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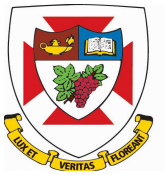

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Environmental Regulation in the Presence of an Informal Sector

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Abstract

We analyze the efficacy of environmental regulation in the presence of an endogenous informal sector. Firms in an imperfectly competitive formal sector produce a final good using a polluting intermediate good. The firms can either produce the intermediate good or purchase it from a price-taking informal sector. An environmental regulator sets the emission intensity of the intermediate good that all formal sector firms implement honestly but informal sector firms seek, and are sometimes able, to evade. We show that, depending on the stringency of the regulation and its enforcement, the informal sector can act as a source of pollution leakage. Stricter regulation can increase (when the "composition effect" of regulation dominates its "scale effect") or decrease total pollution, and may even have a non-monotonic impact. Further, price discrimination by the formal sector, when it purchases the intermediate good from the informal sector, can worsen regulatory compliance by the informal sector and lead to lower welfare.

JEL codes: Q56, O17, K42

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1 Introduction

A growing global concern about anthropogenic impacts on the environment has led to increasing pressure on countries to undertake policies that seek to protect the environment. Governments in many countries have responded, in part, by mandating environmental taxes and standards on their producers. However, given the relatively weak institutions and legal systems and greater corruption that characterize most developing countries, the question remains as to how completely and effectively the environmental regulations can be enforced on polluting producers in such countries.

In particular, the presence of a large informal sector poses a serious challenge for the implementation of environmental regulations in developing countries.[3] A large part of the urban informal sector in these countries is concentrated in resource extraction, manufacturing, servicing and retailing activities such as artisanal mining, bleaching and dyeing of garments, leather tanning, brick manufacturing, automotive repair, metalworking, and hawking. Most of these activities have considerable negative environmental impacts.[4] Artisanal mining of gold uses mercury which pollutes rivers (Dondeyne, *et al.*, 2009). Similarly, effluents from bleaching, dyeing and tanning contain hazardous chemicals which, when disposed of improperly, pollute rivers and groundwater. Brick kilns in the informal sector are of-

[3]Informal economic activities are commonly defined as the production and distribution of goods and services that are unaccounted for in the official National Income Accounts of a country (Smith, 1994; Tanzi, 1999). The central characteristic of informal firms is that they are not regulated, or they are in violation of legal requirements that society imposes on the formal or official sector of the economy (Portes, *et al.*, 1989). Thomas (1992, 2001) defines an informal (underground) sector as one which produces a legal product using a quasi-legal (illegal) process. The relevance of informal activities has been well documented and approximately measured in the literature (e.g. de Soto, 1989; Thomas, 1999; Friedman *et al.*, 2000; Chaudhuri, *et al.*, 2006). Schneider and Enste (2000) report that the average size of the shadow economy varied from 12% of GDP for OECD countries to 26% for transition economies and 37% for developing countries.

[4]Collecting and sorting scrap for recycling is, in contrast, an informal sector activity that is environmentally beneficial.

ten fired using cheap fuel such as old tires, plastic refuse, and used motor oil which create air pollution. Street vending in many developing countries cause littering and congestion (Perera and Amin, 1996).

Although informal economic activities are a significant source of detrimental externalities, very little attention has been paid to this problem by either researchers or policymakers. Blackman and Bannister (1998) identify four reasons why policymakers in developing countries have found tackling informal sector pollution an exceptionally challenging task: (i) the minimal ties that informal sector firms (or "informal firms" in short) have with the state, (ii) difficulty in monitoring informal firms which are small, numerous and widely-dispersed, (iii) tendency of informal firms to be intensely competitive which makes them susceptible to cost-cutting even at the expense of harming the environment, and (iv) the large amount of employment (mostly for the poor) generated by the informal sector. Given these constraints, policymakers in developing countries have tended to focus on the formal sector for pollution control.

Barring a few exceptions, the economics literature has also largely ignored analyzing the informal sector from an environmental standpoint. Blackman and Bannister (1998) use survey data to examine the adoption of propane (a cleaner fuel) by informal brick manufacturers in Cd. Juarez in Mexico, and find that community pressure can play an effective role in such adoption. Peer monitoring and other policy options for controlling informal sector pollution are discussed in Blackman (2000). Further, Blackman (2006) provides various case studies with respect to polluting informal sectors in developing countries. In a theoretical work, Chaudhuri (2005) uses a perfect competition general equilibrium model with a polluting informal sector, a clean formal sector, and a clean agricultural sector. The informal sector produces an intermediate good, while the formal sector produces a final good using the intermediate good (as well as labour and capital) as input. Pollution reduces labour productivity, and the formal sector faces a tax that depends on the extent to

which actual pollution exceeds its permissible level. Chaudhuri finds that a decrease in this permissible level can reduce the tax and increase pollution.

Similar to Chaudhuri (2005), we consider a vertically linked formal and informal sector but allow both the sectors to produce a polluting intermediate good. The intermediate good is then used by the formal sector to produce a final good.[5] The formal sector is imperfectly competitive while the informal sector consists of price-taking firms that are heterogeneous in terms of their cost. Moreover, while both the sectors are subject to an environmental regulation, which makes the intermediate good cleaner but costlier to produce, some of the informal sector firms are able to evade this regulation without getting detected. As a result, the formal sector finds it profitable to procure a part of the intermediate good from the informal sector, even when the informal sector firms are less efficient than the formal sector firms.[6] As shown below, when the environmental regulation is sufficiently lax and/or the probability of detection is sufficiently high, all firms that enter the informal sector comply with the regulation. In the reverse case, the informal sector is only partially compliant. Specifically, more efficient informal firms comply with the regulation while the less efficient ones violate the same.

We find that, depending on the stringency of the regulation and the effectiveness of its enforcement, the informal sector can act as a source of pollution leakage.[7] While stricter environmental regulation reduces the total amount of intermediate good used (a scale effect that reduces pollution), it may also motivate the formal sector to produce less of the intermediate good in-house

[5] As Datta Chaudhuri (1989) notes, empirical evidence suggests that much of the urban informal sector produces intermediate goods for the formal sector.

[6] The setting of our model is, for example, similar to the situation in India where leather tanning is done by Bata at its tanneries in Batanagar and Mokamehghat, as well as by numerous small and informal firms. Bata, a dominant firm in the formal sector, produces shoes and other leather products using leather manufactured in-house and also purchased from the open market.

[7] Leakage refers to the increase in production and associated emission amongst unregulated producers that arises as a direct consequence of an (incompletely enforced) environmental regulation (Fowlie, 2009).

and outsource more from the informal sector. The latter not only increases the size of the informal sector but also changes its composition by increasing (decreasing) the number of violating (compliant) firms. This composition effect of the stricter regulation tends to increase pollution. As a result of the counteracting scale and composition effects, actual pollution can increase if the intensity of regulation exceeds a threshold value that depends positively on the level of enforcement.

The problem of leakage has affected the efficacy of regulations in a variety of areas. With respect to environmental regulations, the literature has noted that relocation of polluting production from jurisdictions with tighter regulations to those with laxer regulations ("pollution havens") can weaken the incentives and impacts of such regulations (e.g. Copeland and Taylor, 2003; Fowlie, 2009). Concerns about such leakage has hindered the widespread adoption of regional environmental initiatives such as the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative (WCI). The present paper identifies a different – sectoral rather than jurisdictional – context in which the leakage effect can arise and undermine an environmental regulation.

Further, the paper examines the impact of price discrimination by the formal sector on the size and composition of the informal sector. If the contractual environment within which formal firms purchase the intermediate good from the informal firms allows the former to exercise their market (buyer) power, then formal firms will find it profitable to price discriminate rather than pay a single market-clearing price. We find that such price discrimination expands the size of the informal sector and may worsen regulatory compliance by the informal sector, thus leading to more pollution and possibly lower welfare.

The paper proceeds as follows. Section 2 presents the theoretical framework and derives the equilibrium. The conditions under which the informal sector can be a source of pollution leakage are derived in section 3. Section 4

examines the role of price discrimination by the formal sector, while the last section concludes.

2 The model and equilibrium

Consider a vertical production structure, where a downstream/final good (e.g. leather shoes) is produced using a polluting upstream/intermediate good (e.g. leather). With appropriate definition of units, one unit of the intermediate good is needed to produce one unit of the final good (i.e. fixed proportions production function). Hence, both the intermediate good as well as the final good can be denoted by the variable X. The final good is produced in a formal sector (denoted as sector 1), which is an m-firm oligopoly ($m \geq 1$). The intermediate good, on the other hand, is produced both by formal sector firms as well as by firms in an informal sector. Each firm in the formal sector thus produces both the intermediate good and the final good, while each informal sector firm produces only the intermediate good. The price of the intermediate good is set by the formal sector. The informal sector (also called sector 2) is endogenously determined and consists of price-taking fringe firms.

Absent any abatement activity, production of one unit of the intermediate good generates one unit of pollution (production of the final good does not generate any pollution). The government's environmental regulation requires each firm to reduce the emission intensity of its intermediate good production to $e < 1$ (for example, by changing the production process, using cleaner inputs or treating effluents before disposal). All firms in the formal sector of the economy implement this policy honestly. Their larger size and smaller number (which makes them more "visible" to society) and other characteristics such as brand name or reputation makes it too costly for them to evade the environmental regulation. In contrast, the fringe firms in the informal sector are corruptible and try to evade the regulation when it is profitable

for them to do so. Hence, the government has to monitor the informal sector in order to enforce regulatory compliance.

The sequence of moves is as follows. In the first stage, each formal firm chooses how much intermediate good to produce it-house and how much to purchase from the informal sector, taking as given the environmental regulation and the enforcement of this regulation on the informal sector. The total amount of intermediate good used determines the quantity of final good produced. Then, in stage two, fringe firms enter the informal sector and produce the intermediate good. The above game is solved using backward induction.

2.1 Stage 2: The informal sector

In the second stage, price-taking fringe firms enter the informal sector and undertake production. For simplicity, we assume that each fringe firm inelastically produces one unit of the intermediate good (recall that informal firms are usually small). Let c denote the per-unit production cost of a fringe firm. These firms are heterogeneous in terms of their cost, and c is assumed to be uniformly distributed over support $[c_2, \overline{c}]$ with probability density N.

As mentioned, the government's environmental regulation requires each formal and informal firm to reduce emission per unit of intermediate good produced to $e(\gamma) \in (0, 1]$, where $\gamma \geq 1$ is a firm's abatement effort, $e(\gamma = 1) = 1$, and $e'(\gamma) < 0$. An informal firm that complies with the regulation faces a unit (abatement-inclusive) cost of $c\gamma$.[8] We assume that the environmental regulator chooses $\gamma > 1$; when there is no regulation $\gamma = 1$. A stricter environmental policy increases γ, and makes a firm's intermediate good cleaner but more expensive to produce.

Given the legal infrastructure, and the effectiveness of monitoring and enforcement activities carried out under it, an informal firm that chooses not to comply with the regulation gets detected with a probability $\beta \in (0, 1)$.

[8] A similar formulation for modeling abatement by polluting firms is used by Kennedy (1994).

Any violating firm that is apprehended has its output confiscated – such a firm incurs the production cost (and generates pollution) but is unable to earn any revenue. Let ρ denote the price of the intermediate good, as it is determined in stage 1. An informal firm will comply with the regulation rather than violate it if its profit from compliance exceeds its (expected) profit from violation,[9] i.e. if

$$\rho - c\gamma \geq (1-\beta)\,\rho - c$$

or,

$$c \leq \frac{\rho\beta}{\gamma - 1} \equiv c_3 \tag{1}$$

We note that compliance is itself profitable when

$$c \leq \frac{\rho}{\gamma} \equiv c_4 \tag{2}$$

and violation is profitable when

$$c \leq (1-\beta)\,\rho \equiv c_5 \tag{3}$$

From the above cutoffs, two mutually exclusive cases that can arise are as follows.

Case A: $\gamma\,(1-\beta) \leq 1$. Suppose the environmental regulation is sufficiently lax, and/or its enforcement sufficiently stringent, so that $\gamma\,(1-\beta) \leq 1$. In this case we have $c_5 \leq c_4 \leq c_3$, with equality of these cutoffs arising if and only if $\gamma\,(1-\beta) = 1$. All fringe firms with $c \in [c_2, c_4]$ comply with the regulation, while firms with $c > c_4$ do not enter the informal sector. In other words, there is full compliance by the informal sector and all firms are green/legal.

[9] It is assumed, throughout the paper, that when both compliance and violation yield equal profit, an infomal firm chooses to comply.

Using (2), the number of green informal firms in case A (n^A_{green}) as well as the total amount of the intermediate good produced by the informal sector (X^A_2), is

$$n^A_{green} = X^A_2 = \int_{c_2}^{c_4} N dc = N\frac{\rho - \gamma c_2}{\gamma} \tag{4}$$

Case B: $\gamma(1-\beta) > 1$. In this case, we have $c_3 < c_4 < c_5$ with the following equilibrium sorting amongst the informal firms. All firms with $c \in [c_2, c_3]$ comply with the regulation, those with $c \in (c_3, c_5]$ violate, and finally firms with $c > c_5$ do not enter the informal sector. Using (1) and (3), the number of green/legal informal firms that comply in case B is

$$n^B_{green} \equiv \int_{c_2}^{c_3} N dc = N\frac{\beta\rho - c_2(\gamma - 1)}{\gamma - 1}$$

while the number of grey/illegal informal firms that violate is

$$n^B_{grey} \equiv \int_{c_3}^{c_5} N dc = \rho N\frac{\gamma(1-\beta) - 1}{\gamma - 1}$$

so that the total amount of the intermediate good produced by the informal sector is[10]

$$X^B_2 = \int_{c_2}^{c_5} N dc = N(\rho(1-\beta) - c_2) \tag{5}$$

2.2 Stage 1: The formal sector

We now endogenize the price of the intermediate good, ρ, which is influenced by the intensity of regulation. The m firms in the oligopolistic formal sector

[10] We assume that all intermediate good produced, including those by violating firms that are apprehended, is sold to the formal sector. This can happen either because the violating firms are apprehended after they sell their product (their revenue is confiscated), or because the confiscated intermediate good is sold to the formal sector by the enforcement agency or its designate. The alternative possibility that all confiscated intermediate good is unavialable to the formal sector (e.g. if it is destroyed by the government) lengthens the algebra without adding further insights.

(sector 1) are assumed to be identical to each other. In the first stage, each formal firm chooses the amount of the intermediate good it produces itself (denoted by x_1) and the amount of the intermediate good it purchases from the informal sector (denoted x_2) to maximize

$$\pi_1 = p(X)\, x - c_1 \gamma x_1 - \rho x_2$$

In the above profit function, $p(X)$ is the inverse demand for the final good, with $x = X/m = x_1 + x_2$ being the amount of final good sold by a representative firm in the formal sector. The formal firm's total cost of producing x_1 units of the intermediate good is $TC_1 = c_1 \gamma x_1$ (recall that the formal sector honestly implements the regulation), and its total cost of purchasing x_2 units of the intermediate good from the informal sector is $TC_2 = \rho x_2$.[11] Without loss of generality, the (constant) unit cost of transforming the intermediate good into the final good is assumed to be zero.

The profit-maximizing level of the final good, $x^*(\gamma)$, is given by the value of x that solves

$$p + p'x = c_1 \gamma \tag{6}$$

where the LHS of (6) is the formal firm's marginal revenue and the RHS is its marginal cost of producing the intermediate good in-house. Moreover, using (6) and the second order condition for profit maximization, we have

$$\frac{dx^*}{d\gamma} = \frac{c_1}{2p' + xp''} < 0 \tag{7}$$

In our model, the total amount of final good produced (and intermediate good used), x^*, depends on its demand and characteristics of the formal sector, and is independent of the informal sector parameters (i.e. c_2, β and N). Similarly, the price of the final good, $p^* = p(mx^*)$, and consumer surplus do not depend on the informal sector. Instead, what the informal sector

[11] Thus, c_1 and c_2 are parameters while c_3, c_4 and c_5 are variables in our model.

influences is the manner in which the intermediate good is obtained by the formal firms (i.e. in-house production versus purchasing from the informal sector). The source of the intermediate good used by a formal firm depends on which of the two above-mentioned cases prevails.

Case A: $\gamma(1-\beta) \leq 1$. This is the case of complete compliance by the informal sector. Using (4), we have

$$TC_2^A = \rho x_2 = \frac{(\chi_2 + x_2 + Nc_2)\gamma}{N} x_2$$

where χ_2 is the amount of intermediate good purchased from the informal sector by all other $(m-1)$ formal firms (so that $\chi_2 + x_2 = X_2^A$). Thus, the representative formal firm's marginal cost of procuring the intermediate good from the informal sector is

$$MC_2^A = \frac{(\chi_2 + 2x_2 + Nc_2)\gamma}{N}$$

Notice that $MC_1 = c_1\gamma \geq MC_2^A$ for all $x_2 \leq \frac{1}{2}(N(c_1 - c_2) - \chi_2)$, or using the fact that $\chi_2 = (m-1)x_2$ due to symmetry, we have $MC_1 \geq MC_2^A$ for all x_2 less than (or equal to)

$$\frac{N(c_1 - c_2)}{m+1} \equiv x_2^A \tag{8}$$

As long as the profit-maximizing output of the final good is less than x_2^A, a formal firm will buy the intermediate good from the informal sector rather than produce it. When final good output exceeds x_2^A, the equilibrium amount of intermediate good produced by the representative formal firm is

$$x_1^A = x^* - x_2^A \tag{9}$$

We assume parameter values are such that both the sectors produce the intermediate good, i.e. $x_1^A > 0$ and $x_2^A > 0$.

A more stringent environmental policy (a higher γ) increases the formal firms' cost of producing the intermediate good. As shown by (7), this decreases the total amount of final good produced, and intermediate good used, by these firms (the "scale effect" of regulation). Further, as long as the informal sector is fully compliant, a higher γ increases both the formal and informal firms' marginal costs so that each formal firm's purchase of the intermediate good from the informal sector (x_2^A) remains unchanged. Hence, the size and composition of the informal sector remains unchanged as well (i.e. there is no "composition effect"). The reduced need for the intermediate good is instead met by a reduction of in-house production by the formal firms, i.e. $\frac{\partial x_1^A}{\partial \gamma} < 0$.

Using (4) and (8), we get the equilibrium price of the intermediate good

$$\rho^A = \frac{\gamma\left(mx_2^A + Nc_2\right)}{N} = \frac{\gamma\left(c_2 + mc_1\right)}{m+1} \tag{10}$$

and, using (2), the informal sector threshold in case A

$$c_4^A = \frac{c_2 + mc_1}{m+1} \tag{11}$$

so that the number of green informal firms is

$$n_{green}^A = N\left(c_4^A - c_2\right) = \frac{mN\left(c_1 - c_2\right)}{m+1}$$

Lemma 1 summarizes the above.

Lemma 1: *As γ increases within $\left(1, \frac{1}{1-\beta}\right)$ and the environmental regulation becomes more stringent, the size and composition of the informal sector does not change (all informal firms are green).*

Since all firms reduce their emission intensity as required, the equilibrium

amount of pollution generated from production of the dirty intermediate good by both formal and informal firms, Z^A, is given by

$$Z^A = \left[mx_1^A + N\left(c_4^A - c_2\right)\right] e\left(\gamma\right) \tag{12}$$

Case B: $\gamma\left(1-\beta\right) > 1$. In this case, some informal firms violate the environmental regulation. Using (5), we have

$$TC_2^B = \rho x_2 = \frac{\chi_2 + x_2 + Nc_2}{N\left(1-\beta\right)} x_2$$

where χ_2 is the amount of intermediate good purchased from the informal sector by all other $(m-1)$ formal firms (so that $\chi_2 + x_2 = X_2^B$). The representative formal firm's marginal cost of buying the intermediate good from the informal sector is

$$MC_2^B = \frac{\chi_2 + 2x_2 + Nc_2}{N\left(1-\beta\right)}$$

Now, $MC_1 = c_1\gamma \geq MC_2^B$ for all $x_2 \leq \frac{1}{2}\left(N\gamma c_1\left(1-\beta\right) - \chi_2 - Nc_2\right)$, or using $\chi_2 = \left(m-1\right)x_2$ due to symmetry, we have $MC_1 \geq MC_2^B$ for all x_2 less than (or equal to)

$$N\frac{c_1\gamma\left(1-\beta\right) - c_2}{m+1} \equiv x_2^B \tag{13}$$

When x^* exceeds x_2^B, the equilibrium amount of intermediate good produced by the representative formal firm is

$$x_1^B = x^* - x_2^B \tag{14}$$

Once again, we assume that the parameters in our model take values such that $x_1^B > 0$ and $x_2^B > 0$. It is interesting to note from (13) that, when $\gamma\left(1-\beta\right) > 1$, the informal sector can be active even when all firms in this sector are less efficient than the formal firms (i.e. $c_2 > c_1$). This

is because, with the environmental regulation in place, the (abatement cost inclusive) unit cost of a formal firm is $c_1\gamma$ while the lowest-cost informal firm can violate and produce as long as it gets a price of $\frac{c_2}{1-\beta}$. In contrast, when $\gamma(1-\beta) \leq 1$, (8) shows that the fully compliant informal firms can produce only when they have a lower cost than their formal sector counterparts (i.e. $c_2 < c_1$).

As earlier, the scale effect of a more stringent regulation decreases the total amount of intermediate good used by the formal sector. Unlike the case of full compliance, however, an increase in γ does not increase the formal sector's marginal cost of procuring the intermediate good from the informal sector in case B. This is due to the fact that the marginal firms that enter the informal sector do not comply with the regulation in the present case. As a result, unlike in case A, an increase in γ leads to more outsourcing (i.e. higher x_2^B) by the formal firms in case B. In-house production of the intermediate good falls as well, i.e. $\frac{\partial x_1^B}{\partial \gamma} < 0$.

Not only does a stricter regulation increase the size of the partially compliant informal sector, by increasing price of the intermediate good it also changes the composition. This is seen as follows. Using (5) and (13), we get the equilibrium price of the intermediate good

$$\rho^B = \frac{mx_2^B + Nc_2}{N(1-\beta)} = \frac{c_2 + m\gamma c_1(1-\beta)}{(m+1)(1-\beta)} \tag{15}$$

Substituting (15) in (1) and (3), we have the informal sector thresholds that determine the number of complying and violating firms in case B

$$c_5^B = \frac{c_2 + m\gamma c_1(1-\beta)}{m+1} > c_3^B = \frac{\beta c_5^B}{(1-\beta)(\gamma-1)} \tag{16}$$

Consequently, we have

Lemma 2: *When the informal sector is partially compliant (i.e.* $\gamma(1-\beta) > 1$*), a more stringent environmental regulation (i) increases the size of the*

informal sector, and (ii) changes its composition by increasing (reducing) the number of noncompliant (compliant) firms.

PROOF: From (16), we have (i) $\frac{\partial c_5^B}{\partial \gamma} = \frac{mc_1(1-\beta)}{m+1} > 0$, and (ii) $\frac{\partial c_3^B}{\partial \gamma} = -\frac{\beta(mc_1(1-\beta)+c_2)}{(m+1)(1-\beta)(\gamma-1)^2} < 0$.

Since all formal firms and some informal firms comply with the regulation, the equilibrium amount of pollution generated by the formal and informal sector, Z^B, is

$$Z^B = \left[mx_1^B + \left(c_3^B - c_2\right) N\right] e\left(\gamma\right) + \left(c_5^B - c_3^B\right) N \tag{17}$$

The first term on the RHS of (17) represents the emissions from the formal sector and compliant informal firms. The second term represents emissions from the noncompliant informal firms.

3 Pollution leakage

This section examines the impact of a stricter environmental regulation on total pollution when a violating informal firm's probability of detection is exogenously given.[12] Using (12) and (17), the impacts of an increase in γ on total pollution in cases A and B are given by

$$\frac{\partial Z^A}{\partial \gamma} = \left(\underbrace{m\frac{\partial x_1^A}{\partial \gamma}}_{<0} + \underbrace{N\frac{\partial\left(c_4^A - c_2\right)}{\partial \gamma}}_{=0} \right) e\left(\gamma\right) + \left(mx_1^A + N\left(c_4^A - c_2\right)\right) \underbrace{e'\left(\gamma\right)}_{<0} < 0 \tag{18}$$

[12] In the appendix, we endogenize enforcement activity by modeling a specific form of bureaucratic behaviour.

and

$$\frac{\partial Z^B}{\partial \gamma} = \left(\underbrace{m\frac{\partial x_1^B}{\partial \gamma}}_{<0} + \underbrace{N\frac{\partial \left(c_3^B - c_2\right)}{\partial \gamma}}_{<0} \right) e\left(\gamma\right) + \left(m x_1^B + \left(c_3^B - c_2\right) N\right) \underbrace{e'\left(\gamma\right)}_{<0} + \underbrace{N\frac{\partial \left(c_5^B - c_3^B\right)}{\partial \gamma}}_{>0 \text{ (leakage)}} \gtrless 0 \tag{19}$$

By increasing the formal firms' operating costs, an increase in γ reduces their use of the dirty intermediate good, and through this scale effect tends to reduce total pollution in both cases A and B. Further, when there is full compliance by the informal sector (case A), an increase in γ leads to less in-house production of the intermediate good by the formal firms but does not change the size and composition of the informal sector. Consequently, total pollution falls monotonically as γ increases within $\left(1, \frac{1}{1-\beta}\right)$ in case A.

In contrast, when there is partial compliance by the informal sector (case B), an increase in γ leads to less in-house production and more outsourcing by the formal firms. This not only increases the size of the informal sector, but also expands (contracts) the illegal (legal) component of that sector. This compositional change of the informal sector is the source of a leakage that tends to increase total pollution. The scale and the composition effects of the stricter environmental policy counteract each other in terms of their impact on total pollution, leading to the possibility that total pollution may increase as γ increases above $\frac{1}{1-\beta}$.

Proposition 1 follows from the above discussion.

Proposition 1: *A partially compliant informal sector acts as a source of pollution leakage. As a result, a more stringent environmental regulation, i.e. a higher γ, will initially reduce total pollution (when $\gamma \in (1, \frac{1}{1-\beta})$ and the informal sector is fully compliant) but may subsequently increase it (when $\gamma > \frac{1}{1-\beta}$ and the informal sector is partially compliant).*

Proposition 1 suggests that total pollution can, under certain conditions, be non-monotonic and convex in the environmental policy variable γ. The

following result illustrates this point.

Result 1: *For the purposes of this result, assume* $p = a - X$, $c_2 = 0$ *and* $e(\gamma) = \frac{1}{\gamma}$. *A more stringent environmental regulation, i.e. a higher* γ, *(i) reduces total pollution when* $\gamma \in (1, \frac{1}{1-\beta})$, *and (ii) initially reduces total pollution (for* $\gamma < \sqrt{\frac{a}{c_1 N(1-\beta)}} \equiv \gamma_1$*) but subsequently increases it (for* $\gamma > \gamma_1$*) when* $\gamma \in (\frac{1}{1-\beta}, \gamma^B_{\max})$.

PROOF: When $p = a - X$, $c_2 = 0$ and $e(\gamma) = \frac{1}{\gamma}$, from (9) and (14) we have $x_1^A = \frac{a-\gamma c_1 - N c_1}{m+1} > 0$ if and only if $\gamma < \frac{a-Nc_1}{c_1} \equiv \gamma^A_{\max}$ and $x_1^B = \frac{a-\gamma c_1(1+N(1-\beta))}{m+1} > 0$ if and only if $\gamma < \frac{a}{c_1(1+N(1-\beta))} \equiv \gamma^B_{\max}$. Moreover, using (12) and (17), we get (i) $\frac{\partial Z^A}{\partial \gamma} = -\frac{ma}{(m+1)\gamma^2} < 0$, and (ii) $\frac{\partial Z^B}{\partial \gamma} = \frac{m\left(N\gamma^2 c_1(1-\beta) - a\right)}{(m+1)\gamma^2} \leq 0$ if and only if $\gamma \leq \gamma_1$. Note that $\gamma_1 \in (\frac{1}{1-\beta}, \gamma^B_{\max})$ if and only if $a > \max\{\frac{c_1 N}{1-\beta}, \frac{c_1(1+N(1-\beta))^2}{N(1-\beta)}\}$, which is assumed to hold.

As indicated by Proposition 1, an informal sector acts as a source of pollution leakage only when $\gamma(1-\beta) > 1$. An important implication for policy is that increasing the intensity of a regulation, without giving complementary attention to its enforcement, can undermine the regulation and lead to counterproductive outcomes.

The impact of introducing more competition in the formal sector on the informal sector and total pollution can be analyzed in a similar manner. As the number of formal firms m increases and the formal sector becomes more competitive, production of the final good increases. The consequent increase in demand for the intermediate good is met by increased production of that good by both the sectors. This leads to an expansion of the informal sector in cases A and B, and increases the number of both green and grey informal firms in case B.[13] Hence, total pollution increases monotonically as m increases in both the cases.

[13] In case A we have $\frac{\partial\left(c_4^A - c_2\right)}{\partial m} > 0$, while in case B we have $\frac{\partial\left(c_3^B - c_2\right)}{\partial m} > 0$ and $\frac{\partial\left(c_5^B - c_3^B\right)}{\partial m} > 0$.

4 Price discrimination by the formal sector

As shown above, the equilibrium price of the intermediate good is determined through the interaction of the formal and informal sectors. Moreover, we have the following:

Lemma 3: *The equilibrium price paid by the formal sector for intermediate goods outsourced from the informal sector is less than the formal sector's marginal cost of producing the intermediate good.*

PROOF: Using (10) and (15) we have, $c_1\gamma - \rho^A = \frac{(c_1-c_2)\gamma}{m+1} > 0$ and $c_1\gamma - \rho^B = \frac{c_1\gamma(1-\beta)-c_2}{(m+1)(1-\beta)} > 0$.

The above result is a consequence of the oligopsony power enjoyed by the formal sector when it buys the intermediate good from the informal sector. Given its market power, the formal sector finds it profit-maximizing to buy less than the competitive amount from the informal sector so that it can benefit from a lower price. As m increases, and the formal sector becomes more competitive, the price of the intermediate good increases until $\lim_{m\to\infty}(\rho^i) = c_1\gamma$, $i = A, B$.

Lemma 3 suggests that the contractual environment within which the formal firms procure the intermediate good from the informal firms, and in particular whether this environment allows for the possibility of price discrimination, will play a crucial role in the determination of the size and composition of the informal sector. When the formal firms buy the intermediate good produced by the informal sector through an open market where a single price prevails, they pay a price which is less than their own cost of producing the intermediate good. Hence, if a formal firm was able to price discriminate, it would have an incentive to cut back on in-house production of the intermediate good and buy additional amounts from the informal sector, thereby increasing its size. Repeated interactions and long term contracts between a formal firm and a set of informal firms can reveal the informal

firms' cost to the formal firm and facilitate such price discrimination.

To see the impact of price discrimination more clearly, assume for the remainder of this section that $m = 1$, i.e. the single firm in the formal sector is a monopolist (monopsonist) in the market for the final (intermediate) good. Figures 1 and 2 provide diagrammatic representations of the equilibrium in cases A and B respectively, when there is a single market-clearing price of the intermediate good. To ensure that the informal sector is operative we assume that $c_1 > c_2$ in Figure 1, and $c_1\gamma(1-\beta) > c_2$ in Figure 2. In these figures, points G ($MR = MC_1$) and H ($MC_1 = MC_2$) determine the quantities x^*, $x_2^A = \frac{1}{2}N(c_1 - c_2)$ and $x_2^B = \frac{1}{2}N(c_1\gamma(1-\beta) - c_2)$. Since the single price in each case, $\rho^A = \frac{1}{2}\gamma(c_1 + c_2)$ and $\rho^B = \frac{1}{2}c_1\gamma + \frac{c_2}{2(1-\beta)}$, is less than $MC_1 = c_1\gamma$, the monopsonist will find it profitable to price discriminate and purchase additional amounts of the intermediate good from the informal sector.

When perfect price discrimination is possible, the monopsonist will offer a unique price to each informal firm that is just sufficient to cover the informal firm's cost.[14] Two alternative possibilities that can arise are as follows. In the first, suppose the formal firm expects all informal firms to comply, and pays firm indexed c a unique price $\rho_c = c\gamma$. Given this price, if the informal firm c complies it earns zero profit, while if it violates it earns a profit of $(1-\beta)\rho_c - c = c(\gamma(1-\beta) - 1)$. The latter is negative (positive) when $\gamma(1-\beta)$ is less (greater) than 1. Hence, in case A ($\gamma(1-\beta) \leq 1$) the informal firm c will comply while in case B ($\gamma(1-\beta) > 1$) it will violate.

Alternatively, suppose the formal firm expects the informal firms to violate and offers a firm indexed c the price $\rho_c = \frac{c}{1-\beta}$. Now, if the informal firm violates it earns zero profit, while if it complies it earns a profit of $\rho_c - c\gamma = \frac{c}{1-\beta}(1 - \gamma(1-\beta))$. The latter is positive (negative) when $\gamma(1-\beta)$

[14] We assume that an informal firm's decision to comply with or violate the environmental regualtion is an unobservable (to the formal firm) attribute of the intermediate good. In other words, the intermediate good is a credence good. However, in order to price discriminate, the monopsonist must be able to observe the informal firms' cost type. Thus, the price discriminating monopsonist is able to observe an informal firm's type but not its action.

is less (greater) than 1. Hence, once again, the informal firm c will comply in case A and violate in case B.

From the above, we have the following. With perfect price discrimination, the informal sector is fully noncompliant (respectively, compliant) when $\gamma(1-\beta) > 1$ (respectively, $\gamma(1-\beta) \leq 1$). Moreover, the price offered by the formal firm to a type c informal firm is $\rho_c = \min\{c\gamma, \frac{c}{1-\beta}\}$.

In case A, price discrimination results in entry of informal firms up to $c = c_1$, which expands the size of the informal sector to $(c_1 - c_2)N \equiv x_{2D}^A$. This quantity is shown in Figure 1 at point J (intersection of MC_1 and the informal sector's inverse supply curve ρ). Since all informal firms are compliant, price discrimination leaves total pollution unchanged, but improves productive efficiency and welfare as production of some of the intermediate good gets shifted from the higher cost formal firm to the lower cost informal firms (recall we have assumed $c_2 < c_1$ in case A).[15]

In case B, price discrimination results in entry of informal firms up to $\frac{c}{1-\beta} = c_1\gamma$, which expands the size of the informal sector to $(c_1\gamma(1-\beta) - c_2)N \equiv x_{2D}^B$. This quantity is shown in Figure 2 at point J (intersection of MC_1 and ρ). While productive efficiency can still improve with price discrimination, the complete noncompliance by all informal firms generates additional pollution. Consequently, social welfare (consisting, *inter alia*, of the formal firm's profit and pollution damage) may decrease.

Proposition 2 summarizes the above discussion.

[15] In analyzing the informal sector, the literature has often modeled a (homogeneous) informal sector as being less productive than the formal sector (due to the informal sector's limited access to public goods, credit markets, import channels, etc.). Nevertheless, it is quite plausible that when the informal firms are heterogeneous, at least some firms in this sector have a lower unit cost compared to the formal sector. This may arise, for instance, if the informal firms face lower labour costs (due to labour provided by family members, absence of unions and benefit payments like pension or medical facilities, and lack of protection provided by labour laws, etc.) or use a labour-intensive technology that leads to lower costs but is only suitable for small-scale production and cannot be used by the larger formal sector firms. As Datta Chaudhuri (1989) notes, "Hence, wage costs in the informal sector are lower than that in the formal sector."

Proposition 2:
(i) Imperfectly competitive formal sector firms will find it profitable to price discriminate rather than pay a single market-clearing price for the intermediate good they purchase from the informal sector. Price discrimination by the formal sector increases the size of the informal sector.
(ii) Suppose $c_2 < c_1$*. When* $\gamma(1-\beta) \leq 1$*, all informal firms are compliant and social welfare increases with perfect price discrimination. Alternatively, when* $\gamma(1-\beta) > 1$*, price discrimination worsens regulatory compliance (as it leads to violation by all informal firms) and may reduce welfare.*

In practice, it is likely that formal sector firms are able to first degree price discriminate in their transactions with an informal sector. Repeated dealings over time with the same set of informal firms can provide information about their costs to the formal firms. Moreover, long-term contracts and other arrangements with the formal sector (e.g. access to credit), and high transportation costs, can also limit the informal firms' ability to profit from arbitrage opportunities. Of course, in the event that price discrimination turns out to be detrimental for pollution and welfare (as per Proposition 2), its impact can be lessened by a policy that facilitates the informal firms to coordinate amongst themselves (through the formation of associations, for example) and set a single price for their product.

5 Conclusion

The paper examines the efficacy of environmental regulation in the presence of an endogenous informal sector. We model the vertical linkage between a formal and an informal sector, where the former can contract out production of some of the polluting intermediate good to the latter. This turns out to be profitable for the formal sector when some of the informal sector firms have lower costs either because they are intrinsically more efficient or because they are able to violate a cost-increasing regulation.

When the environmental regulation is sufficiently stringent and/or its enforcement sufficiently lax, more efficient informal firms comply with the regulation while the less efficient ones violate the same. Tightening the regulation in this case reduces the overall amount of the polluting good produced (scale effect) but leads to a larger informal sector with proportionately more noncomplying firms (composition effect). We show that the composition effect causes pollution leakage, which can undermine the regulation and even lead to counterproductive outcomes. We further analyze price discrimination by the formal sector in its transactions with the informal sector and find that, vis-a-vis a single price equilibrium, such exercise of market power by the downstream sector can increase (decrease) welfare when the regulation is sufficiently lax, i.e. $\gamma \leq \frac{1}{1-\beta}$ (stringent, i.e. $\gamma > \frac{1}{1-\beta}$).

Overall, our results point to the need for giving adequate attention to enforcement issues during the formulation of regulations. They suggest that, in the presence of an informal sector, the existing enforcement-related infrastructure of a country effectively imposes a constraint on the intensity of regulations. Beyond this constraint, better environmental quality cannot be ensured with stricter regulations alone, but only in conjunction with improvements in the enforcement system.■

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Appendix

While the rest of the paper assumes an exogenous probability of detection β, here we endogenize that probability by modeling a specific form of bureaucratic behaviour.[16] To this end, we consider a hierarchical public administration structure consisting of an environmental regulator and an enforcement agency. The regulator (say, part of the federal government of a country) sets the stringency of regulation γ, while its enforcement is delegated to an enforcement authority (say, part of a local government in the country). We assume that the enforcement agency moves after the regulator announces its chosen value of γ but before the formal and informal sector firms undertake production. Thus, the agency is able to precommit to its chosen level of β.

To ensure a detection probability of β, the enforcement agency has to monitor a fraction β of all informal sector firms that operate. We assume that, for each violating firm that it is able to detect the enforcement agency gets a reward of r, while inspecting each informal firm costs the agency an amount δ, with $r > \delta$.[17] For analytical simplicity, we additionally assume that $c_2 = 0$. Thus, the "reward conscious" enforcement agency chooses β in order to maximize

$$V \equiv r\beta N \left(c_5^B - c_3^B\right) - \delta\beta N c_5^B \tag{20}$$

where the first term on the RHS of (20) is the total reward the agency gets from detecting $\beta N \left(c_5^B - c_3^B\right)$ violating firms, while the second term is the agency's total cost of inspecting $\beta N c_5^B$ firms in the informal sector. More deterrence activities (i.e. higher β) lead to a smaller informal sector and

[16] In practise, public enforcement agencies do not necessarily maximize social welfare. For a discussion on various positive theories of enforcement agency behaviour, see the survey by Cohen (1999).

[17] The reward r can itself be legal or illegal. A legal reward can be a monetary payment or a non-monetary benefit (e.g. promotion, perks and stature) of (psychic) value r. On the other hand, an illegal reward can be the value the (corrupt) enforcement agency extorts from a violating firm that it detects. Recall that the detected violating firms do not receive any revenue in our model.

increases (decreases) the number of compliant (noncompliant) firms.[18]

Substituting (16) in (20), we have, $\frac{\partial^2 V}{\partial \beta^2} = -\frac{2Nm\gamma c_1(\delta+\gamma(r-\delta))}{(\gamma-1)(m+1)} < 0$ and V is maximized when

$$\beta^* = \frac{(\gamma-1)(r-\delta)}{2(\delta+\gamma(r-\delta))} \tag{21}$$

Stricter regulation leads to more enforcement as $\frac{\partial \beta^*}{\partial \gamma} > 0$. Moreover, the following result holds.

Result 2: *Regulatory enforcement by a net reward maximizing enforcement authority leads to partial compliance by the informal sector (i.e. case B).*

PROOF: Using (21), we have $\gamma(1-\beta^*) = \frac{1}{2}\frac{\gamma(\delta+\gamma(r-\delta)+r)}{\delta+\gamma(r-\delta)} > 1$.

If the enforcement agency is solely motivated by the net reward (i.e. net of inspection costs) it obtains for detecting violating firms, full compliance by the informal sector cannot be an equilibrium. This is because a level of β that ensures full compliance gives a negative net reward to the agency. On the other hand, given a regulation (i.e. $\gamma > 1$), zero monitoring (i.e. $\beta = 0$) cannot lead to full compliance either.[19]

In the presence of deterrence activities by the reward conscious enforcement agency, a stricter environmental regulation increases the number of both compliant and violating informal sector firms.[20] The latter implies that pollution leakage will arise in this scenario.

[18] As $\frac{\partial c_5^B}{\partial \beta} < 0$ and $\frac{\partial c_3^B}{\partial \beta} > 0$.

[19] Instead, if the enforcement agency was at least partially motivated by welfare considerations, this could lead it to choose a detection probability high enough to ensure full compliance by the informal sector. Even though the reward part of its objective function would then be zero, the associated higher welfare can offset this under appropriate conditions.

[20] Substituting (21) into (16) and then differentiating w.r.t. γ, we have $\frac{\partial c_3^B}{\partial \gamma} > 0$ and $\frac{\partial\left(c_5^B - c_3^B\right)}{\partial \gamma} > 0$.

Figure 1: case A when $m = 1$ and $c_1 > c_2$

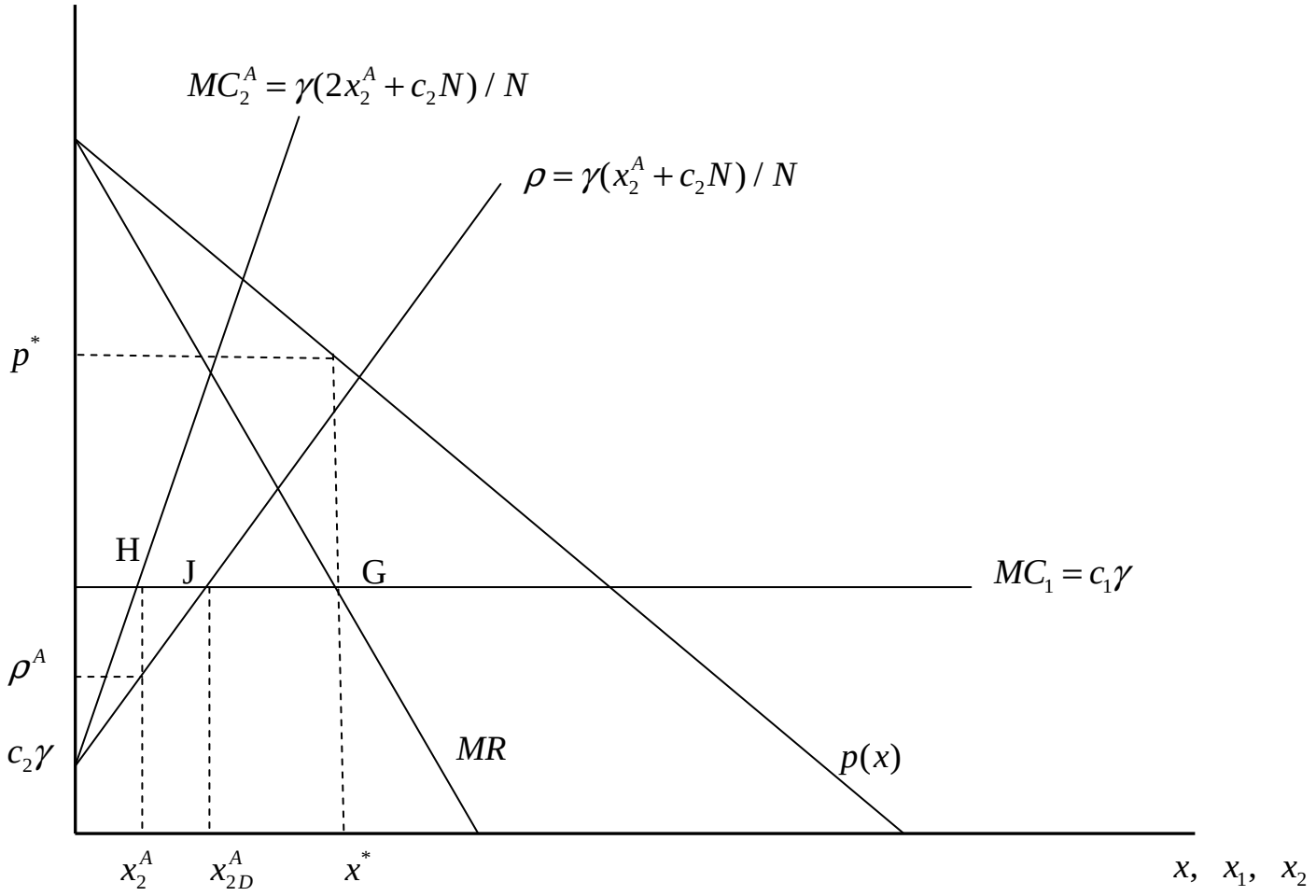

Figure 2: case B when $m=1$ and $c_1\gamma(1-\beta)>c_2$