Self–Regulation of Pollution: The Role of Market Structure and Consumer Information

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1. Introduction

The purpose of this paper is to provide an analytical framework in which the efficiency, distributional, and environmental consequences of voluntary codes in pollution–generating industries can be assessed. In particular, the conditions under which voluntary regimes are likely to be a viable alternative to mandatory regimes are identified. Attention is focussed upon the complex interaction among market structure, demand, and environmental factors including imperfect competition among pollution–generating firms and imperfect consumer knowledge of environmental consequences of production.

Voluntary codes are a form of self–regulation. Any regulatory regime — whether it be a self-regulatory or voluntary regime versus a mandatory regime — consists of a goal or target and a set of institutional arrangements which provide incentives to attain the target. A set of institutional arrangements is composed of a rule (for example, a voluntary or mandatory code for emissions) and an ex–post governance structure (monitoring and sanctioning activities) which ensure compliance with the rule. A key difference between voluntary and mandatory regimes is that the choices of target and institutional arrangements are private rather than

commit to comply with an industry code, the industry association must provide sufficiently strong compliance incentives or an ex–post governance structure to prevent instability. Although enforcement issues are potentially important, we restrict our attention to an analysis of the incentives to adopt voluntary codes at both the firm and industry level.

Four potential sources of market failure are present in our analysis of voluntary compliance regimes: (i) pollution, a byproduct of production, generates a negative externality, (ii) imperfect competition among an industrial population of firms, (iii) emission reduction is a public good, and (iv) imperfect consumer information regarding the environmental impact of the industry's production activities. These sources of market failure interact and determine firm and industry incentives to adopt voluntary codes.

In an oligopolistic market structure with pollution generating firms, the first two sources of market failure work in conflicting directions. The oligopoly itself tends to restrict output relative to the socially efficient (and perfectly competitive) level. In contrast, the presence of an unpriced pollution externality leads to overproduction and hence excessive environmental damage relative to the social optimum. Whether the externality effect or the imperfect competition effect dominates will depend upon the degree of concentration in the industry, technology and demand conditions, the type of pollutant being emitted and the current assimilative capacity of the environment (the degree of environmental damage). For instance, the externality effect will tend to dominate the imperfect competition effect in a less concentrated industry which emits persistent pollutants while the opposite will hold in a highly concentrated industry which emits pollutants which tend to break down fairly quickly.

The public good nature of pollution abatement efforts leads to an underprovision of abatement technology; firms cannot be excluded from benefitting from competitors' abatement efforts since consumer demand depends upon industry environmental performance. The free–rider problem is particularly pronounced when consumers are well–informed and can lead to a significant gap in the performance of firm versus industry codes; an industry association is better placed

mulative and noncumulative pollutants.[1] In the case of cumulative pollutants, we ...nd that voluntary regimes perform best when consumer sanctioning power and market power is strong. The identity of winners and losers in voluntary compliance regimes is highly dependent upon the respective levels of consumer sanctioning power and market power.

The paper is organized as follows. An overview of alternative solutions to the externality problem is presented in Section 2. In Section 3, a graphical analysis of voluntary compliance is presented. A simulation analysis is presented in Section 4. Concluding remarks are presented in Section 5. The formal analytical models which provide the basis for the graphical analysis and simulation analysis are presented in a Technical Appendix at the end of the paper.

2. Alternative Solutions to the Externality Problem

The idea of fully privatizing or delegating traditional regulatory tasks to a polluting industry may initially seem to be a perversion of economic logic. It is certainly a radical departure from conventional economic thought on solutions to the externality problem. During the last 75 years, two broad schools of thought — Pigovian and Coasian — have dominated the economic analysis of externalities and hence policy–making.[2] While Pigovians and Coasians agree that externalities are caused by market failure and that correction requires government intervention, they disagree on the scope and degree of public intervention which is required. Neither school of thought suggests full delegation or decentralization as a viable solution.

Pigovians believe that the source of market failure is the missing market for pollution, that is, environmental assets are not priced. A Pigovian prescription for government intervention entails centralized choice of targets and institutional arrangements; for example, command–and–control regimes based on performance or design standards and incentive–based regimes based on taxes or marketable permits are both centralized solutions to the externality problem — they are

centralized solutions because targets, rules, and ex–post governance structures are chosen by central authorities even though individual emission decisions may be decentralized under incentive–based regimes. The regulatory agency, acting in the public interest, acquires and processes information about the costs and benefits of pollution control and chooses a set of institutional arrangements which maximizes social welfare. Pigovian solutions implicitly define a set of property rights for polluters.[3] Incentive–based rules are based on a polluter pays principle, forcing polluters to internalize external costs imposed on others as a result of their polluting activities.

In contrast, Coasians maintain that the source of market failure is ill–defined property rights. They argue that if property–rights are well–defined over environmental assets, then decentralized bargaining between polluters and victims will lead to a Pareto–improving and self–enforcing agreement consisting of a mutually acceptable level of pollution and compensatory payment. Moreover, if transaction costs are zero, then the self–enforcing agreement will attain the social optimum. A Coasian prescription for government intervention is restricted to the definition of property rights. While the initial assignment of property rights does not have allocative consequences — even if property rights are not assigned efficiently, decentralized bargaining will lead to an efficient allocation of property rights — it does have distributional consequences. For instance, if a polluter has the right to pollute, then correction of the externality requires that the victim pays the polluter to restrict emissions; in contrast, if the victim has the right to a pollution–free environment, then the polluter must compensate victims for any pollution generated. Thus, unlike incentive–based Pigovian rules which require that a polluter always pays for the right to pollute, the identity of who pays under decentralized bargaining is determined by the initial assignment of property rights.[4]

In theory, Pigovian and Coasian solutions can both sustain competitive equilibria characterized by externalities as Pareto optimum under well–specified conditions. Again, although there are no efficiency consequences of choosing one solution over the other, there will be distributional consequences.

In practice, the implementation of Pigovian and Coasian solutions in West-

ern economies has met with limited success. As predicted by innumerable non–Coasians, Coasian solutions are not well–suited to many environmental problems. Many environmental assets are either public goods or common property resources for which property rights cannot be de...ned. In addition, many environmental problems involve large numbers of polluters and victims, leading to substantive coordination problems, free–riding and high transaction costs. Finally, imperfect information regarding the opponent's bargaining curve can result in missed Pareto–improving bargains.[5] In short, decentralized bargaining cannot resolve the externality problem because of multiple sources of market failure.

Centralized Pigovian solutions have also failed to solve the externality problem because of multiple sources of regulatory failure. Regulators have imperfect knowledge about the costs and bene...ts of pollution abatement which result in errors in the target and rule–setting process and, consequently, welfare losses. Regulatory capture by interest groups such as environmental groups or industry itself also leads to suboptimal outcomes. In addition, limited regulatory resources for monitoring and enforcement leads to underprovision of compliance incentives and hence incomplete enforcement of environmental laws.

Neither decentralized bargaining nor mandatory compliance regimes have been e¤ective choices for managing the environment. In addition, mandatory compliance regimes, particularly the prevalent command–and–control regime, have proven to be prohibitively expensive. It is not surprising that debt–ridden governments are searching for more cost–e¤ective solutions to the externality problem. The key question which this paper addresses is whether or not voluntary compliance regimes can provide su₵cient incentives for the correction of externalities in a cost–e¤ective manner.

The success or failure of voluntary and mandatory regimes is, in large part, determined by the strength of compliance incentives provided by the regime. In traditional Pigovian analysis, incentives to comply with mandatory codes are provided in the form of expected ...nancial penalties for noncompliance with the law. The source of compliance incentives is the government — the regulatory agency and statutory law.[6] In contrast, incentives to comply with voluntary

codes are primarily provided by consumers of the pollution–generating product and, in the case of industry codes, the industry association.

Our analysis departs from traditional Pigovian analysis by explicitly recognizing the role that consumers play in the environmental protection process. In the absence of an agency acting in the public interest, consumers can both acquire and process information regarding the environmental consequences of industrial activities as well as exercise a powerful sanctioning role in the marketplace through reduced demand or consumer boycotts. Depending upon preferences, quality of information, and budget constraints, consumers will, to some extent, internalize the externality in their consumption decisions; in this sense, the role of consumers in a voluntary compliance regime may play a similar role to pollution victims in a Coasian bargaining situation. The key difference between the role of consumers in a voluntary compliance regime and victims in a Coasian bargaining situation is that the behaviour of agents in a voluntary compliance regime is mediated by prices.

3. A Graphical Analysis

3.1. Environmental Preferences and Consumer Demand

Consumers can play a pivotal role in the provision of incentives for firms to voluntarily reduce emissions in the absence of regulatory directives. A growing empirical literature in environmental benefit measurement identifies a positive willingness to pay on the part of consumers for improvements in environmental quality.[7] A positive willingness to pay for environmental improvements is a monetary indicator that consumers hold preferences over different states of the environment. As a result, consumer demand depends, in part, on the environmental consequences of production. Let us suppose, for the sake of argument, that consumers' willingness to pay for a pollution–generating good, Q, is given by the following relationship:

$$P(Q; Z) = f(Q) - MD \qquad (3.1)$$

where Z is the industry level of pollution emitted during the production process and MD is the monetized value of the environmental damage caused by an additional unit of output — in other words, the marginal environmental damage curve. If consumers do not care about the environmental consequences of production, then willingness to pay for a good depends solely upon the quantity consumed, $f(Q)$; $P = f(Q)$ is a standard inverse demand curve — willingness to pay is decreasing in the level of consumption, Q, due to diminishing marginal benefits of consumption. When consumers care about environmental consequences of production, then their willingness to pay for a product is also decreasing in the level of pollution which the industry generates.[8]Consumer demand will be dampened in pollution–intensive industries and enhanced in environmentally friendly industries. An implication of environmental preferences is that consumers are willing to pay higher prices for environmentally friendly goods.

3.2. Impact of Industrial Pollution Abatement on Consumer Demand

Firms can, to some extent, control their pollution emission levels. In particular, several options for reducing pollution may be available to ...rms; ...rms' may be able to reduce pollution emissions by reducing output, shifting their product mix toward low pollution–intensive goods, changing their production process or by installing pollution abatement equipment which lowers the level of waste residuals created per unit of output. Let us suppose, for simplicity, that a ...rm is restricted to two options for reducing pollution emissions: a ...rm can reduce output and/or install an emission control input. For instance, a public utility could reduce sulphur dioxide emissions by reducing electricity generation and/or by installing scrubbers in their tall stacks or switching to low sulphur coal. The total level of emission control input used by the industry is denoted by E. Pollution is thus generated by a process involving output and emission control inputs — $Z = Z(Q; E)$ — where pollution levels are increasing in the level of industry output and declining in the industry's level of emission control input usage.

Firm level choices of output and emission control input usage directly a¤ect
the level of pollution and hence consumer demand. To see this assume that

example, the marginal environmental damage function) is described by $Z = Q - \gamma E$, where $\gamma < 1$ parameterizes the efficiency level of the emission control input. The pollution production function assumes that a unit of production increases pollution by one unit while installation of a unit of emission control input reduces pollution by less than one unit γ. As the abatement technology becomes more efficient, γ increases and a higher proportion of a unit of pollution can be reduced. Substituting $Z = Q - \gamma E$ into $P(Q;Z)$ yields $P(Q;E) = A + \gamma E - 2Q$. We can now see that consumer demand or willingness to pay, $P(Q;E)$ is a function of E and Q; willingness to pay for a good is increasing in the industry's usage of abatement technology and decreasing in the level of output.

Figure 1 illustrates consumer demand, $P(Q;E = 0)$, when the industry does not install any emission control inputs. Note that $P(Q;E = 0)$ is simply the difference between $f(Q)$ and $MD(Q;E = 0)$ — consumers' willingness to pay for a pollution–generating good is net of the value of any environmental damage costs generated during the production process. In other words, consumers internalize the value of environmental damage costs in their consumption decisions. Pollution emissions cause the demand curve to pivot inward towards the origin, resulting in a steeper demand curve, and a lower willingness to pay for any given level of production; the total reduction in consumers' willingness to pay for Q is given by the area ABC.

By installing emission control inputs, the industry can reduce the level of emissions per unit of output, hence the level of environmental damage for any given level of output. The marginal environmental damage curve for a fixed level of industry emission control input usage, $\overline{E}$, is labelled $MD(Q;\overline{E})$ in Figure 2. The installation of $\overline{E}$ shifts the marginal damage curve $MD(Q;E = 0)$ down and to the right to $MD(Q;\overline{E})$; the downward shift is equal to $\gamma\overline{E}$ — the amount of waste residuals removed and the environmental damage prevented by the emission control inputs. Notice that when production is below $Q(\overline{E})$, no environmental damage is incurred when $\overline{E}$ units of emission control inputs are installed. Environmental damage is increasing for levels of production in excess of $Q(\overline{E})$. As the industry's level of emission control input usage is increased, $Q(\overline{E})$ is increasing

$$P(Q; \overline{E}) = \begin{cases} A + \circ\overline{E}\ \text{¡}\ 2Q & \text{if } Q \ge Q(\overline{E}) \\ A\ \text{¡}\ Q & \text{otherwise} \end{cases} \qquad (3.2)$$

$P(Q; \overline{E})$ is illustrated in Figure 2. Note that the $\circ\overline{E}$ downward shift in the marginal damage curve leads to an $\circ\overline{E}$ upward shift in the demand curve for levels of production in excess of $Q(\overline{E})$. Further, by installing $\overline{E}$, the industry can lower the reduction in consumers' willingness to pay by the area $ADFC$. Thus, industry output and emission control input usage a¤ect consumer demand in two ways. First, pollution emissions cause environmental damages which reduce consumers' willingness to pay for a good (inward pivoting of the demand curve). Second, ...rm investment in pollution abatement technology can reduce the level of emissions per unit of output and hence environmental damages, thereby o¤setting the reduction in consumers' willingness to pay (outward shift of the demand curve).

3.3. Impact of Pollutant Type and Consumer Knowledge on Consumer Demand

Two additional factors a¤ect the shape and location of the consumer demand curve: the type of pollutant emitted as a byproduct of production and the extent of consumer knowledge about the environmental consequences of production. Pollutants can be grouped into two broad categories — cumulative and noncumulative pollutants. Cumulative pollutants accumulate in the environment as the environment has no assimilative capacity to break them down. Examples of cumulative pollutants include inorganic chemicals, minerals, plastics and radioactive waste. In contrast, the environment has some natural assimilative capacity to break down noncumulative pollutants. Provided that the absorptive capacity of the environmental medium is high enough relative to the emission rate, noncumulative pollutants may not accumulate in the environment at all. For instance, degradable wastes such as organic residuals are attacked and broken down by bacteria in a body of water while the atmosphere has some capacity to absorb carbon dioxide emissions. If the assimilative capacity of the environment is ex-

marginal damage curves (low values of $\pm$).

Consumer knowledge about the true environmental consequences of production also plays a major factor in the determination of demand for pollution–generating products. Consumer knowledge about environmental consequences is captured by the parameter $\mu \in [0;1]$ in the inverse demand curve $P(Q;Z) = f(Q) \text{ ¡} \mu MD$. In words, willingness to pay for a pollution–generating good depends upon how well–informed consumers are about the true marginal damage curve.[9] For instance, consumers of paper products are relatively well–informed (high value of μ) about clear–cutting practices in the British Columbia lumber industry and the consequent environmental impacts due largely to the public education e¤orts of Greenpeace. In contrast, consumers were relatively poorly–informed (low value of μ) about the environmental impact of unlined oil sumps used in Alberta during the oil boom in the 1980s.

Taking into account the type of pollutant and the extent of consumer knowledge about the environmental consequences of the pollutant, we can rewrite consumer demand given by equation 3.2 as follows:

$$P(Q;\overline{E};\mu;\pm) = \begin{cases} A + \mu\pm°\overline{E} \text{ ¡ } (1+\mu\pm)Q & \text{if } Q \text{ ¸ } Q(\overline{E}) \\ A \text{ ¡ } Q & \text{otherwise} \end{cases}$$

Referring again to Figure 2, if consumers are well–informed about the environmental consequences of highly toxic emissions (high μ and $\pm$), then the inward pivoting (measured by $\mu\pm$) and the outward shift (measured by $\mu\pm°\overline{E}$) in the demand curve will be large. If, on the other hand, consumers are poorly–informed about the environmental impact of relatively benign emissions (low μ and $\pm$), then the impact of environmental preferences on consumer demand will be small.

3.4. Socially Optimal Pollution Control

The social optimum is a useful benchmark for evaluating industry choices of output and emission control input levels and the resulting level of environmental quality in voluntary regimes. A benevolent, perfectly informed social planner will

social optimum is provided in the Technical Appendix. Figures 3 and 4 provide a graphical representation of the social optimum.

Social welfare maximization requires choosing an activity level so as to equate the social marginal benefit of the activity with the social marginal cost. The social marginal benefit of installing emission control inputs, $MB_E^\pi = -D_Z Z_e$, is equal to the reduction in environmental damages which can be obtained by installing an additional unit of emission control input. Referring to Figure 3, notice that the social marginal benefit of emission control inputs is downward–sloping, reflecting diminishing marginal returns from the installation of emission control inputs; diminishing marginal returns arise because the marginal benefits accruing from emission reductions are falling. The social marginal cost of installing emission control inputs, MC_E, is simply the marginal cost of installation; MC_E is assumed to be upward–sloping, reflecting increasing marginal costs of abatement. The socially optimal level of emission control input usage, E^π, is found at the intersection point of MB_E^π and MC_E. Note that E^π is independent of μ.

The socially optimal output choice, given installation of E^π, is illustrated in Figure 4. As noted earlier, the choice of E determines the location of the marginal damage curve. Installation of E^π shifts the marginal damage curve southeast to MD^π. When consumers fully internalize the externality ($\mu = 1$), the demand curve is given by $P(Q; E^\pi)$ which is simply the difference between $f(Q)$ and MD^π; $P(Q; E^\pi)$ measures the net social marginal benefit of output, that is, the marginal benefit of consumption net of environmental consequences. The socially optimal level of output, Q^π, is found at the intersection point of $P(Q; E^\pi)$ and MC_Q, where MC_Q measures the marginal cost of producing Q. The socially optimal price of Q when consumers fully internalize the externality is denoted by $P^\pi(\mu = 1)$. If consumers do not internalize the externality ($\mu = 0$), then the demand curve is given by $f(Q)$. The socially optimal level of output is now the intersection point of $f(Q)$ and MC^π, where MC^π is the social marginal cost incurred with the production of Q; MC^π is the vertical summation of MD^π and MC_Q. Notice that while there are no allocative consequences associated with the value of μ — Q^π is independent of μ — the price of Q does vary with μ. When consumers do

3.5. Industrial Incentives to Adopt Voluntary Codes

What incentive do ...rms have to voluntarily install emission control inputs? Suppose that there is a single producer of the product who has the power to set prices. A pro...t–maximizing monopolist will choose a level of emission control input usage by equating the private marginal bene...t of an additional unit of input to the marginal cost of installation. The marginal bene...t to the monopolist of installing the input, MB_E^M, is the incremental revenue earned; $MB_E^M = P_E Q$, where $P_E = ¡ D_{ZE} = \mu \pm °$ is the value of the reduction in the marginal damage when an additional unit of the emission control input is installed. Alternatively, P_E is the increment which consumers are willing to pay for a unit of a more environmentally friendly good. Referring to Figure 2, each additional unit of emission control input installed results in an outward shift in the demand curve of $\mu \pm °$. Thus, the incentive for a monopolist to install abatement technology is a pecuniary one — the monopolist can increase pro...ts by exploiting consumers' environmental preferences to raise consumers' willingness to pay. It is important to emphasize that the monopolist's decision to install abatement technology is a purely voluntary decision. The decision is motivated by self–interest and does not require government intervention in any form, including mandated technology–based standards wherein regulations require the installation of a particular kind or level of emission control input.

The monopolist's privately optimal choice of emission control input is illustrated in Figure 3. Note that, in contrast to MB_E^{π}, MB_E^M is upward–sloping. The monopolist's pro...t–maximizing choice of E is found at the intersection point of MB_E^M and MC_E and is denoted by E^M. It can be shown that MB_E^M will always cut MC_E below MB_E^{π}, hence a monopolist will install too low a level of emission control inputs relative to the social optimum — $E^M < E^{\pi}$.

Underprovision of abatement technology results in a higher level of environmental damages for any given level of output. The marginal damage curve associated with E^M is labelled MD^M in Figure 5. Note that MD^M lies everywhere above and to the left of MD^{π}.

When $\mu = 1$, market demand for the monopolist's output Q is given by

The divergence between Q^π and Q^M is decreasing in μ. In words, as consumers become better informed about the environmental consequences of production, a monopolist will adopt more environmentally friendly production processes, raising consumers willingness to pay for its product and hence enhancing the monopolist's incentive to produce output. As μ decreases, consumers willingness to pay for the product is less responsive to the monopolist's choice of abatement technology, reducing both the incentive to adopt more environmentally friendly production processes and to expand output. For instance, when $\mu = 0$, any pecuniary advantage of installing emission control inputs is removed as demand is no longer responsive to environmental performance. Consequently, $MB_E^M = 0$ and hence $E^M = 0$. Referring to Figure 5, demand is now given by $P(Q; E^M = 0)$. The monopolist's optimal output choice is restricted further to $Q^M(\mu = 0)$. Notice, however, that the monopoly price which emerges when $\mu = 0$, labelled $P^M(\mu = 0)$, is lower than $P^M(\mu = 1)$. When $0 < \mu \leqslant 1$, Q^M and P^M will lie in the respective intervals $Q^M(\mu = 0); Q^M(\mu = 1)$ and $P^M(\mu = 0); P^M(\mu = 1)$.

The monopolist's ability to mark–up prices derives directly from its market power. Figure 5 illustrates a paradox — a monopolist's market power is increasing in consumer knowledge about the environmental consequences of production. To see this, observe that the monopolist's market power or ability to mark–up prices is directly related to the price elasticity of the demand curve, $\varepsilon_{Q;P}$:

$$\frac{P \mathbin{\text{\small i}} MC_Q}{P} = \frac{1}{|\varepsilon_{Q;P}|} \tag{3.3}$$

where $0 < |\varepsilon_{Q;P}| \cdot 1$. As the price elasticity of demand declines, demand becomes less responsive to price changes and the monopolist's ability to mark–up prices increases. The price elasticity of demand is strictly decreasing in μ, hence, market power is strictly increasing in μ. Intuitively, as consumers become better informed about environmental consequences, the demand curve becomes steeper and hence demand is less responsive to price changes.

The price elasticity of demand (market power) is also decreasing (increasing) in $\pm$, the slope parameter of the marginal damage curve. Hence, the monopolist's

the industry is concentrated, consumers are well–informed and the pollutant in question is particularly damaging to the environment.

The extent to which consumers' environmental preferences a¤ect ...rm choice of emission control input usage also depends upon the level of competition in the industry. As competition in the industry increases, individual ...rm's market power is declining and, as a result, incentives to install emission control inputs are diminished. In a perfectly competitive industry, for instance, ...rms are su¢ciently small that individual decisions will not a¤ect market prices. When ...rms are price–takers, there is no incentive to voluntarily install emission control inputs since ...rms cannot capture the pecuniary bene...t. In other words, the marginal bene...t to a perfectly competitive ...rm of installing abatement technology is zero and, given positive costs of installation, pro...t maximization requires that no technology be installed. The perfectly competitive output equilibria $Q^C(\mu = 0)$ and $Q^C(\mu = 1)$ are shown in Figure 5. When $0 < \mu < 1$, the competitive outcome will lie somewhere between these two solutions.

3.6. Company versus Industry Codes: The Free–Rider Problem

The oligopoly outcome lies somewhere between the monopoly outcome and the perfect competition outcome. We distinguish between two possible oligopolistic voluntary code regimes — company codes and industry codes. Company codes are chosen by members of an industry noncooperatively while ...rms can collude on the choice of an industry code. We assume that ...rms can only collude on the choice of abatement technology since output collusion is speci...cally prohibited by anti–trust laws. We further assume that the industry chooses an uniform code to be adopted by all members which maximizes industry pro...ts.

The incentive to voluntarily install abatement technology is generally stronger in the case of industry codes. When ...rms choose voluntary codes noncooperatively, they only consider the private bene...ts of installation. Installation of emission control inputs are a public good. No ...rm can be excluded from the positive bene...ts (outward shift in the demand curve) of an individual ...rm's installation decision. Nonexclusivity leads to a free rider problem. Since ...rms know they

level of installation. Since industry bene...ts of emission control input installation always exceed individual bene...ts, underprovision of abatement technology will be less pronounced in the case of company codes.

The gap between the performance of company and industry codes is larger when consumers are well–informed and pollusion emissions are cumulative; incentives to adopt voluntary codes are strongest under these conditions and hence the free–rider problem will be most pronounced.

Finally, although ...rms do not explicitly collude on output choice when industry codes are adopted, one must recognize that whenever ...rms behave strategically, output and emission control input decisions are interdependent. As a result, market power is enhanced when industry codes are adopted.

4. Simulation Analysis

Simulation of the oligopoly models of company and industry voluntary codes provide important insights into the conditions under which a voluntary compliance regime is likely to be a viable alternative to a mandatory regulatory regime for protecting the environment. Closed form solutions of the oligopoly models used in the simulations are provided in the Technical Appendix. The simulations focus on the roles of three critical parameters in the model: μ (consumer knowledge), n (market structure), and $\pm$ (environmental damage). Simulation results for varying values of these parameters are presented in Tables 1–3. Each Table provides data on proportionate changes in market price (P) and industry quantity variables (output, Q, emission control input usage, E, and pollution discharges, Z) which emerge under company codes (labelled c) and industry codes (labelled J) relative to the socially optimal variables. In addition, proportionate changes in consumer surplus (CS), producer surplus (PS), environmental damages (D) and social welfare (W) relative to the social optimum are also reported for the two regimes to facilitate analysis of the distributional and e¢ciency consequences of voluntary codes.

Table 1 reports the simulation results regarding the role of consumer informa-

ronmental consequences of production, ...rm incentives to reduce pollution levels are enhanced; pollution abatement is achieved by installing increasingly higher levels of emission control inputs and reducing production levels as μ increases. Although emission control inputs are underprovided in both industry and company code regimes, higher levels are installed when ...rms coordinate; the gap between installation levels in industry and company code regimes is increasing in μ and is particularly large when the free–rider problem is signi...cant (high μ; ± and n). Output levels are also higher when ...rms coordinate on abatement technology choices. When consumers are poorly–informed, pollution levels will be excessive, particulary in competitive industries, leading to market prices which do not re‡ect the full social costs of production. However, as μ increases, higher levels of emission control input usage and output levels in highly concentrated industries can lead to a reduction in pollution below the socially optimal level. This strategic manipulation of pollution levels enhances market power, leading to high mark–up pricing. Referring back to Figure 4, recall that the socially e¢cient price is declining in μ. When μ = 0, the socially e¢cient price equals the full social marginal cost of production. As μ increases, consumers internalize an increasingly higher level of the externality in their consumption decisions and hence, the socially e¢cient price is falling. When μ = 1, the socially e¢cient price re‡ects only the marginal production cost. In contrast, in a market economy, price is an increasing function of μ. Thus, the proportionate change in price between a voluntary regime and the social optimum is increasing in μ.

Given that the adoption of pollution reduction practices is voluntary and that ...rms are pro...t–maximizers, ...rms will always gain as a result of the introduction of voluntary regimes. Producer surplus will also be higher when ...rms can coordinate and resolve the free–rider problem. We ...nd that producer gains are highest when consumers are well–informed (as market power is increasing in μ) and are particularly high in concentrated industries. Consumer surplus, on the other hand, is strictly decreasing in μ in a voluntary regime — knowledge makes consumers worse o¤; in contrast, consumer surplus evaluated at the socially e¢-cient levels of output and emission control inputs in strictly increasing in μ, that

dent on the level of consumer information. In general, environmental damages are declining as μ increases. However, damages will be excessive (and perhaps catastrophic) in competitive industries. Environmental damages will also be excessive in concentrated industries when consumers are poorly–informed. However, as consumer knowledge increases, strategic behaviour will result in substantially reduced emission levels and damage levels below the socially optimal level.

Welfare losses will always arise in voluntary regimes but are declining in μ. Welfare losses will be signi…cantly higher in company code regimes whenever the free–rider problem is signi…cant. As seen in Table 1, the magnitude of welfare losses depends upon the key parameters of the model. Welfare losses will be high in the case where consumers are poorly–informed about the environmental consequences of cumulative pollutants and in the case of a competitive industry emitting a noncumulative pollutant. Interestingly though, welfare losses are relatively small when consumers are well–informed and the industry is highly concentrated.

Table 2 reports the simulation results regarding the role of market structure, n. Simulation results are reported for four di¤erent environments: (i) consumers are well–informed about environmental consequences of cumulative pollutant (± = 4; μ = :8), (ii) consumers are poorly–informed about environmental consequences of cumulative pollutant (± = 4; μ = :2), (iii) consumers are well–informed about environmental consequences of noncumulative pollutant (± = :5; μ = :8), and (iv) consumers are poorly–informed about environmental consequences of noncumulative pollutant (± = :5; μ = :2). As the level of competitiveness in a pollution–generating industry increases, the ability of …rms to exploit consumer environmental preferences declines. As a result, the capacity of a voluntary regime to control emission quantities, a fundamental concern of environmental regulators, rapidly deteriorates. Excessive emissions lead to the highest level of damages and the highest welfare losses when pollutants are cumulative and consumers are poorly–informed. Referring to the last two columns in Table 2, it can be seen that welfare losses are not signi…cant when there is a small degree of competition (when market share ranges from 10% to 50%) in industries which emit noncumulative pollutants and in industries which adopt industry codes to limit emissions

sumers, highly competitive industry ($\mu = :8; n = 250$), (iii) poorly–informed consumers, highly concentrated industry ($\mu = :2; n = 2$), and (iv) poorly–informed consumers, highly competitive industry ($\mu = :2; n = 250$). Focussing on the last two columns of Table 3, it can be seen that voluntary regimes result in relatively small welfare losses when consumers have strong sanctioning power (high μ) and producers have strong market power (low n) for a wide range of pollutants. In contrast, voluntary regimes result in relatively large welfare losses whenever producers have weak market power; the exception is the case of strong consumer power and an extremely benign pollutant. Voluntary regimes also perform well in the case of noncumulative pollutants, weak consumer power and strong producer power.

The results of Tables 1–3 are conveniently summarized in Tables 4 and 5. Conclusions, derived from Tables 1-5, are summarized in Tables 6 and 7. Whether voluntary regimes may provide more efficient and cost–effective arrangements for protecting the environment depends upon the relative performances of voluntary and mandatory regimes. As discussed in Section 2 of the paper, there is considerable evidence that current regulatory structures are neither efficient nor cost–effective. Measures of welfare losses incurred under current regulatory structures are not available but anecdotal evidence suggests that losses may potentially be quite large. We adopt the rather arbitrary rule–of–thumb that if welfare losses under a voluntary regime are less than 12-15%, then voluntary regimes are potentially a viable alternative to mandatory regulation. Applying this rule–of–thumb to our simulation results we ...nd that there are indeed conditions under which voluntary regimes should be seriously considered as a viable alternative to mandatory regulation.

Referring to Table 6, we conclude that voluntarism or self–regulation should not generally be considered as a viable means of dealing with cumulative pollutants except in an environment where consumers are well–informed and an industry code can be successfully implemented in a highly concentrated industry. In this case only, the imperfect competition effect dominates the externality effect, leading to small welfare losses overall. However, it must be recognized that in

cept in an environment where consumers are poorly–informed and the industry is relatively competitive. When both consumers and producers are weak, voluntarism can potentially have disastrous environmental and welfare implications. Whether voluntarism may potentially dominate mandatory regulation in a competitive environment as consumers become better informed depends largely on how rapidly environmental damages escalate. If consumers are strong and producers are weak, voluntarism should be considered if and only if damages from the pollutant are rising slowly and gradually and competition is not too strong. In contrast, when producers are strong, the models analysed and simulated above predict that overall welfare losses are well–contained in voluntary regimes. Again, there are distributional and environmental consequences associated with the adoption of voluntarism. Voluntary regimes lead to a transfer of surplus away from consumers to producers. In addition, whenever there is an asymmetric distribution of power between consumers and producers, the environment loses. The environment wins only in the case of strong producers and strong consumers.

5. Conclusions

An analytical framework for assessing the e¢ciency, distributional and environmental consequences of voluntary codes is derived and presented in the paper. The analysis shows that conditions do exist under which welfare losses incurred under voluntary regimes can be relatively small. For instance, voluntary regimes may provide viable alternatives to mandatory regulation when consumers are well–informed and producers have signi…cant market power. In addition, if pollutants are of a noncumulative nature, voluntary regimes can be a viable alternative even when there is an asymmetry in producer and consumer power.

A number of important issues emerge from the foregoing analysis. When …rms have price–setting power, market incentives do exist for …rms to voluntarily reduce pollution emissions in the absence of regulatory directives. Moreover, market incentives are enhanced the better informed consumers are regarding the environmental consequences of production. We …nd that …rms will strategically exploit

A direct implication of the positive relationship between consumer knowledge and producer power is that government strategies which focus exclusively on public information provision to enhance the e￠ciency of voluntary regimes may have the unexpected and undesired e¤ect of strenthening the anti–competitive e¤ects of voluntary codes. The analysis strongly suggests that delegation of environmental regulation to the private sector should be subject to some form of government oversight. For instance, voluntary codes should be subject to vigorous scrutiny or monitoring by the government agency charged with the task of enforcing anti–trust laws since voluntary codes may have strong anti–trust implications.

The analysis also emphasizes the importance of understanding the role of market structure when deciding among alternative approaches for protecting the environment. Although the analysis presented above focusses on an oligopolistic model of industry structure, preliminary analysis of a dominant ...rm–competitive fringe market structure shows that voluntary regimes can potentially have less extreme distributional consequences when a ...rm with strong market power is subject to the pressure of a competitive fringe. The presence of the competitive fringe restricts the ability of the dominant ...rm to exploit consumers environmental preferences and hence the exercise of market power. In particular, consumers may actually gain from a transition to voluntarism. In addition, a model with entry and exit could be examined to determine whether the adoption of voluntary codes can act as a strategic barrier to entry. Thus, further analyses of alternative market structures should be undertaken to obtain additional insights into the workings of voluntary regimes.

Although the above analysis focusses on the use of voluntary codes for controlling pollution, the framework could, with the appropriate modi...cations, be used to analyse the use of voluntary codes in other areas. For instance, the analysis could be fruitfully applied to the adoption of voluntary codes in the area of industrial health and safety practices as well as industrial labour practices. The framework presented above is useful for understanding the e￠ciency and distributional consequences of voluntary codes whenever a demand externality is present, that is, whenever consumer demand is dependent upon industrial practices. In addition,

A. TECHNICAL APPENDIX

A.1. The Model

For simplicity, a general model of homogeneous ...rms will be used to introduce notation. An industrial population of n ...rms each produces a pollution–generating good q_i, where $i = 1, ..., n$ and $Q = \sum_{i=1}^{n} q_i$ is industry output. Individual producers may choose to install an emission control input e_i to reduce emission levels; for example, two possible emission control inputs can be used to reduce SO_2 emissions — scrubbers can be installed in tall stacks or low sulphur coal can be used. An individual producer's pollution emissions, $z_i = z(q_i; e_i)$, is a function of output and emission control inputs, where $z_q > 0$ and $z_e \leq 0$. Industrial emission control usage and pollution emissions are given by $E = \sum_{i=1}^{n} e_i$ and $Z = \sum_{i=1}^{n} z_i$, respectively. An individual producer's costs of production and abatement is given by $C(q_i; e_i)$, where costs are assumed to be concave in output and convex in emission control input levels. Pollution generated by the industry causes environmental damage $D(Z)$, where $D(Z)$ is assumed to be convex in Z.

A representative consumer has preferences $U(q; y; Z)$ over the pollution–generating good q, a numeraire good y, and industrial pollution Z. The consumer's utility is assumed to be concave in q and y and convex in Z. The consumer's budget constraint is given by $pq + y \cdot B$, where p is the market price of q and B is the consumer's budget. Consumer demand $q^d(p; Z)$ is implicitly de...ned by the following equation:

$$q^d(p; Z) : \frac{U_q + U_Z Z_Q}{U_y} = p \tag{A.1}$$

For simplicity, we assume that the consumer's utility is quasi–linear in $(q; Z)$ and y so that $U_y = 1$. Using the Implicit Function Theorem, we have that demand is decreasing in price and the associated pollution level, $q_p^d < 0$ and $q_Z^d < 0$. Thus, when choosing consumption levels, consumers care not only about price levels but also about the environmental impact of production of the good.

We further assume that the representative consumer's marginal disutility from

the good. If $\mu = 1$, then a consumer fully internalizes external costs associated with production when making consumption choices. If $\mu = 0$, then external costs are fully externalized in consumer choices.

The inverse aggregate demand curve $P(Q; Z(Q; E)) = f(Q) - \mu D_Z(Z) Z_Q$ can be derived from equation A.1. For notational simplicity, we will suppress the arguments of the inverse demand curve, hence $P(Q; Z) = f - \mu D_Z Z_Q$. The inverse demand curve is downward–sloping in output, $P_Q = f_Q - \mu D_{ZZ} Z_Q^2 < 0$, and increasing in the level of abatement technology, $P_E = -\mu D_{ZZ} Z_Q Z_E > 0$; note that E can be thought of as a shift parameter in the demand curve — increases in E will shift the demand curve outward.

A.2. Social Optimum

In this section, we derive the ...rst–best or social optimum as the benchmark to assess the e¢ciency, distributional and environmental consequences of a voluntary compliance regime when ...rms in an industry are homogeneous and consumers are imperfectly informed about the environmental consequences of the industry's production activities. The number of ...rms, n, is ...xed, hence there is no entry or exit into the industry; n, however, can be varied to assess the e¤ect of changes in the degree of competitiveness in the industry.

We assume that the social planner has full information about the environmental consequences of production and hence incorporates environmental damages not internalized by consumers into the planning problem, that is, $(1 - \mu) D(Z)$. The social planner will choose levels of q and e to maximize social welfare $SW(Q; E; n)$, where social welfare is the sum of gross surplus, $U(Q; Y; Z)$, where $Y = \sum_{i=1}^{n} y_i$, less uninternalized environmental damage costs and industry production and abatement costs, $C(Q; E)$:

$$\max_{q;e} SW(Q; E; n) = U(Q; Y; Z) - (1 - \mu) D(Z) - C(Q; E)$$

The social planner's decision rules for output and emission control input are

A social planner will choose individual firm output levels to equate the net social marginal benefit of output, $U_q + U_z Z_q$, to the residual social marginal cost, $(1 - \mu) D_z Z_q + C_q$; the residual social marginal cost is simply the sum of the uninternalized marginal damage cost and the marginal production cost. Similarly, a social planner will choose firm emission control input usage to equate the social marginal benefit of abatement, $U_z Z_e - (1 - \mu) D_z Z_e$, which is the value of the reduction in marginal damages as a result of abatement, to the social marginal cost of abatement C_e. Substituting $U_z Z_q = -\mu D_z Z_q$ into equations A.2 and A.3 and rearranging yields the more familiar Pareto conditions:

$$q^* : U_q = D_z Z_q + C_q$$

$$e^* : -D_z Z_e = C_e$$

Note that the Pareto optimal decision rules do not depend upon μ.

A.3. Uncoordinated Industry Equilibrium: Firm–Level or Company Codes

Individual producer profit is given by $\pi_i(q_i; e_i) = P(Q; Z)q_i - C(q_i; e_i)$, where $P(Q; Z) = f - \mu D_z Z_Q$. Following convention, we adopt the standard assumption that firms behave as Cournot–Nash competitors, that is, each producer chooses output and emission control input levels to maximize own profits, taking as given that the other producers are also choosing their best actions:

$$\max_{q_i; e_i} \pi_i(q_1; ....; q_n; e_1; ....; e_n; n) = [f - \mu D_z Z_Q] q_i - C(q_i; e_i)$$

An individual firm's decision rules are characterized by the following equations:

$$q_i^c : [f - \mu D_z Z_Q] + [f_Q - \mu D_{zz} Z_Q z_q] q_i = C_q \qquad (A.4)$$

i $\mu D_{zz} Z_Q z_e q_i > 0$, with the marginal cost, C_e. An additional unit of the emission control input shifts the demand curve out by P_e, leading to a higher output price.

Totally differentiating equations A.4 and A.5 and applying Cramer's rule, we can obtain comparative statics on individual firm output and emission input rules with respect to a competitor's output and emission control input level: $\frac{dq_i^c}{dq_j^c} < 0$, $\frac{dq_i^c}{de_j^c} > 0$, $\frac{de_i^c}{dq_j^c} < 0$, and $\frac{de_i^c}{de_j^c} > 0$.

In equilibrium, since firms are symmetric, $q_i^c = q_j^c = q^c$ and $e_i^c = e_j^c = e^c$. Substituting $q_i^c = q_j^c = q^c$ and $e_i^c = e_j^c = e^c$ into equations A.4 and A.5 yields two equations with two unknowns, $q^c(e^c)$ and $e^c(q^c)$.

A number of results are immediately apparent from equations A.4 and A.5. First, examine equation A.5: an individual firm's private incentive to undertake abatement is directly related to the level of consumer information, parameterized by μ. μ also indicates the degree of consumer sanctioning power. For instance, if consumers have no information regarding an industry's environmental performance, then $\mu = 0$ and the marginal benefit to a firm from abating pollution vanishes since price no longer varies with e. When $\mu = 0$, consumers have no effective sanctioning power and, as a result, firms do not have any incentive to adopt pollution control methods, hence $e^c = 0$. If, on the other hand, consumers do have knowledge about industrial environmental performance, then $0 < \mu \cdot 1$ and consumers can exercise their power to discipline an industry. Provided that $\mu \neq 0$, firms have an incentive to voluntarily undertake abatement efforts to reduce emission levels — the incentive is the increase in price. The price effect directly proportional and increasing in the degree of consumer information. Note that the incentive to voluntarily comply is also related to a firm's market power: if firms are price–takers, then the positive price effect is absent and the incentive to voluntarily comply is absent.

Second, abatement effort will be underprovided relative to the social optimum. The magnitude of the downward distortion in emission control input levels is directly proportional to the degree of consumer knowledge.

A third result which can be obtained from A.5 is that a free–rider problem exists in the choice of abatement efforts. Abatement efforts or emission control

industry marginal revenue.

Turning to equation A.4, we can observe that an individual producer's output level also depends upon consumer knowledge about the industry's environmental performance as well as own and competitors abatement e¤orts and competitors output levels. The direction of the distortion in output levels will largely depend upon the relative magnitudes of the externality e¤ect and the imperfect competition e¤ect. Output levels will be too high if the externality e¤ect dominates and too low if the imperfect competition e¤ect dominates.

To determine which output e¤ect dominates — the externality e¤ect or the imperfect competition e¤ect — we can determine whether prices are too low or too high relative to the socially optimal price. The imperfect competition e¤ect dominates if and only if the following inequality holds:

$$\frac{P \; ¡ \; C_q \; ¡ \; (1 \; ¡ \; \mu) \, D_Z Z_Q}{P} > 0 \qquad (A.6)$$

Equation A.6 will be satis…ed whenever the following condition is met:

$$\frac{s}{j"j} > \frac{1 \; ¡ \; \mu}{\mu} \left[\frac{f(Q)}{P} \; ¡ \; 1 \right]^{\#} \qquad (A.7)$$

The left–hand side of equation A.7 measures the degree of market power. Equation A.7 is more likely to hold when μ is large and n is small.

A.4. Coordinated Industry Equilibrium

Industries have the legal option of coordinating on pollution control e¤orts. Although …rms cannot explicitly collude on output levels without violating anti–trust laws, they can coordinate on pollution levels by cooperatively choosing abatement technologies. The irony is clear — choice of an industry code results in price collusion since the industry association e¤ectively holds price–setting power. Accordingly, we model a coordinated industry equilibrium as a two–stage game. In the …rst stage of the game, an industry association chooses a level of emission control

Second, the sequential moves of the industry association and ...rms introduces the ability of the industry association to commit to a voluntary code. We adopt the equilibrium concept of subgame perfection and hence, solve the game backwards.

In the second stage of the game, an individual producer chooses an output level to maximize own pro...ts, taking the voluntary code as ...xed:

$$\max_{q_i} \frac{1}{4}_i(q_1; ....; q_n; e; n) = f\left(\sum_{i=1}^{n} q_i\right) \, \mu D_z \left(\sum_{i=1}^{n} z_i(q_i; e)\right) Z_Q \, q_i \, C(q_i; e)$$

An individual ...rm's output decision rule is characterized by the following equation:

$$\frac{@\frac{1}{4}_i}{@q_i} = [f \, \mu D_z Z_Q] + [f_Q \, \mu D_{zz} Z_Q z_q] q_i \, C_q = 0 \qquad (A.8)$$

Equation A.8 implicitly de...nes an individual producer's output level as a function of competitors output levels, q_j^J, where $j \neq i$, and the industry voluntary code, e. Applying the Implicit Function Theorem, it is easy to show that $\frac{dq_i^J}{dq_j^J} < 0$ and $\frac{dq_i^J}{de} > 0$. Given ...rm symmetry, $q_i^J = q_j^J = q^J$, we can write an individual producer's output rule or voluntary code response function as $q^J = q^J(e)$.

In the ...rst stage of the game, the industry association chooses an emission control input level, e, to maximize industry pro...ts subject to ...rms' voluntary code response function $q^J = q^J(e)$. Clearly, the ability to choose and commit to a voluntary code e¤ectively gives an industry association price–setting power. The industry association's decision problem can be written as:

$$\max_{e} \, | = n\frac{1}{4} = n \left[f(nq^J(e)) \, \mu D_z \left(nz(q^J(e); e) \right) Z_Q \, q^J(e) \, C(q^J(e); e) \right]$$

The industry association's decision rule is characterized by the following equation:

$$\frac{@ \, |}{\ } \left[@\frac{1}{4} \, dq^J \quad @\frac{1}{4} \right] \qquad (A.9)$$

Substituting for $\frac{\partial \frac{1}{4}}{\partial e}$ yields:

$$e^J: \left[(f_Q - \mu D_{zz} Z_Q z_q) \frac{(n-1)}{n} \frac{dq^J}{de} - \mu D_{zz} Z_Q z_e \right] Q^J = C_e \qquad (A.11)$$

Two key results emerge from equation A.11: the industry association resolves the free–rider problem and takes into account the strategic costs associated with the indirect e¤ect on industry output. Comparing A.11 and A.5, it is immediately apparent that an industry association can resolve the free–rider problem: an industry association recognizes the public good nature of abatement e¤orts and chooses a voluntary code which internalizes the direct marginal bene...ts to the industry of each ...rm's abatement e¤orts, that is, the increase in industry marginal revenue due to higher demand for environmentally friendly products, $- \mu D_{zz} Z_Q z_e Q^J$; the direct marginal bene...t is due to the demand externality — increasing the voluntary code results in an outward shift in the demand curve. The industry also takes into account the indirect output e¤ect on industry marginal revenue, $(f_Q - \mu D_{zz} Z_Q z_q) \frac{(n-1)}{n} \frac{dq^J}{de} Q^J$; the indirect output e¤ect is a cost associated with increasing the level of a voluntary code — an additional cost of increasing e is the loss in marginal revenue due to movement down the demand curve.

For any given level of output q, an industry association will choose a higher level of emission control input usage, that is, $e^J(q) > e^c(q)$; the proof is provided in the Appendix. In addition, since $\frac{dq}{de} > 0$, it follows that $q \left(e^J \right) > q \left(e^c \right)$.

As in the uncoordinated case, the degree of consumer knowledge a¤ects the industry association's incentive to adopt a voluntary code. In the absence of consumer knowledge, no industry level voluntary code will be adopted and environmental damage will be excessive, resulting in welfare losses. Introducing the endogenous feedback e¤ect on consumer demand for the industry's products, stemming from consumer concerns about the industry's polluting activities provides the industry with an incentive to adopt a voluntary code. A voluntary code can inspire consumer con...dence, e¤ectively shifting consumer demand upwards. The stronger the consumer feedback e¤ect, the greater will be the impact on the

A.5. Simulation Analysis

Speci...cation of functional forms which satisfy the assumptions of the model enable us to ...nd closed form solutions for the three regimes characterized above. We specify a linear–quadratic model with the following functional forms: $f(Q) = A - \beta Q$, $D(Z) = \frac{1}{2}Z^2$, $z = q - \gamma e$, $C(q;e) = F + bq + \frac{k}{2}e^2$. In order to satisfy the Second Law of Thermodynamics, we make the following parameter assumption[10]:

$$\gamma < \sqrt{\frac{k}{\mu\delta}}$$

The solutions are presented in the table below.

variables	Social Optimum	Uncoordinated	Coordinated
q	$(k + n\delta\gamma^2)\frac{(A-b)}{F}$	$k\frac{(A-b)}{G}$	$k(1+n)\frac{(A-b)}{H}$
e	$n\delta\gamma\frac{(A-b)}{F}$	$\mu\delta\gamma\frac{(A-b)}{G}$	$2n\mu\delta\gamma\frac{(A-b)}{H}$
z	$k\frac{(A-b)}{F}$	$(k - \mu\delta\gamma^2)\frac{(A-b)}{G}$	$(k(1+n) - 2n\mu\delta\gamma^2)\frac{(A-b)}{H}$

where $F = n[k(\beta + \delta) + \beta n\gamma^2]$, $G = k(1 + n)(\beta + \mu\delta) - n(\mu\delta\gamma)^2$, and $H = k(1 + n)^2(\beta + \mu\delta) - 2(n\mu\delta\gamma)^2$.

The signs on the comparative statics for the variables in the three regimes are identical except for the changes in socially optimal variables with respect to μ — since they are independent of μ.

Parameters	Comparative Statics
Demand	$\frac{dq}{dA}, \frac{de}{dA}, \frac{dz}{dA} > 0$; $\frac{dq}{d\beta}, \frac{de}{d\beta}, \frac{dz}{d\beta} < 0$:
Cost	$\frac{dq}{db}, \frac{de}{db}, \frac{dz}{db} < 0$; $\frac{dq}{dk}, \frac{de}{dk} < 0$; $\frac{dz}{dk} > 0$:
Environmental	$\frac{dq}{d\delta}, \frac{dz}{d\delta} < 0$; $\frac{de}{d\delta} > 0$; $\frac{dq}{d\gamma}, \frac{de}{d\gamma} > 0$; $\frac{dz}{d\gamma} < 0$:
Consumer knowledge	$\frac{dq}{d\mu}, \frac{dz}{d\mu} < 0$; $\frac{de}{d\mu} > 0$:
Market structure	$\frac{dq}{dn}, \frac{de}{dn}, \frac{dz}{dn} < 0$; $\frac{dQ}{dn}, \frac{dE}{dn}, \frac{dZ}{dn} > 0$: