From Green Markets to Black Markets: Environmental Regulation, Illicit Behavior, and Equilibrium Fraud

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1. Introduction

Markets for "environmentally-friendly" goods and services are becoming increasing common. In the United States, green products account for approximately 9 percent of all new-product introductions (Marketing Intelligence Service, 1999), and green certification, or "eco-labeling," programs govern the sale of thousands of products in more than 20 countries (U.S. EPA, 1993; OECD, 1997). Green products often are perfect substitutes in consumption for conventional products, and a so-called "green market" is said to exist for the traded environmental attribute. Demand for environmental attributes sold in a green markets typically is driven by consumer preferences for production technology. Consumers voluntarily pay premium prices for "green electricity" generated from renewable energy sources, for "fair-trade" coffee produced through fair labor practices, for "shade grown" coffee grown under the canopy of tropical rainforest, and for such productive characteristics as organic, "free-range", and "cruelty-free".[1] Of course, preferences for production technology by nature are independent of the fungible consumptive characteristics of goods (e.g., fair-trade coffee tastes just like unfair-trade coffee), and this creates the potential for fraud.

There is considerable evidence that fraud does in fact occur in green markets. In 1995, Made in Nature and Mexican American Fruit paid a $300,000 settlement for marketing fungicide-treated bananas in the U.S. organic market, and two of the largest certifying agencies for organic produce in the United States --the Organic Crop Improvement Association (OCIA) and Quality Assurance International (QIA)-- paid settlements for failing to enforce detected violations. Several well-known companies in the U.S., including Dole foods and Glacial Ridge Foods, have faced accusations of fraudulently marketing chemically-treated barley, beans, apples and bananas as organic. In the European Union, Euro Bio Korn, a German grain dealer,

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[1] More than 80 public utilities in 28 states have developed voluntary green-electricity programs for their customers, and projections of domestic-market potential for shade-grown coffee exceed $100 million per year in the United States (Commission for Environmental Cooperation, 1999).

allegedly sold 10,000 tons of conventional feed grain as organic over a six month period in 1999-2000. In the soap and shampoo industry, the Organic Consumers Association recently reported that "almost every product out there labeled organic isn't" (Leland 2003). What are the industry features that determine the extent of fraud in green markets? And is there a link between fraud and environmental regulations?

The basic message of this paper is that environmental regulations on polluting techniques increase the incidence of fraud in green markets. Indeed, for various parameterizations of the model, environmental regulations foreclose truthful sales of green products entirely and transform green markets into black markets. The likelihood of such an outcome is greater, moreover, for regulated techniques that involve high environmental damages on the margin.

The analysis is framed in a way that directs attention to market incentives for fraud. Consumers have positive, but heterogeneous demand for the green attribute. The focus on attribute demand suppresses strategic issues which can arise when the choice of production technology jointly provides private and public goods (issues which are relatively well understood.) Censored attribute demand at zero confines attention to circumstances in which consumers have a common preference ranking of technologies.[2] For transparency, the model considers only two technologies, a "clean" technique which does not pollute and a "dirty" technique which does. Consumer demand in the green market is for products produced with the clean technique. To allow for fraud, the production technology used to produce the good or service cannot be verified through consumption. However, despite the indistinguishability of production technology in consumption, consumers form rational beliefs about the extent of market fraud. For example, consumers cannot distinguish between fair-trade coffee and unfair-trade coffee in consumption, but can observe the extent of fair labor practices in the industry.

Several industry features influence the extent of illicit activities in green markets. The

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[2] In principle, consumers may not agree on the environmental implications of technology choice. Some consumers may be opposed to genetic engineering on the basis of the "precautionary principle", while others may favor genetically modified crops on the grounds of lower pesticide use. Confining attention to positive attribute demand eliminates this form of environmental ambiguity.

interesting cases arise under oligopoly, where there is both an element of hidden action among firms (the firm is not the industry) and at least some attenuation of the common property problem (firms recognize the link between individual technology choices and industry pollution). Whether or not fraud occurs in an oligopolistic green market depends on the market share of firms, on the relative marginal cost of production using clean and dirty techniques, and on demand for the green attribute. A key feature of the model is that fraud is more likely when the cost differential required to produce the environmental attribute is large relative to the premium price the attribute commands in the green market.

Environmental regulation on the polluting production technology has two direct effects on the market outcome. Regulation raises the marginal cost of goods produced with dirty techniques, narrowing the cost differential required to produce the green attribute. Regulation also increases the equilibrium price of goods produced with dirty techniques, and this reduces the equilibrium price premium in the green market. The direct effects of regulation create offsetting incentives for fraud. However, environmental regulation also has an indirect effect on the green market. Fraudulent sale of dirty goods in the green market evades the environmental regulation, and this leaves firms engaging in illicit activities exposed to only demand-side effects in the green market. Fraud emerges as an equilibrium outcome where it otherwise would not.

The paper also examines monitoring and enforcement strategies. When regulators (or private certifying agents) randomly inspect production, firms engaging in illicit behavior respond by simultaneously employing dirty and clean techniques and selling output to both markets. Clean techniques may be used strictly to launder illicit activities. Consequently, penalties assessed for non-compliance deter fraud, but, at the same time, increase the return to laundering activities, and it follows that illicit activities cannot be eliminated without complete monitoring of all production units. Black markets, when they emerge, persist.

The paper is organized as follows. Section 2 formulates a model of consumer demand in green markets. Sections 3 and 4 characterize the social optimum and the unregulated market equilibrium, respectively. Section 5 derives the outcome under environmental regulation of dirty production techniques. Section 6 examines the implication of illicit activities on monitoring and enforcement strategies and Section 7 concludes.

2. The Model

Consider a market with two technologies and two goods. The goods contain an identical set of consumptive characteristics, but differ according to the production technology that generates them. One production technology pollutes and the other does not and, throughout, the good produced with the non-polluting technology is referred to as the "clean" good and the good produced with the polluting technology is referred to as the "dirty" good. At equal market prices, all consumers prefer the clean good to the dirty good. Consumers are heterogeneous, however, and vary in the intensity of their preferences for the clean good. Thus, positive demand generally exists for the dirty good whenever a positive price premium emerges for the clean good. To make matters interesting, clean goods are more costly to produce than dirty goods.

In many regards, consumer preferences for production technology are no different than consumer preferences for other attributes of product quality, such as sweetness, texture, performance, or durability. A relevant distinction is that the production technology used to create market goods cannot be verified ex post through consumption. This creates an extreme form of the so-called "credence qualities", a class of experience goods in which both pre-purchase and post-purchase costs of determining whether a desired attribute truly exists are high (see, e.g., Darby and Karni, 1973; Smallwood and Conlisk, 1979; and Rogerson, 1983). Here, when only a single productive attribute of the two goods differs (whether the process is clean or dirty), the nature of a market good can be verified only through observation at the production point or through laboratory testing of consumer products.[3] When observation is costly, this creates an incentive for firms to engage in fraudulent sales of dirty goods as clean ones.

To fix the main ideas of the paper, consider a market where consumers choose between pesticide-treated and "organic" food varieties. Pesticide-treated and organic foods differ

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[3] Even laboratory testing may not be able to discern the production technique. For example, it may not be possible to determine whether a food product is produced from genetically modified seed, or whether meat is produced from a cloned animal.

according to production technique, but are otherwise identical in terms of their salient consumptive qualities.[4] The production technology is *ex post* unobservable in the sense that non-systemic pesticide residues can be washed away. Nonetheless, for a food item of a given size, appearance, and taste, consumers voluntarily pay a premium price to acquire the organic variety.[5]

The setting for the model is as follows. Consumers are unable to distinguish a dirty good from a clean one in the green market. Nonetheless, consumers have full information regarding the problem facing firms, and form rational beliefs on the overall extent of fraud. Consumers are assumed to be risk neutral in the sense that their preferences for the clean good depend only on the probability that a randomly chosen sample from the green market results in the selection of a truly clean good (and not a fraudulently labeled dirty one). Throughout, the probability that a truly clean good is selected is referred to as the purity level of the green attribute. If all goods sold in the green market are in fact fraudulently labeled dirty goods, then the green attribute has zero purity, and consumer demand in the green market goes to zero. In all other cases, consumer demand in the green market increases as the green attribute becomes more pure.

Consider, first, production of the dirty good. To streamline the model, suppose the dirty good is produced by a competitive industry at a constant unit production cost of c_d. Let y_d denote total output of the dirty good. Production of the dirty good generates pollution, and pollution damages are given by the damage function $e = e(y_d)$, where $e' > 0$ and $e'' < 0$.

The clean good is produced by a quantity-setting oligopoly industry at a constant unit cost of $c_c > c_d$.[6] The number of firms is exogenous and equal to n, so that the model encompasses circumstances of monopoly ($n = 1$) and perfect competition ($n \rightarrow \infty$). A firm that sells clean goods can either produce the clean good or produce the dirty good and dress it up for

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[4] In a blind taste test, consumers consistently failed to distinguish between organic and pesticide-treated fruits and vegetables (*Consumer Reports*, 1998).

[5] Consumer preferences for organics may be driven in some cases by latent health motivations resulting from personal pesticide exposure, and in other cases by environmental health motivations resulting from the adverse effects of pesticides on birds, fish, and wildlife (see Hamilton, Sunding, and Zilberman, 2003).

[6] Under price-setting oligopoly, the clean good would require an additional element of product differentiation to generate equilibrium prices above marginal cost. As demonstrated below, this additional element would be necessary to generate fraud in pure strategy price equilibria.

sale as a clean good at a unit disguise cost of d. For example, a firm that sells pesticide-treated produce as organic might incur costs associated with washing away visible pesticide residues. To allow for the possibility of fraud, fraudulent clean goods are assumed cheaper to produce than true clean goods, $c_c > c_d + d$.

Let y_c denote the total output of the clean good. All clean goods are sold in the clean market. In addition, some dirty goods may be sold in the clean market. Let y_f denote the quantity of dirty goods that are subsequently dressed for fraudulent sale in the clean market. There are three types of production (y_d, y_f, and y_c) and only two markets. To reconcile production and sales, let $\hat{y}_d$ denote the total quantity sent to the dirty market and let $\hat{y}_c$ denote the total quantity sent to the clean market. For now, suppose neither consumers nor the regulator engage in any monitoring and enforcement activities. In this case, firm attempts at fraudulent sales are always successful, so that $\hat{y}_d = y_d - y_f$ and $\hat{y}_c = y_c + y_f$. The purity of the clean good sold in the clean market is then given by $\rho = \frac{y_c}{\hat{y}_c} = \frac{y_c}{y_c + y_f}$.

Consumers choose between three types of goods: an outside good (the numeraire), the dirty good, and the clean good. Consumers are heterogeneous, and differ according to their demand for product quality. Product quality, q, is comprised of a bundle of fungible consumptive characteristics, k, that are common to both goods, and, in the case of the clean good, an additional productive characteristic embodied in its purity level, ρ. For simplicity, these characteristics are assumed to be additively separable, so that $q(k, \rho) = \psi(k) + \rho$.[7] Consumers differ in their preferences for the product according to a taste parameter, θ, which is assumed to be continuously indexed and uniformly distributed over the unit interval. Each consumer has an exogenous income of m.

Let p_c and p_d denote the market price of clean and dirty goods, respectively. The indirect

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[7] This assumption simplifies the analysis by separating the two margins of the model; the margin that divides consumers between the product market and an outside good, and the margin that divides consumers between the dirty and clean markets within the product category. The problem can then be conceived as if consumers first decide which product they prefer in the space of consumptive characteristics, and then decide whether or not to pay an additional market premium to secure the desired productive attribute.

utility of a consumer of type θ who buys good *i* with quality level *k* and purity level ρ is

$$V_i(p_i, k, \rho, \theta) = m - p_i + \theta\left(\psi(k) + \rho\right), \qquad i = c,d$$

where $\rho = 0$ for the dirty good. The system of market demands is determined from two critical values of the taste distribution. The preference level of the consumer who is indifferent between purchasing clean and dirty goods, $\theta_c^* = \theta_c^*(p_d, p_c, \rho)$, is found by setting $m - p_c + \theta_c(\psi(k) + \rho) = m - p_d + \theta_c \psi(k)$ and solving for θ_c. Doing so yields

$$\theta_c^* = \frac{p_c - p_d}{\rho}. \tag{1}$$

All consumers with values of θ that satisfy $\theta \geq \theta_c^*$ purchase the clean good and the remaining consumers purchase either the dirty good or the outside good. The preference level of the consumer who is indifferent between purchasing the dirty good and the outside good, $\theta_d^* = \theta_d^*(p_d, k)$, is found by setting $m - p_d + \theta_d \psi(k) = m$ and solving for θ_d. This gives

$$\theta_d^* = p_d / \psi(k) \tag{2}$$

Demand for the dirty good and the clean good is defined from (1) and (2) as

$$D_d(p_d, p_c, \rho) = N(\theta_c^* - \theta_d^*) = \frac{N}{\rho\psi(k)}\left(\psi(k)p_c - (\psi(k) + \rho)p_d\right) \tag{3}$$

and

$$D_c(p_d, p_c, \rho) = N\left(1 - \theta_c^*\right) = \frac{N}{\rho}(\rho - p_c + p_d), \tag{4}$$

respectively. Finally, letting $\tilde{c} = c_c - c_d$ denote the marginal cost differential between premium and conventional brands, assume that

$$1 - \tilde{c} > 0. \tag{C1}$$

Condition (C1) ensures that demand for the premium product in (4) is strictly positive at a unit purity level ($\rho = 1$) and competitive prices.

Making use of the definition of sales in each market, $D_d = \hat{y}_d$ and $D_c = \hat{y}_c$, demand equations (3) and (4) can be inverted to yield

$$p_d(\hat{y}_d, \hat{y}_c) = \psi(k) - \frac{\psi(k)}{N}(\hat{y}_d + \hat{y}_c) \tag{5}$$

and

$$p_c(\hat{y}_d, \hat{y}_c, \rho) = \psi(k) - \frac{\psi(k)}{N}\left(\hat{y}_d + \hat{y}_c\right) + \rho\left(1 - \frac{\hat{y}_c}{N}\right). \tag{6}$$

Notice that the derived demand for the environmental attribute sold in the green market is $p_c - p_d = \rho\left(1 - \hat{y}_c/N\right)$. Put somewhat differently, if the equilibrium price of the dirty good is $\overline{p}_d$, inverse demand for the clean good is

$$p_c(\overline{p}_d, \hat{y}_c, \rho) = \overline{p}_d + \rho\left(1 - \frac{\hat{y}_c}{N}\right). \tag{7}$$

Demand for the environmental attribute in (7) depends on total output of the clean good and on the degree of purity in the green market. At a zero level of purity, the environmental attribute is no longer traded in the green market, and (inverse) demand for the clean good in (7) becomes horizontal at price $\overline{p}_d$. For positive levels of purity, a premium price emerges in the green market. In this case, market demand for the clean good in (7) depends both on the value of the common attributes shared with the dirty good, which is embodied in the price $\overline{p}_d$, and on the value of the additional environmental attribute contained (on average) in a unit of the clean good.

3. The Social Optimum

Now consider the socially optimal resource allocation. The social problem is expressed as the selection of an output-purity triple $\{\hat{y}_d, \hat{y}_c, \rho\}$ to maximize the standard welfare measure of consumption benefits less production costs. Making use of the identities $y_f = (1-\rho)\hat{y}_c$, $y_c = \rho\hat{y}_c$, and $y_d = \hat{y}_d + (1-\rho)\hat{y}_c$, the total social cost of production can be written as

$$C(\hat{y}_d, \hat{y}_c, \rho) = c_d\left[\hat{y}_d + (1-\rho)\hat{y}_c\right] + c_c\rho\hat{y}_c + d(1-\rho)\hat{y}_c + e(\hat{y}_d + (1-\rho)\hat{y}_c). \tag{8}$$

Throughout, the solution to the social problem is assumed to be non-trivial. This requires that extent of external damage in equilibrium be limited by the condition

$$\tilde{c} > e'. \tag{C2}$$

When condition (C2) fails to hold, the marginal social cost of producing the dirty good, $c_d + e'$, exceeds the marginal social cost of producing the clean good, c_c, and the socially optimal resource allocation eliminates dirty production entirely.

The social optimum is completely characterized as the solution to

$$\underset{\hat{y}_d,\hat{y}_c,\rho}{Max}\int_0^{\hat{y}_d} p_d(x,\hat{y}_c)dx+\int_0^{\hat{y}_c} p_c(\hat{y}_d,x,\rho)dx-C(\hat{y}_d,\hat{y}_c,\rho),$$

where total social cost is given by (8). The social optimum satisfies the first-order necessary conditions

$$p_d(\hat{y}_d,\hat{y}_c)=c_d+e'(.), \tag{9}$$

$$p_c(\hat{y}_d,\hat{y}_c,\rho)=\rho c_c+(1-\rho)[c_d+d+e'(.)], \tag{10}$$

$$\Sigma\equiv\frac{1}{\hat{y}_c}\int_0^{\hat{y}_c}\frac{\partial p_c(\hat{y}_d,x,\rho)}{\partial\rho}dx-\left(\tilde{c}-d-e'(.)\right)\geq 0;\qquad (1-\rho)\Sigma=0 \tag{11}$$

Equation (9) is the standard condition that the price of the dirty good be set equal to its marginal social cost. Expressions (10) and (11) have the following interpretation. The blended marginal social cost of producing the clean good to a purity standard of ρ is $\rho c_c+(1-\rho)\left[c_d+d+e'(.)\right]$, and this is set equal to the clean price in (10). Expression (11) is the Kuhn-Tucker condition on the socially optimal degree of purity, which holds with equality when $\rho^* < 1$. To achieve a purity increase of $d\rho$, this requires replacing a marginal unit of the dirty good with a unit of the clean good. The marginal benefit of doing so is $\int_0^{\hat{y}_c}(\partial p_c(\hat{y}_d,x,\rho)/\partial\rho)dx/\hat{y}_c$, and the marginal social cost is $\tilde{c}$ - d - e'.[8] In (11), purity is provided until either the marginal social benefit of providing greater purity equates with its marginal social cost or else purity meets its upper boundary at unity.

Notice that the social planner faces a trade-off in the allocation of purity. When goods sold in the clean market have an element of impurity, demand for the clean good is lower than in the case where $\rho^* = 1$, and this reduces consumer benefits through the purity channel in (11). But reducing purity in the clean market also lowers the price of the clean good in (10) and makes the clean good accessible to more consumers. In (7), demand for the environmental attribute is linear in the purity level, and this leads to the following result.

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[8] If the social optimum involves a degree of impurity in the clean market, then the regulator must also pay the cost of disguising the dirty good as a clean good in the clean market. Otherwise, consumers would be able to distinguish between the two types in the market and purchase only clean units.

Proposition 1. The social optimum involves unit purity, ρ^* = 1.

Proof. Making use of (5) and (6), equations (9)-(11) reduce to

$$\psi(k)-\frac{\psi(k)}{N}(\hat{y}_d+\hat{y}_c)=c_d+e', \tag{9'}$$

$$\psi(k)-\frac{\psi(k)}{N}(\hat{y}_d+\hat{y}_c)+\rho\left(1-\frac{\hat{y}_c}{N}\right)-c_d-e'=\rho\left(\tilde{c}-d-e'\right)+d, \tag{10'}$$

$$1-\frac{\hat{y}_c}{2N}\geq\tilde{c}-d-e'. \tag{11'}$$

Next substitute (9') into (10') and combine this expression with (11') to get $\frac{\rho\hat{y}_c}{2N}\geq -d$. This condition must be met with a strict inequality for any positive disguise cost, $0 < d$. Hence, the social optimum involves $\rho^* = 1$. □

Complete purity is optimal in the green market. The intuition for this is straightforward. With unit costs of production and competitive pricing of the environmental attribute, all rents in the green market go to consumers. As purity is introduced in the green market, a positive premium price emerges to recover the social increment in cost. If consumers benefit from this unit of purity more than the cost of providing it, then consumer surplus exists in the green market. With linear demand and constant unit costs, this must continue to be true for any increment in purity. The social return to purity always exceeds the social cost and unit purity is optimal.[9]

The solution to (9′)-(11′) involves unit purity, $\rho^* = 1$, and this reconciles production and consumption units in each market, $\hat{y}_d^{\,*} = y_d^{\,*}$ and $\hat{y}_c^{\,*} = y_c^{\,*}$, at levels that lead to marginal cost pricing, $p_d^* = p_d(\hat{y}_d^{\,*}, \hat{y}_c^{\,*}) = c_d + e'$ and $p_c^* = p_c(\hat{y}_d^{\,*}, \hat{y}_c^{\,*}) = c_c$. The premium price in the green market is equal to the marginal social cost of the environmental attribute, $p_c^{\,*} - p_d^{\,*} = \tilde{c} - e'$.

4. The Unregulated Outcome

Now consider the outcome when neither the government nor private certification agencies monitor the productive activities of individual firms. In this case, consumers are

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[9] In general, impure attributes can be optimal in green markets if the cost of providing purity is a sufficiently convex function (or benefits are sufficiently concave). However, extending the model to permit such an outcome would provide a larger apparatus to sift through, and this would detract from the present focus on fraud.

entirely incapable of detecting fraud. Nonetheless, consumers are rational and are able to form accurate beliefs on the average purity level of clean goods traded in the market (e.g., by solving the problem of firms). From the perspective of firms, this implies that the average purity level of clean goods is a common property resource.

In the unregulated competitive equilibrium, the price of the dirty good is $\overline{p}_d = c_d$. For a firm that produces for the clean market, let $\hat{y}_{ic} = y_{ic} + y_{if}$ denote the output sold as a clean good by firm *i*. Inverse demand under *n*-firm oligopoly is then defined by (7) in terms of the price of the dirty good, $\overline{p}_d = c_d$, the industry output level, $\hat{y}_c = \sum_i \hat{y}_{ic}$, and the industry average level of purity, $\rho = \sum_i y_{ic} \big/ \hat{y}_c$.[10]

Firm *i*'s problem is to select y_{ic} and y_{if} to maximize profits, π_i, where

$$\pi_i(y_{ic}, y_{if}, \hat{y}_c, \rho) = \left(\overline{p}_d + \rho\left(1 - \frac{\hat{y}_c}{N}\right)\right)(y_{ic} + y_{if}) - \left(c_d + d\right) y_{if} - c_c y_{ic}.$$

In addition, sunk costs must exist to justify the oligopoly equilibrium; however, sunk costs play no role in the analysis and are consequently omitted. Let $\hat{s}_{ic} = \hat{y}_{ic} \big/ \hat{y}_c$ denote firm *i*'s market share of the clean good. The first-order necessary conditions for a maximum can be written

$$\Gamma_{if} \equiv \overline{p}_d + \rho\left(1 - \frac{\hat{y}_c}{N}\right) - \rho \hat{s}_{ic} - c_d - d \le 0, \qquad y_{if}\Gamma_{if} = 0; \tag{12}$$

$$\Gamma_{ic} \equiv \overline{p}_d + \rho\left(1 - \frac{\hat{y}_c}{N}\right) + (1-\rho)\hat{s}_{ic} - \frac{\hat{s}_{ic}\hat{y}_c}{N} - c_c \le 0, \qquad y_{ic}\Gamma_{ic} = 0; \tag{13}$$

where all values are expressed in terms of market share and purity. Expression (12) gives the optimality condition on fraud. A unit of fraudulent output that is sold as a clean good receives the clean market price, $p_c = \overline{p}_d + \rho\left(1 - \hat{y}_c / N\right)$. The additional unit of fraudulent output also increases the quantity sold in the clean market, which reduces the premium price by $-\rho / N$, and dilutes market purity, which decreases the premium price by $-\rho\left(1 - \hat{y}_c / N\right) / \hat{y}_c$. The net effect of an additional unit of fraud on the market price is $-\rho / \hat{y}_c$, and this lowers firm profits by $-\rho \hat{s}_{ic}$. In expression (12), the firm engages in fraud as long the marginal private benefit of

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[10] It is straightforward to verify that the conditions for existence and stability of the Cournot-Nash equilibrium are satisfied with linear demands and constant marginal cost. That is, the reaction function slopes downward for each good and demand in each market crosses marginal cost from above (see Novchek (1985)).

fraudulent production, $p_c - \rho\hat{s}_{ic}$, exceeds its marginal private cost, $c_d + d$. Expression (13) gives the necessary condition for production of the clean good. A marginal unit of clean production has offsetting effects on the premium price in the green market. An additional clean unit increases the quantity sold in the green market, which reduces the premium price by $-\rho / N$, but also increases product purity, which raises the premium price by $(1-\rho)\left(1-\hat{y}_c / N\right)/\hat{y}_c$. The net effect of an additional unit of clean production on price is $(1-\rho)/\hat{y}_c - 1/N$, and this augments firm profits by $(1-\rho)\hat{s}_{ic} - \frac{\hat{s}_{ic}\hat{y}_c}{N}$. In (13), the firm produces truthful clean output as long as the marginal private benefit of doing so, $p_c + (1-\rho)\hat{s}_{ic} - \frac{\hat{s}_{ic}\hat{y}_c}{N}$, exceeds the marginal private cost, c_c.

Substituting the unregulated price of the dirty good, $\overline{p}_d = c_d$, into (12) and (13), and evaluating these expressions in the symmetric case, $\hat{s}_{ic} = 1/n$, gives

$$\Gamma_f = \rho\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right) - d \le 0, \qquad y_f\Gamma_f = 0; \tag{12'}$$

$$\Gamma_c = \rho\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right) + \frac{1}{n}\left(1 - \frac{\hat{y}_c}{N}\right) - \tilde{c} \le 0. \qquad y_c\Gamma_c = 0. \tag{13'}$$

Let $(\hat{y}_c^e, \rho^e)$ denote the solution to (12') and (13'). The symmetric, pure strategy oligopoly equilibrium can take one of three potential forms: (*i*) unit purity may be produced in equilibrium; (*ii*) an impure premium good may be produced; or (*iii*) zero purity may be provided. Throughout, these cases are referred to, respectively, as a region I outcome, a region II outcome, and a region III outcome.

Suppose the oligopoly equilibrium involves a region I outcome with unit purity ($\rho^* = 1$). In this case, $\Gamma_f < 0$ in (12') and $\Gamma_c = 0$ in (13') and equilibrium output is derived from (13') as

$$\hat{y}_c^{e,I} = \left(\frac{n}{n+1}\right)N(1-\tilde{c}), \tag{14}$$

where the superscript denotes the region I equilibrium quantity. Making use of this in (12'), it follows after some manipulation that unit purity is an outcome whenever $\tilde{c} < \frac{1}{n^2} + \left(\frac{n+1}{n}\right)d$.

Next, suppose the oligopoly equilibrium involves a region II outcome with an element of impurity ($0 < \rho^* < 1$) in the green market. In this case, interior solutions obtain in (12') and (13'), so that $\Gamma_f = 0$ and $\Gamma_c = 0$. Solving these equations simultaneously for $\hat{y}_c$ and ρ gives

$$\hat{y}_c^{e,II} = N\left(1 - n(\tilde{c} - d)\right), \tag{15}$$

$$\rho^e = \frac{nd}{n^2(\tilde{c} - d) - 1}. \tag{16}$$

Notice that $\hat{y}_c^{e,II} \to 0$ in (15) as $\tilde{c} - d \to 1/n$, but the level of purity remains positive in (16). This is because production of the clean good can be optimal only when the equilibrium price of a clean good with purity ρ at least weakly exceeds its marginal cost, $\rho c_c + (1-\rho)(c_d + d)$. As $\tilde{c} - d \to 1/n$, $\rho^e \to \left(\frac{n}{n-1}\right)d$ in (16), and the marginal cost premium necessary to produce for the green market, $\left(\frac{n}{n-1}\right)d$, rises to the choke price on attribute demand. A region II outcome obtains for a cost differential that satisfies

$$\frac{1}{n^2} + \left(\frac{n+1}{n}\right)d \leq \tilde{c} \leq \frac{1}{n} + d.$$

Finally, when the unit cost premium associated with the clean technology is sufficiently high, $\frac{1}{n} + d < \tilde{c}$, a region III outcome occurs in which positive purity cannot be supported in pure strategies. However, it is straightforward to demonstrate that a Nash equilibrium does exist in mixed strategies. To see this, assume a pure strategy Nash equilibrium obtains with the outcome $(\hat{y}_c^e, \rho^e)$ = (0, 0) and consider the incentive for a unilateral defection by a single firm. Suppose a firm defects by selecting a positive level of purity. In this case, $n = 1$ in the clean sector, and it follows in (13') that $\Gamma_c < 0$ if and only if $1 - \tilde{c} < 0$, which contradicts by (C1). Hence, providing a positive purity level is a profitable defection strategy. In the remainder of this paper, attention is confined to circumstances in which a symmetric, pure strategy Nash equilibrium emerges.

Figure 1 depicts the outcome under symmetric oligopoly in $(d, \tilde{c})$-space. The bold 45-degree line ($\tilde{c} = d$) depicts the lower boundary on the cost premium that supports equilibrium fraud. For cost pairs below this line, $\tilde{c} < d$, producing the clean good truthfully is less costly than disguising dirty goods as clean ones and fraud can never occur in equilibrium. The dashed line at $\tilde{c} = 1$ denotes the upper limit on the cost premium given by (C1). The upper triangle of the figure thus delineates the cost pairs encompassed by the analysis. The remaining lines divide this area into regions I, II, and III. The bold line at $\tilde{c}^d = 1/n + d$ represents the upper boundary on the cost premium that supports a pure strategy Nash equilibrium. This is the locus of cost pairs for which firms earn zero profit from production of a clean good with positive purity. Region III in the figure represents all cost pairs above this locus. These cost pairs involve a sufficiently high cost premium on the clean good to preclude the possibility of a green market as a pure strategy equilibrium outcome. The area beneath the $\tilde{c}^d$ locus represents cost pairs that do support a green market. This area is further divided into region I and region II by the locus $\tilde{c}^u = \frac{1}{n^2} + \left(\frac{n+1}{n}\right)d$. Region I lies below the $\tilde{c}^u$ locus, and, for these cost pairs, unit purity is an outcome. Region II depicts cost pairs that lie between the $\tilde{c}^u$ and $\tilde{c}^d$ loci. For these cost pairs, a degree of impurity occurs in equilibrium. The location of these cost loci depend on the equilibrium number of firms in the industry, and hence its market structure.

Proposition 2. In an unregulated environment, green markets may or may not exist as a pure strategy equilibrium outcome under oligopoly. However,

(i) a green market does not exist under competition; and

(ii) unit purity is provided in a green market under monopoly,

Proof. For part (*i*) notice that $\Gamma_f = \rho\left(1 - \hat{y}_c / N\right) - d$ in (12') and $\Gamma_c = \rho\left(1 - \hat{y}_c / N\right) - \tilde{c}$ in (13') when $n \to \infty$. If true clean output is produced, $\Gamma_c = 0$, it follows that $\rho\left(1 - \hat{y}_c / N\right) = \tilde{c}$. Substitution of this into (12') yields $\Gamma_f = \tilde{c} - d \leq 0$ for the competitive case, which contradicts. Therefore, true clean output is not produced, and it follows immediately that $y_f = 0$.

For part (*ii*) notice that $\Gamma_f = -\left(\rho\hat{y}_c/N + d\right) < 0$ when $n = 1$. Hence, fraud is never optimal, and the clean good is always unit pure. It remains only to be shown that the clean good is produced in the monopoly equilibrium. At a unit purity level, $\Gamma_c = 1 - 2\frac{y_c}{N} - \tilde{c} \leq 0$ and it follows from (C1) that $y_c^e > 0$ must hold in the monopoly equilibrium. □

In the unregulated market equilibrium, oligopoly firms face two opposing motivations for fraud in the green market. On the one hand, the residual demand function of each firm in the market shifts upward with the average purity level, and this provides an incentive to produce clean goods. On the other hand, firms view the average purity level in the market as a common property resource, and this creates an adverse selection problem. The balance between these opposing incentives determines the equilibrium purity level in the market. Under competition, firms perceive the composition of their output to have no effect on average purity in the market, and the first effect disappears. Competition drives away clean production and forecloses the green market. Under monopoly, the adverse selection problem is internalized, and the second effect disappears. A monopolist considers only the residual demand effect of purity in the market, and consequently does not engage in fraud. Under oligopoly, both effects impact firm behavior, and the relative importance of each depends on the number of firms and on the cost differential required on the margin to produce truthful (as opposed to fraudulent) clean goods.

The outcome under various market structures can be seen in Figure 1. Under monopoly, both the $\tilde{c}^u$ locus and the $\tilde{c}^d$ locus have a unit intercept, so that the entire upper triangle considered in the model becomes region I. As the number of firms increases, both loci shift down as the number of firms increases, and, in the limit as n tends to infinity, both the $\tilde{c}^u$ locus and the $\tilde{c}^d$ locus converge to the 45-degree line and the entire upper triangle becomes region III.

5. The Effect of Environmental Regulation

Suppose environmental policy is now imposed in the market for the dirty good. This section considers the outcome when market-based policy controls are levied in the markets.[11,12]

A natural policy to consider is the Pigouvian tax. An environmental tax set at the level of

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[11] In many cases, environmental damages depend on input use. As demonstrated below, environmental regulation can introduce black market activities for goods sold in markets that are horizontal to the regulated product. In the case of a regulated input, identical qualitative predictions to those derived here would arise in a model where input suppliers face derived demand for clean and dirty inputs from a competitive finished product industry.

[12] Market-based controls, and not outright technological bans, are the focus here. Nevertheless, qualitatively similar results would obtain under a technology ban whenever international trade in dirty goods occurs. For example, a pesticide may be banned in the domestic country, while the importation of foreign products produced with the pesticide may not be banned. In this case, a premium price may emerge in the domestic country for the green technology and importers would face qualitatively similar incentives to those described here for fraudulently labeling foreign goods as produced with green technology.

marginal damage, $t = e'(y_d^*)$, would serve to align private and social incentives for production of the dirty good in (9). However, such a policy, alone, would be sub-optimal. The model consists of two markets, and a second instrument is required to correct for the (potential) oligopoly distortion in the green market. Under oligopoly, the market price of the clean good generally exceeds the social price level, $p_c^* = c_c$, which solves (10). A standard correction for the output reduction under oligopoly is a subsidy, and the possibility for such a policy is considered by allowing for a subsidy on the clean good of $s \geq 0$. If fraud occurs in equilibrium, monitoring and enforcement also may be necessary; however, before examining policies that involve monitoring and enforcement, it is instructive to consider the effect of corrective policy alone.

Suppose the regulator taxes the dirty good at the rate $t = e'(y_d^*)$ and subsidizes production of the clean good at a unit rate of $s \geq 0$. Under symmetric conditions, the first-order necessary conditions for the oligopoly equilibrium are

$$\Phi_f = \overline{p}_d + s + \rho\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right) - c_d - d \leq 0, \qquad y_f \Phi_f = 0; \tag{17}$$

$$\Phi_c = \overline{p}_d + s + \rho\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right) + \frac{1}{n}\left(1 - \frac{\hat{y}_c}{N}\right) - c_c \leq 0. \qquad y_c \Phi_c = 0. \tag{18}$$

Notice that the production subsidy on the clean good increases the incentive to produce both types of goods, whereas the environmental tax on the dirty good does not directly impact the clean sector. Nevertheless, the tax indirectly affects the incentive to produce clean goods by adjusting relative prices to fully internalize marginal social costs. Under a Pigouvian tax, the regulated price of the dirty good is $\overline{p}_d = c_d + t$, where $t = e'(y_d^*)$. Substituting this value into (17) and (18) gives

$$\Phi_f = \tau + \rho\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right) - d \leq 0, \qquad y_f \Phi_f = 0; \tag{17'}$$

$$\Phi_c = \tau + \rho\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right) + \frac{1}{n}\left(1 - \frac{\hat{y}_c}{N}\right) - \tilde{c} \leq 0, \quad y_c \Phi_c = 0. \tag{18'}$$

where $\tau = s + t$. Notice that a tax on the dirty good is fully equivalent to a subsidy on the clean good as a production incentive in the clean sector. An increase in either the dirty tax or the clean subsidy increases the marginal private benefit of both truthful and fraudulent clean goods. A subsidy on the clean good adjusts relative prices in the same direction as an environmental tax on the dirty good, and demand for the clean good in (7) is linear in the dirty price. A clean subsidy and a dirty tax therefore produce isomorphic effects in the clean industry.

The model nests two types of regulatory policies, an environmental tax levied in isolation, $t = \tau$, and a combination of tax and subsidy instruments, t and s. The former case might apply if the regulation of environmental externalities is a separate activity from the regulation of oligopoly by competition authorities. The latter policy is superior, because it allows independent controls to be levied in the dirty and clean market. However, the qualitative implication of either policy on the incidence of fraud is identical. As before, there are three regions for the oligopoly equilibrium, and each case is considered in turn.

Consider a regulated oligopoly equilibrium that results in unit purity ($\rho^* = 1$). In this case, $\Phi_f < 0$ (17') and $\Phi_c = 0$ in (18') and the equilibrium output level is derived from (18') as

$$\hat{y}_c^{e,I} = y_c^{e,I} = \left(\frac{n}{n+1}\right) N(1+\tau-\tilde{c}) . \tag{19}$$

Notice that the effect of environmental policy ($\tau > 0$) is to increase the output of the clean good (19) relative to that in the unregulated case (14). When fraud does not occur in the economy (i.e., the non-negativity constraint on y_f always binds), environmental policy alters the relative prices of market goods in a manner that reduces dirty output and increases clean output as consumers substitute towards the now relatively inexpensive attribute sold in the green market. In the case of independent controls on s and t, such a policy can attain the first-best outcome.

But it is also possible that regulation causes the non-negativity constraint to go slack. Indeed, it is possible to show that an outcome with unit purity obtains less often under environmental regulation than it does without any regulation at all. Making use of (19) in (17'), unit purity is an equilibrium outcome whenever $\tilde{c} < \frac{1-n\tau}{n^2} + \left(\frac{n+1}{n}\right)d$. Positive values of τ reduce the locus that defines region I to $\tilde{c}^r < \tilde{c}^u$. Environmental regulation changes the relative price of clean and dirty goods, and this increases firm incentives for fraud.

Next consider the region II outcome in which the regulated equilibrium involves a degree of impurity ($0 < \rho^* < 1$). In this case, an interior solution obtains where $\Phi_f = 0$ and $\Phi_c = 0$ in (17') and (18'). Solving these equations simultaneously for $\hat{y}_c$ and ρ gives

$$\hat{y}_c^{e,II} = N\left(1 - n(\tilde{c} - d)\right), \tag{20}$$

$$\rho^e = \frac{n(d-\tau)}{n^2(\tilde{c}-d)-1}. \tag{21}$$

Positive purity is only supported in (21) in the case where $\tau \le d$. Otherwise, it would be possible for firms to produce a fraudulent unit at a cost of $c_d + d$, acquire the subsidy for it, then sell the unit for a profit in the green market at the dirty price, $\bar{p}_d = c_d + t$. Firms could then earn greater rents by defrauding the regulator than by defrauding consumers and a region II outcome does not obtain. To eliminate such perverse outcomes, attention is confined to cases in which $\tau < d$, which ensures fraud is never possible when both types of good sell at a common price.[13]

The region II outcome has an interesting feature. Notice that the level of clean output in (20) is identical to that in the unregulated case (15), but product purity is now lower under environmental regulation (21) than in the case of no regulation at all (14). Regulation has no effect on green market sales, but increases the incidence of fraud.

Figure 2 shows the outcome under regulated oligopoly for various $(d, \tilde{c})$-pairs. As before, the cost pairs encompassed by the analysis are represented by the upper triangle between the 45-degree line ($\tilde{c} = d$) and the dashed line at $\tilde{c} = 1$. The location of region III does not change under environmental regulation, and the bold line at $\tilde{c}^d = 1/n + d$, as before, is the locus of cost pairs that divides regions II and III. Environmental regulation alters the dimensions of regions I and II, however; under regulated oligopoly, region I and region II are now divided by the locus $\tilde{c}^r = \frac{1-n\tau}{n^2} + \left(\frac{n+1}{n}\right)d$. This is parallel to and below the $\tilde{c}^u$ locus that divided these regions under unregulated oligopoly. The shaded region between $\tilde{c}^r$ the $\tilde{c}^u$ loci therefore denotes cost pairs for which environmental regulation introduces black market activities in the

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[13] Alternatively, the case where $\tau > d$ can be formally addressed by considering discontinuous policies. A natural way to do this is to assume that the regulator levies both the clean subsidy and the dirty tax whenever a premium price, $p_c - p_d$, exists in equilibrium, and otherwise levies a Piguovian tax on all goods. Doing so would complicate the model, but not alter its qualitative implications.

green market that otherwise would not occur.

The main effects of environmental regulation under oligopoly are summarized as follows.

Proposition 3. For a range of cost parameters under oligopoly, environmental policy:

(i) generates illicit activities that otherwise would no occur; and

(ii) causes substitution from clean techniques into dirty techniques.

Environmental regulations change the relative prices of clean and dirty goods in the economy, and this has socially beneficial effects when illicit activities are not possible. When fraud is possible, the change in relative prices not only favors production of the clean good, but it also increases the marginal return from fraud. In response to environmental regulations, the level of illicit activities generally increases and black markets can emerge under cost conditions that would otherwise not support them.

Nonetheless, for various parameterizations of the model, a socially optimal resource allocation can obtain under environmental regulation. This potential is summarized as follows.

Proposition 4. In the absence of monitoring and enforcement activities, a socially optimal resource allocation:

(i) can always obtain under regulated monopoly;

(ii) can never obtain under perfect competition; and

(iii) can obtain under oligopoly for a range of cost parameters.

Proof. To obtain the social optimum, the tax must be set at the Pigouvian level in the dirty market, $t = e'(y_d^*)$, and the value of τ in (17') and (18') must be selected to simultaneously induce unit purity and the social output level that solves (10'). Noting that the premium price on the clean attribute at the optimal resource allocation is defined by $p_c^* - p_d^* = 1 - y_c / N$, the social output level of the clean good solves $\tilde{c} - e'(y_d^*) = 1 - y_c / N$. Doing so yields

$$y_c^* = N\left(1 + e'(y_d^*) - \tilde{c}\right). \tag{22}$$

The social optimum can obtain only when firms produce unit purity. Hence, the goal is to reconcile the output levels in (19) and (22). It follows after some manipulation that $y_c^{e,I} = y_c^*$ for

$$s^* = (1 + e'(y_d^*) - \tilde{c})/n \tag{23}$$

Substitution of (23) and $t = e'(y_d^*)$ into (17′), unit purity is an equilibrium outcome when

$$\tilde{c} \leq \left(\frac{n}{n-1}\right)d - \frac{e'(y_d^*)}{n-1}. \tag{24}$$

For part (*i*), notice that the inequality in (24) always holds for the case of $n = 1$. For part (*ii*), notice that the inequality in (24) fails to hold for any $\tilde{c} > 0$ as $n \to \infty$. It remains only to show that a range of costs exists under which an unregulated oligopoly industry produces unit purity. To see this, define the locus of points that meets (24) with equality by $\tilde{c}^f = \left(\frac{n}{n-1}\right)d - \frac{e'(y_d^*)}{n-1}$. The $\tilde{c}^f$ locus equates with $\tilde{c} = 1$ when $d' = (n - 1 + e'(y_d^*))/n$. To complete the proof, notice that $(d, \tilde{c})$-pairs exist for which unit purity obtains under oligopoly when $d' < 1$. This implies $e'(y_d^*) < 1$, which holds by the feasibility condition (C2) on dirty production, $e'(y_d^*) < \tilde{c}$. □

Under oligopoly, it is conceivable to obtain the social optimum with policies that do not rely on monitoring and enforcement. However, because regulation also widens the range of cost parameters for which fraud occurs, additional instrument(s) are needed to align the green market equilibrium with the socially optimal resource allocation when black markets emerge.

6. Monitoring and Enforcement

This section considers the possibility of implementing a socially optimal resource allocation when monitoring and enforcement can be used to penalize firms for fraud. It follows from the discussion above that positive monitoring effort is necessary to obtain unit purity under perfect competition and under various circumstances of oligopoly. In these cases, a first-best resource allocation is conceivable only when monitoring does not consume resources. This is assumed to be the case here. Nonetheless, even in this case, it is demonstrated below that the social optimum generally cannot be obtained.

Consider, as before, the situation in which a regulator levies subsidies and taxes on the sale of clean and dirty goods. But, suppose now that the regulator also has the ability to monitor firms and assess fines on detected fraud.[14] Let $\alpha \in [0,1]$ denote the monitoring frequency, which is assumed to be exogenous to firms. However, the detection rate for a given monitoring frequency may be endogenous. In particular, the detection rate is endogenous when monitoring involves an element of random sampling (e.g., through spot inspections of firms or through testing of consumer products). In this case, the conditional probability of detection depends on the magnitude of firm offenses. If firms do not engage in fraud, detection can never occur, and, in general, the detection rate increases with the incidence of fraud.

Suppose the regulator imposes two forms of sanctions on detected offenses. First, when fraud is detected, all fraudulent output is destroyed.[15] Second, the firm pays a fine of $f \geq 0$ on all fraudulent units detected by the regulator.

Let $\alpha h(\rho_i)$ denote the detection frequency of firm i, where $h(\rho_i)$ is the conditional probability of detection given that a monitoring event occurs. Two scenarios are considered, a benchmark case with exogenous detection, $h(\rho_i) = \overline{h}$ for all ρ_i, and the case of endogenous detection. In the first case, truthful activities cannot be used to launder fraudulent activities in the sense that firms cannot influence the detection rate. In the second case, the function $h(\rho_i)$ is assumed to be differentiable, with $h(0) = 1$, $h(1) = 0$, $h'(\rho_i) < 0$, and $h''(\rho_i) < 0$. Given a monitoring event, the detection frequency decreases in the level of purity selected by firm i, and this occurs at a decreasing rate. With endogenous detection, firms may engage in truthful production of the clean good to launder revenues earned through fraudulent sales.[16]

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[14] In principle, monitoring activities can be undertaken either by the government regulator or through a private certifying agent. As the main purpose here is to assess whether efficiency can be attained in a regulated equilibrium, no attempt is made to distinguish between the two cases, other than to observe that a private certifying agent may have a limited ability to enforce fines following the detection of fraud.

[15] Alternatively, the fraudulent output could be relabeled and sold as a dirty good. However, this would complicate the equilibrium outcome for the dirty good. When the regulator levies fines on offenses, the value of the output sold at the dirty price can be subsumed without loss of generality into the fine.

[16] In some cases, the regulator may be able to observe whether or not a dirty technique is in operation. To eliminate trivial cases in which the regulator can infer fraud simply by observing the dirty technique in operation, firms that fraudulently produce the clean good may also produce the dirty good for legitimate sale as dirty goods. However, because the dirty good is produced by a perfectly competitive industry, conditions on the extent of production observability can be suppressed without loss of generality.

To illustrate the nature of the detection function, $\alpha h(\rho_i)$, and to show that the assumptions made on it above are reasonably natural, consider the following example. Firms produces three types of goods: dirty goods, clean goods, and disguised dirty goods sold as clean. The three types of goods are placed in two types of boxes, labeled "dirty" and "clean" respectively, and fraud is detected when disguised dirty goods are revealed to exist in clean boxes. The regulator monitors the firms by randomly sampling from their clean boxes.[17] The probability of finding a true clean good in a given box sampled from firm *i* is ρ_i. If the regulator samples *n* boxes in a given monitoring event, the detection frequency is $h(\rho_i) = 1 - \rho_i^{\,n}$. This function satisfies all the properties assumed for $h(\rho_i)$; that is, $h(0) = 1$, $h(1) = 0$, $h' < 0$, and $h'' < 0$.

Suppose the regulator fully inspects all output of a firm whenever fraud is detected. Hence, if firm *i* produces the clean good to a purity standard of ρ_i, the firm anticipates that $\alpha h(\rho_i)y_{if}$ of its fraudulent units will be destroyed and expects to make successful clean sales of

$$\hat{y}_{ic} = y_{ic} + (1 - \alpha h(\rho_i))y_{if}\,. \tag{25}$$

On average, the quantity of the clean good sold in the market is $\hat{y}_c = \sum_i \hat{y}_{ic}$. However, because the regulator removes detected fraudulent output from the market, this creates an additional distinction between purity produced by firms and the purity level in the consumer market. The purity produced by firm *i* is given by $\rho_i = y_{ic}/(y_{ic} + y_{if})$, but the purity level of its product sold in the market (after inspection for and removal of fraud) is

$$\hat{\rho}_i = \frac{y_{ic}}{\hat{y}_{ic}} = \frac{\rho_i}{1 - \alpha h(\rho_i)(1 - \rho_i)}\,. \tag{26}$$

On average, the purity of the clean good sold in the market is $\hat{\rho} = \sum_i y_{ic} \big/ \hat{y}_c$.

In the analysis to follow, it is helpful to define the effect of firm *i*'s output choice on its total conviction level, $C_i = \alpha h(\rho_i)y_{if}$, with the conviction response functions

$$\phi_{if}(\rho_i) = \frac{\partial C_i(\rho_i, y_{if})}{\partial y_{if}} = \alpha h(\rho_i) - \rho_i(1 - \rho_i)\alpha h'(\rho_i) > 0,$$

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[17] Alternatively, it may be the case that laboratory testing of products cannot reveal the production technology that created them, as in the case of certain GMO foods. In this case, the production process of firms can be conceived as divided into a number of locations, where each location produces either clean or dirty units. Now, rather than randomly sampling boxes, the regulator randomly selects a number of production locations to monitor.

$$\phi_{ic}(\rho_i) = \frac{\partial C_i(\rho_i, y_{if})}{\partial y_{ic}} = \alpha h'(\rho_i)(1-\rho_i)^2 < 0.$$

The conviction response functions have two important properties. First, the change in the conviction level following a marginal increase in either type of output is a function only of the current purity level produced by the firm. This implies that $\phi_{if}(1) = \phi_{ic}(1) = 0$. Second, the conviction response function of firm *i* is specific to firm *i*. Because each firm receives the full rent from its laundering activities, the incentive to launder goods is independent of market structure.

Making use of these definitions, it is straightforward to verify that the effect of a change in production quantity on market output of the clean good is $\frac{\partial \hat{y}_c}{\partial y_{if}} = 1-\phi_{if}$ and $\frac{\partial \hat{y}_c}{\partial y_{ic}} = 1-\phi_{ic}$.

The marginal effect of production on market sales is the unit increase in output less the marginal change in conviction. For each unit of fraud produced, market sales of the clean good (on average) go up by less than a unit because of the effect of fraud on the detection frequency. Similarly, for each unit of truthful clean output produced, market sales of the clean good (on average) go up by more than a unit because the additional clean unit makes detection of fraudulent units more difficult for the regulator. The effect of change in production quantity on market purity is

$$\frac{\partial \hat{\rho}}{\partial y_{if}} = \frac{-\hat{\rho}}{\hat{y}_c}\left(1-\phi_{if}\right); \qquad \frac{\partial \hat{\rho}}{\partial y_{ic}} = \frac{1}{\hat{y}_c}\left(1-\hat{\rho}(1-\phi_{ic})\right).$$

Firm *i*'s problem is

$$\underset{y_{ic}, y_{if}}{Max}\left(\overline{p}_d + \hat{\rho}(1-\hat{y}_c/N)\right)\hat{y}_{ic} - (c_c + d + \alpha h(\rho_i) f) y_{if} - c_c y_{ic} + s\hat{y}_{ic}.$$

The first-order necessary conditions for this problem are

$$\Omega_{if} \equiv \left(\overline{p}_d + \hat{\rho}(1-\hat{y}_c/N) - \hat{\rho}\hat{s}_{ic} + s\right)(1-\phi_{if}) - \phi_{if} f - c_d - d \le 0, \qquad y_{if}\Omega_{if} = 0; \tag{27}$$

$$\Omega_{ic} \equiv \left(\overline{p}_d + \hat{\rho}(1-\hat{y}_c/N) - \hat{\rho}\hat{s}_{ic} + s\right)(1-\phi_{ic}) + \hat{s}_{ic}\left(1-\hat{y}_c/N\right) - \phi_{ic} f - c_c \le 0, \quad y_{ic}\Omega_{ic} = 0. \tag{28}$$

Under symmetric oligopoly conditions, $\hat{s}_{ic} = 1/n$, $\phi_{if} = \phi_f$, and $\phi_{ic} = \phi_c$, substitution of the regulated dirty price, $\overline{p}_d = c_d + t$, into (27) and (28) gives

$$\Omega_f = \left(\tau + \hat{\rho}\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right)\right)\left(1-\phi_f\right) - \phi_f(c_d + f) - d \le 0; \qquad y_f\Omega_f = 0, \tag{27'}$$

$$\Omega_c = \left(\tau + \hat{\rho}\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right)\right)(1-\phi_c) + \frac{1}{n}\left(1 - \frac{\hat{y}_c}{N}\right) - \phi_c(c_d + f) - \tilde{c} \le 0; \quad y_c\Omega_c = 0, \qquad (28')$$

Notice that (27′) and (28′) differ from (17′) and (18′) only by the magnitude of fines, *f*, and the ϕ_f and ϕ_c terms, which now adjust the equilibrium conditions to account for the effect of each type of production on anticipated market sales, market prices, and penalties. In (27'), the marginal private benefit of fraud is now lower than in the case without monitoring and enforcement (i.e., $\phi_f < 0$), because a marginal unit of fraud now makes detection more likely, and this reduces expected sales. The marginal private cost of fraud is also higher than in (17'), because additional fraud on the margin increases convictions, and this raises fines. Monitoring and enforcement thus deters fraud. In (28'), truthful production is now more valuable to firms than in the case without monitoring and enforcement (i.e., $\phi_c > 0$). This is because truthful production now has the additional benefit of laundering a firm's fraud.

Notice, also, that c_d and *f* enter linearly in (27') and (28'). When detected fraudulent output is destroyed, the marginal cost of the destroyed output has the same kind of effect on deterrence as a fine.

Consider, first, the benchmark case of exogenous detection, $h(\rho_i) = \bar{h}$ for all ρ_i. In this case, it follows that $\phi_f = \alpha\bar{h}$ and $\phi_c = 0$, and (27′) and (28′) reduce to

$$\Omega_f = \left(\tau + \hat{\rho}\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right)\right)\left(1 - \alpha\bar{h}\right) - \alpha\bar{h}(c_d + f) - d \le 0; \qquad y_f\Omega_f = 0, \qquad (29)$$

$$\Omega_c = \tau + \hat{\rho}\left(\frac{n-1}{n} - \frac{\hat{y}_c}{N}\right) + \frac{1}{n}\left(1 - \frac{\hat{y}_c}{N}\right) - \tilde{c} \le 0; \qquad y_c\Omega_c = 0. \qquad (30)$$

Notice that (30) is identical to (18′). This is because the production of truthful clean goods is no longer useful for laundering fraud under exogenous detection. Monitoring and enforcement effort reduces the incentive to produce fraudulent goods in (29), but has no direct bearing on the production of clean goods. An important aspect in (29) and (30) is that the monitoring and enforcement instruments α and *f* uniquely target fraud, and this provides the regulator with an independent instrument to control it. This leads to the following result:

Proposition 5. With exogenous detection, a socially optimal resource allocation can be obtained under regulated oligopoly. Moreover, fines are not necessary to support the social outcome.

Proof. The social optimum involves $\Omega_c = 0$ in (30) and $\Omega_f < 0$ in (29). The solution to (30) is given by (19), so that the social output levels can be obtained through an environmental policy that combines a Pigouvian tax with the subsidy rate in (23). It remains only to show that a monitoring and enforcement policy can be designed to produce a clean good that is unit pure. Noting that $\tau^* = t^* + s^*$, substitute $t^* = e'(y_d^*)$, y_c^* from (22) and s^* from (23) into (29) to get

$$\Omega_f = \left(\tilde{c}\left(\frac{n-1}{n}\right)+\frac{e'(y_d^*)}{n}\right)\left(1-\alpha\bar{h}\right)-\alpha\bar{h}(c_d+f)-d\,.$$

Unit purity obtains in equilibrium when $\Omega_f < 0$. This holds when $\alpha\bar{h} < 1$ for sufficiently large levels of f. In particular, any monitoring frequency suffices that satisfies

$$\alpha\bar{h} > \frac{\tilde{c}(n-1)+e'(y_d^*)-nd}{\tilde{c}(n-1)+e'(y_d^*)+n(c_d+f)} \tag{31}$$

To complete the proof, notice that the right-hand side of (31) is strictly less than unit value. This condition therefore can be met when $f = 0$ for sufficiently large values of α. □

When detection is exogenous, the social optimum can be supported for various parameterizations of the oligopoly equilibrium. Indeed, the usual result arises in which the social optimum can be obtained through infinitely many (α, f) combinations. When monitoring effort is costly, (α, f) pairs which involve larger fines and smaller monitoring frequency may be preferred for the reasons originally pointed out by Becker (1968). The more interesting result here is that fines are not necessary at all to obtain a socially optimal resource allocation. The social optimum can be supported through private certification, even in the case where private firms cannot enforce the payment of fines. The intuition for this is that disguise costs and the value of the discarded output act as an implicit penalty on fraud. In the competitive case, for example, a private certification agency can enforce unit purity as long as the monitoring effort exceeds $\alpha\bar{h} > \dfrac{\tilde{c}-d}{\tilde{c}+c_d}$.

Now consider the case of endogenous detection. From (27') and (28'), it follows that

Proposition 6. In a regulated oligopoly market with endogenous detection, a socially optimal resource allocation cannot be obtained under perfect competition and can only be obtained under a limited set of parameters under oligopoly.

Proof. Under endogenous detection, $\phi_f(1) = \phi_c(1) = 0$ at a unit purity level. Hence, (27') and (28') are identical to (17') and (18') at a unit purity level. It follows immediately that regulatory policy combined with monitoring and enforcement is insufficient to obtain the social optimum under perfect competition and, under oligopoly, the social optimum can only be obtained for $(d, \tilde{c})$-pairs that satisfy $\tilde{c} \le \left(\frac{n}{n-1}\right) d - \frac{e'(y_d^*)}{n-1}$. □

When truthful production can be used to launder fraudulent production, monitoring and enforcement activities cannot foreclose black market sales. The monitoring instruments, in this case, do not uniquely target fraud. Full deterrence does not obtain, because the ability of firms to launder fraudulent activities increases as products become more pure. When detection is endogenous, a socially optimal resource allocation is possible, but under precisely the same conditions that support this outcome under no enforcement at all. In figure 2, the loci that define regions I and II under endogenous detection are precisely as depicted in the case without monitoring and enforcement. Monitoring and enforcement deters, but does not eliminate, black market activities in region II, and unit purity is provided only for $(d, \tilde{c})$-pairs in region I.

A monitoring scenario with endogenous detection generally cannot be used to implement a first-best welfare outcome. Moreover, for $(d, \tilde{c})$-pairs in the shaded region of figure 2, the regulator faces an interesting dilemma in implementing a second-best welfare outcome. For an industry with cost conditions in the shaded region, the regulator can either adjust outputs to the socially optimal levels, and in so doing create a black market, or maintain unit purity by implementing an environmental policy that does not fully internalize damages on the margin.

7. Concluding Remarks

Much of the literature that discusses environmental regulation focuses either on the case in which fraud cannot emerge or on the case in which truthful production cannot be used as a means to launder it. In either case, a first-best environmental policy can be obtained. This paper relaxes these conditions and finds that environmental regulations tend to increase the extent of fraud in the economy and may even cause black markets to emerge where they otherwise would not. Moreover, black markets, when they arise, tend to persist.

The performance of environmental regulation also depends on green market structure. In a monopoly green market, the socially optimal resource allocation can always be obtained, whereas, under competition, the social optimum can never be obtained. Under oligopoly, the social optimum can be obtained for various parameterizations of the model; however, environmental regulations also encourage illicit activities, and can even cause fraud to emerge in equilibrium, by altering relative prices in the economy. Fraud is always more likely to occur after environmental regulation is implemented than absent any form of intervention at all.

Monitoring and enforcement activities can reduce the extent of fraud, but cannot entirely eliminate black market activities when the detection frequency is endogenous. When detected fraud is removed from the green market, this also raises the interesting possibility that random monitoring introduces covariance in the market. An interesting possibility for future research is to examine whether actions by the regulator to increase the variability of convictions (e.g., more intense, but less frequent inspections) may be desirable.

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Figure 1. Equilibrium Outcomes Under Unregulated Oligopoly

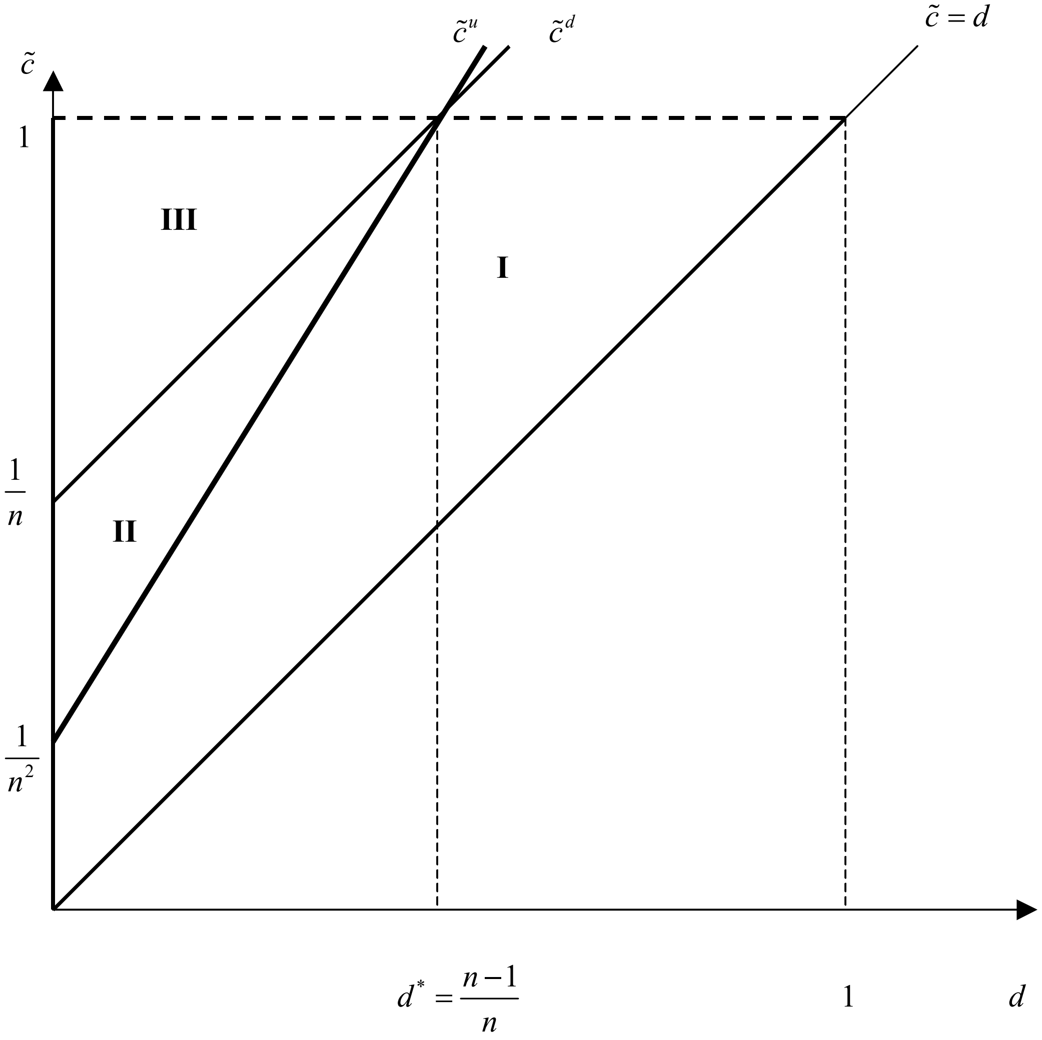

Figure 2. Equilibrium Outcomes Under Regulated Oligopoly