School of Economic Sciences

Working Paper Series
**WP 2015-7**

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**May 2015**

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**Abstract**

This article shows how policies to attract foreign direct investment (FDI) in a polluting sector affect home-country welfare relative to the autarky case. A welfare-maximizing government sets public infrastructure and environmental regulations while accounting for environmental quality and FDI in a polluting sector. We show that under autarky, environmental regulations are increasing over infrastructure. However, with FDI, optimal environmental regulations may be a subsidy if the wage benefits outweigh the pollution damages. Also, we find that countries with poor infrastructure levels are better off deterring FDI entrance but as infrastructure quality increases, welfare is higher with FDI than under autarky.

Keywords: Environmental Regulations; Infrastructure; Welfare; Pollution Haven

JEL Codes: F64, Q58, O44

## 1. Introduction

The pollution haven hypothesis states that strict environmental regulations may induce polluting firms to relocate to jurisdictions that have less stringent environmental regulations because doing so lowers the cost of production. The jurisdiction with a more lax environmental regulation has comparative advantage in the production of the polluting good, which may explain how developed countries with strict environmental regulations produce relatively less polluting goods than developing countries with lax environmental regulations (Copeland and Taylor 2004). Empirical literature that used cross-sectional data to test the hypothesis failed to find a statistically significant effect of environmental regulations on a firm's decision to relocate to a different jurisdiction (Jaffe et al. 1995). More recent empirical literature that uses panel data find a statistically significant and reasonable magnitude of the impact of environmental regulations on location decisions (Brunnermeier and Levinson 2004).

Given the growing evidence that polluting firms relocate to jurisdictions with lax regulations, a question now arises: is the welfare of the jurisdiction experiencing an influx of foreign direct investment (FDI) in the polluting sector increasing or decreasing? Also, given that jurisdictions can choose their level of environmental regulation and infrastructure, what policy maximizes domestic welfare? There may be negative consequences from FDI in polluting sectors because more production increases pollution. On the other hand, there may also be positive benefits of FDI within the jurisdictions, such as increased employment, higher wages, capital accumulation and technology transfer (Lee et al. 2009).

The objective of this article is to develop a model that shows how policies to attract FDI in polluting sectors affect economic welfare. We begin by observing that foreign owners of polluting firms not only consider the stringency of environmental regulations when making investments but infrastructure quality as well. Firms are more likely to invest if there is a high infrastructure quality level, such as communication, energy, transportation infrastructures or a more skilled labor force (Goodspeed et al. 2011). A jurisdiction that does not have well developed infrastructure may choose to lower their environmental regulations to entice FDI into the sector. Lower environmental regulations increases pollution damage but the influx of firms may also raise the value of marginal product of labor leading to an overall ambiguous effect on economic welfare.

Our article contributes to the pollution haven literature by understanding the welfare effects of polluting industry movement. Previous work has found that FDI is an important part of how multinationals participate in international trade (Helpman, 1984). Some recent work has paid special attention to the roll environmental regulation play in attracting FDI. There is a significant positive effect of environmental policy laxity on inward bound FDI (Cole and Elliot, 2005; Wagner and Timmins 2009). Multinational corporations that are mobile but produce significant pollution, such as firms in the electronics manufacturing industry, are more likely to locate to countries that have less stringent environmental regulations (Kellenberg 2009). The market for output from multinational corporations, be it local-market oriented or export-oriented, has varying responses to environmental regulations (Tang 2015). In general, lower environmental regulations will lead to an increase in FDI and more pollution.

A rise in pollution does not necessarily imply a decline in economic welfare since other benefits such as higher wages, increased output, technology spillover and fostering linkages with other firms may exist with FDI. Lipsey (2002) survey the empirical literature and show that such positive spillovers are significant but there is no consistent positive relationship with Gross Domestic Product (GDP) and growth. Alfaro (2003) find 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. All the empirical FDI and growth studies we are aware of uses GDP or growth rate of GDP as a measure of economic welfare. In the context of the pollution haven literature, economic welfare should also include damages from pollution. We fill this void in the literature by developing a theoretical model that endogenously determines the environmental regulations and infrastructure level to attract polluting FDI while accounting for a measure of economic welfare that includes pollution damages.

Mobile polluting industries such as electronic manufacturing produce differentiated products. In our theoretical model, we incorporate heterogeneous firms and monopolistic competition similar to Melitz (2003) to account for the differentiated goods characteristic of the industry. Our model differs from Melitz (2003) in three aspects. First, we analyze the effects of FDI instead of international trade. Second, unlike Melitz's one sector model, we build a two sector model by adding a homogeneous manufacturing sector. This allows us to see the flow in labor between domestic and foreign firms. Finally, we solve optimal infrastructure levels and environmental regulations in the presence of pollution damages.

We develop a two-sector general equilibrium model that illustrates the effect on the economy when a government allows FDI in a polluting sector versus the case when it remains in autarky. The first sector is a manufacturing sector composed of homogeneous firms while the second sector is a polluting sector comprised of heterogeneous firms that create pollution during the production process. There is also a heterogeneous group of foreign polluting firms that have higher productivity and higher pollution intensity than domestic polluting firms. If the government allows FDI, the government maximizes the sum of aggregate consumer welfare, producer surplus in the manufacturing sector and the total value of labor in the polluting sector by optimally choosing the level of environmental regulations and public infrastructure. However, when there is no FDI in the polluting sector, the government maximizes the sum of aggregate consumer welfare and producer surplus from both sectors by optimally choosing the level of environmental regulations and public infrastructure. Thus, the welfare attached to the polluting sector differs under autarky versus with FDI.

We simulate the model and compare the cases under autarky versus allowing FDI in the polluting sector. Our simulation shows that the environmental tax rate unambiguously increases with the infrastructure level in autarky. This occurs because a higher tax rate is needed to internalize the increase in pollution intensity as infrastructure quality increases output. However, when the country allows FDI, the optimal environmental tax rate may rise over infrastructure quality but at a much slower rate than under autarky. Also, when environmental damages are relatively low, it may decline altogether and become a subsidy. This may occur when the wage benefit from FDI is larger than environmental damages.

Our model shows that lowering environmental regulations to attract FDI in a polluting sector can contribute to lower welfare compared to the case where the country remains in autarky. In particular, we find that it is beneficial to allow FDI in a polluting sector only when the quality of infrastructure is high. When the infrastructure quality is very low, autarky leads to higher welfare than with FDI. In this case, the relative price of the good is lower under autarky leading to higher consumer surplus which outweighs the value of labor gains from FDI in the polluting sector. However, as infrastructure quality increases, the effects are reversed where the value of labor gains from FDI outweigh the consumer surplus making welfare higher when FDI is allowed into the polluting sector. Thus, a critical infrastructure level exists where welfare is equal in both trade regimes. We test the sensitivity of this critical infrastructure level to different parameters. Higher output elasticity of infrastructure in the polluting sector and lower fixed cost of production increases the critical infrastructure level but changes in marginal pollution damages have no effect on its position.

The results have important policy implications. First, there are some studies that argue for using FDI as an engine of growth for developing economies but our results point to a need to develop infrastructure and supporting institutions before such investments can be beneficial to the economy. Second, 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 (polluting and non-polluting) sectors in the economy. This implies that the timing of opening the polluting sector to FDI is crucial for the country to avoid lower economic welfare since countries that allow polluting foreign firms are more likely to experience higher welfare when their infrastructure is well developed.

The remainder of the article is organized as follows: Section 2 provides an overview of the model. Section 3 describes the equilibrium properties of the model. Section 4 summarizes the parameters used for simulating the model. Section 5 discusses simulation results and Section 6 provides concluding remarks.

## 2. Model

We develop a two-sector general equilibrium model with heterogeneous firms in a polluting sector and homogeneous domestic firms in a manufacturing sector. The model has an analytic solution and remains tractable allowing us to show the mechanisms relating infrastructure, environmental regulations and welfare. However, due to the complexity of the model, we turn to simulations to illustrate how changes in one parameter affect the variables of interest.

*2.1 Consumers*

The representative consumer has quasi-linear utility that depends on the level of consumption in the two final goods from the manufacturing sector, $Q_m^c$, and the polluting sector, $Q_p^c$, as well as pollution, *Z*,

(1) $V = Q_m^c + u(Q_p^c) - \delta Z,$

where $\delta > 0$ is the marginal disutility from pollution. Pollution is based on the level of production in the polluting sector such that $Z = \mu Q_p^c$ where $\mu$ is a parameter converting the level of output in the polluting sector to pollution units. The representative consumer is endowed with *L* units of labor. The consumer inelastically supplies their entire labor endowment at wage rate *w*, and spends all their income on consumption. The consumer's budget constraint is,

(2) $wL = PQ_p^c + Q_m^c,$

where $P$ is the endogenously determined relative price of the final good in the polluting sector.

*2. 2 Manufacturing Sector*

Labor is the primary input used in production in the two sectors of the economy along with an infrastructure quality level. Output in the manufacturing sector is,

(3) $y_m = il_m,$

where $l_m$ is the labor input and *i* is the level of publically available infrastructure. Infrastructure can be thought of as either physical infrastructure such as roads, telecommunications, and airports or human capital levels such as skill that boosts labor. 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. The sector is characterized by monopolistic competition and constant returns to scale. Firms use labor to produce a final good. Pollution is emitted as a by-product of production. Firms pay a sunk entry cost, $\varphi_e$, measured in labor units to receive a productivity draw, $x$, from a known cumulative distribution function, $G(x)$. Firms operate or exit upon observing their productivity draw. We assume that the main difference between owners of polluting firms in foreign countries and owners of domestic polluting firms is that productivity draws in the former contain higher efficiency parameters than the latter. This implies that the foreign owners will crowd out domestic owners in the polluting sector if the country opens to FDI.

Given our quasi-linear utility function, there is separability in the consumption of both final goods. This implies that we can derive the demand for each firms' product in the polluting sector without considering the demand for the good in the manufacturing sector. The consumer minimizes expenditure on output purchased from the polluting sector by choosing their consumption level for each polluting firm's output, subject to the constraint that aggregate consumer demand is equal to the sum of each firm's individual demand in the polluting sector,

(4) $Q_p^c = \left(\int_{j\in J} q^{\theta} dj\right)^{\frac{1}{\theta}},$

where $1 > \theta > 0$ and $q$ is the demand for the output from an individual firm. Note that there are $j$ individual firms so that the individual prices and quantities are indexed by $j$ which we suppress to reduce notation clutter. The elasticity of substitution between varieties is $1/(1-\theta) > 0$.The solution to the cost minimization problem yields the individual demand for each firm,

(5) $q = \left(\frac{P}{p}\right)^{\frac{1}{1-\theta}} Q_p^c,$

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

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

(6) $\pi_p = (1-\tau)pq - wl_p - w\varphi$,

where $\tau$ is the environmental regulation level in the domestic country,[1] $l_p$ is labor input and $\varphi$ is the fixed cost of operating measured in units of labor. Output by a firm in the polluting sector is

(7) $q = xi^{v} l_p$

where $x$ is the productivity draw and $v$ is output elasticity of infrastructure. The firm chooses labor input to meet demand for their variety. Labor demand is derived by equating (5) and (7) and solving for $l_p$,

(8) $l_p = \frac{1}{xi^{v}}\left(\frac{P}{p}\right)^{\frac{1}{1-\theta}} Q_p^c$.

## 3. Theoretical Solution and Results

We solve the three stage complete information game using backward induction.

(I) In the first stage, the government selects the infrastructure level.

(II) In the second stage, the government chooses the optimal environmental regulation level given the infrastructure level.

(III) In the third stage, firms in the manufacturing and polluting sectors simultaneously and independently select labor and prices to maximize profit while consumers maximize utility by choosing consumption in both sectors.

Note that the solution to stages I and II will differ in the cases of autarky versus with FDI. In stage III, the equilibrium solution is similar under both trade regimes with the only difference being the parameters in the cumulative distribution function, $G(x)$, used to derive the productivity draws.

### *3.1 Third Stage – Individual Decisions and Aggregate Outcomes*

[1] In this article, environmental regulations are modeled as an ad valorem tax on output in the pollution sector. The tax rate per unit of pollution is $\tau_z = \tau/\mu$.

Consumers maximize utility by choosing the level of output in both final goods that maximize (1) subject to (2) yielding the optimal level of aggregate demand in the manufacturing and polluting sectors. The corresponding indirect utility is,

(9) $V^* = wL + C - \delta Z,$

where $C \equiv u\left(u_Q^{-1}(P)\right) - Pu_Q^{-1}(P)$ is consumer surplus from consuming the good in the polluting sector and $u_Q^{-1}$ is the inverse of $\partial u/\partial Q_p^c$.

In the manufacturing sector, given constant returns to scale in the sector, wages and profit are $w = i$ and $\pi_m = 0$, respectively. Total number of firms in the sector are normalized to 1 so that in equilibrium, the level of output produced in the manufacturing sector is equal to the demand by consumers such that $y_m = Q_m^c$.

In the polluting sector, each firm choose their optimal price, $p$, after substituting (7) and (8) into (6) to maximize profits,

(10) $p = \frac{w}{(1-\tau)xi^v\theta}.$

The price of the polluting good is increasing in the wage rate and environmental regulation level, 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, $1/\theta > 1$, 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.

To derive the aggregate price in the polluting sector, we determine the cutoff productivity level for firms to operate by following Melitz (2003). The minimum productivity level firms need to profitably operate satisfies $\pi_p(\hat{x}) = 0$, where $\hat{x}$ is the cutoff productivity level. From this condition, we solve for the cutoff productivity required to operate in the polluting sector,

(11) $$\hat{x} = \omega\left(\frac{\varphi\theta}{\varphi_E(\gamma(1-\theta)-\theta)}\right)^{\frac{1}{\gamma}}.$$

Equilibrium in this stage is characterized as a set of firms entering into the polluting sector given a distribution of productivity level meeting the minimum threshold, $\hat{x}$. Let $M$ be the measure of firms that operate in the polluting sector. Given the range of efficiencies for which firms are willing to operate, the aggregate price and production index are, respectively,

(12) $P = \left(M\int_{\hat{x}}^{\infty} p(x)^{\frac{-\theta}{1-\theta}} dH(x)\right)^{\frac{\theta-1}{\theta}}$; and

(13) $Q_p^c = \left(M\int_{\hat{x}}^{\infty} q(x)^{\theta} dH(x)\right)^{\frac{1}{\theta}}$.

Here, $H(x) = \frac{G(x)}{1-G(\hat{x})}$ is the cumulative distribution function of the successful firm entrants. Similar expressions also exist for aggregate labor in the polluting sector, $L_p = M\int_{\hat{x}}^{\infty} l(x) \quad dH(x)$, and aggregate profit, $\Pi_p = M\int_{\hat{x}}^{\infty} \pi_p(x) \quad dH(x)$. Note also that expected profits cannot be negative otherwise firms would be unwilling to enter. Likewise, they cannot be positive because free entry allows more firms to enter at any time. Firms enter until the expected profit from entry equals the cost of entry, $(1-G(\hat{x}))\int_{\hat{x}}^{\infty} \pi_p(x) \quad dH(x) = w\varphi_e$.

Finally, labor markets clear such that total labor is allocated between the polluting sector, the manufacturing sector and the labor used for fixed and entry cost, $L = L_p + l_m + \varphi M + \varphi_e M_e$ where $M_e$ is the total number of potential new entrants in the polluting sector. We assume the number of firms in the market is fixed at *M*. This implies that the number of firms that exit the market from the existing number of firms in *M*, equals the number of successful entrants in $M_e$, i.e., $(1-G(\hat{x}))M_e = \beta M$, where $\beta$ represents the probability of failing to operate in the market.

*3.2 Second Stage – Optimal Environmental Regulations*

Under autarky, both sectors of the economy are populated by domestic firms. In this case, the government chooses the level of environmental regulation in order to maximize welfare. Welfare is the sum of producer surplus from both sectors, consumer welfare from equation (9) and total tax revenues,

(14) $W^A = \Pi_m + \Pi_p + C - \delta Z + \tau p Q_p^c$.

where $\Pi_m$ and $\Pi_p$ are aggregate profits in the manufacturing and polluting sectors, respectively. The aggregate profit in the manufacturing sector is zero since each individual firm earns zero.

Employing envelope theorem, the first order condition to the government's welfare maximization problem when choosing τ is,

(15) $-M\int_{\hat{x}}^{\infty} p(x)y(x)dH(x) + \frac{dC}{dp}\frac{\partial p}{\partial \tau} + PQ_p^c + \tau\left(\frac{\partial p}{\partial \tau}Q_p^c + \frac{\partial Q_p^c}{\partial \tau}P\right) - \delta\mu\frac{\partial Q_p^c}{\partial \tau} = 0.$

In equilibrium, supply equals demand, which implies $M\int_{\hat{x}}^{\infty} p(x)y(x)dH(x) = PQ_p^c$. Also, $\frac{dC}{dp} = 0$ since marginal utility equals price for the marginal consumer. Equation (15) shows that the optimal environmental tax is chosen such that the marginal cost from the environmental regulation, which include the change in tax revenues, equal the marginal benefits in reduced damages from the pollution. Manipulating (15) to solve for the optimal environmental tax yields,

(16) $\tau = \frac{\delta\mu}{p\left(\frac{1}{\epsilon}+1\right)}$,

where $\epsilon \equiv \frac{\partial Q_p}{\partial P_p}\frac{P_p}{Q_p}$ is the own price elasticity of demand. Equation (16) is the standard Pigouvian tax rate for the firm in monopolistic competition. The tax depends on the own price elasticity of demand and marginal disutility. If the marginal disutility is high or the elasticity of demand is low, the Pigouvian tax rate is large.

Higher infrastructure quality leads to higher environmental regulations under autarky. 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 equation (10). An increase in infrastructure leads to lower mark-up price. This, in turn, results in greater production and more pollution. The increased disutility is offset by setting higher environmental regulations.

Recall that we assume foreign owners will crowd out domestic owners in the polluting sector because of significantly larger productivity draws. With FDI in the polluting sector, profits are no longer considered by the government in their welfare function since revenues are acquired by foreign firms. Welfare is composed of producer surplus in the manufacturing sector, consumer surplus by the representative consumer, total taxes and welfare from the polluting sector. The government maximizes welfare by selecting the level of environmental regulations,

$$(17)\ W^F = wL_p + w\varphi M + w\varphi_e M_e + \Pi_m + C - \delta Z + \tau p Q_p^c.$$

The government benefits from allowing FDI into the polluting sector through higher wages earned by workers, $wL_p$, the value of fixed cost from labor, $w\varphi M$, the value of entry cost from labor, $w\varphi_e M_e$, and total tax revenues. In the model, fixed costs use up labor resources. As a result, they enter the labor market clearing condition and influence the wage rate in equilibrium, which causes the government to consider them as part of their welfare maximization. The first order condition to the government's welfare maximization problem when choosing τ is,

$$(18)\ w\frac{\partial L_p}{\partial \tau} + w\varphi\frac{\partial M}{\partial \tau} + w\varphi_e\frac{\partial M_e}{\partial \tau} + \frac{dC}{dp}\frac{\partial p}{\partial \tau} + pQ_p^c + \tau\left(\frac{\partial p}{\partial \tau}Q_p^c + \frac{\partial Q_p^c}{\partial \tau}p\right) - \delta\mu\frac{\partial Q_p^c}{\partial \tau} = 0.$$

As in equation (15), $\frac{dC}{dp} = 0$. The marginal benefit from the environmental tax regulations remains the same since it includes the reduction of pollution damages. However, the marginal cost of environmental regulation is different with FDI because it includes the reduction in the value of labor from the polluting sector.

Manipulating (18) solves the optimal tax regulation with FDI,

$$(19)\ \tau = \frac{\delta\mu - \frac{pQ_p^C}{\frac{\partial Q_p^C}{\partial \tau}} - w\frac{dL_p}{dQ_p^C} - w\varphi\frac{\partial M}{\partial Q_p^C} - w\varphi_e\frac{\partial M_e}{\partial Q_p^C}}{p\left(\frac{1}{\epsilon}+1\right)}.$$

Unlike (16), there are four extra terms in the numerator of the optimal tax. The second term in the numerator is total revenues weighted by the change in polluting output from the tax. The remaining terms represent the reduction in the value of labor, the number of firms and the number of potential entrants brought about by a change in output demand, respectively. Since the first two terms are positive but the latter terms are negative, the environmental tax regulation with FDI may be lower than tax regulations under autarky. Interestingly, if the wage benefits are significant enough, the overall environmental tax rate may be negative (an environmental subsidy) with FDI. In this case, the government views the benefits from higher total labor income greater than the benefits from the reduction in environmental damages.

With FDI, the relationship between infrastructure and environmental regulation is not as straightforward. Additional infrastructure can lead to increased environmental regulations through the decline in price and increase in output. However, there is also a wage effect as shown in equation (19). The stock of public infrastructure increases the productivity of all firms in the economy, which subsequently increases labor productivity and the wage rate which induces lower environmental regulation to attract more employment. As a result, there are two countervailing effects that determine the impact of infrastructure on environmental regulations with FDI. If the effect of infrastructure through prices outweighs the effect through wages, environmental regulations rise.

### *3.3 First Stage – Optimal Infrastructure Level*

The government maximizes net welfare by selecting the infrastructure level in the first stage,

(20) $\max_i V^j - ri$,

where $V^j \equiv \max_\tau W^j$ is the indirect welfare from the country for the $j^{th}$ regime $j$=$A$,$F$ (under autarky or with FDI) and $r$ is the price of infrastructure. The optimal condition that determines the level of infrastructure is,

(21) $V_i^j - r = 0$,

where the marginal welfare from infrastructure is equal to the price of infrastructure. The marginal welfare from infrastructure under autarky is decomposed into the marginal profits from the polluting sector and marginal consumer surplus gains while the marginal cost of infrastructure include the marginal damages from pollution as well as the infrastructure price. The marginal benefits from infrastructure are different with FDI. Here, instead of the marginal profits from the polluting sector, the value of marginal product of labor in the polluting sector along with the marginal tax revenue is included in marginal benefits from infrastructure. Thus, the infrastructure level chosen under autarky versus with FDI may differ.

*3.4 Environmental Regulations, Infrastructure and Welfare*

Infrastructure level is likely to have a positive impact on welfare under autarky and with FDI. In autarky, infrastructure affects welfare through producer surplus, consumer surplus, total tax revenues and pollution damages. Public infrastructure increases the productivity and output of firms in both the manufacturing and polluting sectors. As labor productivity increases so does the wage rate. Labor shifts from one sector to another depending on the output elasticity of infrastructure in both sectors among other factors. Since firms are competitive in the manufacturing sector, producer surplus is still zero over different infrastructure levels.

Infrastructure's influence in the polluting sector is less straight forward. Individual firm profit is unchanged by the stock of infrastructure because increases in output are directly offset by falling prices. So while aggregate output increases, the extent to which firms in the polluting sector see an increase in producer surplus depends on the aggregate number of firms in the sector. The aggregate number of firms in the polluting sector is decreasing in the level of infrastructure but increasing in the aggregate demand for the polluting good. An increase in the level of public infrastructure leads to an increase in firm-level productivity. Firms with higher productivity levels enjoy greater market power (i.e., set lower mark-ups) and have more market share, both of which reduce the aggregate number of firms leading to lower the aggregate producer surplus. Also, infrastructure decreases the average price of the good leading to more aggregate demand and more firms entering the market to meet that demand results in higher aggregate producer surplus. Thus, infrastructure may increase producer surplus in the polluting sector if its effect on aggregate demand outweigh its effect on the aggregate number of firms.

Since price declines and output increases with higher infrastructure level, consumer surplus rises. In contrast, pollution damages increase as infrastructure rises because of more output. Finally, the effect of infrastructure on environmental tax revenues is ambiguous because infrastructure directly increases the tax rate and output but lowers the price. If the positive effect of infrastructure on consumer surplus (and potentially producer surplus) outweighs the effect of pollution damage, then welfare increases as infrastructure rises under autarky.

With FDI, total welfare in the economy still includes a measure of welfare in the polluting sector, total tax revenue, consumer surplus and pollution damages. The main difference between autarky and FDI is that the welfare attributed to the polluting sector is no longer producer surplus but the value of labor. The total value of labor depends on wages, total labor employed in the polluting sector and aggregate number of firms in the polluting sector.

The wage rate is unambiguously increasing in infrastructure. The aggregate number of firms may increase with infrastructure as long as the increase through aggregate demand is outweighed by the direct effect similar to the autarky case. Labor in the polluting sector may also increase with infrastructure in a similar way as the aggregate number of firms. More infrastructure directly reduces the number of firms leading to less labor hired because each firm has more market power but there is also a countervailing effect through aggregate demand where labor increases to meet demand. As long as the wage effect outweighs any potential countervailing effects from total labor and the aggregate number of firms then the total effect of infrastructure on the value of labor is increasing. The overall effect of infrastructure on welfare with FDI is likely to be positive as long as the pollution damage is relatively small.

Even though we are able to determine the mechanisms by which infrastructure, environmental regulations and welfare are related, the size and direction of each cannot be fully derived analytically. To shed further light on each mechanism we turn to simulations.

**4. Functional Forms and Parameters**

In this section, we specify functional forms, which allow us to solve the model. First, we assume the quasilinear utility function of the consumer is of the form,

(22) $U = Q_m + \left(Q_p\right)^{\frac{1}{2}}$.

This allows us to arrive at interior solutions for aggregate demand in the polluting sector. Next, we follow the majority of the applied literature and let firms in the polluting sector receive productivity draws from a Pareto distribution,

(23) $G(x) = 1 - (\omega/x)^{\gamma}$,

where $\omega > 0$. Using this distribution most of the objects in the model have closed forms, which we provide in the Appendix A. The Pareto distribution has been found to be a good approximation to productivity distribution of firms (Gibson and Graciano, 2011). Because foreign firms are more productive, the probability density function should be less steep when the country opens to FDI. We achieve this by normalizing the parameter $\omega$ to 1 but setting $\gamma = 6.02$ in autarky and $\gamma = 4.02$ with FDI.

One challenge in the simulation is to peg the relevant range of infrastructure in the model. We use data on the share of labor in the polluting sector and an infrastructure index to set the relevant range for infrastructure in the model. We use Nigeria, a country with a significant polluting sector from oil production with FDI in the sector as our representative country. First, we obtain the infrastructure index of Nigeria which is 2.4 on a scale of 1 to 7. [2] The share of population working in the oil sector is 0.3% of the total labor force.[3] By normalizing total labor to 0.01, the infrastructure level that corresponds to a labor share of 0.3% in the polluting sector in our model simulation is $i = 0.287$. This labor normalization maps the value of $i = 0.287$ to the infrastructure level of 2.4 from the data. Given an infrastructure quality index from 1 to 7, the total range of infrastructure in our model is from 0 to 1.23.

We normalize the entry cost $\varphi_e$ to 1, so that all other fixed costs in the model are relative to the entry cost, when the country opens to FDI. Under autarky, entry cost is smaller for domestic firms in developing countries; therefore, we assume the autarky entry cost $\varphi_e$ is 0.00001. According to Atkeson and Kehoe (2005), the elasticity of infrastructure in production of resource intensive goods $\nu = 0.85$. The elasticity of substitution between the heterogeneous goods, $\theta$, is 0.6, which is close to the number used by Ruhl (2004). Given the unavailability of other parameters in our model such as the marginal disutility of pollution, $\delta$, the fixed cost, $\varphi$,

[2] See data from the World Economic Forum available at:
http://www.photius.com/rankings/infrastructure_quality_country_rankings_2011.html.

[3] This value is derived from Nigeria's National Bureau of Statistics national manpower stock and employment generation survey.

the probability of failure in the market, $\beta$, or the pollution conversion parameter, $\mu$, we assume values for these parameters and conduct sensitivity analysis to check their impact on the model. Table 1 summarizes the parameters used in our simulations.

We also gathered data to calculate simple correlations between our main variables of interest. Summary statistics are presented in Table 2 and Appendix B shows detailed descriptions of the data and their sources. The three most important variables are a measure of environmental regulations, infrastructure and economic welfare. We use a measure developed by Van Soest et al. (2006) which estimates the shadow price of energy use for select 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, since it is difficult to obtain GDP adjusted for environmental degradation across countries, we use the World Bank's adjusted net national income measure which incorporates natural resource degradation as our proxy for economic welfare.

## 5. Simulation Results

We determine the relationship between infrastructure on environmental tax regulations and welfare under autarky versus FDI using simulations.

### *5.1 Environmental Regulations*

Figure 1 shows the optimal environmental tax rate across varying levels of infrastructure under autarky versus with FDI for different damage levels. In the baseline case, an increase in the infrastructure level decreases the individual firm price and increases aggregate output under autarky. As a response, the government increases the environmental tax rate. The optimal environmental tax rate increases at a decreasing rate over different infrastructure levels.

A similar relationship can be derived in the case where FDI enters the polluting sector. Although the environmental tax rate rises with infrastructure, there are two main differences compared to the autarky case. First, since the welfare from the polluting sector is based on the value of labor, the rise in environmental taxes are not as dramatic in order to not discourage entrants of foreign firms and their hiring of labor. Second, there is an initial decline in environmental tax rate as infrastructure increases, but at higher levels of infrastructure the optimal environmental tax rate rises. Our expression in equation (19) helps explain this phenomenon. As infrastructure improves, the value of labor increases – increasing welfare – which pushes the tax rate down. After reaching a particular infrastructure level, the effect of infrastructure through damages and prices dominate the effect through the value of labor leading to an increase in the optimal level of environmental taxes.

Marginal damages from pollution significantly affect the infrastructure and environmental tax relationship with FDI. If damages are low enough, we find that an increase in infrastructure could cause optimal tax rates to be negative (i.e., a subsidy) as shown in Figure 1B. In this case, the effect of infrastructure through the value of labor dominates the price effect and disutility from pollution. Optimal subsidies would increase as infrastructure improves, in order to increase the amount of labor hired by the polluting sector, as well as the number of firms in that sector. In contrast, when marginal damages are significantly higher than the baseline case, the price effect dominates any potential effect through wages leading to rising environmental taxes over all infrastructure levels, as illustrated in Figure 1C.

Using data for select 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 strong positive correlation between the two variables. Note that all our sample countries with available environmental regulation measures are open to FDI. This implies that the type of pollution damages associated with energy use is not low.

Figure 2 illustrates the effect of an increase in the output elasticity of infrastructure in the polluting sector on environmental tax rates. In the autarky case, the environmental tax rates rise more quickly at increasing infrastructure levels. In this case, each individual firm sets a lower price leading to an increase in aggregate output and, consequently, more pollution. The government reacts by increasing environmental taxes. In contrast, for the case with FDI, there is an initial decline in the optimal tax rate before it rises again. This can be attributed to the value of labor effect dominating the marginal damage effect at low infrastructure levels. With sufficiently high infrastructure levels, output and pollution are large enough for the government to set higher tax rates. Taxes under autarky are still higher than taxes with FDI at high levels of infrastructure.

Figure 3 shows the effect of high fixed costs of production on the optimal environmental tax rate. Under autarky, the entire curve shifts down to accommodate entrance of more firms. The response with FDI is more dramatic. Even with relatively high environmental damages, the government may set subsidies to entice more foreign firms to enter into the sector in order to hire more workers to overcome the high fixed cost.

*5.2 Welfare*

Welfare unambiguously increases with infrastructure under autarky and with FDI, as shown in Figure 4. 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 strong 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 autarky as opposed to the case with FDI. As a result, a critical infrastructure level exists where welfare with FDI equals welfare under autarky. The critical infrastructure level delineates when it is optimal for a country to allow FDI into a polluting sector. An infrastructure level lower than this point would mean it is more beneficial for the country to close off the polluting sector to FDI.

The crossing point exists because of two important factors: the difference in consumer surplus and the difference in welfare measures in the polluting sector between autarky and FDI. Consumer surplus increases over infrastructure in both cases, as illustrated in Appendix C1. At low levels of infrastructure, consumer surplus is higher under autarky than with FDI. Since the entry cost is higher with FDI, the price is higher and output is lower compared to the autarky case at low infrastructure levels. As the infrastructure level increases, price declines and output increases – in both cases – but there are more productive firms when FDI is allowed than under autarky, which leads to higher aggregate output, lower prices, and higher consumer surplus.

The second factor is the difference between benefits from the polluting sector in the two cases as summarized in Appendix C2. The benefits from producer surplus in the polluting sector under autarky are significantly lower compared to the benefits from the value of labor in the polluting sector with FDI. The relatively lax environmental regulations with FDI can be attributed to this difference. To increase the number of foreign firms and labor employed in the polluting sector, environmental regulations must be set at a lower rate. Therefore, given the initial higher consumer surplus under autarky and small difference in benefits from the polluting sector at low infrastructure levels, welfare under autarky is higher. However, as infrastructure quality increases, welfare with FDI dominates as consumer surplus and wage benefits increase.

The infrastructure level where the crossing point occurs may be sensitive to some parameters but may be robust to others. If the marginal damages from pollution are lower or higher than the baseline, the critical infrastructure levels do not change as shown in Figures 4B and 4C. Any change in marginal damages lead to a similar shift in the welfare curves so that the critical infrastructure level is not affected. It is worth pointing out that at low infrastructure levels, the welfare curve with FDI given a low damage factor is convex while the welfare curve with FDI given a high damage factor is concave. This implies that at a low infrastructure level, welfare will be higher with FDI when the damages from pollution are large and perceptible to the regulator compared to the case with FDI when the damages are low. This is because when damages are low, a regulator tends to impose a subsidy thereby increasing the total damages from pollution. On the other hand, when damages are high, a regulator imposes environmental taxes, which decreases total damages with FDI in the polluting sector.

An increase in the output elasticity of infrastructure increases output in the polluting sector, which moves the critical infrastructure level to the right as shown in Figure 5. The shift can be attributed to the optimal level of environmental regulations chosen under each case. Increasing the output elasticity of infrastructure increases optimal environmental tax rates in autarky but initially decreases them with FDI. The decline in environmental taxes (and a subsequent subsidy), not only increases the externality but there is also a decline in tax revenue leading to lower welfare with FDI. As a result, the welfare crossing point shifts to the right. Note that the increase in welfare with FDI in this case closely coincides with the increase in environmental tax rates.

Increasing the fixed cost of production shifts the critical infrastructure level to the left, as shown in Figure 6. A higher fixed cost of production reduces the number of less productive firms. The resulting decline in the number of firms reduces aggregate output and increases output price. The main difference between autarky and FDI is the effect of the fixed cost on the optimal environmental taxes. In autarky, the environmental tax increases over infrastructure because only the most productive domestic firms continue to produce. But with FDI, the optimal tax rate decreases in order to entice additional firms to enter, thereby increasing the value of labor. This results in a larger gap between producer surplus in autarky and the value of labor with FDI as infrastructure rises.

Based on our simulations, we find that the welfare gains of moving from autarky to allowing FDI to enter the polluting sector is greater in countries that have larger infrastructure stocks than those that have poor infrastructure levels. For very underdeveloped countries with very poor infrastructure, allowing FDI in a polluting sector may even lower welfare.

*5.3 Infrastructure Choice*

We simulate the marginal welfare from infrastructure with FDI versus autarky in Figure 7 using the parameters for the high pollution damage case. Since a welfare crossing point exists for infrastructure between the trade regimes, we also find a similar crossing point for marginal welfare. Recall that the infrastructure level is determined when marginal welfare equals the infrastructure price. If the price of infrastructure is low, countries with FDI have more infrastructure than countries under autarky at equilibrium. However, at relatively high infrastructure prices, countries with FDI would choose a lower infrastructure level than under autarky. Such a switch occurs due to the differences in marginal benefits from the polluting sector in the two trade regimes.

Using our available data, we calculate the correlation coefficient between infrastructure level and trade openness for different groups of countries to determine if the correlations follow the predictions from our simulations. First, we rank all countries from lowest to highest based on their price of infrastructure. Then, we calculate the correlation coefficient of trade openness and infrastructure quality for the first 50 countries. We do the same for the second through the 51$^{st}$ country and continue with groups of 50 until we reach the last 50 countries with the highest infrastructure price. We plot the correlation coefficients across different average infrastructure prices. The correlation coefficient remains positive but decreases in strength as price of infrastructure rises as shown in Figure 8. This lends support to our simulation results in Figure 7 since the difference between infrastructure quality levels are largest when infrastructure price is low and becomes smaller as infrastructure price rises. Also, since the correlation coefficient remains positive, the infrastructure price is never high enough to reach the crossing point in Figure 7 for our set of countries.

## 6. Conclusions

This article investigates how welfare is affected when governments enact policies to entice FDI in a polluting sector by endogenously selecting an environmental tax rate and infrastructure level. We develop and simulate a model that shows how policies to attract FDI in a polluting sector can lead to lower welfare than in the case of autarky. An economy that does not have well developed infrastructure may choose to lower environmental regulations to entice FDI into the economy. In fact, we show that it may be optimal to offer a subsidy to increase the number of foreign firms in the polluting sector. Welfare under both trade regimes differ depending on the level of infrastructure quality. Countries with high infrastructure quality are more likely to experience higher social welfare with FDI than autarky but the results reverse when infrastructure quality is low.

The main difference between the two trade regime cases is the welfare in the polluting sector. With FDI, the government takes the value of labor as a measure of producer welfare in the polluting sector while under autarky, producer surplus is a measure of producer welfare in the sector. With FDI, governments have the incentive to increase the number of foreign firms that operate in the polluting sector by setting less stringent environmental regulations. When infrastructure quality is low, employing negative environmental tax regulations to attract FDI can lead to lower welfare compared to the autarky case.

Our results have important policy implications for developing economies. Given the mounting evidence that pollution havens exist, we provide a conditionally positive message. Though an increase in pollution is likely as a result of the influx of FDI, welfare may still increase. This result is conditional on the home country having a sufficient level public infrastructure. Opening a country 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 fuel growth over time. Also, if a government does decide to open the polluting sector to FDI even with low infrastructure levels, we find that imposing an environmental tax closer to Pigouvian level will lead to higher welfare gains than imposing a subsidy to entice more foreign firm entrance.

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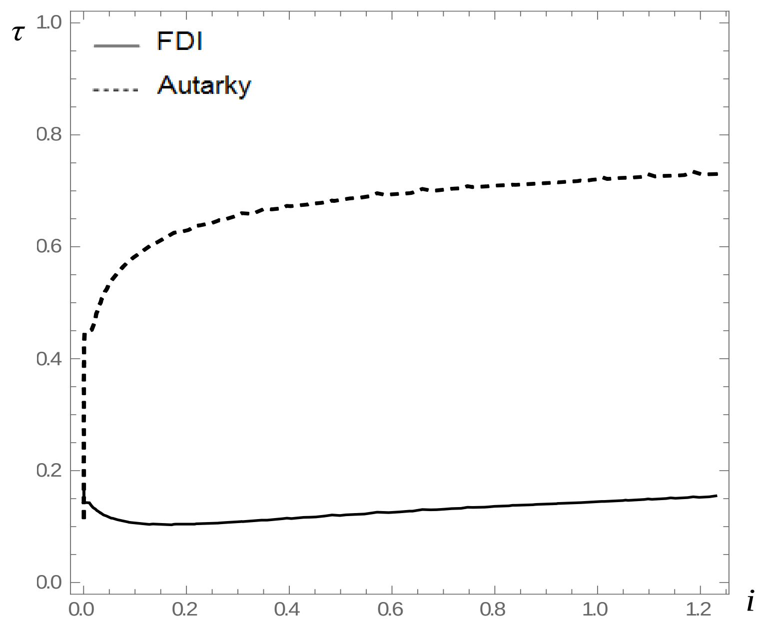
**Table 1. Summary of parameters**

| **Parameters** | **Values** | **Note / Source** |
|---|---|---|
| $\overline{L}$ | 0.01 | Normalization |
| $\varphi_e$ | 0.00001 | Autarky/Assumption |
| $\varphi_e$ | 1 | FDI/Normalization |
| $\omega$ | 1 | Normalization |
| $\gamma$ | 4.02 | FDI/Assumption |
| $\gamma$ | 6.02 | Autarky/Assumption |
| $\nu$ | 0.85 | Atkeson and Kehoe (2005) |
| $\theta$ | 0.6 | Ruhl (2004) |
| $\varphi$ | 2 | Assumption |
| $\Delta$ | 1500 | Assumption |
| $\beta$ | 0.001 | Assumption |
| $\mu$ | 1 | Assumption |

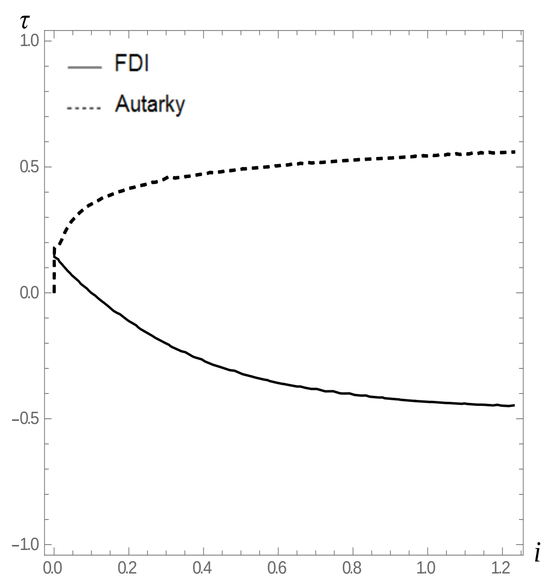
**Table 2. Summary Statistics**

| Variable | Number of observations | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Environmental regulation stringency indicator (millions of US dollars per ton) | 8 | 0.1589 | 0.1327 | 0.0069 | 0.4235 |
| Trade openness (%GDP) | 132 | 84.68 | 51.30 | 22.12 | 374.58 |
| Infrastructure quality Index (1-7) | 132 | 4.34 | 1.20 | 2.00 | 6.80 |
| Adjusted Net National Income (million US dolloar) | 123 | 380,434 | 1,248,032 | 671 | 12,047,418 |
| Price of infrastructure (PPP over investment, US PPP =100) | 132 | 71.77 | 58.32 | 26.13 | 672.86 |

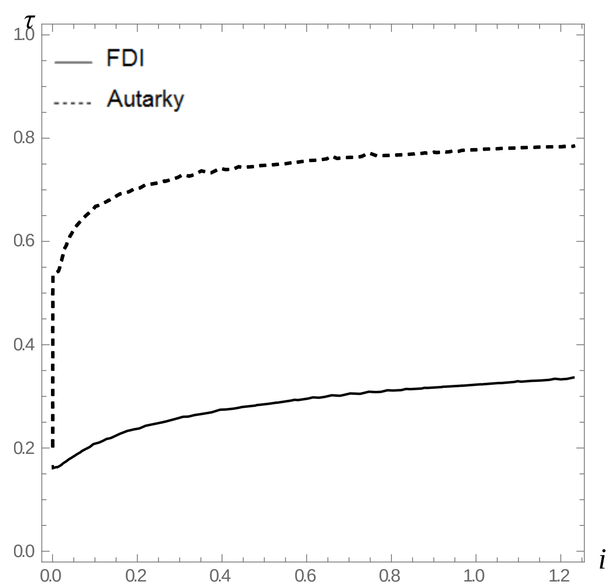
## Figures




(a) Baseline case with damage factor δ=1500




(B) Low Damage Factor (δ=100)




(C) High Damage Factor (δ=5000)

Figure 1: Optimal environmental tax over infrastructure levels for different damage factors

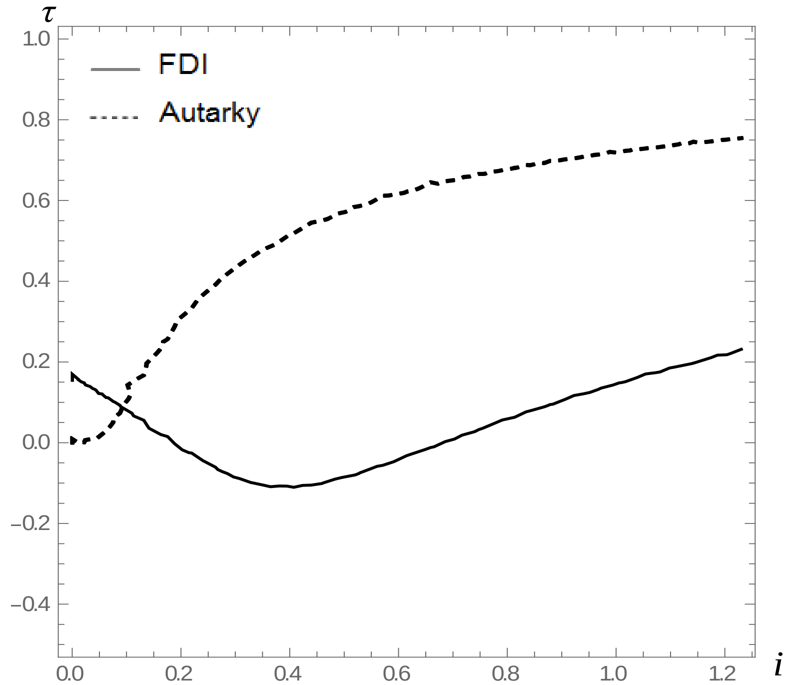



Figure 2: Optimal environmental tax over infrastructure levels with high elasticity of infrastructure ($\upsilon = 1.2$)

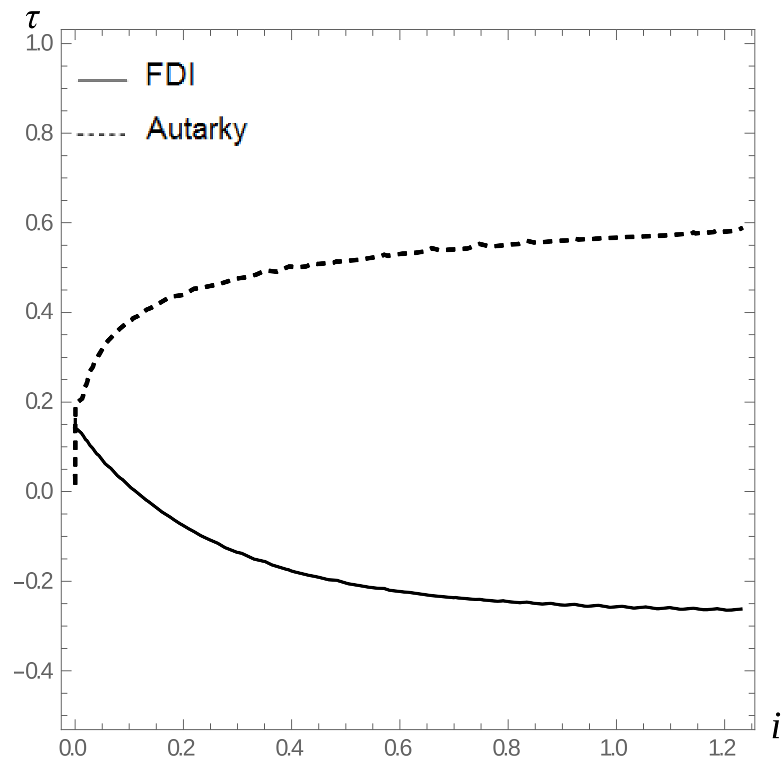
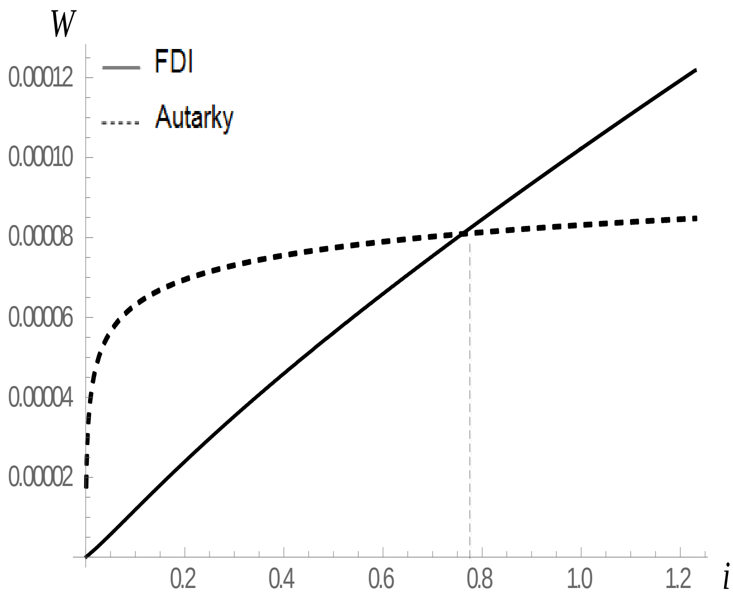
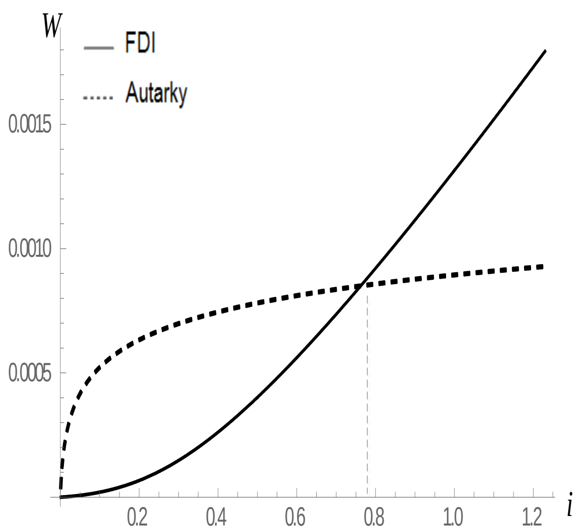


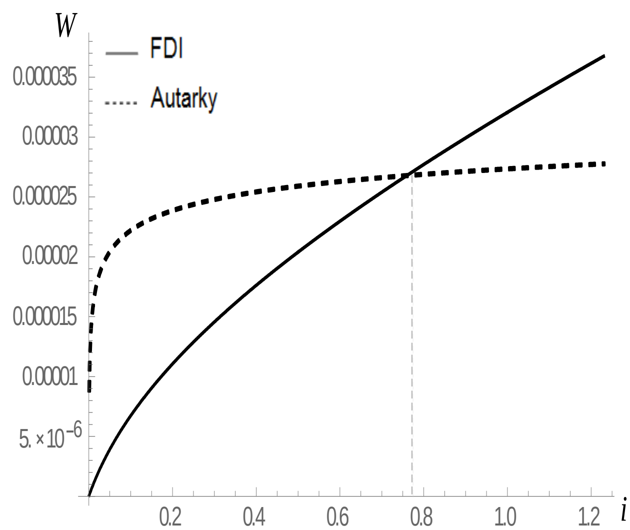

Figure 3: Optimal environmental tax over infrastructure levels with high fixed cost ($\varphi = 10$)




(a) Baseline case with damage factor δ=1500




(B) Low Damage Factor (δ=100)




(C) High Damage Factor (δ=5000)

Figure 4: Welfare at different levels of infrastructure levels for different damage factors

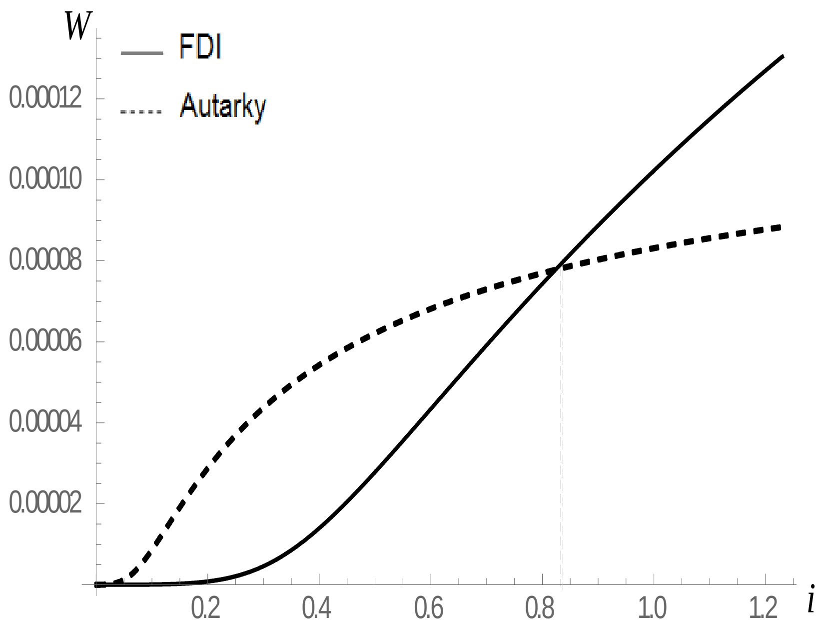



Figure 5: Welfare at different infrastructure levels with high level of output elasticity of infrastructure ($\upsilon = 1.2$)

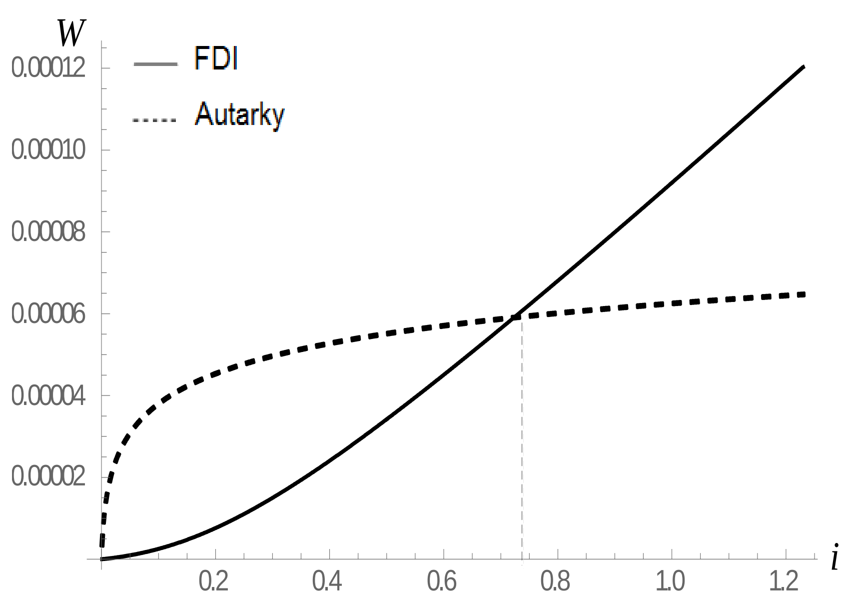



Figure 6: Welfare at different infrastructure levels with high fixed cost ($\varphi = 10$)

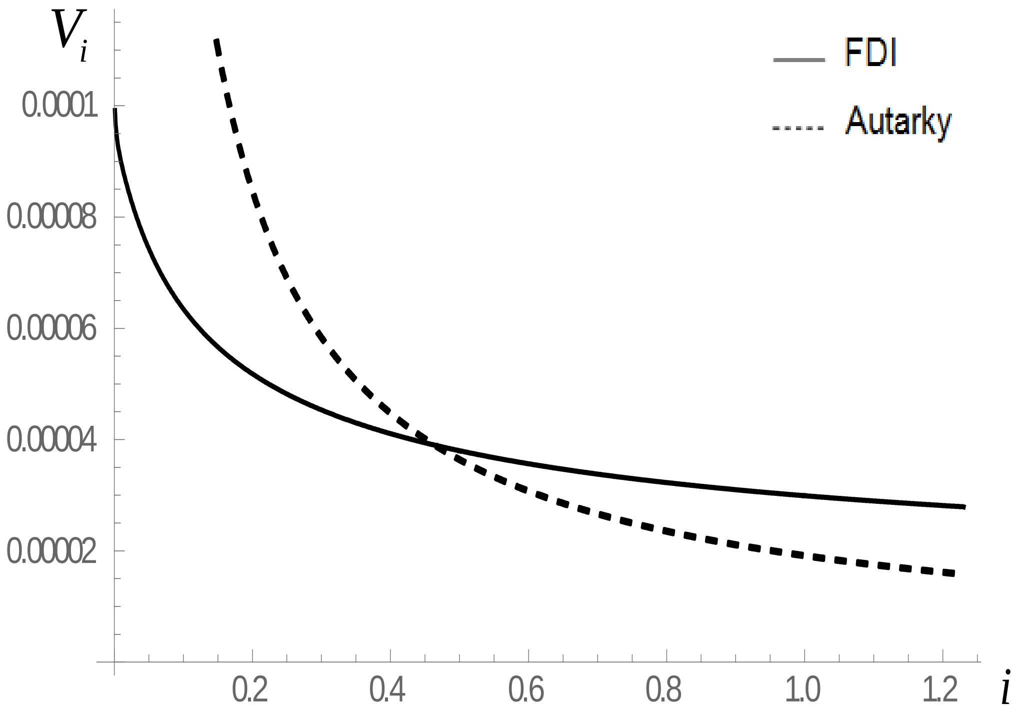



Figure 7: Marginal Welfare of Infrastructure

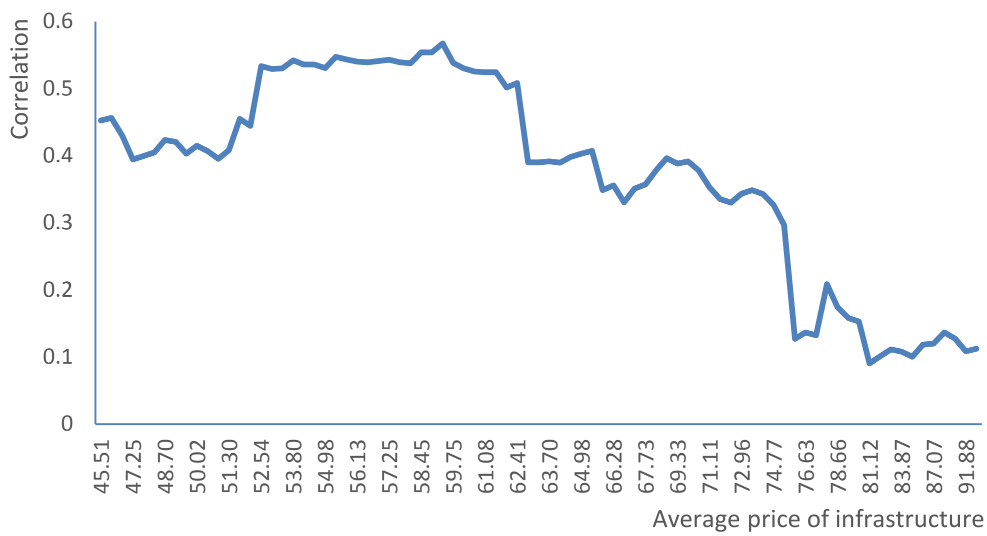



Figure 8: Correlation between infrastructure and trade openness ranked by the price of infrastructure

**Appendix A. Derivation of Closed Form Solutions**

Given constant returns to scale in the manufacturing sector along with equation (3), the resulting wage rate is,

$$w = i.$$

Zero profit productivity cut off function is derived by first equating the individual profit to zero, $\pi_p = (1-\tau)pq - wl_p - w\varphi = 0$. Substituting the $\hat{x}$ from this equation into $(1 - G(\hat{x})) \int_{\hat{x}}^{\infty} \pi_p(x) \quad dH(x) = w\varphi_e$ and simplifying yields,

$$\hat{x} = \omega \left( \frac{\varphi\theta}{\varphi_E(\gamma(1-\theta) - \theta)} \right)^{\frac{1}{\gamma}}.$$

To derive the expression for the total number of firms in the polluting sector, first equate the individual profit to zero, $\pi_p = (1-\tau)pq - wl_p - w\varphi = 0$ to derive $\hat{x}$ as a function of P and M. From equation (12), one can solve P as a function of M. Plugging P into the $\hat{x}$ function yields $\hat{x}$ as a function of M. Finally, substituting this into $\int_{\hat{x}}^{\infty} \pi_p(x) \quad dH(x) = w\varphi_e$ and solving for M leads to

$$M = \varphi_E^{\frac{\theta}{\gamma}} (\gamma(1-\theta) - \theta)^{\frac{\theta}{\gamma}+1} (1-\theta)^{\theta-1} \omega^{-\theta} \left( \frac{i^{\nu}}{Q} \right)^{-\theta} (\varphi\theta)^{-\theta - \frac{\theta}{\gamma}} \gamma^{-1}.$$

The demand function for aggregate polluting goods using equation (22) along with equation (2) yields,

$$Q_p = \frac{1}{4P^2}.$$

The resulting consumer surplus is,

$$C = \frac{1}{4P}.$$

By substituting M back into equation (12), we derive price as a function of quantity demanded.

Using the above aggregate demand we can solve for the equilibrium price,

$$P = \left[ i^{\nu(\theta-2)+1} \left(\frac{1}{4}\right)^{\theta-1} \hat{x}^{-1} \left(\frac{1}{(1-\tau)}\right) \left(\varphi_E(\gamma(1-\theta) - \theta)\right)^{-\frac{1-\theta}{\gamma}} \left(\frac{1-\theta}{\omega}\right)^{-(1-\theta)} (\varphi)^{1-\theta+\frac{1-\theta}{\gamma}} (\theta)^{-\theta+\frac{1-\theta}{\gamma}} \right]^{\frac{1}{2\theta-1}}.$$

Using $L_p = M \int_{\hat{x}}^{\infty} l(x) \quad dH(x)$ yields aggregate labor in the polluting sector,

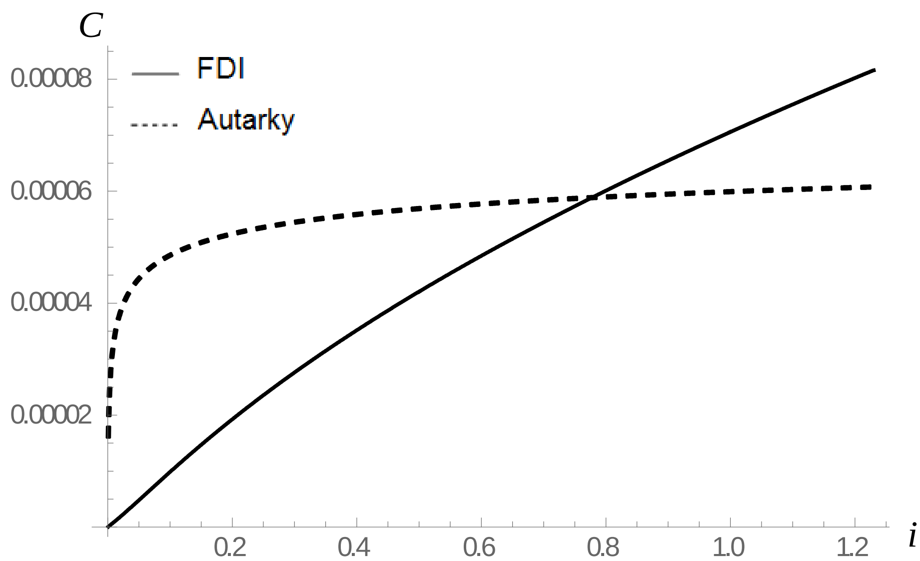
$$L_p = \frac{Q}{\hat{x} i^{\nu}} \left[ \frac{(1-\theta)\gamma M}{\gamma(1-\theta) - \theta} \right]^{\frac{\theta-1}{\theta}}.$$

**Appendix B. Sources and Description of Data**

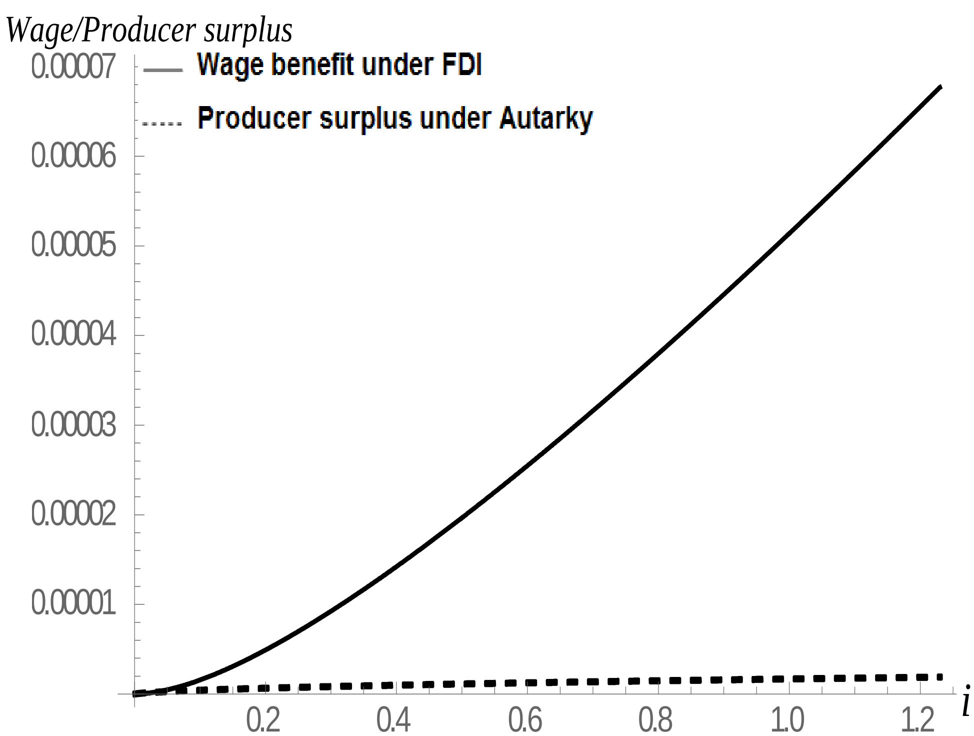
Appendix 2. Data Sources

| Variable | Description of Variables | Source |
|---|---|---|
| Environmental regulation stringency indicator | Difference between a polluting input's shadow price and its purchase price | Van Soest et al. (2006) |
| Trade openness | Exports and Imports as a percentage of GDP | The World Bank |
| Infrastructure quality Index | Index level from 1 to 7 | World Economic Forum |
| Adjusted Net National Income | Gross national income minus consumption of fixed capital and natural resources depletion | The World Bank |
| Price of infrastructure | Price level of investment | Penn World Table |

**Appendix C. Additional Figures**




Appendix C1: Consumer Surplus at different levels of infrastructure levels




Appendix C2: Wage benefit with FDI versus producer surplus under autarky