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The Welfare Effects of Opening to Foreign Direct Investment in Polluting Sectors

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Abstract

This article investigates how attracting foreign direct investment (FDI) in a polluting sector affects home-country welfare relative to a closed polluting sector scenario. A welfare-maximizing government sets environmental regulations while accounting for public infrastructure levels, environmental quality, and FDI in a polluting sector. We show that in a closed polluting sector, environmental regulations are increasing over infrastructure. With FDI, a similar relationship holds but the optimal environmental regulation is higher to account for the decrease in domestic producer surplus and increase in pollution damages. A critical infrastructure level exists where welfare under a closed polluting sector and welfare with polluting FDI are equal. Countries with underdeveloped infrastructure below the critical infrastructure level are better off deterring FDI entrance into the polluting sector. As infrastructure quality increases beyond the critical infrastructure level, welfare is higher with FDI than under a closed polluting sector because of an increase in consumer surplus from lower prices.

Keywords Environmental regulations · Infrastructure · Foreign direct investment · Welfare · Heterogeneous firms

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1 Introduction

Attracting foreign direct investment (FDI) in polluting sectors through lower environmental regulations has been adopted by less developed and developing economies as a means to boost the economy. Copeland and Taylor (2004) find that developed countries with strict environmental regulations produce relatively less polluting goods than developing countries with lax environmental regulations. Studies show that environmental policy laxity encourages inward bound FDI (Cole and Elliott 2005; Kellenberg 2009; Wagner and Timmins 2009).

The influx of FDI in polluting sectors raises two important questions. What is the welfare implication for jurisdictions experiencing an influx of polluting FDI and what is the socially optimal level of environmental regulation that maximizes domestic welfare in the presence of more polluting FDI? The impact of introducing FDI in a polluting sector is ambiguous because of the existence of both negative and positive consequences from FDI in polluting sectors. The negative consequences could include the reduction in market share of domestic firms and increase in pollution from foreign firms. The benefits could involve an increase in consumer surplus, increased employment, higher wages, capital accumulation and technology transfer (Lee and Chang 2009).

The objective of this article is to develop a model that shows the optimal environmental regulations under a closed polluting sector and with FDI in polluting sector, and to compare the economic welfare of both regimes. We begin by observing that polluting firms consider the stringency of environmental regulations and public infrastructure quality when investing in countries. Public infrastructure refers to communication, energy, transportation infrastructures or skilled level of labor force. Firms are more likely to invest if infrastructure quality is high (Goodspeed et al. 2011). More firms in a polluting sector imply more pollution. Thus, the infrastructure level is expected to be positively correlated with the optimal environmental regulations to internalize the increase in pollution damage from more firms entering the market.

By including the role of public infrastructure, this study contributes to the literature on environmental regulations by providing two important policy implications. First, the so-called *race-to-the-bottom* in attracting FDI is not inevitable when the government invests in public infrastructure that can support the growth of all sectors in the economy. Second, some studies argue for leveraging FDI as an engine of growth for developing economies, but our results point to a need to develop infrastructure and support institutions before such investments are beneficial to the economies. The timing of opening the polluting sector to FDI is crucial for the country to avoid lower economic welfare since countries that have comparative advantage in the polluting sector are more likely to experience higher welfare when their infrastructure is well developed.

If the role of infrastructure is not considered, a *race-to-the-bottom* may exist where low environmental standards and regulations are established in the domestic country as a consequence of attracting FDI. Attracting FDI may reduce tariff revenues (Vezina 2014), lower real wages (Mehmet and Tavakoli 2003) and lower labor regulation standards (Olney 2013). However, studies also show that attracting FDI induces additional social spending on services that implies improvements in health and education of the domestic population (Hecock and Jepsen 2013), which can be seen as public infrastructure. This study analyzes infrastructure's role in determining the optimal environmental regulation to attract FDI and the corresponding welfare implication.

In the literature, all the empirical FDI and growth studies that we are aware of use Gross Domestic Product (GDP) or growth rate of GDP as a measure of economic welfare. There is no consistent relationship between opening to FDI and GDP or growth in these studies (Lipsey 2002). Alfaro (2003) finds that the relationship between FDI and growth depends on the sector. FDI positively affects growth in the manufacturing sector but it negatively affects growth in the primary sector. However, when considering negative production externalities, social welfare should include damages from pollution. We consider this in our theoretical model.

To our knowledge, the closest article to our study is Ferrara et al. (2015) where they address a similar problem. There are two major differences between our model and their model. First, Ferrara et al. solve for optimal environmental regulations and social welfare by assuming exogenous weights for environmental damages in the welfare function for different countries. Instead, we consider the role of infrastructure as a tradeoff from the government's point of view who decides the level of environmental regulation to entice FDI. Second, while Ferrara et al. assume a homogeneous representative firm, we allow for firm heterogeneity in productivity levels.

We incorporate heterogeneous firms and monopolistic competition to account for the differentiated goods characteristic of mobile polluting industries, such as electronic manufacturing, machinery and appliances (Kellenberg 2009). There are at least two benefits of modeling heterogeneous polluting firms instead of a homogeneous representative firm. First, we show how individual firms with varying productivity levels contribute to pollution, which allows us to investigate how aggregate firm distribution affects total pollution in addition to individual-firm pollution levels. Second, we determine how the pollution tax affects the marginal operating firms and industry entrants, which allows us to examine the responsiveness of aggregate firm entrants into the sector to changes in the pollution tax. A representative-firm model does not allow for investigation into these possibilities.

Helpman et al. (2004) also model heterogeneous firms engaged in FDI in monopolistic competition. Our model differs from Helpman et al. in three aspects. First, instead of a one-sector model, we build a two-sector model to see the flow in labor between the non-polluting and polluting sectors, which allows us to predict labor employment across both sectors. Second, we consider the role of infrastructure in affecting the number of firm entrants which elucidates the mechanism relating infrastructure to welfare with FDI versus the closed economy scenario. Finally, we solve the optimal environmental regulations and conduct welfare analysis.

We construct a two-sector general equilibrium model with a non-polluting sector and a polluting sector. Social welfare consists of aggregate consumer welfare, producer surplus of domestic producers in both the non-polluting and polluting sector, total value of labor, pollution damage and tax revenue. Welfare is maximized by optimally choosing the level of environmental regulations under different levels of public infrastructure quality.

Our simulation shows that the environmental tax rate unambiguously increases with the infrastructure level in both regimes because a higher environmental regulation is needed to account for the increase in pollution intensity as infrastructure quality increases output. The optimal environmental tax rates with FDI are higher than in a closed economy to account for the additional pollution from foreign firm production and the reduction of domestic producer surplus. We show the possibility that it is beneficial to allow FDI in a polluting sector only when the quality of infrastructure is sufficiently high. If the infrastructure quality is low, welfare in a closed polluting sector is higher than welfare with FDI because aggregate domestic producer surplus is larger with a closed polluting sector than additional consumer surplus gains with FDI in the polluting sector. As infrastructure quality rises, the effects are reversed. A critical infrastructure level exists where welfare is equal in both regimes. The critical infrastructure level decreases when the fixed and entry cost of production for foreign firms is low or domestic firms' fixed and entry costs are high.

Our model provides insight on how market power (the ability to set price above marginal cost), which may proxy for market structure to some extent, affects the critical infrastructure level. In perfect competition, more firms in the market result in lower price, more production and more pollution relative to a market in monopolistic competition. Consequently, consumer surplus is higher through lower price and more consumption, but welfare is reduced with more pollution damages. More firm entrants will lower the average firm's profit in the short run compared to monopolistic competition and in the long run, profit is zero. Thus, allowing more foreign firms to enter is likely to increase consumer surplus and disutility from pollution. If the rise in consumer surplus is larger than the disutility in pollution as infrastructure increases, the critical infrastructure level is likely to decline as market power is reduced and approximates perfect competition.

2 Model

We develop a two-sector general equilibrium model with heterogeneous firms in a polluting sector and homogeneous domestic firms in a clean non-polluting sector.[1] We compare the case with FDI in a polluting sector and another without it. To avoid confounding effects, we do not include imports and exports.

2.1 Consumers

A representative consumer has quasi-linear utility[2] that depends on consumption of goods in the non-polluting sector, Q_n, and goods in the polluting sector, Q_p, as well as pollution, Z,

$$U\left(Q_n, Q_p\right) = Q_n + \theta Q_p^{\alpha} - \delta Z, \tag{1}$$

where $\theta > 0$, $0 < \alpha < 1$ and $\delta > 0$ is the marginal disutility from pollution. Pollution is based on the level of production in the polluting sector. The consumer spends all their income I on consumption. The consumer's budget constraint is

$$I = PQ_p + Q_n, \tag{2}$$

[1] We assume asymmetry in firm heterogeneity in the two sectors to make solving and simulating the model more tractable. Kellenberg (2009) provides examples of mobile polluting industries that produce differentiated goods such as electronic manufacturing, machinery and appliances, so we assume our polluting sector is monopolistic competition. Since the non-polluting sector proxies for a large composite good sector, our assumption of homogeneous firms in a competitive market is reasonable for this purpose.

[2] We assume a quasi-linear utility to focus on the polluting sector only in demand aggregation without any cross-price effects from the non-polluting sector. We also assume separability in pollution disutility. Michel and Rotillon (1995) show that there may be a "distaste effect" where a rise in pollution reduces consumption demand for items like food. This may not hold for electronics, machineries and appliances so we assume that the "distaste effect" is negligible in our model which makes our separability assumption plausible.

where P is the endogenously determined relative price of the aggregate final good in the polluting sector. The price of the good from the non-polluting sector is normalized to 1.

Aggregate consumer demand in the polluting sector is equal to the sum of individual demand that each firm faces in the polluting sector,

$$Q_p = \left(\int_{j \in J} q^{\rho} dj \right)^{\frac{1}{\rho}}, \tag{3}$$

where $1 > \rho > 0$ and q is the demand for the output from an individual firm. There are J individual firms. The individual prices, p, and quantities, q, are indexed by j which we suppress to reduce notation clutter. The elasticity of substitution between varieties is $1/(1-\rho) > 0$.

2.2 Non-polluting Sector

Labor is the primary input along with an infrastructure level in both sectors of the economy. In the non-polluting sector, the production function of the representative firm is,[3]

$$y_n = i^{\nu} l_n, \tag{4}$$

where l_n is the labor input in the non-polluting sector, i is the level of publicly available infrastructure and ν denotes the output elasticity of infrastructure in the sector. We assume perfect competition in the non-polluting sector to represent a composite good where firms' profits are zero. Labor moves freely between the two sectors causing the wage rate to equalize.

2.3 Polluting Sector

The polluting sector consists of a continuum of heterogeneous firms with constant returns to scale technology in monopolistic competition. Firms that wish to enter the market pay an entry and fixed cost. Firms hire labor and use existing infrastructure and a productivity draw to produce a final good. Pollution is emitted as a by-product of production.

The main difference between the entry cost and fixed cost is the time and purpose of the costs (Melitz 2003; Helpman et al. 2004; Helpman 2006). Entry cost is the cost of receiving a productivity draw and it is paid before the firm makes a decision to enter the market. For example, this can refer to the research or consultation costs for assessing the feasibility and expected profit of setting up a new business in an industry. On the other hand, a fixed cost is paid for setting up production after the firm decides to enter the market. For example, it can be the cost to set up the production facility, distribution networks or pay administrative fees to government.

Both entry cost and fixed cost are functions of infrastructure. Both costs could be lowered with well-developed infrastructure quality because it reduces the cost of investigating the profitability to launch a new business and the cost of initiating the new business (Murphy et al. 1989; Aghion and Schankerman 1999). We specify the following equation to denote the entry cost functions for foreign firms and domestic firms, measured in labor units, respectively,

[3] The linear production function represents a constant return to scale technology which is standard in the trade literature (see Bhagwati et al. 1998 for examples).

$$\epsilon_j(i) = b_j + \vartheta \frac{1}{i} \quad \forall j = f, d; \tag{5}$$

where b_f and b_d are positive parameters and ϑ denotes the sensitivity of entry cost to public infrastructure.[4] The fixed cost functions for foreign firms and domestic firms are also measured in labor units such that,

$$\varphi_j(i) = r_j + \lambda \frac{1}{i} \quad \forall j = f, d; \tag{6}$$

where r_f and r_d are positive parameters and λ is the sensitivity of fixed cost to infrastructure.

Domestic and foreign firms face different entry cost and fixed cost. Foreign firms invest in investigating market opportunities across different countries around the world and usually pay more to overcome cultural and market differences. In addition, foreign firm's expenditure on market investigation are higher than domestic firms (Caves 1971). Therefore, we assume the foreign firms' entry cost is higher than the domestic firms' entry cost, such that $b_f > b_d$. On the other hand, foreign firms tend to incur lower cost than domestic firms to acquire intellectual property and technology to set up production, given their prior experience in their country (Caves 1971; Blomström and Kokko 1998). Thus, we assume the fixed cost of establishing plants is smaller for foreign firms than for domestic firms, such that $r_f < r_d$.

Potential firm entrants pay the entry cost to receive a productivity draw, a, from a known cumulative Pareto distribution function,

$$G(a) = 1 - \left(\frac{\omega}{a}\right)^{\gamma}, \tag{7}$$

where γ and ω are positive parameters. We assume a Pareto distribution since it is a good approximation to the productivity distribution of firms (Gibson and Graciano 2018). Firms operate or exit upon observing their productivity draw. A firm with the critical cutoff productivity level $\hat{a}$ has zero profit. To operate in the market, a firm's productivity draw must be larger than $\hat{a}$ to achieve positive profit. Any productivity lower than $\hat{a}$ yields negative profit for firms, which drives them out of the market.

The firm's production function in the polluting sector is

$$q = ai^{\eta} l_p \tag{8}$$

where l_p is labor input and η is output elasticity of infrastructure in polluting sector.

Pollution is external to both producers and consumers. It is created as a by-product during the production process where one unit of output corresponds to some units of pollution such that,[5]

$$z = \frac{\mu}{a} q, \tag{9}$$

where z is pollution from q units of output by one firm with a productivity draw, a, and μ is a conversion coefficient from output to pollution. Equation (9) supports the observation in the literature that more productive firms pollute less per unit of the good produced (Bloom

[4] We use subscripts f and d to denote parameters of foreign firms and domestic firms respectively.

[5] An alternative way to model pollution is as a dirty polluting input. All qualitative results still hold as long as the pollution tax is modeled as an input tax instead of an output tax.

et al. 2010; Holladay 2010; Martin 2011; Shapiro and Walker 2015). Aggregate pollution may still be larger from productive firms since they also tend to produce more output than less productive firms.

In monopolistic competition, each firm selects their own price, p, that maximizes profit. Firm-level profits in the polluting sector are equal to total revenues from production net wages, fixed costs and the environmental tax,

$$\pi_p = pq - \tau z - wl_p - w\varphi, \tag{10}$$

where w is wage rate and τ is the environmental pollution tax in the domestic country.

2.4 Labor Supply

Labor, L, is an exogenous total domestic labor endowment from the local economy and immigration is not allowed. Labor markets clear such that total labor is allocated between the polluting sector, the non-polluting sector and the labor used for fixed and entry cost, i.e. $L = L_p + l_n + \varphi M + \epsilon M_e$, where M refers to the measure of total operating polluting firms and M_e is the total measure of entrants including both successful and unsuccessful entrants in the polluting sector.[6] In this case, any remaining labor not hired in the polluting sector is employed in the clean sector, and we assume L is large enough to meet labor demand from both sectors.[7]

2.5 Stages of the Game

There are two stages in this game. In the first stage, the government chooses the optimal environmental regulation level given the infrastructure level. In the second stage, consumers maximize utility by choosing consumption from both sectors and firms in the polluting sector decide to enter the market by paying the entry cost. Those that remain in the market pay a fixed cost of building the plant and all firms in both sectors simultaneously and independently select labor and prices to maximize profit. Note that since the government is aware of the productivity draw of firms, this is a complete information game.

3 Theoretical Solution and Results

We solve the two-stage complete information game using backward induction.

3.1 Second Stage

We first solve each individual agent decision and then aggregate all relevant variables.

[6] Under the closed polluting sector case, $M = M_A$. When FDI is allowed in polluting sector, $M = M_d + M_f$. Note that M is a subset of M_e. Therefore, we use the firms' distribution and cutoff productivity to solve M_e as a function of M, i.e. $(1 - G(\hat{a}))M_e = M$. M_e is different under closed polluting sector and with FDI.

[7] The assumption of sufficient exogenous labor supply is also used in Grossman and Helpman (1994), Damania et al. (2003) and Melitz and Ottaviano (2008).

3.1.1 Second Stage: Individual Decisions

The representative consumer maximizes utility by choosing the level of consumption in both goods that maximizes (1) subject to (2) yielding the optimal level of aggregate demand in the polluting and non-polluting sectors,

$$Q_p = \left(\frac{\alpha\theta}{P}\right)^{1/(1-\alpha)}, \tag{11}$$

$$Q_n = I - P^{\frac{-\alpha}{1-\alpha}}(\alpha\theta)^{1/(1-\alpha)}. \tag{12}$$

The corresponding indirect utility is,

$$V = I + C - \delta Z, \tag{13}$$

where $C \equiv \theta\left(\frac{\alpha\theta}{P}\right)^{\alpha/(1-\alpha)} - P\left(\frac{\alpha\theta}{P}\right)^{1/(1-\alpha)}$ is consumer surplus from the polluting sector good.

Once aggregate consumption levels are chosen, individual firm demand is solved. This is done by minimizing the consumer's expenditure on output purchased from the polluting sector by choosing the consumption level for each polluting firm's output, i.e. $\min_q \int_{j\in J} pqdj$, subject to Eq. (3). The solution to the cost minimization problem yields each firm's individual demand,

$$q = \left(\frac{P}{p}\right)^{\frac{1}{1-\rho}} Q_p^c, \tag{14}$$

where the aggregate price index, P, is defined as $P \equiv \left(\int_{j\in J} p^{\frac{-\rho}{1-\rho}} dj\right)^{\frac{\rho-1}{\rho}}$.

Since we assume perfect competition in the non-polluting sector, the long run equilibrium profit is zero, $\pi_n = y_n - wl_n = 0$. Given the production function in Eq. (4), wage is a function of the infrastructure level, $w = i^\nu$. In equilibrium, the level of output produced in the non-polluting sector is equal to the demand by consumers such that $y_n = Q_n$.

In the polluting sector, individual polluting firm labor demand is derived by equating (8) and (14),

$$l_p = \frac{1}{ai^\eta}\left(\frac{P}{p}\right)^{\frac{1}{1-\rho}} Q_p. \tag{15}$$

Each firm chooses their optimal price, p, after substituting (5), (6), (8), (9), (14), and (15) into (10) to maximize profit. This yields a firm price level of,

$$p = \frac{1}{\rho a}\left(\tau\mu + \frac{w}{i^\eta}\right). \tag{16}$$

The price of the polluting good is increasing in the wage rate and level of environmental regulation, but decreasing in the stock of infrastructure and the elasticity of substitution. The pricing rule is the familiar fixed markup over marginal cost. The markup, $1/\rho > 1$, is determined by the elasticity of substitution between varieties and the degree to which producers have market power. More productive foreign firms will set lower output prices, produce more, and have higher profits than firms with lower levels of efficiency.

The cutoff value $\hat{a}$ is solved as a function of the aggregate price index P and aggregate equilibrium output Q by plugging Eqs. (5), (6), (8), (9), (12), (14)–(16) into (10) and setting it to zero,

$$\hat{a} = \frac{w + i^{\eta}\tau\mu}{i^{\eta}\rho}\left[\frac{w\varphi}{(1-\rho)(P)^{\frac{1}{1-\rho}}Q_p}\right]^{\frac{1-\rho}{\rho}}. \tag{17}$$

This is a variation of Melitz's (2003) Zero Profit Cutoff Productivity condition.

Firms enter until the expected profit from entry equals the cost of entry, $[1 - G(\hat{a})]\int_{\hat{a}}^{\infty}\pi(a)dH(a) = w\epsilon$, where $1 - G(\hat{a})$ is the probability of an entrant successfully entering the market and $H(a) = \frac{G(a)}{1-G(\hat{a})}$ is the truncated cumulative distribution function of productivity draw for successful firm entrants. The cutoff productivity that satisfies this condition is,

$$\hat{a} = \left(\frac{\varphi\omega^{\gamma}\rho}{\epsilon[\gamma(1-\rho)-\rho]}\right)^{\frac{1}{\gamma}}. \tag{18}$$

This is a variation of Melitz's (2003) Free Entry condition.

Given the assumptions of entry and fixed costs for domestic and foreign firms, the cutoff productivity of foreign firms is smaller than that of domestic firms. From Eq. (18), when $\varphi_d < \varphi_f$ and $\epsilon_d > \epsilon_f$, it follows that $\hat{a}_d > \hat{a}_f$, which implies that more foreign firms operate in the market than the domestic firms. The relatively large influx of foreign firms is due to the lower fixed cost of establishing plants.

The aggregate price, P, of polluting goods can be solved by equating (17) to (18) and plugging the results into (11),

$$P = \left[\frac{(1-\rho)}{w\varphi}\left(\frac{i^{\eta}\rho\hat{a}}{w + i^{\eta}\tau\sigma}\right)^{\frac{\rho}{1-\rho}}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{\frac{(1-\alpha)(1-\rho)}{\alpha-\rho}}. \tag{19}$$

Aggregate price is increasing in the wage rate and environmental regulation level, but decreasing in the infrastructure stock when the elasticity of substitution is sufficiently large, i.e. $\rho > \alpha$.

3.1.2 Second Stage: Aggregate Outcomes

Given the distribution of productivity draws from profitable firms, the aggregate price is,

$$P_A = \left(M_A\int_{\hat{a}_A}^{\infty} p(a)^{\frac{-\rho}{1-\rho}}dH_d(a)\right)^{\frac{\rho-1}{\rho}}. \tag{20}$$

where subscript A denotes a closed polluting sector case populated with domestic firms. The aggregate price index in the closed sector case shows how the mass of operating firms (M_A) and the cutoff productivity required to operate ($\hat{a}_A$) influence the price level in the economy. A higher cutoff productivity raises prices through the intensive margin as the average productivity of firms that choose to produce increases. The mass of operating firms represents the extensive margin.

When foreign firms enter the domestic market, both foreign firms and domestic firms compete in the market and the aggregate price with FDI, P_F, becomes,

$$P_F = \left(M_d \int_{\hat{a}_d}^{\infty} p(a)^{\frac{-\rho}{1-\rho}} dH_d(a) + M_f \int_{\hat{a}_f}^{\infty} p(a)^{\frac{-\rho}{1-\rho}} dH_f(a) \right)^{\frac{\rho-1}{\rho}}. \tag{21}$$

In the case where foreign firms enter, the aggregate price index is a function of the prices charged by domestic firms (the first term) and foreign firms (the second term). The price indices in (20) and (21) share the same form but differ in the cutoff productivity required to operate in the economy and mass of firms that successfully operate in the market. The productivity draws for foreign and domestic firms come from their own Pareto distribution and differ on their cutoff productivity levels too.[8] The relationship between the measures of domestic (M_d) relative to foreign (M_f) operating firms is,

$$\frac{M_f}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}} = \frac{M_d}{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}. \tag{22}$$

Equating (19) and (20) solves the measure of operating firms in a closed polluting sector, M_A. Using the measure of operating firms, we can derive other aggregate measures such as aggregate pollution and aggregate profit, respectively,

$$Z_A = M_A \int_{\hat{a}_A}^{\infty} z(a) dH_d(a), \tag{23}$$

$$\Pi_p^A = M_A \int_{\hat{a}_A}^{\infty} \pi_p(a) dH_d(a). \tag{24}$$

With FDI, the measure of operating domestic and foreign firms is solved by equating (19)–(21) and using (22). From these measures of operating firms, other aggregate expressions are derived such as aggregate pollution and aggregate domestic profit in the polluting sector, respectively,

$$Z_F = M_d \int_{\hat{a}_d}^{\infty} z_d(a) dH_d(a) + M_f \int_{\hat{a}_f}^{\infty} z_f(a) dH_f(a), \tag{25}$$

$$\Pi_p^d = M_d \int_{\hat{a}_d}^{\infty} \pi_d(a) dH_d(a) \tag{26}$$

From our assumptions on entry and fixed cost from domestic and foreign firms, the proportion of pollution contributed by foreign firms is larger than domestic firms as long as the productivity parameters of all firms come from the same distribution.

[8] We assume total potential firms entrants are the same for domestic and foreign firms for simplicity and tractability, i.e. $M_d^e = M_f^e$, where $M_d^e = \frac{M_d}{1-G(\hat{a}_d)} = \frac{M_d}{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}$ and $M_f^e = \frac{M_f}{1-G(\hat{a}_f)} = \frac{M_f}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}}$.

3.2 First Stage: Optimal Environmental Regulations

Optimal environmental regulation is selected to maximize welfare. In both cases, welfare consists of the sum of aggregate profit of domestic firms from polluting sector [Eq. (26)] and non-polluting sector; total welfare of consumers [Eq. (13)] which includes consumer surplus, disutility from pollution and total income; and tax revenues,[9]

$$W^K = \Pi_n + \Pi_P^d + wL + C - \delta Z + \tau Z \quad \forall\, K = A, F. \tag{27}$$

The aggregate profit in the non-polluting sector is zero ($\Pi_n = 0$) since each individual firm in a perfectly competitive industry earns zero in equilibrium. Pollution tax revenues and wages are transfers from firms to the government and consumers, respectively. There are differences in the welfare function components between the two regimes. For instance, when FDI is allowed in the polluting sector, wages from labor paid by foreign firms and pollution tax revenues are considered as surplus by the domestic economy.

Taking the first order condition of the welfare function with respect to τ yields,

$$\frac{\partial W^K}{\partial \tau} = \frac{\partial \Pi_P^d}{\partial \tau} + \frac{\partial C}{\partial \tau} + Z + (\tau - \delta)\frac{\partial Z}{\partial \tau} = 0 \quad \forall\, K = A, F. \tag{28}$$

The optimal environmental tax equates the marginal costs from the environmental regulation, which include the change in consumer surplus and aggregate profit in the polluting sector, with the marginal benefits in reduced damages from the pollution and changes in the tax revenue. Manipulating (28) solves the optimal environmental tax,

$$\tau^K = -\Gamma^K \frac{w}{i^\eta} + \delta \Delta^K \quad \forall\, K = A, F, \tag{29}$$

where Γ^K is the ratio of marginal welfare components from profit and consumer surplus relative to a linear combination of the sum of all marginal welfare components and Δ^K is the ratio of marginal welfare components from pollution damages relative to a linear combination of the sum of all marginal welfare components. Both are functions of wage, price elasticity of demand, and other parameters.[10] Equation (29) is a variation of the Pigouvian tax rate for a firm in monopolistic competition. The tax also depends on the public infrastructure level and marginal disutility. If public infrastructure is high or the marginal disutility is large, the Pigouvian tax rate is large.

Higher infrastructure quality leads to more stringent environmental regulations. All producers benefit from the stock of infrastructure available in the country, such that firms are willing to trade off more stringent regulations for greater infrastructure. The main mechanism that facilitates this result is the impact of infrastructure on the monopolistic price set by firms as shown in Eq. (16) where an increase in infrastructure leads to a lower mark-up price. In turn, this results in greater production and more pollution, necessitating higher environmental regulations.

The expression for the optimal environmental tax is the same in both the closed-sector case and FDI case; however, the values of Γ and Δ are different. It is difficult to compare the magnitude of Γ in both cases. This is because even though marginal welfare of

[9] Our welfare function is similar to the models by Fredriksson and Svensson (2003), Damania et al. (2003) and Fredriksson et al. (2003) who solve for optimal environmental regulations in the presence of corruption.

[10] See "Appendix A" for the derivation.

profits from domestic firms are likely to be higher with FDI since total domestic profits are reduced, marginal welfare from consumer surplus is lower with FDI since total consumer surplus is larger. However, it is most likely that $\Delta^F > \Delta^A$ since marginal damages are likely to be larger with the entrance of more foreign firms in the polluting sector. Thus, there are two interesting results. First, if $\Gamma^F = \Gamma^A$ and $\Delta^F > \Delta^A$, it is most likely that environmental taxes with FDI are higher than if the polluting sector was closed to it, i.e. $\tau^F > \tau^A$. A welfare maximizing government sets higher pollution taxes to counteract the rise in pollution and reduction in domestic producer surplus when foreign firms enter the polluting sector. This is similar to Ferrera et al.'s first proposition. Second, an increase in marginal pollution damages, δ, will increase the environmental tax gap between the FDI and closed economy cases. We explore the sensitivity of select parameters in the simulation.

3.3 Environmental Regulations, Infrastructure and Welfare

Infrastructure is likely to have a positive impact on welfare in both cases (with closed polluting sector and with polluting FDI) since both regimes have the same welfare components. Public infrastructure increases the productivity and output of firms in both the non-polluting and polluting sectors. As labor productivity increases, so does the wage rate. Individual polluting firms are more productive from the increase in infrastructure leading to an increase in aggregate output. More productive firms have more market power and have larger market share, both of which reduce the aggregate number of firms leading to lower aggregate producer surplus. In contrast, infrastructure decreases the average price of the goods leading to more aggregate demand and more firms entering the market to meet that demand resulting in higher aggregate producer surplus. Thus, infrastructure may increase producer surplus in the polluting sector if its effect on individual firms and aggregate demand outweigh its effect on the aggregate number of firms.

Infrastructure quality increases consumer welfare and labor value. Since price declines and output increases with higher infrastructure level, consumer surplus rises. Because the total labor endowment is fixed, the value of labor depends on wages. Since the wage rate is unambiguously increasing in infrastructure, the total effect of infrastructure on the value of labor is increasing.

The total effect of infrastructure quality on welfare depends on the magnitude of the positive benefits gained relative to the effect from pollution damages. Here, pollution damages increase as infrastructure rises because of more output. We find that if the positive effect of infrastructure on consumer surplus, labor value, and potentially producer surplus outweighs the effect of pollution damage, then welfare increases as infrastructure rises.

Even though the welfare components in both cases are the same, there are differences in the composition of firms with and without FDI leading to differences in environmental taxes and prices. We compare welfare levels in a closed polluting sector versus when FDI is allowed into the sector. Using Eq. (27) and aggregate functions in Sect. 3.1, we identify a sufficient condition for welfare under FDI to be greater than welfare under a closed polluting sector,[11]

$$\begin{aligned} &\left(B_{\Pi} + B_C\right)\left(\Omega\left(\tau^A, i\right)\right)^{\frac{\alpha\rho}{\alpha-\rho}} + \left(\tau^A - \delta\right) B_Z\left(\Omega\left(\tau^A, i\right)\right)^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1} \\ &\quad < \left(D_{\Pi} + D_C\right)\left(\Omega\left(\tau^F, i\right)\right)^{\frac{\alpha\rho}{\alpha-\rho}} + \left(\left(\tau^F - \delta\right) D_Z\right)\left(\Omega\left(\tau^F, i\right)\right)^{\frac{\alpha\rho}{\alpha-\rho}-1} \end{aligned} \tag{30}$$

[11] See "Appendix B" for the derivation.

Table 1 Summary of baseline parameters

Name	Parameters	Values
Domestic firm entry cost	b_d	1
Foreign firm entry cost	b_f	5.5
Domestic firm fixed cost	r_d	3
Foreign firm fixed cost	r_f	1
Sensitivity of entry cost to public infrastructure	ϑ	1
Sensitivity of fixed cost to public infrastructure	λ	1
Pareto distribution parameter	ω	1
Pareto distribution parameter for domestic firms	γ_d	4.2
Pareto distribution parameter for foreign firms	γ_f	4.2
Elasticity of infrastructure for polluting firms	η	0.85
Elasticity of infrastructure for non-polluting firms	ν	0.01
Elasticity of substitution proxy	ρ	0.6
Damage factor	δ	50
Conversion coefficient from output to pollution	μ	1
Utility function parameter	α	0.5
Utility function parameter	θ	1

Parameter value of η is from Atkeson and Kehoe (2005); parameter value of ρ is from Ruhl (2004)

where B_{Π}, B_C, and B_Z are marginal welfare effects from profit, consumer surplus, and pollution, respectively, when the polluting sector is closed; D_{Π}, D_C, and D_Z, are marginal welfare effects from profit, consumer surplus, and pollution, respectively, when the polluting sector is open to FDI; and $\Omega\left(\tau^A, i\right)$ and $\Omega\left(\tau^F, i\right)$ are functions proportional to price. Since prices are increasing in taxes, we note that $\Omega\left(\tau^A, i\right) < \Omega\left(\tau^F, i\right)$ as long as $\tau^A < \tau^F$. Also, $\alpha < \rho$ which implies the price effect lowers welfare overall. If environmental taxes are higher with FDI in the polluting sector and the sum of the marginal welfare components are larger in magnitude, we find that welfare under FDI to be higher than when the polluting sector is closed.

Even though we show conditions where welfare is higher in one scenario over another and elucidate the mechanisms by which infrastructure, environmental regulations, and welfare are related; the size and direction of each effect cannot be derived analytically. We turn to simulations.

4 Simulations

We present simulation results given assumed functional forms and parameters.

4.1 Functional Forms and Parameters

We specify functional forms and parameters summarized in Table 1. First, we assume a quasilinear utility function of the consumer,$U = Q_n + Q_p^{0.5} - \delta Z$. This allows us to derive interior solutions for aggregate demand in the polluting sector. Productivity of domestic and foreign firms share the same Pareto distribution in Eq. (7). We also set fixed and entry cost parameters of domestic and foreign firms to satisfy assumptions in the model.

Consistent with Atkeson and Kehoe (2005), the elasticity of infrastructure in production of polluting good is $\eta = 0.85$. In the non-polluting sector, however, we assume the production is less dependent on infrastructure, $\nu = 0.01$, because they are more human capital intensive (Antweiler et al. 2001; López et al. 2011).[12] The parameter related to elasticity of substitution between the heterogeneous goods, ρ, is 0.6, which is close to the value used by Ruhl (2004).

We gathered data to calculate simple correlations between our main variables of interest to provide empirical support to our simulations. Environmental regulations, infrastructure, and economic welfare are the three most important variables. We use a measure developed by Van Soest et al. (2006) who estimate the shadow price of energy use for selected OECD countries as our environmental regulation proxy. One advantage of this dataset is that it allows a comparable measure of environmental stringency across countries. The World Economic Forum measures an infrastructure quality index which is also comparable across countries. Finally, we use the World Bank's adjusted net national income measure which incorporates natural resource degradation as our proxy for economic welfare. Summary statistics and their sources are presented in Table 2.

4.2 Simulation Results

We determine the relationship between effects of infrastructure on environmental regulations and welfare under a closed polluting sector versus with FDI using simulations.

4.2.1 Environmental Taxes

Figure 1 shows the optimal environmental tax rates across varying levels of infrastructure under a closed polluting sector versus with FDI. In a closed polluting sector, an increase in the infrastructure level decreases the individual firm price and increases aggregate output leading to more pollution. As a response, the government increases the environmental tax rate. The optimal environmental tax rate increases at a decreasing rate over infrastructure levels. A similar relationship is derived in the case where FDI enters the polluting sector. The main difference compared to the case of a closed polluting sector is that the rise in environmental tax is more dramatic to offset additional pollution damages from foreign firms and their hiring of labor, which reduces domestic producer surplus. This result is similar to Ferrara et al. (2015) but we also show how changes in infrastructure affect the difference in environmental taxes between the two cases.

Using data for selected OECD countries we find a correlation coefficient of 0.42 between our environmental regulation proxy based on energy use and infrastructure quality measure, which indicates a positive correlation between the two variables. This is reflected in our simulation results relating optimal environmental tax and infrastructure levels.

We examine how changes in some parameters affect the baseline simulation results. When marginal damage from pollution is low, the optimal environmental tax curve

[12] The correlation coefficient of total toxic pollutants by industry (Salman 2011) and their cost elasticities with respect to public infrastructure (Nadiri and Mamuneas 1994) is 0.9 which indicates that more pollution-intensive industries rely on public infrastructure more than less pollution-intensive industries.

Table 2 Summary statistics

Variable	Description of variables	Source	Mean (SD)	Minimum	Maximum
Environmental regulation stringency indicator (millions of US dollars per ton)	Difference between a polluting input's shadow price and its purchase price	Van Soest et al. (2006)	0.1589 (0.1327)	0.0069	0.4235
Trade openness (%GDP)	Exports and Imports as a percentage of GDP	The World Bank	84.68 (51.30)	22.12	374.58
Infrastructure quality index (1–7)	Index level from 1 to 7	World Economic Forum	4.34 (1.20)	2.00	6.80
Adjusted net national income (million US dollar)	Gross national income minus consumption of fixed capital and natural resources depletion	The World Bank	380,434 (1,248,032)	671	12,047,418

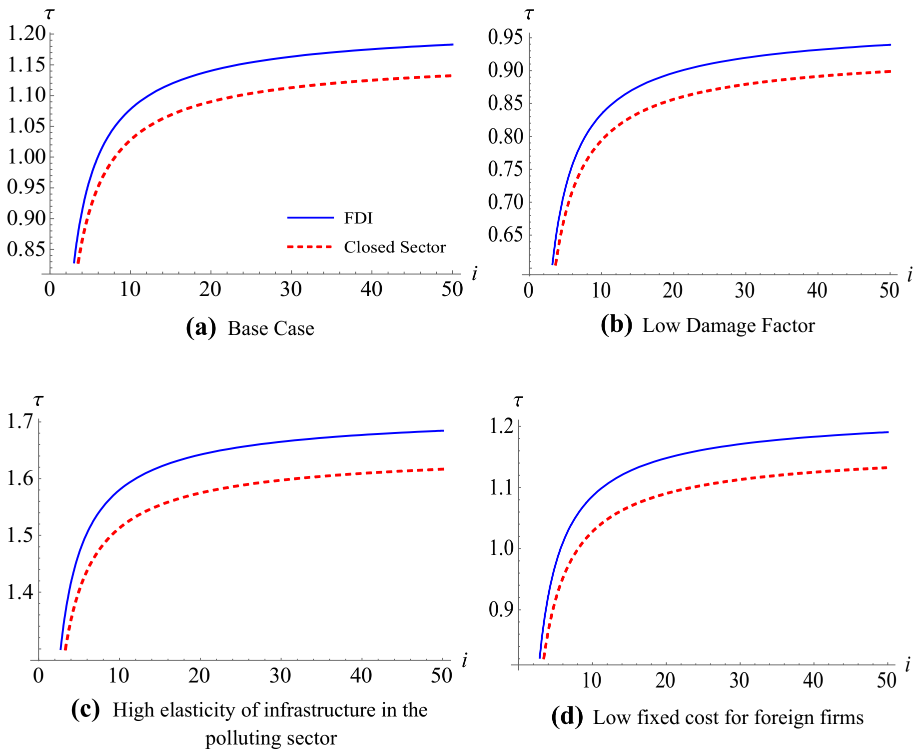
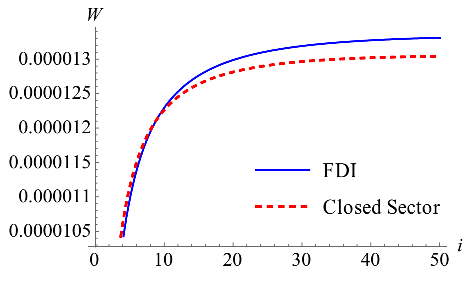


Fig. 1 Optimal environmental tax over infrastructure levels

Fig. 2 Welfare at different levels of infrastructure levels



shifts down across all infrastructure levels with the general relationship unchanged for both closed polluting sector case and with FDI as shown in Fig. 1b. Figure 1c shows the effect of an increase in the output elasticity of infrastructure in the polluting sector on environmental taxes. Optimal environmental tax increases at a faster rate compared to the baseline case. This is because the higher output elasticity of infrastructure increases firm productivity, which increases the marginal producer surplus and marginal pollution damage. If the latter effect outweighs the former effect, environmental tax is higher. Finally, Fig. 1d shows the effect of low fixed costs for foreign firms on the optimal environmental tax rate. A decrease in fixed cost results in more foreign firms entering the market. Benefits from the new entrants (which include higher consumer surplus, more

Table 3 Effect of an increase in select parameters on welfare

Parameter	Critical infrastructure level	Welfare under closed sector	Welfare under FDI
Demand			
Damage factor (δ)	No change	Decrease	Decrease
Elasticity of substitution proxy (ρ)	Increase	Decrease	Decrease
Supply			
Elasticity of infrastructure (η)	No change	Increase	Increase
Foreign firm fixed cost (r_f)	Increase	No change	Decrease
Foreign firm entry cost (b_f)	Increase	No change	Decrease
Domestic firm fixed cost (r_d)	Decrease	Decrease	No change
Domestic firm entry cost (b_d)	Decrease	Decrease	No change
Pareto distribution parameter when $\gamma_d = \gamma_f$	Decrease	Decrease	Increase
Foreign firm Pareto distribution parameter (γ_f) when domestic firm Pareto distribution parameter remains at the baseline level	Increase	No change	Decrease

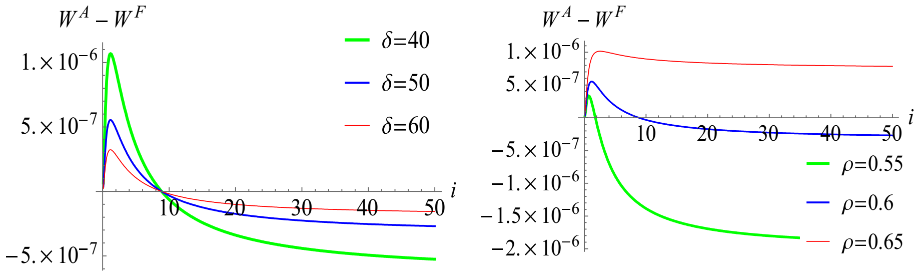
labor surplus, and larger tax revenue) are offset by the added pollution damage from new entrants and reduction in domestic producer surplus yielding the same environmental tax rate.

4.2.2 Welfare

Welfare unambiguously increases with infrastructure in a closed polluting sector and with FDI, as shown in Fig. 2. Our data also supports this relationship. The top 25% of countries in terms of trade openness have a correlation coefficient of 0.50 between the adjusted net national income measure and infrastructure quality. Similarly, the bottom 25% of countries in terms of trade openness have a correlation coefficient of 0.55 between the same variables which implies a positive relationship between economic welfare and infrastructure in both trade regimes.

Interestingly, a crossing point exists between the two curves. At low levels of infrastructure, welfare is higher under closed polluting sector as opposed to the case with FDI. When the infrastructure level is sufficiently high, however, welfare with FDI exceeds welfare under closed polluting sector. A critical infrastructure level exists where the welfare under closed polluting sector equals the welfare with FDI. An infrastructure level lower than this point means that it is more beneficial for the country to close off the polluting sector to FDI. In Ferrara et al. (2015), they show conditions when FDI in polluting industries do not reduce welfare based on differences in plant relocation costs. We show that even if there are differences in plant relocation cost, there are regions where welfare with FDI may be lower than welfare without FDI given particular infrastructure level.

The crossing point exists because of two important factors: the difference in profits of domestic polluting firms and the difference in consumer surplus between the case with a closed polluting sector and FDI. Social welfare from the aggregate profit of domestic firms is reduced more under the case with FDI than the case with a closed polluting sector because foreign firms take some of the share of the market. However, when the additional production of the foreign firms exceeds the production reduction of domestic firms, the

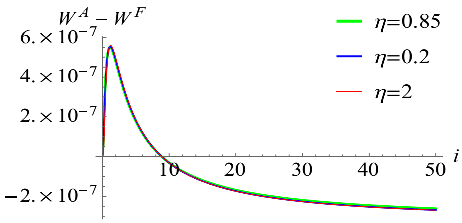


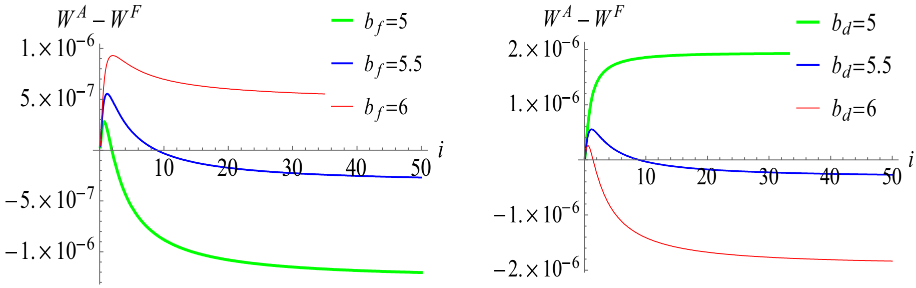
(a) Changing Damages from Pollution

(b) Changing the Proxy for Elasticity of Substitution

Fig. 3 Welfare difference between closed versus open to FDI polluting sector given changes in select demand side factors

Fig. 4 Welfare difference between closed versus open to FDI polluting sector given a change in the elasticity of infrastructure





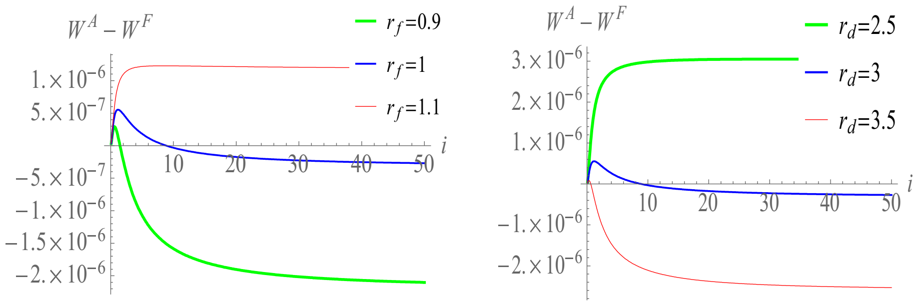
(a) Foreign Firm Entry Cost

(b) Domestic Firm Entry Cost

Fig. 5 Welfare difference between closed versus open to FDI polluting sector given changes in entry cost

price is lower leading to a higher consumer surplus with FDI than under a closed polluting sector.

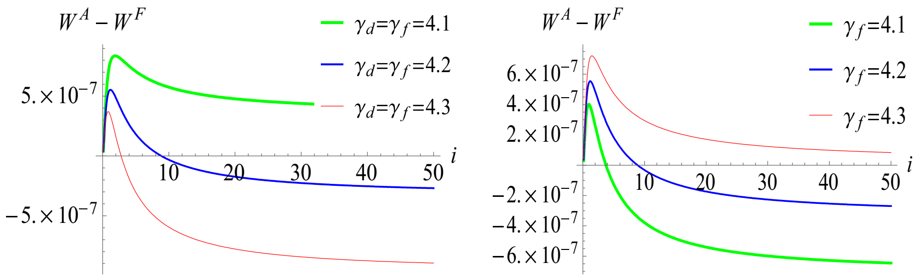
When infrastructure level is low, the gain in consumer surplus is smaller than the loss in profit of domestic firms when opening to polluting FDI, which results in higher welfare when closing the polluting sector. As infrastructure quality improves, the increase in consumer surplus dominates the decrease in aggregate domestic firms' profit, leading to higher welfare with FDI than in the closed polluting sector case. The result implies that the welfare gains of moving from a closed polluting sector to allowing polluting FDI to enter is



(a) Foreign Firm Entry Cost

(b) Domestic Firm Entry Cost

Fig. 6 Welfare difference between closed versus open to FDI polluting sector given changes in fixed cost



(a) Same Pareto distribution parameter across all firms

(b) Changing the Pareto Distribution Parameter for foreign firms only

Fig. 7 Welfare difference between closed versus open to FDI polluting sector given changes in Pareto distribution parameter

greater in countries that have better infrastructure quality than those with poor infrastructure levels. Allowing FDI in a polluting sector in a country with very low infrastructure quality may reduce welfare.

4.2.3 The Critical Infrastructure Level

We examine different factors that affect the position of the critical infrastructure level and summarize the results in Table 3. Figures 3, 4, 5, 6 and 7 illustrate the differences in welfare between the closed polluting sector case versus the case with FDI in the polluting sector under different parameter scenarios.[13] There are two factors of interest from the demand side: the marginal damage parameter and the proxy for the elasticity of substitution. When the marginal pollution damage δ changes, the critical infrastructure level remains the same as shown in Fig. 3a. The critical infrastructure does not change because higher marginal damages from pollution are accompanied by higher environmental taxes which reduce

[13] The vertical axis $W^A - W^F$ denotes the difference in welfare between a closed polluting sector versus when FDI is allowed in the sector.

pollution. Note that the welfare difference diminishes as marginal damage rises since gains from consumer surplus in FDI are reduced because of the higher environmental tax rate and rise in pollution damages.

When the proxy for the elasticity of substitution, ρ, increases, the critical infrastructure level increases as shown in Fig. 3b. A high elasticity of substitution decreases demand and price for individual firm's output leading to a decrease in each firm's profit. The reduction in producer surplus outweighs the gain in consumer surplus from lower prices leading to lower welfare in both cases. However, when FDI is allowed in the polluting sector, welfare decreases more compared to the closed sector case because the domestic producer surplus losses are larger than the net gain in consumer surplus with FDI, which leads to an increase in the critical infrastructure level.

We examine seven supply side parameters that may affect the critical infrastructure level. First, a more elastic infrastructure parameter, η, in the polluting sector has no effect on the critical infrastructure level as shown in Fig. 4. This is because all firms equally benefit from a change in the elasticity of infrastructure, leading to a lower price, more production and higher consumer surplus. Welfare in both cases rise at the same rate resulting in no change in the critical infrastructure level.

Fixed and entry costs have similar effects on the critical infrastructure level. A larger entry cost b_f for foreign firms shifts the critical infrastructure level to the right and if it is large enough, welfare with closed sector dominates as shown in Fig. 5a. The larger entry cost discourages foreign firm entrance which leads to less labor hired and less labor value benefit from the foreign firms. As a result, social welfare in the economy with FDI is lower leading to a higher critical infrastructure level needed to outpace welfare under a closed polluting sector. The opposite relationship holds for the entry cost of domestic firms as shown in Fig. 5b. We also find a similar relationship with fixed cost between the foreign and domestic firm as summarized in Fig. 6. The reason is the same as for a change in the entry cost.

We examine the impact of Pareto distribution shape parameter γ on the critical infrastructure level when it is the same for all firms versus a scenario where it is different between domestic and foreign firms as shown in Fig. 7. Assuming the same distribution draw for all firms, a larger Pareto distribution parameter, γ, implying firms are more heterogeneous in productivity, decreases the critical infrastructure level as shown in Fig. 7a. This is because when firms are more heterogeneous in productivity, more firms with low productivity operate in the market. Since foreign firms have a smaller cutoff productivity than domestic firms, the number of new operating foreign firms is larger than the number of new operating domestic firms. This results in larger consumer surplus gains with FDI that outweigh the increase in pollution damage. Welfare with FDI increases but welfare under a closed polluting sector declines because pollution damages are larger than the gains in consumer surplus when only domestic firms are in the market. The net effect is a decrease in the critical infrastructure level.

As a sensitivity test, we assume that the Pareto distribution parameters between foreign and domestic firms differ such that γ_f for foreign firms is higher than the baseline level. This implies that foreign firms are more heterogeneous. More low productive foreign firms operate and the gain in consumer surplus from opening FDI falls which leads to a lower welfare with FDI. When γ_d does not change for domestic firms, the welfare from a closed polluting sector remains the same. Therefore, a rise in γ_f increases the critical infrastructure level as shown in Fig. 7b.

In our model, we assume monopolistic competition in the polluting sector, but results may differ in a different market structure. If market power declines and approximates perfect competition, more firms will enter in the market leading to lower prices, more production and more pollution relative to monopolistic competition. Long run profits in perfect competition are zero. Thus, when examining the effect of infrastructure on welfare in the FDI and closed polluting sector case, we only need to examine the impact on consumer surplus and pollution. If consumer surplus increases at a faster pace than pollution damages over infrastructure, the critical infrastructure level will likely be lower in perfect competition than monopolistic competition because opening to FDI allows more firms to enter leading to lower prices and more consumer surplus.

5 Conclusions

This article develops and simulates a heterogeneous firm model that investigates how welfare is affected when governments enact policies to entice FDI in a polluting sector by endogenously selecting an environmental tax rate. We show how policies to attract FDI in a polluting sector can lead to lower welfare than in the closed polluting sector case. An economy that does not have well developed infrastructure may choose to lower environmental regulations to entice domestic and foreign firms into the economy. Welfare in both regimes differ depending on the infrastructure level. Countries with high infrastructure quality are more likely to experience higher social welfare with FDI than under a closed polluting sector but the results are reversed when infrastructure quality is low. A critical infrastructure level may exist where welfare in the two cases are the same. This critical infrastructure depends on demand and supply parameters.

Governments set environmental regulations differently when considering FDI entrants depending on the current infrastructure quality in the country. A welfare maximizing government sets more stringent environmental regulations with FDI than a closed polluting sector case because foreign firms reduce aggregate domestic producer surplus and increase pollution. When infrastructure quality is low, employing less stringent environmental tax regulations to attract FDI can lead to lower welfare compared to the closed polluting sector case. In the context of the *race-to-the-bottom* where a suboptimal environmental regulation is implemented, there is a greater possibility that the welfare with FDI is even lower than the closed polluting sector case for a given infrastructure level.

Our results have important policy implications for developing economies. We provide a conditionally positive message for countries that allow polluting firms in the domestic economy. Though an increase in pollution is likely as a consequence of the influx of FDI, overall welfare may still increase. This result is conditional on the host country having a sufficient level of public infrastructure in place. Opening a polluting sector to FDI does not ensure higher growth relative to the status quo. Investments in public infrastructure quality that not only benefit the polluting sector but other non-polluting sectors are likely to increase welfare.

In our model, the government does not use the environmental tax revenues as an investment into an asset. A future study may want to consider a case where such revenues are used to abate technology or invest in a lower emitting technology or even use the revenues to reduce an existing distortionary tax. Also, our model does not allow wages to increase as foreign firms compete for domestic labor. If such an effect is significant in the domestic labor market, there may be an increase in rent from labor which could lower optimal environmental regulations as a way of attracting more foreign firms thereby influencing the critical infrastructure level. A future study may integrate such an effect into the model.

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Appendix A: Derivation of Optimal Environmental Tax for Closed Polluting Sector and FDI

We first derive the optimal environmental tax under a closed polluting sector. From Eq. (19), the aggregate price of polluting goods under a closed polluting sector is,

$$P_A = \left[\frac{(1-\rho)}{w\varphi_d}\left(\frac{i^\eta \rho \hat{a}_A}{w + i^\eta \tau\mu}\right)^{\frac{\rho}{1-\rho}}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{\frac{(1-\alpha)(1-\rho)}{\alpha-\rho}}. \tag{A1}$$

Plugging Eq. (16) and $H(a) = \frac{G(a)}{1-G(\hat{a})}$ with (7), simplifying (20) yields

$$P_A = M_A^{\frac{1-\rho}{-\rho}}[\Omega(\tau,i)]\left(\frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}}\right)^{\frac{1-\rho}{-\rho}}\hat{a}_A^{-1}, \tag{A2}$$

where $\Omega(\tau,i) = \frac{1}{\rho}\left(\tau\mu + \frac{w}{i^\eta}\right)$.

Equating (A1) and (A2), solves for M_A,

$$M_A = \left[\frac{(1-\rho)}{w\varphi_d}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{\frac{-\rho(1-\alpha)}{\alpha-\rho}}(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)}\left(\frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}}\right)^{-1}\left(\hat{a}_A\right)^{\frac{-\alpha\rho}{\alpha-\rho}}. \tag{A3}$$

Using these aggregate measures, we can now derive each component of welfare. We start with aggregate profit. Rearranging (17), we derive the following,

$$\left(P_A\right)^{\frac{1}{1-\rho}}Q = \frac{w\varphi_d}{(1-\rho)}\left[\frac{1}{\rho\hat{a}_A}\left(\tau\mu + \frac{w}{i^\eta}\right)\right]^{\frac{\rho}{1-\rho}}. \tag{A4}$$

Plug (9), (14)–(16), and (A4) into (10) and simplifying yields,

$$\pi_p(a) = w\varphi_d\left(\frac{\hat{a}}{a}\right)^{-\frac{\rho}{1-\rho}} - w\varphi_d. \tag{A5}$$

With (A3), (A5), and $H_d(a) = \frac{G_d(a)}{1-G_d(\hat{a})}$, aggregate profit for domestic polluting firms is,

$$\begin{aligned}\Pi_P^A = M_A \int_{\hat{a}_A}^{\infty} \pi_d(a)dH_d(a) = \left[\frac{(1-\rho)}{w\varphi_d}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{\frac{-\rho(1-\alpha)}{\alpha-\rho}}\left(\hat{a}_A\right)^{\frac{-\alpha\rho}{\alpha-\rho}} \\ \left(\frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}}\right)^{-1} w\varphi_d\gamma_d\left(\frac{1}{\gamma_d - \frac{\rho}{1-\rho}} - \frac{1}{\gamma_d}\right)(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)} = B_\Pi(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}},\end{aligned} \tag{A6}$$

where $B_{\Pi} = \left[\frac{(1-\rho)}{w\varphi_d}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{\frac{-\rho(1-\alpha)}{\alpha-\rho}} \left(\hat{a}_A\right)^{\frac{-\alpha\rho}{\alpha-\rho}} \left(\frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}}\right)^{-1} w\varphi_d\gamma_d\left(\frac{1}{\gamma_d - \frac{\rho}{1-\rho}} - \frac{1}{\gamma_d}\right)$.

The second component of welfare is consumer surplus which is defined as $C = \theta\left(\frac{\alpha\theta}{P}\right)^{\alpha/(1-\alpha)} - P\left(\frac{\alpha\theta}{P}\right)^{\frac{1}{1-\alpha}}$. With (A1), consumer surplus can be written as,

$$C = \left[\frac{(1-\rho)}{w\varphi_d}\left(\hat{a}_A\right)^{\frac{\rho}{1-\rho}}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{-\frac{\alpha(1-\rho)}{\alpha-\rho}} \left(\theta(\alpha\theta)^{\frac{\alpha}{1-\alpha}} - (\alpha\theta)^{\frac{1}{1-\alpha}}\right)[\Omega(\tau,i)]^{\frac{\alpha\rho}{\alpha-\rho}} = B_C(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}}, \tag{A7}$$

where $B_C = \left[\frac{(1-\rho)}{w\varphi_d}\left(\hat{a}_A\right)^{\frac{\rho}{1-\rho}}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{-\frac{\alpha(1-\rho)}{\alpha-\rho}} \left(\theta(\alpha\theta)^{\frac{\alpha}{1-\alpha}} - (\alpha\theta)^{\frac{1}{1-\alpha}}\right)$.

The third component of welfare is pollution damages which depends on pollution levels. Pollution levels for each firm is derived by plugging (14) and (16) into (9), which yields,

$$z(a) = \frac{\tau\mu}{a}\left[\frac{1}{\rho a}\left(\tau\mu + \frac{w}{i^{\eta}}\right)\right]^{-\frac{1}{1-\rho}}(P)^{\frac{1}{1-\rho}}Q. \tag{A8}$$

With (11), (A1), (A3), and (A8), the aggregate pollution can be solved as,

$$Z_A = M_A\int_{\hat{a}_d}^{\infty} z(a)dH_d(a) = (\alpha\theta)^{\frac{-\rho}{\alpha-\rho}}\left(\hat{a}_A\right)^{\frac{-\alpha\rho}{\alpha-\rho}}\left(\frac{w\varphi_d}{(1-\rho)}\right)^{\alpha\frac{1-\rho}{\alpha-\rho}}\mu(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1} = B_Z(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1}, \tag{A9}$$

where $B_Z = (\alpha\theta)^{\frac{-\rho}{\alpha-\rho}}\left(\hat{a}_A\right)^{\frac{-\alpha\rho}{\alpha-\rho}}\left(\frac{w\varphi_d}{(1-\rho)}\right)^{\alpha\frac{1-\rho}{\alpha-\rho}}\mu$.

Plugging (A6), (A7), (A9) and recognizing that $\Pi_n = 0$ because each firm in a competitive industry earns zero profit in equilibrium, into Eq. (27) for K = A and taking the first order condition to solve optimal tax and simplifying yields the following equation,

$$\tau = \frac{\delta\left(\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1\right)B_Z\mu - \left(\frac{\alpha\rho}{\alpha-\rho}B_{\Pi}\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}B_C\frac{\mu}{\rho} + B_Z\right)\frac{w}{i^{\eta}}}{\mu\left[\left(\frac{\alpha\rho}{\alpha-\rho}B_{\Pi}\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}B_C\frac{\mu}{\rho} + B_Z\right) + \left(\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1\right)B_Z\right]} = -\Gamma^A\frac{w}{i^{\eta}} + \delta\Delta^A$$

where $\Gamma^A = \frac{-\left(\frac{\alpha\rho}{\alpha-\rho}B_{\Pi}\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}B_C\frac{\mu}{\rho} + B_Z\right)}{\mu\left[\left(\frac{\alpha\rho}{\alpha-\rho}B_{\Pi}\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}B_C\frac{\mu}{\rho} + B_Z\right) + \left(\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1\right)B_Z\right]}$ and $\Delta^A = \frac{\left(\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1\right)B_Z\mu}{\mu\left[\left(\frac{\alpha\rho}{\alpha-\rho}B_{\Pi}\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}B_C\frac{\mu}{\rho} + B_Z\right) + \left(\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1\right)B_Z\right]}$.

Therefore, we obtain the result in Eq. (29) for K = A.

Next, we derive the optimal tax when allowing FDI into the polluting sector. From Eq. (19), aggregate price of polluting goods with FDI is

$$P_F = \left[\frac{(1-\rho)}{w\varphi_f}\left(\frac{i^{\eta}\rho\hat{a}_f}{w + i^{\eta}\tau\mu}\right)^{\frac{\rho}{1-\rho}}(\alpha\theta)^{\frac{1}{1-\alpha}}\right]^{\frac{(1-\alpha)(1-\rho)}{\alpha-\rho}}. \tag{A10}$$

Plugging Eqs. (16), (22), $H_d(a) = \frac{G_d(a)}{1-G_d(\hat{a})}$, and $H_f(a) = \frac{G_f(a)}{1-G_f(\hat{a})}$ with (7) into (21), and simplifying yields,

$$P_F = \left(M_f\right)^{-\frac{1-\rho}{\rho}} [\Omega(\tau,i)] \left[\frac{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}} \frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}} \hat{a}_d^{\frac{\rho}{1-\rho}} + \frac{\gamma_f}{\gamma_f - \frac{\rho}{1-\rho}} \hat{a}_f^{\frac{\rho}{1-\rho}} \right]^{-\frac{1-\rho}{\rho}}. \tag{A11}$$

Equating (A10) and (A11), solve M_f as

$$M_f = \left[\frac{(1-\rho)}{w\varphi_f} \hat{a}_f^{\frac{\rho}{1-\rho}} (\alpha\theta)^{\frac{1}{1-\alpha}} \right]^{\frac{-\rho(1-\alpha)}{\alpha-\rho}} \left[\frac{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}} \frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}} \hat{a}_d^{\frac{\rho}{1-\rho}} + \frac{\gamma_f}{\gamma_f - \frac{\rho}{1-\rho}} \hat{a}_f^{\frac{\rho}{1-\rho}} \right]^{-1} (\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} = D_M(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}}, \tag{A12}$$

where $D_M = \left[\frac{(1-\rho)}{w\varphi_f} \hat{a}_f^{\frac{\rho}{1-\rho}} (\alpha\theta)^{\frac{1}{1-\alpha}} \right]^{\frac{-\rho(1-\alpha)}{\alpha-\rho}} \left[\frac{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}} \frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}} \hat{a}_d^{\frac{\rho}{1-\rho}} + \frac{\gamma_f}{\gamma_f - \frac{\rho}{1-\rho}} \hat{a}_f^{\frac{\rho}{1-\rho}} \right]^{-1}$.

The aggregate profit for domestic polluting firms is derived by using (22), (A5), (A12) and $H_d(a) = \frac{G_d(a)}{1-G_d(\hat{a})}$,

$$\Pi_F^d = M_d \int_{\hat{a}_d}^{\infty} \pi_d(a) dH(a) = \left[\frac{(1-\rho)}{w\varphi_f} \hat{a}_f^{\frac{\rho}{1-\rho}} (\alpha\theta)^{\frac{1}{1-\alpha}} \right]^{\frac{-\rho(1-\alpha)}{\alpha-\rho}} \left[\frac{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}} \frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}} \hat{a}_d^{\frac{\rho}{1-\rho}} + \frac{\gamma_f}{\gamma_f - \frac{\rho}{1-\rho}} \hat{a}_f^{\frac{\rho}{1-\rho}} \right]^{-1} w\varphi_d \gamma_d \left(\frac{1}{\gamma_d - \frac{\alpha}{1-\alpha}} - \frac{1}{\gamma_d} \right) (\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} = D_\Pi (\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} \tag{A13}$$

where $D_\Pi = \left[\frac{(1-\rho)}{w\varphi_f} \hat{a}_f^{\frac{\rho}{1-\rho}} (\alpha\theta)^{\frac{1}{1-\alpha}} \right]^{\frac{-\rho(1-\alpha)}{\alpha-\rho}} \left[\frac{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}} \frac{\gamma_d}{\gamma_d - \frac{\rho}{1-\rho}} \hat{a}_d^{\frac{\rho}{1-\rho}} + \frac{\gamma_f}{\gamma_f - \frac{\rho}{1-\rho}} \hat{a}_f^{\frac{\rho}{1-\rho}} \right]^{-1} w\varphi_d \gamma_d \left(\frac{1}{\gamma_d - \frac{\alpha}{1-\alpha}} - \frac{1}{\gamma_d} \right)$.

With (A10), the consumer surplus with FDI is,

$$C_F = \theta \left(\frac{\alpha\theta}{P_F} \right)^{\alpha/(1-\alpha)} - P_F \left(\frac{\alpha\theta}{P_F} \right)^{\frac{1}{1-\alpha}} = \left[\frac{(1-\rho)}{w\varphi_f} \left(\hat{a}_f\right)^{\frac{\rho}{1-\rho}} (\alpha\theta)^{\frac{1}{1-\alpha}} \right]^{-\frac{\alpha(1-\rho)}{\alpha-\rho}} \left(\theta(\alpha\theta)^{\frac{\alpha}{1-\alpha}} - (\alpha\theta)^{\frac{1}{1-\alpha}} \right) [\Omega(\tau,i)]^{\frac{\alpha\rho}{\alpha-\rho}} = D_C(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}}, \tag{A14}$$

where $D_C = \left[\frac{(1-\rho)}{w\varphi_f} \left(\hat{a}_f\right)^{\frac{\rho}{1-\rho}} (\alpha\theta)^{\frac{1}{1-\alpha}} \right]^{-\frac{\alpha(1-\rho)}{\alpha-\rho}} \left(\theta(\alpha\theta)^{\frac{\alpha}{1-\alpha}} - (\alpha\theta)^{\frac{1}{1-\alpha}} \right)$.

The aggregate pollution is solved using (11), (22), (A8), (A10), and (A12), $H_d(a) = \frac{G_d(a)}{1-G_d(\hat{a})}$, and $H_f(a) = \frac{G_f(a)}{1-G_f(\hat{a})}$,

$$\begin{aligned} Z_F &= M_d \int_{\hat{a}_d}^{\infty} z_d(a) dH_d(a) + M_f \int_{\hat{a}_f}^{\infty} z_f(a) dH_f(a) \\ &= (\alpha\theta)^{\frac{-\rho}{\alpha-\rho}} \left[\frac{w\varphi_f}{(1-\rho)} \hat{a}_f^{\frac{-\rho}{1-\rho}} \right]^{\frac{\alpha-\rho\alpha}{\alpha-\rho}} \mu\Omega(\tau,i)^{\frac{\alpha\rho}{\alpha-\rho}-1} = D_Z(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}-1}, \end{aligned} \tag{A15}$$

where $D_Z = (\alpha\theta)^{\frac{-\rho}{\alpha-\rho}} \left[\frac{w\varphi_f}{(1-\rho)} \hat{a}_f^{\frac{-\rho}{1-\rho}} \right]^{\frac{\alpha-\rho\alpha}{\alpha-\rho}} \mu.$

According to (22),

$$M_d = M_f \frac{\left(\frac{\omega_d}{\hat{a}_d}\right)^{\gamma_d}}{\left(\frac{\omega_f}{\hat{a}_f}\right)^{\gamma_f}}. \tag{A16}$$

Plugging (A12) into (A16) solves for the measure of all domestic firm entrants.

The expression for welfare with FDI is derived by plugging (A12)–(A16) and $\Pi_m = 0$ into Eq. (27) for K = F. Taking the first order condition and solving the optimal tax yields,

$$\tau = \frac{\delta\left(\left(\frac{\alpha\rho}{\alpha-\rho}\right) - 1\right)D_Z\mu - \left(\frac{\alpha\rho}{\alpha-\rho}D_\Pi\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}D_C\frac{\mu}{\rho} + D_Z\right)\frac{w}{i^\eta}}{\mu\left[\left(\frac{\alpha\rho}{\alpha-\rho}D_\Pi\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}D_C\frac{\mu}{\rho} + D_Z\right) + \left(\left(\frac{\alpha\rho}{\alpha-\rho}\right) - 1\right)D_Z\right]} = -\Gamma^d\frac{W}{i^\eta} + \delta\Delta^d$$

where $\Gamma^d = \frac{-\left(\frac{\alpha\rho}{\alpha-\rho}D_\Pi\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}D_C\frac{\mu}{\rho} + D_Z\right)}{\mu\left[\left(\frac{\alpha\rho}{\alpha-\rho}D_\Pi\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}D_C\frac{\mu}{\rho} + D_Z\right) + \left(\left(\frac{\alpha\rho}{\alpha-\rho}\right) - 1\right)D_Z\right]}$ and $\Delta^d = \frac{\left(\left(\frac{\alpha\rho}{\alpha-\rho}\right) - 1\right)D_Z\mu}{\mu\left[\left(\frac{\alpha\rho}{\alpha-\rho}D_\Pi\frac{\mu}{\rho} + \frac{\alpha\rho}{\alpha-\rho}D_C\frac{\mu}{\rho} + D_Z\right) + \left(\left(\frac{\alpha\rho}{\alpha-\rho}\right) - 1\right)D_Z\right]}.$

Therefore, we obtain the result in Eq. (29) for K = F.

Appendix B: Derivation of Sufficient Condition Where Welfare Under FDI is Larger than Welfare with a Closed Polluting Sector

Plug (A6), (A7), (A9) to (27) for K = A to obtain welfare with a closed polluting sector,

$$W^A = B_\Pi(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} + B_C(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} + (\tau-\delta)B_Z(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1}.$$

Rearrange to derive,

$$W^A = \left(B_\Pi + B_C\right)(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} + (\tau-\delta)B_Z(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1}. \tag{B1}$$

Plug (A13)–(A15) to (27) for K = F to obtain welfare under FDI,

$$W^F = D_\Pi(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} + D_C(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} + (\tau-\delta)D_Z(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1}.$$

Rearrange to derive,

$$W^F = \left(D_\Pi + D_C\right)(\Omega(\tau,i))^{\frac{\alpha\rho}{\alpha-\rho}} + (\tau-\delta)D_Z(\Omega(\tau,i))^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1}. \tag{B2}$$

When $W^A < W^F$, we shave

$$\left(B_{\Pi}+B_{C}\right)\left(\Omega\left(\tau^{A},i\right)\right)^{\frac{\alpha\rho}{\alpha-\rho}}+\left(\tau^{A}-\delta\right)B_{Z}\left(\Omega\left(\tau^{A},i\right)\right)^{\left(\frac{\alpha\rho}{\alpha-\rho}\right)-1}$$
$$<\left(D_{\Pi}+D_{C}\right)\left(\Omega\left(\tau^{F},i\right)\right)^{\frac{\alpha\rho}{\alpha-\rho}}+\left(\left(\tau^{F}-\delta\right)D_{Z}\right)\left(\Omega\left(\tau^{F},i\right)\right)^{\frac{\alpha\rho}{\alpha-\rho}-1}.$$

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