reg}

Substituting this into the domestic free entry condition yields the following expression

$$\frac{f_r}{\varphi_r^{reg k}} = \frac{\eta \delta f_\epsilon}{\sigma - 1} - \frac{f}{\varphi_\epsilon^{reg k}} - \frac{f_x}{\varphi_x^{reg k}}. \quad (\text{A.3})$$

In addition, a slight transformation of the equation that defines the retrofitting cut-off (Equation 21 in the main text) yields

$$\frac{f_r}{\varphi_r^{reg k}} = \left[[1 + \tau]^k - 1 \right]^{\frac{k}{\sigma-1}} \left[\frac{f}{\varphi_\epsilon^{reg \sigma-1}} + \frac{f_x}{\varphi_x^{reg \sigma-1}} \right]^{\frac{k}{\sigma-1}} \frac{1}{f_r^{\frac{\eta}{\sigma-1}}}. \quad (\text{A.4})$$

As $\varphi_x^{reg} = \left[\frac{\sigma f_x}{A_D} \right]^{\frac{1}{\sigma-1}} \left[\frac{1+\tau}{\rho} \right]$, Equations A.3 and A.4 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 equations are continuous functions of $\frac{f_r}{\varphi_r^{reg k}}$ and φ_ϵ^{reg} . In addition, Equation (A.3) is monotonically increasing in φ_ϵ^{reg} , while Equation (A.4) 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 1, 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.¹ Notice that increasing f_r causes Equation (A.4) to flatten, but does not affect Equation (A.3). This shows a useful comparative static result to which we will refer again shortly: $\frac{\partial [f_r / \varphi_r^{reg k}]}{\partial f_r} < 0$.

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

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

$$\varphi_{\epsilon,A}^j = \left[\frac{\sigma f}{E_A} \right]^{\frac{1}{\sigma-1}} \left[\frac{1}{\rho P_A^j} \right], \quad (\text{A.5})$$

where $E_A = \alpha I_A$ and I_A is foreign income. Any foreign firm that draws a productivity level below $\varphi_{\epsilon,A}^j$ 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 $\pi_m^A = \frac{E_A[\rho P^j]^{\sigma-1}}{\sigma} - f_m$. Thus, the indifferent importer is characterized by the following productivity level under domestic regulatory regime j

$$\begin{aligned} \varphi_m^{A,j} &= \left[\frac{\sigma f_m}{E_D} \right]^{\frac{1}{\sigma-1}} \left[\frac{1}{\rho P^j} \right] \\ &= \begin{cases} \left[\frac{f_m}{f} \right]^{\frac{1}{\sigma-1}} \varphi_{\epsilon}^j & \text{if } j = no, \\ \left[\frac{f_m}{f} \right]^{\frac{1}{\sigma-1}} \left[\frac{\varphi_{\epsilon}^j}{1+\tau\kappa} \right] & \text{if } j = reg. \end{cases} \end{aligned} \quad (\text{A.6})$$

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 $\bar{\pi}_A^j = \delta f_{\epsilon}$, where δ is the probability of an exogenous exit, f_{ϵ} is the fixed cost of entry, and $\bar{\pi}_A^j$ is the average profits earned by a foreign firm. It is straightforward to show that $\bar{\pi}_A^j$ 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

$$P^{j^{1-\sigma}} = M_{H,H}^j \int_{\varphi_{\epsilon}^j} p^{j^{1-\sigma}}(\varphi) \frac{d\varphi}{1-G(\varphi)} + M_{A,H}^j \int_{\varphi_m^j} p_m^{j^{1-\sigma}}(\varphi) \frac{d\varphi}{1-G(\varphi)}, \quad (\text{A.7})$$

where $M_{H,H}^j$ 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 $p_m^j(\varphi)$ is the price charged in the domestic market by a foreign firm. Equation (A.7) can be rewritten as

$$P^{j^{1-\sigma}} = M_{E,H}^j \int_{\varphi_\epsilon^j} p^{j^{1-\sigma}}(\varphi) d\varphi + M_{E,A}^j \int_{\varphi_m^j} p_m^{j^{1-\sigma}}(\varphi) d\varphi, \quad (\text{A.8})$$

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

$$P_A^{j^{1-\sigma}} = M_{A,A}^j \int_{\varphi_{\epsilon,A}^j} p_A^{j^{1-\sigma}}(\varphi) \frac{d\varphi}{1 - G(\varphi)}, \quad (\text{A.9})$$

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

$$P_A^{j^{1-\sigma}} = M_{E,A}^j \int_{\varphi_{\epsilon,A}^j} p_A^{j^{1-\sigma}}(\varphi) d\varphi. \quad (\text{A.10})$$

Note that the zero profit conditions and the exit cut-offs yield alternative expressions for the price indices. Thus, combining equations (A.8) and (A.10) with these alternative price indexes 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 $E_0 + A_0$, which is the same with or 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

$$\begin{aligned}\bar{l}^{no} &= \int_{\varphi_\epsilon^{no}} [f + \rho r^{no}(\varphi)] g(\varphi) d\varphi + \int_{\varphi_x^{no}} [f_x + \rho r_x^{no}(\varphi)] g(\varphi) d\varphi \\ &= \rho \bar{r}^{no} + \rho \bar{r}_x^{no} + [1 - G(\varphi_\epsilon^{no})] f + [1 - G(\varphi_x^{no})] f_x.\end{aligned}\quad (\text{A.11})$$

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

$$\bar{l}^{no} = \rho^\sigma \left[\frac{\kappa}{\eta} \right] \left[\frac{E_D P^{no\sigma-1}}{\varphi_\epsilon^{no\eta}} + \frac{A_D}{\varphi_x^{no\eta}} \right] + \frac{f}{\varphi_\epsilon^{no\kappa}} + \frac{f_x}{\varphi_x^{no\kappa}} \quad (\text{A.12})$$

Similarly, average labor demand with regulation is

$$\begin{aligned}\bar{l}^{reg} &= \rho \bar{r}^{reg} + \rho \bar{r}_x^{reg} + [1 - G(\varphi_\epsilon^{reg})] f + [1 - G(\varphi_x^{reg})] f_x + [1 - G(\varphi_r^{reg})] f_r \\ &= \rho^\sigma \left[\frac{\kappa}{\eta} \right] E_D \left[\frac{1}{\varphi_\epsilon^{reg\eta}} - T(\tau) \left[\frac{1}{\varphi_\epsilon^{reg\eta}} - \frac{1}{\varphi_r^{reg\eta}} \right] \right] \\ &+ \rho^\sigma \left[\frac{\kappa}{\eta} \right] A_D \left[\frac{1}{\varphi_x^{reg\eta}} - T(\tau) \left[\frac{1}{\varphi_x^{reg\eta}} - \frac{1}{\varphi_r^{reg\eta}} \right] \right] + \frac{f}{\varphi_\epsilon^{reg\kappa}} + \frac{f_x}{\varphi_x^{reg\kappa}} + \frac{f_r}{\varphi_r^{reg\kappa}},\end{aligned}\quad (\text{A.13})$$

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 regime j occurs where

$$L = M_{E,H}^j \bar{l}^j + E_0 + A_0. \quad (\text{A.14})$$

A.1.5 Foreign Labor Market Clearing

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

$$\bar{l}_A^j = \rho \bar{r}^{A^j} + \rho \bar{r}_m^{A^j} + [1 - G(\varphi_{\epsilon,A}^j)] f + [1 - G(\varphi_m^{A^j})] f_m, \quad (\text{A.15})$$

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

$$\bar{l}_A^j = \rho^\sigma \frac{E_A}{\eta \varphi_{\epsilon,A}^{j^\eta}} + \rho \frac{\sigma f_m E_A}{E_D \varphi_m^{A^j}} + \frac{f}{\varphi_{\epsilon,A}^{j^\kappa}} + \frac{f_m}{\varphi_m^{A^{jk}}}. \quad (\text{A.16})$$

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

$$L_A = M_{E,A}^j \bar{l}_A^j + E_0^A + A_0^A. \quad (\text{A.17})$$

A.2 Proofs of Empirical Predictions

A.2.1 Proof of Empirical Prediction 1

Proof. A firm exits the export market following regulation if its productivity draw falls in the interval $[\varphi_x^{no}, \varphi_x^{reg})$. Using Equation (12), Equation (22), and letting $\eta = k - [\sigma - 1] > 0$, the probability a firm exits exporting is given by:

$$\begin{aligned} Pr(\text{Exit Exporting}) &= \int_{\varphi_x^{no}}^{\varphi_x^{reg}} g(\varphi) d\varphi \\ &= \left[\frac{\rho k}{\eta} \right] \left[\frac{\tau}{1 + \tau} \right] \left[\frac{A_D}{\sigma f_x} \right]^{\frac{k+1}{\sigma-1}} > 0. \end{aligned} \quad (\text{A.18})$$

On average, the likelihood a firm exits exporting due to regulation is positive. \square

A.2.2 Proof of Empirical Prediction 2

Proof. Follows directly from Empirical Prediction 1. 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 $\partial \pi_x^{no}(\varphi) / \partial \varphi > 0$, these firms must be the least productive exporters absent regulation. \square

A.2.3 Proof of Empirical Prediction 3

Proof. To prove Empirical Prediction 3, note that the average export revenues of domestic differentiated goods firms absent regulation are given by:

$$\begin{aligned}\bar{r}_x^{no} &= \int_{\varphi_x^{no}} r_x^{no}(\varphi)g(\varphi)d\varphi \\ &= \left[\frac{k}{\eta}\right] \left[\frac{\rho^{\sigma-1}A_D}{\varphi_x^{no\eta}}\right].\end{aligned}\tag{A.19}$$

Similarly, average export revenues under regulation are given by

$$\begin{aligned}\bar{r}_x^{reg} &= \int_{\varphi_x^{reg}}^{\varphi_r^{reg}} r_x^{reg}(\varphi)g(\varphi)d\varphi + \int_{\varphi_r^{reg}} r_{x,r}^{reg}(\varphi)g(\varphi)d\varphi \\ &= \left[\frac{k}{\eta}\right] [\rho^{\sigma-1}A_D] \left[\left[\frac{1}{\varphi_x^{reg\eta}}\right] - T(\tau) \left[\frac{1}{\varphi_x^{reg\eta}} - \frac{1}{\varphi_r^{reg\eta}}\right] \right],\end{aligned}\tag{A.20}$$

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

Now consider the firms that continue exporting after regulation (those with $\varphi \geq \varphi_x^{reg}$). Average export revenues without regulation for these firms are:

$$\begin{aligned}\bar{r}_x^{no,cont} &= \int_{\varphi_x^{reg}} r_x^{no}(\varphi)g(\varphi)d\varphi \\ &= \left[\frac{k}{\eta}\right] \left[\frac{\rho^{\sigma-1}A_D}{\varphi_x^{reg\eta}}\right].\end{aligned}\tag{A.21}$$

Subtracting Equation (A.21) from (A.20) gives the following expression for the change in average export revenues due to regulation for continuing exporters

$$\bar{r}_x^{reg} - \bar{r}_x^{no,cont} = - \left[\frac{k}{\eta}\right] [\rho^{\sigma-1}A_D T(\tau)] \left[\frac{1}{\varphi_x^{reg\eta}} - \frac{1}{\varphi_r^{reg\eta}} \right].\tag{A.22}$$

By construction, $\varphi_r^{reg} > \varphi_x^{reg}$, which means Equation (A.22) is negative. \square

A.2.4 Proof of Empirical Prediction 4

Proof. Due to the fixed cost of retrofitting, 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

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

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. \square

A.2.5 Proof of Empirical Prediction 5

The following lemma is useful in proving Empirical Prediction 5 from the main text.

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 (A.1) into the domestic free entry condition absent regulation and using the expression for the exit cut-off, φ_ϵ^{no} , and the exporting cut-off, φ_x^{reg} , gives the following expression for the domestic price index absent regulation

$$P^{no^k} = \left[\frac{\eta}{\sigma-1}\right] \left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right] \left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\delta f_\epsilon\right] - \left[\frac{f}{f_x}\right]^{\frac{\eta}{\sigma-1}} \left[\frac{A_D}{E_D}\right]^{\frac{k}{\sigma-1}} \quad (\text{A.23})$$

To solve for the domestic price index under regulation, substitute Equation (A.2) into the domestic free entry condition under regulation and use the expressions for the exit cut-off, φ_ϵ^{reg} , and the exporting cut-off, φ_x^{reg} , to get

$$\begin{aligned} P^{reg^k} = [1+\tau]^k & \left[\frac{\eta}{\sigma-1}\right] \left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right] \left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\delta f_\epsilon\right] - \left[\frac{f}{f_x}\right]^{\frac{\eta}{\sigma-1}} \left[\frac{A_D}{E_D}\right]^{\frac{k}{\sigma-1}} \\ & - [1+\tau]^k \left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right] \left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\frac{f_r}{\varphi_r^{reg^k}}\right]. \end{aligned} \quad (\text{A.24})$$

Now, subtracting Equation (A.23) from Equation (A.24) and rearranging gives

$$P^{reg^k} - P^{no^k} = \left[\frac{\sigma^{\frac{k}{\sigma-1}}}{\rho^k}\right] \left[\frac{f^{\frac{\eta}{\sigma-1}}}{E_D^{\frac{k}{\sigma-1}}}\right] \left[\left[[1+\tau]^k - 1 \right] \left[\frac{\eta\delta f_\epsilon}{\sigma-1}\right] - [1+\tau]^k \frac{f_r}{\varphi_r^{reg^k}} \right]. \quad (\text{A.25})$$

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

$$\left[\frac{[1 + \tau]^k - 1}{[1 + \tau]^k} \right] \left[\frac{\eta \delta f_\epsilon}{\sigma - 1} \right] > \frac{f_r}{\varphi_r^{reg^k}}. \quad (\text{A.26})$$

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 (A.26) is satisfied, and CWS-style regulation must increase the domestic price index. \square

We now turn to our proof of Empirical Prediction 5. Consider a firm with productivity level $\varphi \in [\varphi_x^{reg}, \varphi_r^{reg}]$. Relative domestic revenues with- and without-regulation are given by

$$\frac{r^{reg}(\varphi)}{r^{no}(\varphi)} = \left[\frac{P^{reg}}{P^{no}} \right]^{\sigma-1} \left[\frac{1}{1 + \tau} \right]^{\sigma-1}, \quad (\text{A.27})$$

and relative export revenues are given by

$$\frac{r_x^{reg}(\varphi)}{r_x^{no}(\varphi)} = \left[\frac{1}{1 + \tau} \right]^{\sigma-1}. \quad (\text{A.28})$$

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.

The intuition behind this result is straightforward. If regulation causes the domestic price index to rise, then some of the domestic production cost increase will be passed onto domestic consumers. However, due to the small open economy assumption, the domestic cost shock is never passed onto foreign consumers. With the assumed market structure and technology, the domestic price index only increases if the fixed cost of retrofitting is sufficiently large.

Appendix B Additional Empirical Results

In this section we provide additional empirical results referenced in Section 5 of the main text.

B.1 Flexible Estimates

Section 5.1 includes two figures that display results from two separate sets of regressions meant to test our key identifying assumption. Here we present tables with the corresponding regression coefficients and standard errors. Table B1 reports the results presented in Figure 3. Table B2 reports the results presented in Figure 4. In both cases, columns (1) and (2) report the estimates for exit out of exporting and export revenue, respectively.

As discussed in the main text, the results of both of these tests lend confidence to our research design. Table B1 shows no evidence of a difference in pre-treatment trends between our treated and control plants across any of our main dependent variables. It also shows a significant reduction in export revenues for treated plants following treatment that reaches its largest effect 1-year post regulation, but persists for all subsequent periods. Table B1 shows no systematic pattern in the triple-difference estimates in relatively clean regions across any of our dependent variables. In relatively dirty regions, however, regulation causes a significant reduction in export revenues.

B.2 Spillovers

In Section 5.3.1 we examine the potential spillovers induced by the CWS across industries and CMAs separately. In Table B3 we examine both of these potential spillovers concurrently. Panel A reports the results for export revenues, and Panel B reports the results for domestic revenues. As discussed in the main text, these regressions rely on a sub-sample of our main data, owing to our method of constructing the spillover variables. The first column shows the baseline estimates for export revenues for this sub-sample, while the fourth column shows baseline estimates for domestic revenues. Columns two and three report export revenue estimates measuring spillovers with, respectively, plant shares and export revenue shares as the spillover measure. Columns five and six show these estimates for domestic revenues. In both panels, the first row shows the direct effect of $PM_{2.5}$ regulation. Rows two and three show the within-industry and within-region spillover estimates, measuring both as the share of potential competitor plants regulated by the CWS. Rows four and five show the within-industry and within-region spillover estimates, measuring both as the share of export sales from potential competitors regulated by the CWS.

Table B1: The Effect of PM_{2.5} Regulation by Years Pre/Post Regulation

	Exit from Exporting		Export Revenue	Domestic Revenue
	(1)	(2)	(3)	(4)
PM _{2.5} Std. - $\leq T - 3$		(-)	0.098	-0.037
		(0.086)	(0.128)	(0.141)
PM _{2.5} Std. - $T - 2$	-0.044	(-)	0.108	0.147
	(0.065)	(0.067)	(0.117)	(0.289)
PM _{2.5} Std. - $T - 1$	-0.015			
	(0.037)			
PM _{2.5} Std. - T	0.055	(+)	-0.208	0.157
	(0.033)	(0.037)	(0.204)	(0.171)
PM _{2.5} Std. - $T + 1$	0.016	(+)	-0.439	-0.274
	(0.032)	(0.032)	(0.199)	(0.211)
PM _{2.5} Std. - $T + 2$	-0.006	(-)	-0.149	-0.093
	(0.028)	(0.027)	(0.137)	(0.137)
PM _{2.5} Std. - $\geq T + 3$	0.005	(+)	-0.224	-0.063
	(0.018)	(0.018)	(0.107)	(0.113)
R ²	0.287	0.118	0.298	0.253
Obs.	6418	6501	3807	3807

Notes: Table reports results from an event study estimation of the effects of the PM_{2.5} standard. Results from four different regressions are shown. The dependent variable in columns (1) and (2) is an indicator of exit out of exporting, while the dependent variable in column (3) is the natural log of export revenues and the dependent variable in column (4) is the natural log of domestic revenues. In column (1), the coefficients are measured relative to $\leq T - 3$, while in columns (2)-(4), coefficients are measured relative to $T - 1$. All regressions include plant, industry-year and CMA-year fixed effects, control for the CWS O₃ standard, 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. Coefficients marked (+) are positive, while coefficients marked (-) are negative. These coefficients have been suppressed by Statistics Canada to ensure no confidential information has been disclosed. Suppressed coefficients are not statistically significant at conventional levels.

The results in Panel A of Table B3 show no evidence of spillovers in our export revenue estimates; each spillover coefficient is small and not statistically significant and conventional levels, and the direct estimates of the CWS are statistically indistinguishable from our baseline estimates. In Panel B, we find a significant effect of within-CMA spillovers when measured with plant-shares. However, this is not-robust, as the effect is small and not statistically significant when measured with export shares.

To complement the spillover analysis presented in Section 5.3.1, we perform the same analysis on the extensive margin of trade, by estimating each of the six spillover regressions for the export-exit dependent variable. Recall, we find little evidence of export-exit on average, and thus we are less concerned with the potential for this being an over-estimate as a result of spillovers. Nonetheless, for completeness, we present these results in Table B4.

The first column in Table B4 shows the baseline estimate for the restricted sample used in the spillover analysis, while columns two through seven show the various spillover speci-

Table B2: The Effect of PM_{2.5} Regulation by CMA Air Quality

	<u>Exit from Exporting</u>	<u>Export Revenue</u>	<u>Domestic Revenue</u>
	(1)	(2)	(3)
PM _{2.5} Std. - 24-25 $\mu\text{g}/\text{m}^3$	-0.062 (0.027)	-0.100 (0.123)	-0.327 (0.140)
PM _{2.5} Std. - 26-27 $\mu\text{g}/\text{m}^3$	-0.099 (0.037)	0.119 (0.124)	-0.387 (0.149)
PM _{2.5} Std. - 28-29 $\mu\text{g}/\text{m}^3$	-0.029 (0.056)	0.017 (0.138)	-0.151 (0.133)
PM _{2.5} Std. - 30-31 $\mu\text{g}/\text{m}^3$	0.027 (0.032)	-0.244 (0.152)	-0.076 (0.160)
PM _{2.5} Std. - 32-33 $\mu\text{g}/\text{m}^3$	-0.072 (0.034)	-0.667 (0.204)	-0.149 (0.461)
PM _{2.5} Std. - ≥ 34 $\mu\text{g}/\text{m}^3$	-0.065 (0.028)	-0.295 (0.155)	-0.438 (0.163)
R ²	0.308	0.314	0.283
Obs.	2529	2179	2179

Notes: Table reports estimates from a DDD estimation allowing the effects of PM_{2.5} regulation to vary by CMA air quality. Results from three different regressions are shown. The dependent variable in column (1) is an indicator of exit out of exporting, while the dependent variable in column (2) is the natural log of export revenues and the dependent variable in column (3) is the natural log of domestic revenues. In all three columns, the coefficients are measured relative to the excluded group (air quality below 23 $\mu\text{g}/\text{m}^3$). All regressions include plant, industry-year and CMA-year fixed effects, control for the CWS O₃ standard, 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. Plants in regions without air quality monitors are excluded.

fications. In each column, the first row shows the direct effect of the PM_{2.5} standard. Rows two and three show the within-industry and within-CMA spillover estimates, measured as share of potential competitor plants regulated by the CWS. Rows four and five show the within-industry and within-CMA spillover estimates, measured as share of export revenues from potential competitors regulated by the CWS.

Due to confidentiality restrictions imposed by Statistics Canada, we are unable to report coefficient estimates for the direct effect of the PM_{2.5} standard on export exit.² Instead, we report the sign of these estimates, and standard errors. Each regression produces a positive direct effect of regulation on exit from exporting. None of these coefficients are statistically significant at conventional levels, nor are there statistically significant differences across any specification. Accounting for spillovers does not alter our main conclusions regarding export exit, on average. Turning to the spillover estimates, we find potential evidence of small within-CMA spillovers that reduce export exit. There is a reduction in the likelihood with which a plant exits the export market when they experience an increase in regulation among

²Point estimates are available to be viewed at the Canadian Centre for Data Development and Economic Research at Statistics Canada.

Table B3: The Effects of Air Quality Standards: Industry and CMA Spillovers

	Panel A:			Panel B:		
		Export Revenue		Domestic Revenue		
	(1)	(2)	(3)	(4)	(5)	(6)
PM _{2.5} Std.	-0.230 (0.103)	-0.231 (0.138)	-0.287 (0.112)	-0.147 (0.089)	-0.005 (0.133)	-0.136 (0.100)
Reg. Plant Share: Ind.		0.000 (0.001)			-0.000 (0.002)	
Reg. Plant Share: CMA		0.000 (0.009)			0.018 (0.008)	
Reg. Sales Share: Ind.			0.001 (0.001)			0.000 (0.002)
Reg. Sales Share: CMA			-0.007 (0.005)			0.001 (0.005)
R ²	0.324	0.324	0.324	0.226	0.228	0.227
Obs.	2723	2723	2723	2723	2723	2723

Notes: Table reports estimates of the effects of the CWS concurrently accounting for potential spillovers induced by regulatory exposure amongst competitors in the same industry and in the same CMA. The dependent variables are the natural log of export revenues (Panel A) and the natural log of domestic revenues (Panel B). All regressions rely on a sample of continuing exporters. All regressions include plant, industry-year and CMA-year fixed effects, control for the CWS O₃ standard, 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.

plants in their CMA. While interesting, this effect is small enough not to contaminate our direct estimate.

B.3 Prices

In Section 5.3.2 we examined a key mechanism of our model: the effect of air quality standards on prices. As mentioned in the main text, we do not observe detailed information on prices. Instead, we observe an indicator as to whether a plant reported changing prices in a given year. This important limitation notwithstanding, in Section 5.3.2 we showed that the CWS caused treated plants to change prices. In this section, we show that this average effect masks considerable heterogeneity by estimating Equation (24) using the indicator of whether a plant reported changing its output prices in a given year as the dependent variable.

Results showing the heterogeneity of the CWS on price changes is shown in Table B5. Column one shows the results for the full sample of plants, while column two shows the results for continuing exporters. The first row shows the treatment effect for plants in the smallest size quartile, and the lower rows show the effect for plants in the larger size quartiles. Unfortunately, due to confidentiality restrictions imposed by Statistics Canada,

Table B4: The Effects of Air Quality Standards: Spillovers Along the Extensive Margin

	<u>Industry</u>		<u>CMA</u>		<u>Both</u>		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PM _{2.5} Std.	(+)	(+)	(+)	(+)	(+)	(+)	(+)
	(0.027)	(0.027)	(0.027)	(0.027)	(0.025)	(0.027)	(0.025)
Reg. Plant Share: Ind.		0.000				0.000	
		(0.000)				(0.000)	
Reg. Plant Share: CMA				-0.004		-0.004	
				(0.002)		(0.002)	
Reg. Sales Share: Ind.			0.000				0.000
			(0.000)				(0.000)
Reg. Sales Share: CMA					-0.004		-0.004
					(0.002)		(0.002)
R ²	0.119	0.119	0.119	0.120	0.121	0.120	0.121
Obs.	4680	4680	4680	4680	4680	4680	4680

Notes: Table reports estimates of the effects of the CWS on plant exit while concurrently accounting for potential spillovers induced by regulatory exposure amongst competitors in the same industry and in the same CMA. In all regressions, the dependent variables are an indicator of exit out of exporting. All regressions include plant, industry-year and CMA-year fixed effects, control for the CWS O₃ standard, 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. Coefficients marked (+) are positive, but statistically insignificant at conventional significance levels. These coefficients have been suppressed to ensure no confidential information is disclosed.

we are unable to report some of these coefficient estimates.³ In this case, we report the coefficient’s sign, standard error, and information on whether that coefficient is statistically different from zero at conventional levels.

The results in column one of Table B5 shows heterogeneity in coefficient estimates consistent with our model’s predictions. PM_{2.5} regulation increased the probability a firm in the smallest size quartile changes prices by just under 10 percentage points, but has no statistically significant effect on price changing among plants in any of the larger quartiles. Column two shows a similar pattern when we restrict our analysis to continuing exporters: a significant increase in price changing among plants in the smallest size quartile, and no significant change for larger plants. While these findings are consistent with our model’s predictions, in which only variable costs – and thus prices – change among smaller firms, we caution that these results are relatively imprecise. As a result, we cannot reject the hypothesis of no heterogeneity.

³The suppressed point estimates are available to be viewed at the Canadian Centre for Data Development and Economic Research at Statistics Canada.

Table B5: The Effects of Air Quality Standards on Price Changes by Size Quartile

	Full Sample (1)	Continuing Exporters (2)
PM _{2.5} Standard×Q1	0.097 (0.038)	(+) [†] (0.058)
PM _{2.5} Standard×Q2	(−) (0.033)	(−) (0.084)
PM _{2.5} Standard×Q3	(+) (0.040)	(+) (0.094)
PM _{2.5} Standard×Q4	-0.009 (0.039)	(+) (0.040)
R ²	0.141	0.189
Obs.	6501	3807

Notes: Table reports estimates of the effects of the CWS on an indicator of whether the facility reported changing prices in a given year. The regressions reported in column (1) rely on the full set of plants in our sample, while the regressions reported in column (2) rely on a sample of continuing exporters. Both regressions include plant, industry-year and CMA-year fixed effects, control for the CWS O₃ standard, and are weighted by the inverse of the match probability to control for potential match-induced sample bias. In both cases, standard errors are clustered by CMA-industry. Coefficients marked (+) are positive, while coefficients marked (−) are negative. These coefficients have been suppressed to ensure no confidential information has been disclosed. † indicates suppressed coefficient is statistically significant at conventional levels.

B.4 The Effects of the CWS by Plant Size: An Alternative Size Measure

Our primary method for examining the potential heterogeneity in the effects of the CWS across plants (Equation (24)) was to put plants into different bins according to their relative size along the dependent variable. That is, when assessing heterogeneity in the CWS' effect on export revenues, we split firms into size bins based on their level of exports in the base year. For domestic revenues, we created these bins based on base-year domestic revenues, and for export exit, we split based on total revenues. We adopted this approach because we do not observe plant total factor productivity, and our model produces a one-to-one mapping between productivity and size.

Here we assess heterogeneity along an alternative size measure: employment. To do so, we estimate Equation (24) defining a plant's size as the total number of production workers employed during the first year they enter our sample. We split the employment-size distribution into quartiles, and interact these quartiles with our treatment indicator to obtain treatment effects by employment-size quartile.⁴

The results of this exercise for our three main dependent variables (exit from exporting,

⁴This exercise produces a small reduction in sample size, as employment information is only available for a subset of firms.

Table B6: The Effects of Air Quality Standards on Exporting

	<u>Exit from Exporting</u>	<u>Export Revenue</u>	<u>Domestic Revenue</u>
	(1)	(2)	(3)
PM _{2.5} Std.×Q1	(+) [†] (0.019)	-0.334 (0.169)	-0.219 (0.214)
PM _{2.5} Std.×Q2	(+) (0.025)	-0.188 (0.115)	0.079 (0.158)
PM _{2.5} Std.×Q3	(+) (0.038)	-0.299 (0.135)	-0.008 (0.138)
PM _{2.5} Std.×Q4	(-) (0.033)	-0.123 (0.211)	-0.123 (0.105)
R ²	0.115	0.298	0.256
Obs.	6440	3797	3797

Notes: Table reports estimates of the effects of the CWS on an indicator of exit out of exporting (Panel A), and the natural log of export revenues (Panel B) and the natural log of domestic revenues (Panel C). The regressions reported in Panel A rely on the full set of plants in our sample, while the regressions reported in Panels B and C rely on a sample of continuing exporters. All regressions include plant, industry-year and CMA-year fixed effects, control for the CWS O₃ standard, 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. Coefficients marked (+) are positive, while coefficients marked (-) are negative. These coefficients have been suppressed to ensure no confidential information has been disclosed. † indicates suppressed coefficient is statistically significant at conventional levels.

export revenues, and domestic revenues) are shown in Table B6. Column one assess the CWS' effect on export exit, relying on the full sample of plants. Columns two and three rely on the set of plants that export in all periods, and show the CWS effect on export and domestic revenues, respectively. Due to confidentiality restrictions imposed by Statistics Canada, we are unable to report the coefficient estimates for export exit.⁵ In this case, we report each coefficient's sign, standard error, and information on whether that coefficient is statistically different from zero at conventional levels.

The results in Table B6 are broadly consistent with the findings in our main analysis (Table 2). In column one, the estimate in the first row shows the CWS increased exit from exporting for plants in the smallest employment-size quartile. This increase is statistically significant at conventional levels. For all remaining employment size quartiles, we find no significant change in the likelihood a plant exits the export market. For export revenues, we find less heterogeneity than in the point estimates in our main analysis. As with our primary size measure, the largest point estimate occurs in the smallest employment quartile; however, the effect in the third quartile is also relatively large, and statistically significant. Due to the relative imprecision of these estimates, however, we cannot distinguish between the results in Table 2 and Table B6. For domestic revenues, as in the main text, we find

⁵The suppressed point estimates are available to be viewed at the Canadian Centre for Data Development and Economic Research at Statistics Canada.

no significant effect of the CWS for plants in any size quartiles, although the largest point estimate occurs in the smallest employment-size quartile.