Environmental Regulation in the Presence of Environmentally Conscious Consumers

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Thesis submitted to the Indian Statistical Institute
in partial fulfilment of the requirements
for
the award of
DOCTOR OF PHILOSOPHY

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SUBMITTED IN OCTOBER 2001

Revised in September 2002

To

Sanjeev, Shray and Shubh

Acknowledgements

I would like to thank Prof. Shubhashis Gangopadhyay, my supervisor, for his constant guidance, encouragement, invaluable comments and suggestions. His positive attitude and cheerful nature made thesis writing a wonderful experience for me.

I express my thanks to the faculty at the Indian Statistical Institute, Delhi Centre. The course work was very well designed and it was a pleasure attending these courses. The entire faculty has been extremely helpful, supportive and encouraging. I owe special thanks to Prof. Parkash Chander, Prof. Satya P. Das, Prof. Dipankar Dasgupta, Prof. Bhaskar Dutta, Prof. Bharat Ramaswami, Prof. Arunava Sen, Prof. Arijit Sen, Prof. Arup K.Pal for extending their co-operation and sparing their valuable time. I sincerely appreciate the co-operation extended by the library, the computer centre and the Planning Unit office at ISI, Delhi Centre.

I benefited immensely from many discussions and valuable comments from Prof. V. Bhaskar, Prof. Sjak Smulders, Prof. David Simpson, Prof. M. N. Murty and Prof. Gautam Gupta.

My husband Sanjeev's support has been truly wonderful. My children Shray and Shubh had to bear with my long working hours and preoccupation in the research work.

My father's ambitions for me have been a constant source of inspiration. My mother's unbound and unconditional love takes away the fear of failure. My younger sister's confidence in me boosts up my spirits.

I take this opportunity to express my gratitude to my parents-in-law, who have always supported my endeavors and showered their blessings on me. It is sad that my father-in-law is not there any more to share this moment of happiness with me.

I gratefully acknowledge the study leave granted by Maitreyi College, Delhi University.

Sangeeta Bansal
October 30, 2001

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Chapter 1

Introduction

1.1 The Problem and Literature Review

There is a growing concern for the environmental degradation caused by various economic activities. Clean environment, once regarded as a free good, has now become a scarce resource due to cumulative accumulation of pollution over the years. Being a public good, it may not be possible to assign clear property rights to environment. Hence, even though it has become a scarce resource, economic agents continue to regard it as a free good and tend to ignore the harmful effects of their activities on the environment. This causes a distortion between the market and socially optimal levels. In other words, a negative (environmental) externality is generated. Extensive work has been done to find measures to correct this distortion.

Various measures suggested to correct for the negative externality caused by the generation of pollution can broadly be classified as: command and control (CAC) measures and market based (MB) measures. The various CAC measures are bans, prohibitions, quantity restrictions, emission standards, fines, penalties and threats of legal action against non-complying firms. Here the regulator specifies the requirements the firms have to comply with, failing which, they have to pay fines and penalties. The cost of compliance of these instruments is sometimes very high and, often, it is difficult to enforce them. Therefore, the focus has shifted to the use of MB instruments. They provide economic incentives to the firms to control pollution or adopt cleaner production technologies.

The MB instruments include all forms of taxes/subsidies and tradeable permits. Even among the MB methods, the consensus has not been reached as to the appropriate environment policy. However, emission taxes have emerged as one of the most important instrument in correcting environmental externalities. Apart from the efficiency criterion, there are various political economy issues related to the choice of instruments for environmental regulation. One such issue is, who should bear the cost of cleaning up the environment. Imposition of a tax on firms forces them to bear the cleanup cost, whereas provision of a subsidy may force the consumers to bear the cost of cleanup (depending upon how the subsidies are financed). A brief overview of the literature on corrective measures suggested for the environmental regulation is given below.

Pigou (1920) suggested that a tax or a charge be imposed on the polluter, which is equal to the marginal social damage of pollution, or the (external) costs that are caused by the polluting activity. Such taxes are referred to as Pigouvian (emission) taxes. The tax internalizes the externality completely and under perfectly competitive market conditions, achieves Pareto optimality (Baumol and Oates, 1988). Emission taxes are consistent with the "polluter pays" principle. Under this principle, a polluter has the responsibility of cleaning the pollution.

An alternative approach, which has been suggested in the literature, is the use of emission trading permits (Dales, 1968). Under this approach, permits, equivalent to the targeted level of emissions, are allocated to individual producers. This allocation may either be done in relation to an existing level of activity, referred to as grand fathering or, permits may be auctioned to the highest bidder. These permits are transferable. Firms with low cost of abatement would choose to sell the permits, whereas the ones with high cost of abatement would choose to buy the permits. This way, the total cost of pollution abatement would be minimized. Under perfect competition, tradeable permits achieve the targeted level of pollution at the least cost. Under full information and perfectly competitive conditions, the two instruments discussed above, viz., emission tax and tradeable permit result in the same outcome and achieve Pareto optimality. However the use of tradeable permits is efficient only if the transactions costs are low.

Various papers have compared the implications of different policy instruments on firms' incentives to promote technological change. Milliman and Prince (1989) rank in relative terms, firms' incentive to promote technological change across five policy instruments: direct controls, emission subsidies, emission taxes, free marketable permits and auctioned marketable permits. They break the process of technological change into three basic steps: development of new abatement technology (innovation), its adoption (diffusion) and response of regulatory authorities to readjust regulation after the market penetration of new technology. Innovations lower marginal abatement costs. If losses from diffusion and control adjustment are small then innovation efforts would proceed. On the other hand, innovation activities would be discouraged if the firm believes that these losses would be substantial. They find that emission taxes and auctioned permits are the most effective policy instruments to promote emission control, since they generate additional returns beyond the initial stage of innovation. Jung, Krutilla and Boyd (1996) extend Milliman and Prince comparative approach from the firm to the industry level. Their rankings are generally consistent with the firm level findings of Milliman and Prince. Thus emission taxes and tradeable emission permits are found to be efficient instruments under perfectly competitive markets.

Modern industrial markets, however, are often more realistically described as oligopolistic markets. Market imperfections add another source of distortion and therefore, following the theory of the second-best, the same instruments may no longer be efficient. It has been shown that the socially optimal degree of internalization depends on the market structure; under perfect competition, the desired internalization is complete, while under imperfectly competitive conditions, optimal taxes deviate from external damages. Buchanan (1969) noticed this for the case of monopoly. Under monopoly, complete internalization of external damages will impose additional social cost by further restricting the already suboptimal output. Thus, the optimal effluent fee will be less than the marginal external damages

(Barnett, 1980; Misiolek, 1980).

Katsoulacos and Xepapadaes (1996) examine optimal emission taxes under market oligopoly. For oligopolistic market with a fixed number of firms, their results are similar to the case of monopoly, i.e., the optimal tax is less than the marginal damage. However when the number of firms is endogenous, the optimal emission tax could well exceed marginal external damage. This would happen if in the absence of taxes, the equilibrium number of firms is above the social optimum. The emission tax reduces this distortion and therefore, exceeds marginal damage.

Similarly the papers examining the efficiency of tradeable permits in imperfectly competitive market structures find that these may not be efficient instruments. Malueg (1990) analyzes an oligopolistic goods market in combination with a perfectly competitive permits market. Trading emission permits is characterized as lowering marginal costs of production. He shows that uneven cost reductions may shift production from low cost to high cost firms which may be detrimental for industry profits and therefore for welfare. Fershtman and Zeeuw (1996) consider a structure in which both the product market and the pollution permits market are oligopolistic and the same set of firms operates in both markets. The paper shows that allowing trade in emission permits is not necessarily beneficial as it may lead to the choice of inferior production and abatement technologies. Permits may serve as a precommitment device through which the firms maximize joint profits and reach a market equilibrium with lower output and higher prices. In an empirical study, Gangadharan (1998) finds that the high transaction costs of trading permits may inhibit the participation of firms, reducing the number of transactions and thus hampering the efficiency of the market in permits.

Carraro and Soubeyran (1996) compare environmental taxes with innovation subsidies. They recommend that the government should favor the availability of the cleaner technology on a large scale through promoting R&D and diffusion. Such policy would create conditions under which innovation subsidy is the optimal policy instrument as lower emissions are achieved without reducing output and consumer surplus. However, if the above policy is not feasible, then environmental tax might be the appropriate policy. The tax reduces emissions through three channels: technological change, output contraction and reduced capacity utilization of more polluting plants. Stranlund (1997) examines, how the provision of technological aid to encourage the adoption of superior emission control technology reduces the direct enforcement effort necessary to reach the compliance goal. Technological aid is modeled as a cost-reducing, public input into the production of environmental quality. He finds that more aid should be provided when direct enforcement effort is expensive. Thus when monitoring is difficult because sources of pollution are widely dispersed, regulators should consider substituting technological aid for direct enforcement. The results of Baumol and Oates (1988) indicate that the use of subsidy is inefficient under perfectly competitive markets. Since subsidy increases profits, it affects the entry-exit decision of firms; encouraging larger number of firms to enter the industry and thus, results in higher industrial output of the polluting product.

As an alternative to the above-mentioned instruments, there has been an interest in the use of voluntary agreements between the regulators and polluters to reduce pollution. Miceli and Segerson (1998) examine conditions under which a voluntary agreement leads to an efficient environmental protection. The polluters are induced to participate either by a threat of mandatory controls or by cost sharing subsidies. The level of abatement undertaken is high if the regulator has substantial bargaining power. However, if the firms have the bargaining power, then the level of abatement would be low and can be increased by offering a cost-sharing subsidy.

Another strand of the literature explores the interaction between the environment policy and other distortionary taxes existing in the economy. Environmental levies could help reduce distortionary taxation and thus generate a double dividend. Parry, Williams and Goulder (1999) assess the welfare effects of a revenue-neutral carbon tax and carbon emission permits, taking into account pre-existing tax distortions in factor markets. A tax policy is found to be superior to a permit policy as revenues generated through former can be used to reduce the existing distortions. Sen and Smulders (2000) lay down conditions under which a switch from trade tariffs to environmental taxes can yield an increase in real income thus providing a second dividend in addition to the environmental improvement.

An announcement by Porter (1991) that tougher environmental regulation can lead to improved competitiveness of firms and hence, their profitability, triggered a debate on the impact of environmental regulation on the competitiveness of industry. In Porter's view, the compliance costs of environmental regulation are partially or more than fully offset by the gains that accrue due to regulation. Porter and van der Linde (1995) argue that a stricter regulation spurs innovation, which often improves either product performance or the production process.

In the context of strategic trade models, it has been argued that governments have an incentive to relax environmental standards to increase the competitiveness of domestic firms and hence shift profits from foreign to domestic firms (Rauscher, 1994; Ulph, 1996). Barrett (1994) shows that whether governments have incentives to impose strong or weak environmental standards depend upon the form of competition (price versus quantity) and market structure. Simpson and Bradford (1996) investigate whether tougher environmental policies might be effective in motivating investment in cost-reducing innovation and actually increase domestic industrial advantage. They show that the argument may have a theoretical possibility but not a general validity.

The Porter hypothesis has been criticized on the ground that if such opportunities for increased profitability exist, the firms on their own (without any regulation) will exploit them. The economists have expressed concern over the costs associated with environmental regulation. Oates, Palmer and Portney (1995) emphasize the significance of a cost-benefit analysis, while evaluating any environmental program.

Xepapadaes and de Zeeuw (1998) have tried to reconcile the arguments on both sides of the debate. They consider a model in which firms can invest in newer machines that are more productive and cleaner, but also more expensive than older machines. They show that stricter environmental policy is accompanied by a modernizing effect, which results in increasing the average productivity of the capital stock. Modernization of capital stock partially offsets the compliance costs. Thus with a stricter regulation, emissions are reduced with a small adverse effect on profitability.

The papers discussed above assume perfect information. However, the regulatory authority may not be able to observe either the damage resulting from pollution or the costs of reducing pollution. The papers dealing with asymmetry of information in the context of environment include Roberts and Spence (1976), Kwerel (1977) and Dasgupta, Hammond and Maskin (1980). The first two papers argue that when the regulators are uncertain about firms' cleanup costs, a mixed system of regulation involving effluent charges and marketable licenses is preferable to either effluent fees or licenses used separately.

Roberts and Spence (1976) suggest that the government chooses a mixed pollution control plan, which minimizes the expected total costs of pollution. Effluent charges (when used alone) bring about too little cleanup when cleanup costs turn out to be higher than expected, and they induce excessive cleanup when the cleanup costs turn out to be low. Licenses have the opposite effect. Since the level of cleanup is predetermined, it will be too high when cleanup costs are high and too low when costs are low. Licenses and effluent charges when used together protect against the failings of each other. Licenses can be used to guard against extremely high levels of pollution while, simultaneously, effluent charges can provide a residual incentive to cleanup more than the licenses required, in case costs are low.

Kwerel (1977) proposes a method of inducing firms to reveal their true cleanup cost function to the regulator. He argues that under a pure licensing system, firms have an incentive to exaggerate their cost of cleanup, so that a large number of licenses are issued and the price of a license is brought down. Under the pure effluent charge system, firms have an incentive to understate cleanup costs to minimize the charge. A mixed pollution control plan exactly balances the incentive to overstate costs under licensing with the incentive to understate costs under effluent charges, so that firms are induced to make socially optimal reports to the regulator. Dasgupta *et al.* places some of the earlier work in a more general perspective.

The issue of commitment and time-inconsistency of economic decisions has also been addressed in the context of environmental regulation (Yao, 1988; Biglaiser, Horowitz and Quiggin, 1995; Gersbach and Glazer, 1999; and Marsiliani and Renstrom, 2000). A government policy is dynamically inconsistent when, although being optimal at the outset, it is no longer optimal at a later date. This means that the government has no incentive to be committed to its original plans. Yao analyzes the dynamic interactions between the regulator and industry in the context of standard setting regulation, given technological uncertainty and private information. The information asymmetry about innovation capability of the industry creates incentives for underinvestment in research for all industry types. However, the degree to which industry reduces its investment in order to decrease future expected costs depends on the innovation capability of the industry. Initial period investment increases expected future costs for low-capability type more than it does for higher capability type. Thus the initial level of R&D activity caused by regulation increases with the intrinsic technical capability of industry. Biglaiser *et al.* address the time inconsistency of optimal permit regulation. They show that tradeable pollution permits may not achieve the social optimum because firms behave strategically against the regulator. Gersbach and Glazer examine the issue of hold-up problems in a situation where firms potentially subject to regulation may behave strategically by not investing in equipment that reduces cost of compliance, thereby forcing the regulator to abandon the proposed regulation. They assume that the regulator is unable to commit to the stringency of emission tax and can commit to issue marketable permits. They argue that emission taxes are less suitable to solve the hold-up problem as investing firms only save part of the emission tax, and are not compensated for their investment. Under permits market, however, investing firms may gain from selling pollution permits to firms that did not invest. Thus, while an emission tax cannot overcome the hold-up problem, issuance of tradeable permits overcomes it. Marsiliani and Renstrom present an economy in which government policy of environmental tax is dynamically inconsistent. In such a situation, they show that dedicating specific revenues to the financing of specific public services can act as a commitment mechanism and thus partially solves the time-inconsistency problem.

A common feature, in the analysis of policy measures advocated for correcting the distortion, is the implicit assumption that consumers are either unwilling or unable to take into account the negative externality caused by the production process. A large part of the early environment literature disregards the fact that consumers often perceive the environmental attribute of the product as any other quality attribute. In recent years there has been an increasing evidence of the emergence of *environmentally discerning* consumers. those who feel responsible towards preserving the environment. These consumers not only have a concern for the environment, but also are willing to pay a higher price for the environmentally cleaner products. This is evident in the upsurge of eco-labeling of the products. A label *Green*, indicating that these are eco-friendly products, differentiates products that are otherwise homogenous. Other examples include voluntary participation by the firms in 33/50 Program launched in 1991 by EPA in the US (Arora, 1993; Arora and Cason, 1995). Khanna and Damon (1999) find that public recognition and technical assistance motivated the participation decision of firms. The program resulted in significantly reducing the release of toxic chemical substances.

The phenomenon is more prevalent in the rich countries of Europe and America. However as the per capita incomes rise in the Third world countries, we find an increase in the number of environmentally responsible consumers. This can be explained by the fact that though consumers have a preference for environmentally cleaner products, their choice may be restricted by their affordability, which is determined by their income levels. The view that awareness is high at higher levels of income is supported by the inverted U-shaped or the inverse relationship found between output and environmental deterioration. Grossman and Krugman (1995) argue that economic growth improves the environment quality after a turning point in per capita income has been reached. As nations experience increased economic prosperity, the society has a greater willingness to bear the costs of environmental protection, and hence, citizens demand a cleaner environment from political leaders.

The recent success of the labeling system called PROPER (Program for Pollution Control and Evaluation and Rating) in Indonesia further strengthens the contention that consumers play an important role in inducing firms to reduce their pollution. Under this program, the local environmental agency, BAPEDAL chose to publicly disclose the pollution status of firms by labeling them as Black, Red, Blue or Green. In the first eighteen months itself, effluents were reduced by 40 percent by the firms to avoid being rated as Black or Red (Afsah *et al.*, 1997.)

The assumption of naive consumers undermines the role played by consumer movements or the awareness campaigns carried out by environmental non-governmental organizations. Such an assumption fails to explain phenomena like the boycott by consumer groups of polluting products or that of the environmental performance criterion becoming a strong element in the marketing strategies of firms. Though there is ample empirical evidence of the environmentally conscious consumers, few theoretical papers have incorporated such consumer behavior (Arora and Gangopadhyay, 1995; Cremer and Thisse, 1999). The question then arises: Is there still a role for government intervention? Does consumer concern for the environment result in socially optimal provision of environment quality and the government has no need to regulate polluting firms? Using a vertically differentiated product model, Arora and Gangopadhyay examine the effect of imposing environmental standards on firms competing in a duopoly. In equilibrium, the firms differentiate their products with one firm having a higher level of cleanup than that of the required minimum standard. This firm, therefore, over-complies. Cremer and Thisse (1999) examine a similar research question in a model where cleanup costs increase with the volume of output. They allow for the market structure to change in response to a policy variable. They argue that a well designed commodity tax may reduce the distortion caused by oligopolistic markets, through increasing the number of operating firms and thus, may be welfare improving.

The central objective of this thesis is to study the effects of various types of environmental regulation in an economy where consumers are environmentally conscious. Today consumers differentiate between products on the basis of their impact on the environment, either during production process or through their use, having a preference for environmentally cleaner products. I term this preference for environment-friendly products as *environmental con-*

sciousness. Environmental consciousness translates itself into a higher willingness to pay for the good, which is less polluting.

A possible explanation for such consumer behavior is that consumers treat environment-friendliness as a quality attribute of the product they buy. In other words, consuming a variant with a high environmental quality is in itself gratifying. An individual consumer realizes that her own impact on the overall environment is negligible and benefits of clean environment would accrue to the entire society, but from her perspective what matters is the environment quality of the product she is buying. This quality contributes to her utility like any other quality attribute does. This is because, if a consumer buys an environment-friendly good, she produces a positive externality and helps preserving the environment. This may give her a feeling of satisfaction. This could arise out of a concern for environment or a feeling of "guilt" in supporting the production of environmentally damaging good.

Another reason for consumers preferring the cleaner product could be that the dirty variant, apart from causing degradation to the environment, also generates pollution during its use. This may have direct harmful effect for the user. For example, the use of firewood or kerosene as a fuel has a direct health hazard for the user and also pollutes the atmosphere.

An alternative justification for consumers' willingness to pay more for less polluting goods could be based on social interaction among consumers. In a society in which there is social awareness, there is social pressure to consume environment-friendly products. This social pressure may have different forms. One is simply the appreciation of people that consume such environment friendly goods and a possible social condemnation of people that do not. Another possibility is that the social pressure translates into an inner conviction that people should behave in such a way. This social pressure may be an endogenous pressure. That is, in a society in which there are more people that follow the norm of consuming an environment-friendly good, the social pressure is greater while in a society in which there are less followers of such a norm, the social pressure is less. Different countries may have different norms.

The first three essays of my work assume full information and focus on the effects of various government measures on environment as well as welfare. The analysis uses a variant of the well-known model by Mussa and Rosen (1978).[1] The fourth essay allows for asymmetric information between the regulator and the polluting agent. It focuses on the effect of environmental regulation on the incentives of firms to invest in research and development (R&D) to develop cheaper cleaning technologies, in a scenario, where the regulator cannot observe this effort.

I am considering a general class of products. These products have two attributes — a physical attribute and an environmental impact. The environmental impact has a direct effect and an indirect effect. The former is specific to the consumer and represents the disutility from pollution associated with the agent's own consumption of the good. It can take the form of a health hazard, safety risks, or a feeling of "guilt" in supporting the production of environmentally or socially damaging good or an individual concern for the degradation in the environment. The latter is the usual negative (environmental) externality associated with the product and is uniformly suffered by all agents — consumers as well as non-consumers. It can take the form of atmospheric pollution, depletion of natural resources, etc. While making their choices, the agents take into account the direct effect; however the indirect effect is treated as outside their control. An important aspect of the model is that there is a positive correlation between the direct and the indirect environmental attribute: consumer preferences create a market for clean goods, induce firms to clean up, and thus reduce the pollution externality. Apart from environmental regulation, the results of this research can also be useful for formulating policies for health or safety. For instance, refer to the example of the use of firewood or kerosene as a fuel. Alternatively, any laxity in the safety standards in a car has a direct effect on the automobile user, as well as, an indirect effect on other persons using the road.

I now give a brief discussion of each of the following chapters in my thesis.

[1]Other contributions to the literature using this framework are Gabszewicz and Thisse (1979), Shaked and Sutton (1982), Itoh (1983), Arora and Gangopadhyay (1995) and Cremer and Thisse (1999).

1.2 Chapter 2: Welfare Implications of Commodity Tax/Subsidy Policies

This essay examines the effect of government intervention in the form of commodity taxes, or subsidies, on the average environmental quality and the overall welfare. Consumers consider the environment attribute of the product as any other quality attribute and are willing to pay a higher price for the product variant produced with the environmentally superior production process. However, their income levels limit their actual choice of the product variant. The commodity tax typically requires less information than other instruments like emission standards and emission taxes. A commodity tax requires information on *prices* and *quantities*, both variables can be considered as observable and verifiable, on the other hand, verification of emission levels is likely to be very costly (Cremer and Thisse, 1999). Indeed, in a subsequent chapter, I demonstrate conditions under which a commodity tax dominates an emission tax.

The model formulation is similar to Arora and Gangopadhyay (1995). Using a vertically differentiated product model, they examine the effect of imposing environmental standards on firms competing in a duopoly. In equilibrium, the firms differentiate their products with one firm having a higher level of cleanup than that of the required minimum standard. This firm, therefore, over-complies. The focus in their paper is on cleanup levels and not on welfare or total pollution. I extend their analysis by incorporating the negative externality caused by the production process and examining the welfare implications of various government policies.

Consumers have quasi-linear preferences and derive utility from a polluting product and the composite good money. The polluting product has two attributes. Its use in consumption increases welfare, while the pollution generated in its production process reduces welfare. Consumers are environment conscious and, hence, are willing to pay more for products produced with cleaner technologies. All consumers have identical tastes and preferences but different incomes. The income level of the consumer determines the willingness to pay for superior environmental practices.

Firms play a two stage Nash game. They choose cleanup levels in the first stage and compete in prices in the second stage. The costs of improving the environment involve the use of production processes that produce less pollution. They are one-time costs incurred prior to the commencement of the production process. In this chapter, the cost of cleaning the environment is independent of the quantity of the product produced. For the main results of the chapter, I have the usual assumption of increasing and convex costs. A specific functional form for the cost function has been used, later in the chapter, for some particular results.

I solve for the market equilibrium with two firms. I show that it is never optimal for the firms to serve the entire market, if both have positive levels of cleanup. I term this, a partially covered market solution and then, the equilibrium can sustain both firms producing different variants of the product. In this case, a policy not only affects individual firm behavior but also alters the size of the market being covered.

I proceed to study government intervention. In the literature, the considered policy is usually imposed uniformly on all producers. Thus, for a tax policy, all producers face the same tax rates. However, when products are vertically differentiated, it has the unfortunate implication that a producer who is more environmentally friendly faces the same tax rate as the less friendly producer. In fact, if the tax is a commodity tax, the tax paid per unit of production, as well as tax paid per unit of pollution generated, is higher for the environmentally friendlier producer. Not surprisingly, such policies often face opposition among (the environmentally friendlier) producers. This motivates me to study the implications of discrimination between the firms on the basis of their environmental performance. In particular, I focus on policies that discriminate between the firms: (a) by rewarding the better quality firm, through a direct or an indirect subsidy, and (b) punishing the worse quality firm by making it pay a tax. I consider them as separate policy options. Observe that, in both cases, there is discrimination among the 'good' and 'bad' producers — good producer getting the subsidy and bad producer paying the tax.

I show that average cleanup levels rise with a policy that rewards a good producer and fall with a policy that punishes a bad producer. This is because, an output tax or a subsidy affects the marginal benefit of cleaning effort and hence the relationship between marginal revenue and marginal cost. The level of cleanup is determined at the margin by equating the benefit of cleanup with its cost. A tax reduces the marginal benefit of cleanup to the firm. With increasing marginal cleanup costs, a tax on the worse quality firm, therefore, reduces its net cleanup. Since (it can be shown that) the choices of cleanup levels by the two firms are strategic complements, this reduces the cleanup level of both firms. For a subsidy to the higher quality firm, the effects work in the opposite direction (encouraging a higher level of cleanup through increasing the marginal benefit to the producer). I consider the two policies separately to highlight the mechanism through which each of the regulatory instruments works.

In both cases, however, the price and quantity sold of each variant changes. I show that the changed price-quality pairs are such that the total demand falls with a subsidy rewarding the better firm only, as well as a tax on the worse quality firm only. Observe that cleanup levels are rising in the case of a subsidy and falling in the case of a tax, and demand is falling in both the cases. Thus total pollution clearly falls in the case of a subsidy while, it may rise or fall in the case of a tax.

As expected, a discriminatory tax policy reduces the profit of the dirty firm and increases profit of the cleaner firm. But surprisingly, a discriminatory subsidy policy unambiguously increases the profit of the dirtier firm and has an ambiguous effect on the profit of the cleaner firm. This is interesting because even if the dirty firm does not get any direct support in the form of subsidies, it is able to extract it partly due to price competition. I further show that the changed price-quality pairs are such that the consumer surplus rises with a discriminatory subsidy policy and falls with a discriminatory tax policy.

Since there is a positive correlation between the direct and indirect environmental attribute, ceteris paribus, any policy that induces firms to increase their cleanup levels has a welfare improving effect. Such a policy will make an individual consumer (buying the product) better off. However, consumers who were not buying the product before, may be induced to do so at higher qualities. This may increase the total quantity produced. Thus, while the pollution per unit of output falls total pollution can still go up if the volume of production rises. There are two opposite effects on welfare. It may increase as more consumers are able to afford the product, but at the same time, it may reduce if there is larger quantity of the polluting products. It is, therefore, important to examine the net effect of a policy on welfare.

I now arrive at the central result of this essay. Contrary to the importance that has been assigned to the role of taxes in the environment policy, I find that imposition of an output tax on polluting firms may not only increase total pollution but also reduce aggregate welfare. On the other hand, provision of an output subsidy unambiguously reduces total pollution and improves aggregate welfare. Moreover, using a specific cost function, I also show that at small levels of tax, or subsidy, rewarding the better quality firm with a subsidy dominates the option of punishing the dirtier firm with a tax.

A concern associated with advocating subsidies is that their implementation requires resources. I show that a balanced budget subsidy also improves the aggregate welfare. It is a win-win situation as it results in mitigating total pollution, improving the consumer surplus and aggregate welfare, without exerting any strain on the government budget.

1.3 Chapter 3: Market versus Socially Optimal Provision of Environmental Quality: Policy Alternatives

The second essay generalizes the above cost assumption by assuming that the cost of cleaning increases with the number of units produced. That is, environmental costs are modeled as variable cost. The rest of the model structure is the same as in the previous chapter. A major advantage of this extension is that it is now possible to consider the case where the entire market is served (fully covered, instead of being partially covered) by the two firms, in equilibrium. An additional exercise carried out here is through varying the intensity of the external damage (or negative externality) caused by pollution. I examine the effects of various government policies on environment and welfare. Specifically, I compare commodity tax, commodity subsidy, emission tax and specific tax. I also discuss the political economy issues associated with each instrument.

In general, it is socially optimal to produce two qualities. However, for a sufficiently large pollution damage parameter, only one quality is provided in the optimum. This can be explained by noting that the costs of cleaning are increasing with the number of units produced. When a unit of production is shifted from a high to low quality, there is a trade-off between the loss in utility, and the savings in cost.

I explicitly derive the conditions under which the market is fully covered and consider situations, which were not possible in the previous chapter. I make fully covered markets the focus of my analysis in the rest of this chapter. This exercise is relevant for the study of polluting commodities, like fuel, which are essential for any household, regardless of their income levels. To get sharp results, I use a specific cost function. This makes it possible to compare not only the direction, but also the magnitude of the effect of various policy instruments.

Other things being equal, consumers prefer clean goods to polluting goods, and thus internalize a part of the pollution externality. As a result firms gain market share by investing in cleaner activities. Moreover by providing a good that is cleaner than that of its rival, a firm can strengthen its market position. Hence, cleaning up becomes a strategic variable and a firm may cleanup more than a social planner would prefer. While comparing the market solution with the social optimum, I find that the cleaner firm overcleans in the market solution for a low pollution damage parameter. However, for a sufficiently large pollution damage parameter, the cleaner firm undercleans as compared to the optimum. The lower quality firm always undercleans. The total pollution in the market solution is always greater for a strictly positive pollution damage parameter. Though consumers' concern for the environment induces the producers to adopt positive cleanup levels, the provision of environment quality is sub-optimal. This sub-optimality is caused by two sources of distortion: one, distortion due to the oligopoly power of the firms and the other, due to the negative environment externality generated by the production process.

The provision of a uniform commodity subsidy improves the clean up levels adopted by the firms and reduces total pollution, while a tax has an opposite effect. As explained in the previous chapter, the provision of a subsidy increases the marginal benefit, keeping the marginal cost constant, giving an incentive to improve the adopted quality. Imposition of a tax adversely affects the competitiveness of the firms, thus forcing them to reduce the quality. Taxes reduce the marginal benefits of producing and selling in the market. With higher taxes, it pays less to serve the market, so it pays less to clean up. Moreover, since the focus is on fully covered market, there is no effect from the demand side and total pollution is determined solely by per unit pollution. It immediately follows that the total pollution increases with a tax policy and reduces with a subsidy policy.

The welfare analysis incorporates many effects. Recall the two sources of distortions that cause the market solution to deviate from the social optimum. The welfare effects of any policy instrument depend upon its effect on the interplay of these two distortions. A commodity tax reduces the distortion caused by the duopoly market and increases the distortion due to the externality. The optimal policy is determined by examining which one of the two (distortions) dominates. When intensity of negative externality is sufficiently small, the distortion due to the duopoly power of the firms dominates the distortion due to the externality factor and a small commodity tax is welfare improving. However, as the intensity of negative externality increases from a low to a high value (i.e., when distortion due to the externality dominates the other distortion) the optimal policy shifts from a tax to a subsidy policy.

An emission tax improves the clean up levels adopted by both firms. Also a small emission tax is welfare improving if and only if the pollution damage parameter is positive. This implies that, the optimal emission tax does not account for the market imperfection. It, therefore, does not have the double-dividend effect referred to in the literature at the beginning of this chapter. Moreover, I show that a commodity tax dominates an emission tax for certain values of the emission damage parameter. This makes my investigation of commodity tax/subsidy policy a non-trivial exercise. This is in addition to the problems of implementing an emission tax as noted by Cremer and Thisse (1999). Hence in the class of second best instruments, an emission tax may not be the best policy.

I also find that the adoption of a uniform specific tax has no impact on the quality chosen. Prices and costs move up by the same amount. The entire tax burden is passed on to the consumers. However if the tax receipts are also distributed back to the consumers, it nullifies welfare implications and consumers remain unaffected. Thus it is not a useful policy instrument in improving the environmental quality.

The central message of the essay is that environmental regulation is a very complex process. While formulating environmental policy, the overall scenario of the economy should be taken into account. The optimal environment policy depends upon the extent of externality that has been generated by pollution and how much of it has been internalized by consumers' willingness to pay for better environmental practices. Since societies differ in both these respects, different policies may be optimal for different countries.

1.4 Chapter 4: Change in Income Distribution and Consumer Awareness: Effect on Environmental Quality and Policy

In the previous two chapters, assuming that the consumers' willingness to pay for environmental quality is a function of income and its distribution for the society remains constant, I examined implications of various regulatory tax-subsidy policies. This chapter serves as an extension to the last chapter. It aims at studying the effect of a change in income distribution on the degree of cleaning.

Since there is a one to one relationship between income and the parameter that reflects willingness to pay, θ, a change in income distribution changes the distribution of θ. I am considering distributional changes such that only the support of the distribution function changes and the distribution continues to be uniform.

I analyze both cases, when the increase in income is uniform across consumers and also the case when it is limited to a particular section of the society. I find that a uniform rise in income improves the quality of both variants of the product, while a heterogeneous rise in income may improve the quality of one variant and reduce the quality of the other.

When each consumer's income rises uniformly, her willingness to pay for improved quality also rises uniformly. Firms respond to this by improving the quality as well as increasing the price of both variants of the good.

When the growth in income is limited to the upper end of income distribution, willingness to pay of these consumers increases. The cleaner firm responds by improving the quality supplied, and increases its profit by charging a higher price. The lower quality firm faces a situation, where its competitor has differentiated away from it but the willingness to pay of the lower end consumers has not increased. It can lower its quality, and extract greater surplus from the marginal consumers at the upper end. By doing so, it will not lose demand as these consumers cannot move to the cleaner firm. This is because, it is more expensive now and their willingness to pay has not increased proportionately. This way the firm is able to retain its demand even by lowering its quality.

Such heterogeneous growth in income, deteriorates the lower quality and may have serious implications for the consumers at the lower end of the income distribution, especially if the product has a direct health or safety hazard for the user. This may cause concern to the planner.

So far, I have been concentrating on given levels of consumer awareness. Currently, there are a number of consumer activist groups that are trying to improve environmental consciousness among the general public. These organizations through pamphlets, protests, negotiations with producers, etc., are trying to force all agents to become more responsible towards the provision of a better environment. This is having a significant impact on the degree of awareness among consumers. Policy makers are increasingly turning to voluntary measures as an alternative to the traditional legislative or regulatory approaches.

In our setup, consumer's decision to buy a product with particular environmental characteristics is a function of the net surplus resulting from buying that product. The net surplus is the enjoyment derived from consuming the good minus the price the consumer has to pay. In the previous two chapters, I have used government policy to affect consumers' decisions through the prices they pay. Different degrees of consumer awareness, on the other hand, affect the enjoyment a person derives from consuming the product. Thus, prior to the scientific investigations regarding the harmful effects of asbestos, the use of asbestos, and its substitutes, were governed by prices and income in a different way from the time when the research findings became known. A poor household may change its usage of firewood as fuel, once it appreciates the harmful effects of deforestation on the next generation.

In this chapter, I also attempt to model effects of an increase in the degree of consumer awareness. An increase in consumer awareness increases the marginal benefit of cleanup for the producers, and hence they are induced to clean more. The effect of an increase in consumer awareness is similar to that of a commodity subsidy.

1.5 Chapter 5: Inducements for Technological Development: BAT is Bad

Firms often complain about the high costs of cleanup. Therefore, inducements to technological change must be an important aspect of an environment policy design. This chapter examines the impact of environmental regulation on a firm's incentive to innovate. In addressing this issue, two important aspects of the innovation effort are taken into account. The first is that the outcome of the research and development process is uncertain. While a larger amount of investment in R&D improves the probability of a successful outcome, it never guarantees a successful outcome. The second problem is that while a regulator can observe the technology being used, it cannot infer correctly the effort made by the firm in developing the technology.

Specifically, I focus on two types of policies: a contingent policy and a non-contingent policy. A contingent policy is one where the regulator re-optimizes environmental regulation in response to new technologies, i.e., the regulation is contingent on the available technology. This I call the *best available technology* (BAT). However, in a non-contingent policy, the regulator announces a regulation and sticks to it irrespective of the firm's adopted technology.

The present chapter shows that whether environmental regulation triggers or prevents innovation depends on the details of the regulation. In this setup, I establish that a policy based on best available technology hampers a firm's incentive for developing new and (environmentally) improved technologies and therefore, is bad. Such a policy encourages firms to complain about high compliance costs and exert pressure on governments to stick to current pollution standards.

The central result of the chapter is that no adoption of cleaner technologies takes place if the government re-optimizes environmental regulation in response to new technologies (i.e., the adopted policy is a contingent or BAT policy). As compared to a contingent policy, welfare is higher with a non-contingent policy. In a non-contingent policy, the regulator commits to a certain level of environmental regulation and does not raise it later.

A new technology is modeled as a downward shift in the abatement cost function (reduction in parameter k). The smaller the abatement costs are, the larger the incentives to abate for both the market and the social planner. However, the incentives for the social planner increase faster with the fall in k than the incentives for an unregulated firm, since the former not only takes into account consumers' direct preference for clean goods (as do firms), but also the indirect pollution externality. Hence, if the government wants to impose regulation to induce firms to cleanup as much as in the social optimum, the lower the abatement cost is, regulation has to be more stringent. Since this implies lower profits as well (profits fall when regulation becomes more stringent), firms will not adopt technologies with lower abatement costs. A better policy is to announce environmental regulation and stick to this policy after firms have adopted the cleaner technology (non-contingent policy), even if adoption justified more stringent regulation ex-post in a first best world.

Chapter 2

Welfare Implications of Commodity Tax/Subsidy Policies

2.1 Introduction

Today consumers differentiate between products on the basis of their impact on the environment, either during the production process or through their use. There is enough evidence that firms are aware of this. The various examples include the voluntary participation by the firms in the 33/50 Program launched in 1991 by EPA in the US. Khanna and Damon (1999) find that public recognition and technical assistance motivated the participation decision of firms, leading to significant reductions in the release of toxic chemical substances. The recent success, in Indonesia, of the labeling system called PROPER (Program for Pollution Control and Evaluation and Rating) suggests that producer response to aware consumers is not restricted to developed countries alone.

The purpose of this chapter is to study the welfare implications of various tax-subsidy policies in an imperfectly competitive market in the presence of *environmentally conscious* consumers. We use a vertically differentiated product model with consumers having a preference for environmentally superior products.[1] Consumers realize that it is the aggregate

[1] To the best of our knowledge, the first environmental model of this kind was developed by Arora and

production or consumption that affects the environment. Also, they know that the impact of individual consumption on the overall environment is negligible and the benefits of cleaner environment would accrue to the entire society. They are still willing to pay a higher price for the environmentally friendlier products. That is, they treat *environment friendliness* as a quality attribute of the product they buy.

Our model formulation is similar to Arora and Gangopadhyay (1995). Using a vertically differentiated product model, they examine the effect of imposing environmental standards on firms competing in a duopoly market where consumers are willing to pay more for an environmentally better product. In equilibrium, the firms differentiate their products with one firm having a higher level of cleanup than that of the required minimum standard. This firm, therefore, overcomplies. They also show that while an output tax reduces the cleanup effort by firms, an output subsidy increases it. The focus of their paper is on the effect of environmental regulation on cleanup levels. However, while comparing policy instruments, it is important to examine their effect on welfare. Products with an environmental attribute generate a negative externality in the form of pollution and therefore, any model examining welfare implications should incorporate this externality in the analysis. Since Arora and Gangopadhyay (1995) do not incorporate an externality, their model formulation is inadequate to deal with welfare issues. Moreover, by just looking at the effect of any policy on cleanup levels, its effect on overall pollution cannot be ascertained. This is because, with better quality, more consumers may demand the product and, while the emission per unit of output may fall, the total amount of output, and hence the total pollution, may increase. This chapter incorporates the negative externality caused by the production process and examines welfare implications of various tax-subsidy policies. It is, therefore, an important extension of Arora and Gangopadhyay (1995) analysis.

Consumer preferences for environmental quality create a market for clean goods, induce firms to cleanup and thus reduce the pollution externality. In equilibrium, firms, therefore, adopt a positive level of cleanup even in the absence of any government intervention. While

Gangopadhyay (1995). A more recent work is that of Cremer and Thisse (1999).

examining government intervention, we focus on the implications of policies that discriminate between firms on the basis of their environmental performance: (a) by rewarding the cleaner firm (through a subsidy) and (b) punishing (or taxing) the worse quality firm by making it pay a tax.[2] These are considered as separate policy options.

The motivation for discriminatory policies comes from the observation that when products are vertically differentiated, a uniform policy (all producers face the same tax/subsidy rates) has the unfortunate implication that a producer who is more environmentally friendly faces the same tax rate as the less friendly producer. In fact, if the tax is a *commodity* one, the tax paid per unit of production, or per unit of pollution generated, is higher for the environmentally friendlier producer. Not surprisingly, such policies often face opposition among producers.

The central result of the chapter is that the imposition of a tax on polluting firms may not only increase total pollution but also reduce aggregate welfare. On the other hand, a subsidy unambiguously reduces overall pollution and improves aggregate welfare. Arora and Gangopadhyay do not have this result since they do not consider welfare levels.

The level of cleanup is determined at the margin by equating the benefit of cleanup with its cost. A tax reduces the marginal benefit of cleanup to the firm. With increasing marginal cleanup costs, a tax on the worse quality firm, therefore, reduces its net cleanup. Since the choices of cleanup levels by the two firms are strategic complements, the equilibrium cleanup level of both firms reduces. For a subsidy to the higher quality firm, the effects work in the opposite direction (encouraging a higher level of cleanup through increasing the marginal benefit to the producer.) Indeed, it can be shown that if consumers are unwilling to pay more for an environmentally friendlier product, this distinction between taxes and subsidies disappears.

Since there is a positive correlation between the direct and the indirect environmental attribute, ceteris paribus, any policy that induces firms to increase their cleanup levels has

[2] Salant and Shaffer (1999) argue that in two stage games, greater diversity among firms in the second stage can be welfare improving if this diversity can be induced at low costs in the first stage.

a welfare improving effect. Such a policy will make an individual consumer (buying the product) better off. However, consumers who were not buying the product before may be induced to do so at higher qualities. This may increase the total quantity produced. Thus, while the pollution per unit output falls, total pollution can still go up because the volume of production has increased. A policy not only affects individual firm behavior but also alters the size of the market being covered. An increase in the size of the market has two opposite effects on welfare. Welfare may increase as more consumers are able to afford the product, but at the same time, there is larger quantity of polluting products and this lowers the welfare. The net effect on welfare of any policy instrument is, therefore, an outcome of a complex process and cannot be derived directly from observing the effect on average cleanup levels.

A valid concern associated with advocating subsidies is that their implementation requires additional resources. We show that a balanced budget subsidy improves the aggregate welfare.

The results obtained in this chapter have a wider application. They can be used for designing appropriate policy instruments when the objective is social rather than environmental. An interesting example is the concern shown by Germany for the use of child labor in the Indian carpet industry. This is an example of *responsible* consumers, as the children working in the carpet industry do not affect them directly. Our results suggest that banning trade or taxing these producers may not be an appropriate policy. Instead, subsidizing the producers may help them adopt better social standards. Another example of socially responsible consumer behavior is the successful functioning of the *Fair Trade Labeling Organization (FLO)*. Fair Trade proposes to give a better deal to the small, disadvantaged and marginalized South producers through a labeling system called the *Fair Trade Label*. The organization supports the farmers in many ways to help them come out of poverty and the entire cost is borne by the consumers.[3]

In the literature, emission taxes have emerged as one of the important instruments for

[3]Meeting minimum environmental requirement is one of the conditions for the grant of the label.

correcting environmental externalities. Under perfectly competitive markets selling homogeneous products, Pigouvian taxes (tax rate equal to the marginal social damage of pollution) completely internalize the externality and achieve Pareto optimality (Baumol and Oates, 1988). Similarly, tradeable emission permits achieve targeted levels of pollution at the least cost under perfect competition (Dales, 1968). However, modern industrial markets are often more realistically described as oligopolistic.

It has been shown that under imperfectly competitive market conditions, the optimal tax is less than the marginal damage (Katsoulacos and Xepapadeas, 1996). Stranlund (1997) examines how the provision of technological aid to encourage the adoption of superior emission control technology reduces the direct enforcement effort.

The rest of the chapter is organized as follows. The model and its equilibrium outcome are described in section 2.2. Section 2.3 analyses government intervention in the form of discriminatory policies. Section 2.4 examines the welfare implications of different government policy measures. Some extensions of the earlier results are provided in section 2.5. Section 2.6 contains concluding remarks. All proofs are given in the Appendix.

2.2 The Model

Two firms 1,2, produce a (physically) homogeneous good x. Production of this output generates a per unit pollutant at the level $D > 0$. There is a cleaning technology that reduces the pollution per unit to $D - e$, at a cost $c(e)$.[4]

A.2.1: $c(0) \geq 0$, $c'(0) = 0$, *and* $c'(e) > 0, c''(e) > 0$ *for* $0 < e \leq D$.

Firms play a two stage Nash game. In the first stage, each chooses the cleanup level, e_i,

[4] One way to think of the cleaning technology is an effluent treatment process. For example effluents discharged from leather tanneries may contain various types of pollutants like biological-oxygen demand (BOD), chemical-oxygen demand (COD), total dissolved solids (TDS) etc. The cost of setting up an effluent treatment plant (ETP) designed to treat TDS in addition to BOD and COD is much higher.

$i = 1, 2$. In the second stage, they compete in prices, p_i being the price chosen by firm i. Once a plant is set up to provide a particular clean up level, it may be difficult to change it in the short run. Choice of cleanup process in the context of environment is often a long run decision. This justifies the setting that cleanup decisions are taken in the first stage and price decisions in the second stage. For simplicity, we assume that the cost of production is zero.[5]

Consumers derive utility, U, from the pollution producing good x and a composite good, money,[6] while pollution reduces their welfare. Each consumer buys only one unit of x. Consumers are environmentally conscious. They are willing to pay a higher price for x, if it is environmentally better. Production of the homogeneous composite good has no environmental impact. For a consumer buying both the composite good and x, the utility, U, is given by:

$$U = y + I[v + \theta(y)e_i - p_i] - Z \tag{2.1}$$

where y is the money endowment, or income of the consumer, v is the utility derived from one unit of the physical property of the good x, I is an indicator function taking the value 0 or 1, e_i is the cleanup level of the firm from which the consumer buys x, $i = 1, 2$, p_i is the price paid by the consumer for the good x if it is bought, $i = 1, 2$ and Z is the aggregate level of pollution. I takes the value 1 if the consumer buys x and 0 if the consumer does not buy good x. Z depends on cleanup levels and amounts produced.[7] The important thing is that the consumers treat Z as a public bad and, hence, Z does not affect individual actions.

The marginal willingness to pay for environmental quality is denoted by $\theta(y)$, where θ is a monotonically increasing function of y; people are willing to pay more for environmental quality if they have higher incomes. Alternatively, the reciprocal of $\theta(y)$ can be interpreted

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[5]The qualitative results do not change if we allow for positive costs of production. Assuming them to be zero, vastly simplifies the algebra.

[6]Mussa and Rosen (1978); Shaked and Sutton (1982); Itoh (1983).

[7]This implies that the pollution generated depends upon the volume of production as well as the cleanup chosen. However it can be easily shown that results go through, even for the case when the amount of pollution is independent of the volume of production and depends only on the chosen cleanup levels.

as the marginal utility of money.

A.2.2: *θ is distributed uniformly over $[\underline{\theta}, \overline{\theta}]$, and the distribution function of θ is denoted $F(\theta)$.*

If we assume that y is distributed uniformly with support $[\underline{y}, \overline{y}]$, then θ will be distributed uniformly with support $[\underline{\theta}, \overline{\theta}]$, since θ has a one-to-one relationship with y. Here, $\underline{\theta} = \theta(\underline{y})$ and $\overline{\theta} = \theta(\overline{y})$. Given the one-to-one relationship between θ and y, we can characterize consumers by θ rather than y. From now on, therefore, θ will denote the consumer type, with a higher θ implying a consumer with greater money endowment. Henceforth, we will suppress the argument y from θ. The total population of consumers is normalized to unity.

A consumer will buy one unit of x only if the net gain in utility from consuming the good is positive, i.e., $v + \theta(y)e - p \geq 0$. For the rest of our analysis, we will assume that v is normalised to zero, to keep the algebra simple. *Without loss of generality, we assume that firm 1 has the higher clean up level, or $e_1 \geq e_2$.*

Let α_i, $i = 1, 2$, denote the proportion of people buying from firm i. Also, let θ_1 be a consumer indifferent between buying qualities 1 and 2, and θ_2 be a consumer who is indifferent between buying quality 2 or none at all. From Arora and Gangopadhyay (1995), it follows that, all consumers with

$$\theta \geq \frac{p_1 - p_2}{e_1 - e_2} \equiv \theta_1 \tag{2.2}$$

will buy from firm 1. Similarly, all consumers between θ_2 and θ_1 will buy from firm 2, where

$$\theta_2 \equiv \frac{p_2}{e_2} \tag{2.3}$$

In the Appendix (Lemma 1), we show that in our model, it is never optimal for the firm to serve the entire market, if both have positive levels of cleanup, i.e., $\theta_2 > \underline{\theta}$. (In the next chapter, we show that this arises because of our cost assumption.) With $\underline{\theta} < \theta_2 < \theta_1 < \overline{\theta}$ (Lemma 1 in the Appendix), A.2.2 and $e_1 < e_2$, we have

$$\alpha_1 = \int_{\theta_1}^{\overline{\theta}} dF(\theta) = \frac{1}{R}(\overline{\theta} - \theta_1) = \frac{1}{R(e_1 - e_2)}(\overline{\theta}(e_1 - e_2) - p_1 + p_2) \tag{2.4}$$

$$\alpha_2 \quad = \quad \int_{\theta_2}^{\theta_1} dF(\theta) = \frac{1}{R}(\theta_1 - \theta_2) = \frac{1}{Re_2(e_1 - e_2)}(p_1 e_2 - p_2 e_1) \tag{2.5}$$

where $R = \overline{\theta} - \underline{\theta}$.

The Second Stage Price Game

Here firms compete in prices. Let π_i be the profit of firm i in this stage, for given choices of e_1 and e_2. With zero cost of production, the second stage profit expression is given by

$$\pi_i = \alpha_i p_i, \quad i = 1, 2 \tag{2.6}$$

If $e_1 = e_2$, we have a second stage price game in a homogeneous product market and one has to consider the possibility of mixed strategy equilibria as there may be no pure strategy equilibrium. However, Lemma 1 in the Appendix shows that $e_1 = e_2$ is never an equilibrium in the first stage. Once the cleanup levels are fixed, and $e_1 > e_2$, the price game is in heterogeneous products and a pure strategy equilibrium exists. We will restrict attention to pure strategy equilibria.

The necessary conditions for an interior solution are:

$$\frac{d\pi_1}{dp_1} = \frac{d}{dp_1}\frac{p_1\{\overline{\theta}(e_1 - e_2) - p_1 + p_2)\}}{R(e_1 - e_2)} = 0$$

$$\frac{d\pi_2}{dp_2} = \frac{d}{dp_2}\frac{p_2(p_1 e_2 - p_2 e_1)}{Re_2(e_1 - e_2)} = 0$$

Alternatively,

$$\overline{\theta}(e_1 - e_2) - 2p_1 + p_2 = 0 \tag{2.7}$$

$$p_1 e_2 - 2p_2 e_1 = 0 \tag{2.8}$$

Let a superscript ^ denote the value of a variable in equilibrium. Equilibrium prices in the second stage, given the emission levels are

$$\hat{p_1} = \frac{2\overline{\theta}e_1(e_1 - e_2)}{(4e_1 - e_2)} \tag{2.9}$$

$$\hat{p_2} = \frac{\overline{\theta}e_2(e_1 - e_2)}{(4e_1 - e_2)} \tag{2.10}$$

with $\hat{p_1} > \hat{p_2}$.

Choice of Abatement Activity

This is the first stage of the game, where firms choose the cleanup levels. Using (2.9) and (2.10), we can write the first stage profits for each firm wholly in terms of e_1 and e_2. Let the first stage profit of firm i be denoted by Π_i. Then,

$$\Pi_i = p_i\alpha_i - c(e_i), \quad i = 1, 2 \tag{2.11}$$

Plugging in the values of α_i from (2.4) and (2.5) and p_i from (2.9) and (2.10), we get

$$\Pi_1(e_1, e_2) = \frac{\overline{\theta}^2 4e_1^2(e_1 - e_2)}{R(4e_1 - e_2)^2} - c(e_1) \tag{2.12}$$

$$\Pi_2(e_1, e_2) = \frac{\overline{\theta}^2 e_1 e_2(e_1 - e_2)}{R(4e_1 - e_2)^2} - c(e_2) \tag{2.13}$$

Assuming interior solutions, we put $(d\Pi_1(e_1, e_2)/de_1) = (d\Pi_2(e_1, e_2)/de_2) = 0$ which imply the following expressions:

$$\frac{\overline{\theta}^2}{R}\frac{16e_1^3 - 12e_1^2e_2 + 8e_1e_2^2}{(4e_1 - e_2)^3} - c'(e_1) = 0 \tag{2.14}$$

$$\frac{\overline{\theta}^2}{R}\frac{4e_1^3 - 7e_1^2e_2}{(4e_1 - e_2)^3} - c'(e_2) = 0 \tag{2.15}$$

Let $\hat{e_1}$, $\hat{e_2}$ be the solutions to the above equations.

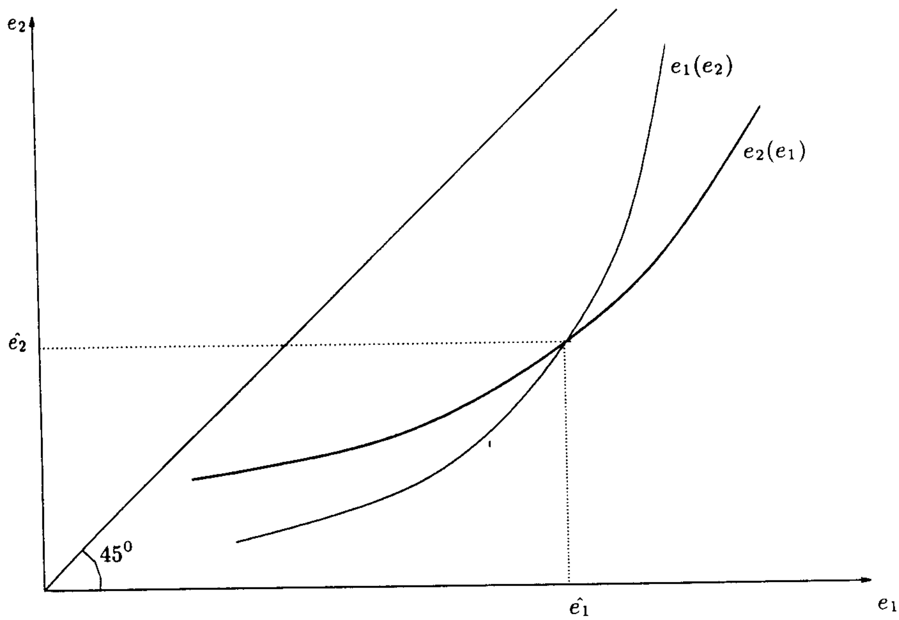

Figure 2.1: Reaction functions in cleanup levels

From Arora and Gangopadhyay (1995), we know that the reaction functions are positively sloped and convex.[8] Also, the reaction function of firm 1 is steeper than that of firm 2. This gives us a unique equilibrium, with $\hat{e_1} > \hat{e_2} > 0$. This is shown in Figure 2.1 by the point of intersection of the two reaction functions, which is below the 45^o line. If firm 1 increases its cleanup, a consumer who was almost indifferent between firms 1 and 2 now prefers firm 1. This, *ceteris paribus* reduces the profit of firm 2. To win back this marginal (set of) consumer(s), firm 2 increases its own cleanup. A similar effect works on firm 1 as firm 2 comes closer to firm 1 in its cleanup. In other words, the first stage marginal profit of firm $i, i = 1, 2$ is increasing in the cleanup level of firm $j, j = 1, 2;\ \ j \neq i$. Thus, the cleanup levels chosen by the two firms are strategic complements.[9]

Consumer Welfare

[8]In equation (2.35) of the Appendix , if we put $t_1 = t_2 = 0$ and evaluate (de_2/de_1) of both the firms, it follows that both are positive. Convexity of the reaction functions can also be demonstrated.

[9]This is evident from the signs of the off-diagonal terms in the first matrix on the left-hand side of (2.35) in the Appendix. See Bulow, Geanakoplos and Klemperer (1985) and pages 207-208 of Tirole (1988).

The consumers get segmented by θ_1 and θ_2. Aggregate consumer surplus Σ can be measured as the sum of the surplus enjoyed by the consumers with $\theta < \theta_2$, $\theta_2 \leq \theta < \theta_1$ and $\theta_1 \leq \theta \leq \overline{\theta}$. Thus

$$\begin{aligned}\Sigma &= 0 + \int_{\theta_2}^{\theta_1} (\theta e_2 - p_2) dF(\theta) + \int_{\theta_1}^{\overline{\theta}} (\theta e_1 - p_1) dF(\theta) \\ &= \frac{\overline{\theta}^2}{R} \frac{2e_1^2(e_1 + e_2)}{(4e_1 - e_2)^2} + \frac{\overline{\theta}^2}{R} \frac{e_1^2 e_2}{2(4e_1 - e_2)^2} \\ &= \frac{\overline{\theta}^2}{R} \frac{e_1^2(4e_1 + 5e_2)}{2(4e_1 - e_2)^2} \end{aligned} \tag{2.16}$$

Consumer welfare, Ω, is the consumer surplus minus total pollution, Z, generated by the production of x.

$$\Omega = \Sigma - Z, \tag{2.17}$$

The total pollution (Z) is determined by the total number of units of x sold in the market and the choice of cleanup levels by the two firms.

$$Z = \alpha_1(D - e_1) + \alpha_2(D - e_2) \tag{2.18}$$

Observe that though the consumers' concern for the environment results in firms abating pollution to a certain extent, the pollution abatement may still be sub-optimal. This may require the government to intervene to further reduce the pollution. Notice we are in the second best world and even government intervention may not achieve the first best. We are looking for government policy measures, which improve aggregate welfare. In the next section we study the impact of government intervention and compare different government policies in terms of their impact on average environmental quality.

2.3 Government Intervention: Discriminatory Tax versus Discriminatory Subsidy

Let t_i be a commodity tax (i.e., a per-unit tax, which is proportional to the price level) on firm i, $i = 1, 2$. If t_i is positive, we term it a tax and, if negative, a subsidy. The second stage profit functions are

$$\pi_i(t_i) = (1 - t_i)\alpha_i p_i, \quad i = 1, 2 \tag{2.19}$$

Observe that, in this case, the tax and no-tax price equilibrium expressions are the same as in equations (2.9) and (2.10) because, maximizing $\alpha_i p_i$ is the same as maximizing $(1-t_i)\alpha_i p_i$. Plugging in the values of α_i and $p_i, i = 1, 2$ from the second stage equilibrium. we obtain the first stage profit functions as:

$$\Pi_1 = (1 - t_1)\frac{\overline{\theta}^2 4e_1^2(e_1 - e_2)}{R(4e_1 - e_2)^2} - c(e_1) \tag{2.20}$$

$$\Pi_2 = (1 - t_2)\frac{\overline{\theta}^2 e_1 e_2(e_1 - e_2)}{R(4e_1 - e_2)^2} - c(e_2) \tag{2.21}$$

The necessary first order conditions for an interior solution are

$$(1 - t_1)\frac{\overline{\theta}^2}{R}\frac{16e_1^3 - 12e_1^2 e_2 + 8e_1 e_2^2}{(4e_1 - e_2)^3} = c'(e_1) \tag{2.22}$$

$$(1 - t_2)\frac{\overline{\theta}^2}{R}\frac{4e_1^3 - 7e_1^2 e_2}{(4e_1 - e_2)^3} = c'(e_2) \tag{2.23}$$

After characterising the equilibrium with government intervention, we can study various government policies by assigning different values to t_1 and t_2.

We study two natural ways of discriminating between the firms. In one, good producers get a subsidy, while in the other, bad producers have to pay a tax. That is, we first study the effect of the imposition of a discriminatory commodity tax on the dirty firm. In such a tax policy regime, the government taxes the firm adopting the lower cleanup but does not punish the better firm. Then we study a policy where the government decides to reward the firm with a higher cleanup level.

Discriminatory Tax

Let t_d be the commodity tax on the dirty firm 2; $t_1 = 0, t_2 = t_d > 0$. This is a weak pollution control system as even though both firms are net polluters, only the firm with the lower cleanup pays the tax. While the profit expression for the first firm will remain the same, that of the second will be different. Thus,

$$\Pi_1(e_1, e_2, t_d) = \frac{\overline{\theta}^2 4e_1^2(e_1 - e_2)}{R(4e_1 - e_2)^2} - c(e_1) \tag{2.24}$$

$$\Pi_2(e_1, e_2, t_d) = (1-t)\frac{\overline{\theta}^2 e_1 e_2(e_1 - e_2)}{R(4e_1 - e_2)^2} - c(e_2) \tag{2.25}$$

Let $e_1(t_d)$ and $e_2(t_d)$ be the equilibrium outcomes.

Proposition 1: *Let A.2.1 and A.2.2 hold. Let* $t_1 = 0$, $t_2 = t_d > 0$. *As compared to no government intervention, a discriminatory commodity tax on the dirty firm*
(i) reduces the clean up efforts by both the firms,
(ii) reduces the total demand for the good x*, as well as the individual demand for each firm,*
(iii) reduces the profit of the dirty firm and increases the profit of the clean firm,
(iv) reduces the consumer surplus enjoyed by the consumers.

Proof: The proof is in the Appendix.

The imposition of a discriminatory tax does not directly affect the second stage profit expression of firm 1. The stage 2 profit of firm 1, is however, affected indirectly by the behavior of firm 2 which has to pay the tax. Thus, such a tax does affect the cleanup levels in the first stage of the game. When a tax is imposed on firm 2, it reduces the marginal benefit of cleanup for firm 2, keeping the marginal cost constant. Since marginal cleanup costs are increasing, it is induced to reduce its cleanup level. This immediately reduces its demand at the (pre-tax equilibrium) prices. To recover a part of the lost demand, it is forced to reduce its price. In response to this, firm 1 also reduces its cleanup level and could also reduce its price. A lower price increases demand, but a lower cleanup reduces demand. Our Proposition shows that the fall in cleanup levels is sufficiently large, even if prices were to fall, to result in a drop in aggregate demand. Also, the profit of the cleaner firm rises at the expense of the dirty firm. The new equilibrium is shown in Figure 2.2. The reaction curve for firm 1 remains same as before, while that of firm 2 shifts to the right and becomes flatter.

The equilibrium is reached at lower cleanup levels for both the firms.

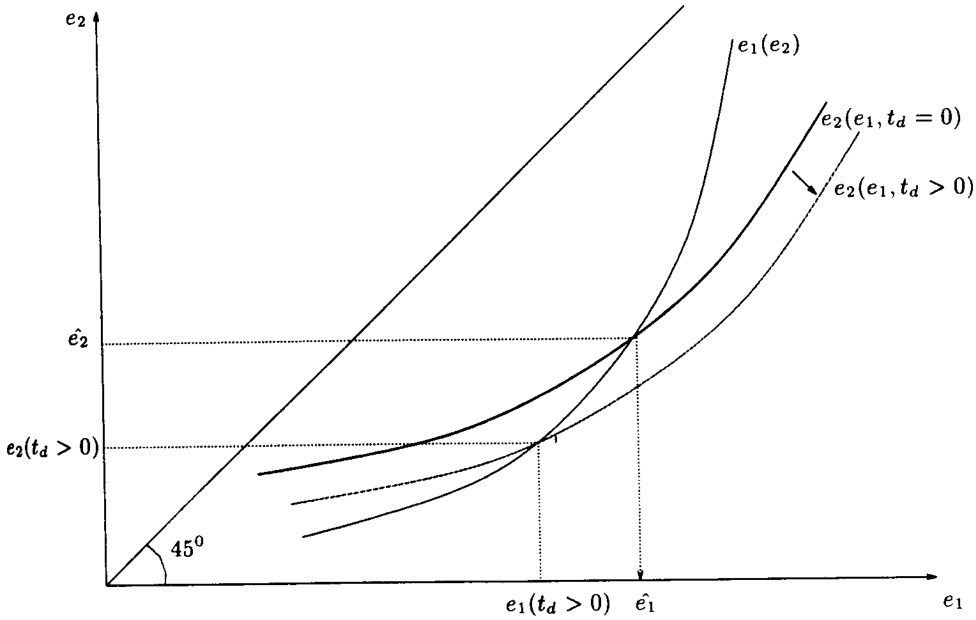

Figure 2.2: Effect of a discriminatory tax on cleanup levels

We now consider the case where, instead of punishing the firm with a lower cleanup level, the government decides to reward the firm with a higher cleanup level.

Proposition 2: *Let A.2.1 and A.2.2 hold. Let* $t_1 = -s_d, s_d > 0, t_2 = 0$. *As compared to no government intervention, a discriminatory commodity subsidy to the cleaner firm*

(i) increases the clean up efforts by both the firms,

(ii) reduces the total demand for the good x, as well as the individual demand for each firm.

(iii) increases the profit of the dirty firm and results in an ambiguous change in the profit of the clean firm,

(iv) increases the consumer surplus as well as consumer welfare.

Proof: The proof is in the Appendix.

Again a commodity subsidy provided to the clean firm does not affect the second stage profit expression of firm 2. However it increases the marginal benefit of the cleaning effort of firm 1 in the first stage of the game. This induces firm 1 to increase its cleanup level as well as its price. Since the response function of firm 2 is upward sloping, firm 2 also increases its cleanup level. This creates a problem for firm 1. The improved quality of firm 2 product, takes away the lower end consumers of firm 1. The lower end consumers of firm 1 are the higher end consumers of firm 2. Firm 2 by improving its cleanup quality can increase its price, losing its lower end consumers but extracting more from its higher end consumers. So firm 2 increases its profits. However there are two opposite effects on the profit of firm 1. It increases due to an increase in the marginal benefit of cleaning effort but falls due to the improved cleanup level of firm 2. The overall effect is ambiguous. The equilibrium with a discriminatory subsidy is illustrated in Figure 2.3. The reaction curve of firm 1 shifts to the right and becomes flatter, while that of firm 2 does not change. The equilibrium is reached at improved cleanup levels for both the firms.

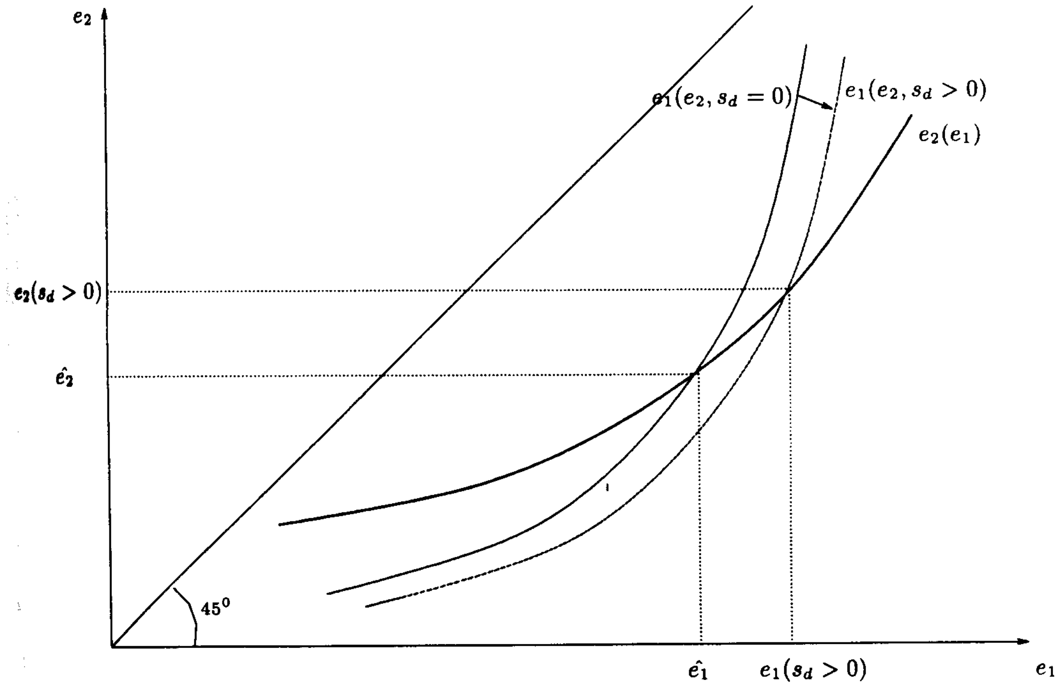

Figure 2.3: Effect of a discriminatory subsidy on cleanup levels

Part (ii) of Proposition 3 is counterintuitive. Conventional reasoning would predict that subsidizing the cleaner quality should increase demand. In our model, the aggregate demand falls with the policy of rewarding better producers. Part (iii) is interesting, as it suggests that the dirty firm extracts a part of the subsidy. Thus even if the dirty firm does not get any direct support in the form of subsidies, it is able to appropriate it partly due to price competition. It is therefore clear that, the dirty firm would support a discriminatory subsidy more than a discriminatory tax.

It is interesting to note that though the taxes have an effect opposite to that of subsidies on all the variables except demand, demand falls with both the policy instruments. The price cleanup pair offered by firm 2 determines total demand. This goes up with both the instruments, bringing down the demand. Given that the cleanup levels rise with a subsidy and fall with a tax, and the demand falls with both, it becomes important to examine the effect of the two policies on consumer surplus, total pollution and the aggregate welfare, at comparable rates of tax and subsidy.

With a subsidy, cleanup levels rise and prices may rise or fall. If prices fall, then consumer surplus clearly increases. But even in the case when prices rise, the increase in the cleanup levels is more than the equivalent increase in prices. Thus the *consumer surplus* rises with a subsidy. However in the case of a tax, cleanup levels fall and again the direction of price change is ambiguous. If prices rise then, consumers' surplus falls trivially. Even if prices fall, the fall in prices is not matched by the fall in cleanup levels. Consequently, taxes adversely affect consumers.

Next we analyze the problem of collecting resources for funding the subsidy. Since firm 1 is getting support in the form of subsidies, the most obvious way is to collect the resources from it. Let us consider the case where the government finances subsidies by collecting an equivalent lump sum tax from firm 1. Similarly, in the case of taxes, it distributes the collected tax revenue to firm 2 in a lump sum fashion. Thus the government budget is balanced.

Let profit of firm i inclusive of transfer be called *net profit* (Φ_i).

$$\Phi_i = \Pi_i + B_i \tag{2.26}$$

where B_i is the government transfer to firm $i (i = 1, 2)$. If firm 1 is subsidized, then B_1 is negative while $B_2 = 0$. If firm 2 is taxed, $B_1 = 0$ and $B_2 > 0$.

Proposition 3: *Let A.2.1 and A.2.2 hold. As compared to no government intervention, under a balanced budget policy, the net profit of firm 1*
(i) falls when it is given a discriminatory subsidy that is financed by a lump sum tax on it
(ii) increases when a discriminatory tax is imposed on firm 2, and the tax revenue is distributed back to firm 2.

Proof: The proof is in the Appendix.

As already shown, a part of the subsidy provided to firm 1 gets leaked and is appropriated by firm 2. Thus the strategic gain to firm 1 of the subsidy is less than the amount of the subsidy bill. This has a negative effect on the net profit of firm 1. The clean firm may, therefore, lose out if it is supported by a subsidy. Firm 1 may not like such support, which increases the profit of the relatively dirty firm at the clean firm's expense. However, irrespective of the manner in which collected tax revenue is distributed, firm 1's net profit increases when a tax is imposed on firm 2.

Proposition 4: *Let A.2.1 and A.2.2 hold. As compared to no-government intervention, under a balanced budget policy, the net profit of firm 2*
(i) falls when a discriminatory tax is imposed on it and distributed back to it,
(ii) increases with a discriminatory subsidy to firm 1 who also pays for the subsidy.

Proof: The proof is in the Appendix.

Proposition 4 implies that firm 2 would not like to participate in the tax scheme, even if the entire tax receipts were refunded to it. That is, the strategic loss to firm 2 due to the

the effect of reducing the welfare except for the ambiguity in the direction of change of total pollution. Here we do not get a clear result about aggregate welfare as in the case of a subsidy.

If we use a specific functional form for cost function, e.g., $c(e) = a + (1/2)ke^2$, where $a \geq 0, k > 0$, we get the stronger result that even when the effect of a tax on the aggregate welfare is positive, a small subsidy dominates a small tax. In the next section, we assume a specific functional form for the cost function assumed in A.2.1 and obtain some more results.

Before we move on to the next section, we briefly discuss the case of a uniform policy, i.e., when the government treats both the firms equally and imposes the same rate of tax or subsidy on them. This means $t_1 = t_2 = t_u$.

Proposition 6: *Let A.2.1 and A.2.2 hold. An increase in the uniform tax rate*
(i) reduces the cleanup levels by both firms
(ii) reduces the profit of firm 2, *but has an ambiguous effect on the profit of firm* 1.

Proof: The proof is in the Appendix.

If we begin with a subsidy, that is $t_u < 0$, an increase in the subsidy is (algebraically) the same as a *reduction* in the tax rate. An increase in the uniform subsidy rate to both firms increases marginal benefit of the cleanup effort for both the firms, keeping the marginal cost constant. Thus they are induced to improve their cleanup levels. Figure 2.4 shows the effect of a uniform subsidy on the cleanup levels. In response to a uniform subsidy, both reaction functions shift. The new equilibrium is at higher levels of cleanup by both firms.

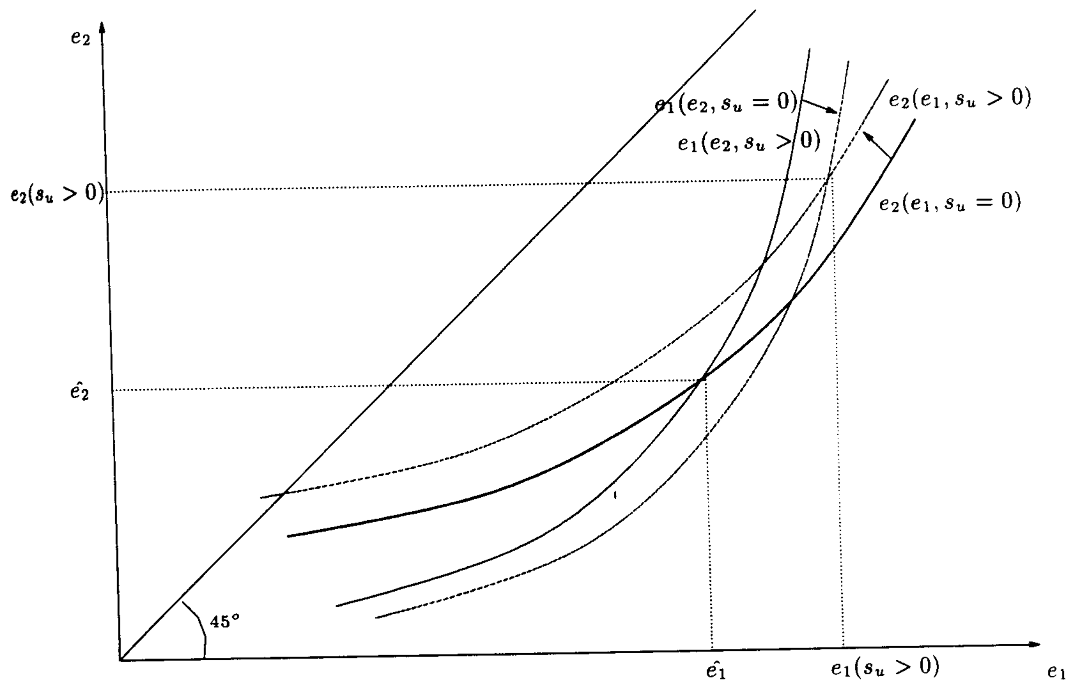

Figure 2.4: Effect of a uniform subsidy on cleanup levels

Similarly, effect of a uniform tax is illustrated in Figure 2.5.

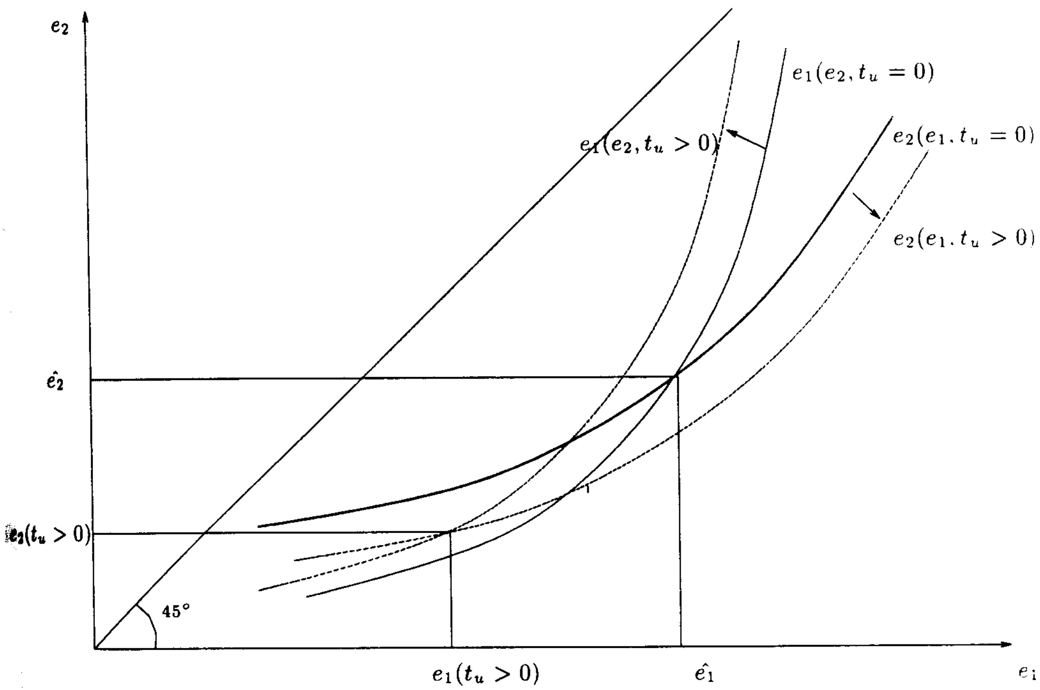

Figure 2.5: Effect of a uniform tax on cleanup levels

The tax per-unit of pollutant for firm i, r_i, can be written as the total tax bill of firm i divided by the amount of pollution generated by the firm. Thus,

$$r_i = \frac{t\alpha_i p_i}{\alpha_i(D - e_i)} = \frac{tp_i}{D - e_i}, i = 1, 2$$

Since $p_1 > p_2$, and $e_1 > e_2$, in a uniform tax policy regime, firm 1, the cleaner firm, ends up paying a higher rate of tax per unit of pollutant as compared to firm 2. Such a policy may face opposition from the producers, producing environmentally better quality. This motivated us to study implications of discriminatory policies..

2.5 A Specific Cost Function

In this section, we sharpen the earlier results by assuming a specific cost function.

A.2.3: $c(e) = a + (1/2)ke^2$ *where* $a \geq 0, k > 0,$ *are constants.*

Corollary 1: *Let A.2.2 and A.2.3 hold. An increase in the uniform tax rate*
(i) keeps the total size of the market served and proportion of consumers served by each firm constant
(ii) reduces profits obtained by both firms
(iii) increases total pollution.

Proof: The proof is in the Appendix.

Part (i) of the current corollary proves that with the specific cost function assumed in A.2.3, total or individual demand from firms is not affected. Proposition 1 (i) claims that cleanup levels fall with an increase in the uniform tax rate. Reduced cleanup levels and constant demand reduce the total pollution.

With the specific cost function assumed in A.2.3, we can also compare the two discriminatory policies studied above, in terms of their effect on total pollution. The effect of subsidies on total pollution is obvious from Proposition 2. The two effects, one through demand and the other through cleanup levels, move in the same direction, that of reducing pollution. However in the case of taxes, these two effects move in the opposite direction. The fall in demand brings down pollution, whereas the reduced cleanup levels increase it. Thus the overall effect is not clear.

Proposition 7: *Let A.2.2 and A.2.3 hold. Starting from $t_i = s_i = 0, i = 1, 2$, the marginal reduction in total pollution is higher with the introduction of a discriminatory subsidy as compared to a discriminatory tax, i.e.,*

$$\frac{dZ}{ds_d}|_{s_d=0} < \frac{dZ}{dt_d}|_{t_d=0}$$

<u>Proof:</u> The proof is in the Appendix.

Recall that we have shown that a discriminatory subsidy always reduces pollution. A discriminatory tax, on the other hand, could reduce total pollution as the output of x produced goes down. Proposition 7 says that even if the pollution were to go down with a discriminatory tax, the reduction would be less than that resulting from a discriminatory subsidy at the same rate.

We have already claimed that the aggregate welfare increases with a small discriminatory subsidy (Proposition 5). Also with a small discriminatory tax, the change in all the components have the effect of reducing the welfare except for the ambiguity in the direction of change of total pollution. (See discussion of Proposition 5.) Combining Propositions 5 and 7, we have the following result.

Proposition 8: *Assume A.2.2 and A.2.3 hold. Consider an initial situation where there is no government intervention, i.e.,* $t_i = s_i = 0, i = 1, 2$. *Then, the improvement in aggregate welfare is higher with a small discriminatory subsidy as compared to a small discriminatory tax.*

This is an important result, as it may shed light on the reasons for a particular type of policy being implemented. Welfare analysis demands that the government subsidize the firm with a better cleanup level. However, the effect of such a policy on firm 1's profit is not clear. In Corollary 1, we have shown that with a uniform subsidy and the quadratic cost curve, profits of both firms go up. Thus, the government may find more universal support for a policy that subsidizes a dirty firm along with a clean firm, rather than one, which subsidizes a clean firm only.

2.6 Conclusion

The phenomenon that the consumers have a preference for the environment friendly products and are willing to pay more for better environmental quality is now well accepted in the empirical literature. Using a vertically differentiated product model, Arora and Gangopadhyay (1995) showed that adopting *minimum emission standards* results in voluntary overcompliance. However, it did not examine the welfare implications and the problems faced in implementing the *standards*. The problem of enforcing standards is more pronounced in developing countries where the governments may face strong political lobbies against stringent environment policy.

This chapter studies the implications of a tax/subsidy policy in the presence of environmentally discerning consumers. It focuses on a discriminatory tax/subsidy policy. The policy consists of either rewarding the better performer or punishing the worse producer. A discriminatory policy is a more aggressive policy than a uniform policy. This policy chooses the firm, which should be rewarded with a subsidy, according to its performance. Subsidy is provided only to the firm, which adopts a higher cleanup level. It acts more like a reward for winning the competition. This also provides a justification for the provision of subsidy. The paper shows that a policy of discriminatory subsidy is welfare improving and also mitigates total pollution. Since the aggregate welfare improves, the subsidy can be financed within the economy, leaving a positive surplus with each agent. It also shows that the discriminatory subsidy policy dominates the discriminatory tax policy.

APPENDIX

Lemma 1: *If both firms have positive levels of cleanup, then* $e_1 > e_2$ *and* $\overline{\theta} > \theta_1 > \theta_2 > \underline{\theta}$.

Proof: Observe that, with $e_1 = e_2$, the second stage price game yields zero profit. This is because, in the second stage firms are competing in prices and, if the emission levels are the same, competition will ensure that both prices are zero. For any positive level of cleaning effort, this will mean negative profits in the overall game. On the other hand, if $e_1 = e_2 = 0$, it pays one firm to choose a positive cleanup level, given A.1. Thus identical positive levels of cleaning technologies are never optimal.

Suppose $\theta_2 = \underline{\theta}$. Then, the amounts sold by each firm, using (2.4) and (2.5) in the text, can be written as

$$\alpha_1 = \frac{1}{R(e_1 - e_2)}(\overline{\theta}(e_1 - e_2) - p_1 + p_2) \tag{2.28}$$

$$\alpha_2 = \frac{1}{R(e_1 - e_2)}(p_1 - p_2 - \underline{\theta}(e_1 - e_2)) \tag{2.29}$$

Maximizing π_i with respect to p_i, we get

$$p_1 = \frac{(2\overline{\theta} - \underline{\theta})(e_1 - e_2)}{3} \tag{2.30}$$

$$p_2 = \frac{(\overline{\theta} - 2\underline{\theta})(e_1 - e_2)}{3} \tag{2.31}$$

Using these price expressions in the demand equations, we get,

$$\alpha_1 = \frac{1}{3R}(2\overline{\theta} - \underline{\theta}) \tag{2.32}$$

$$\alpha_2 = \frac{1}{3R}(\overline{\theta} - 2\underline{\theta}) \tag{2.33}$$

The first stage profit function for firm 2 is

$$\Pi_2 = \frac{1}{9R}(e_1 - e_2)(\overline{\theta} - 2\underline{\theta})^2 - c(e_2) \tag{2.34}$$

It is immediate that the solution to e_2 is zero as Π_2 is everywhere falling in e_2. This violates $e_2 > 0$.

Now, let $\theta_1 = \overline{\theta}$. Since $e_1 \geq e_2 > 0$, $c(e_1) > 0$ from A.2.1. But the measure of demand is zero; hence stage 2 revenue is zero while first stage costs are positive. *QED.*

Before we prove the Propositions, it will be helpful to list the properties of the general model. Totally differentiating (2.20) and (2.21), we get

$$\begin{pmatrix} -(1-t_1)E - c''(e_1) & (1-t_1)F \\ (1-t_2)J & -(1-t_2)H - c''(e_2) \end{pmatrix} \begin{pmatrix} de_1 \\ de_2 \end{pmatrix} = \begin{pmatrix} V & 0 \\ 0 & N \end{pmatrix} \begin{pmatrix} dt_1 \\ dt_2 \end{pmatrix} \tag{2.35}$$

where

$$E \equiv \frac{\overline{\theta}^2}{R} \frac{8e_2^2(5e_1 + e_2)}{(4e_1 - e_2)^4}$$

$$F \equiv \frac{\overline{\theta}^2}{R}\frac{8e_1e_2(5e_1+e_2)}{(4e_1-e_2)^4}$$
$$H \equiv \frac{\overline{\theta}^2}{R}\frac{2e_1^2(8e_1+7e_2)}{(4e_1-e_2)^4}$$
$$J \equiv \frac{\overline{\theta}^2}{R}\frac{2e_1e_2(8e_1+7e_2)}{(4e_1-e_2)^4}$$
$$V \equiv \frac{\overline{\theta}^2}{R}\frac{16e_1^3-12e_1^2e_2+8e_1e_2^2}{(4e_1-e_2)^3} = \frac{c'(e_1)}{(1-t_1)}$$
$$N \equiv \frac{\overline{\theta}^2}{R}\frac{4{e_1}^3-7{e_1}^2e_2}{(4e_1-e_2)^3} = \frac{c'(e_2)}{(1-t_2)}$$

and we have used (2.20) and (2.21) for the equalities in the expressions defining V and N. Also note that $EH = JF$ and $e_2H - e_1J = e_2F - e_1E = 0$.

Lemma 2: *Let q denote any parameter. Then, the change in total demand as well as individual demand from firms, with respect to q, have a sign opposite to the sign of*

$$(\frac{de_1}{dq}e_2 - e_1\frac{de_2}{dq}).$$

Proof: Total demand for the environmental product is given by $1 - F(\theta_2)$. Therefore, total demand is inversely related to changes in θ_2. Using the definition of θ_2 and the price expression for p_2 in (2.10),

$$\theta_2 = \frac{p_2}{e_2} = \frac{\overline{\theta}}{R}\frac{(e_1-e_2)}{(4e_1-e_2)}$$

Differentiating with respect to the parameter q, we get

$$\frac{d\theta_2}{dq} = 3\frac{\overline{\theta}}{R(4e_1-e_2)^2}(\frac{de_1}{dq}e_2 - e_1\frac{de_2}{dq})$$

and the result follows.

Further $\alpha_1 = 2\alpha_2$ follows from substituting (2.9) and (2.10) in (2.4) and (2.5), to get

$$\alpha_1 = \frac{\overline{\theta}}{R}\frac{2e_1}{4e_1-e_2} \tag{2.36}$$

$$\alpha_2 = \frac{\overline{\theta}}{R}\frac{e_1}{4e_1-e_2} \tag{2.37}$$

Since α_1 and α_2 move in the same direction, individual demand for both firms moves in the same direction as the total demand. Observe that the tax/subsidy parameters t_1 and t_2 do not affect θ_2 directly. They affect total or individual demand indirectly through their effects on the clean-up levels e_1 and e_2.

Note: In each of the proofs to the Propositions, it is clearly stated whether we are considering a uniform or a discriminatory policy regime. For expositional convenience, from now on, we suppress the subscript u, d.

Proof of Proposition 1 :

Here $t = t_2 > t_1 = 0$.

(i) Using (2.35), it follows that

$$\frac{de_1}{dt} = -\frac{FN}{M} \tag{2.38}$$

$$\frac{de_2}{dt} = -\frac{EN + c''(e_1)N}{M} \tag{2.39}$$

where $M \equiv Ec''(e_2) + (1-t)Hc''(e_1) + c''(e_1)c''(e_2)$. Since $E, F, N, M > 0$,

$$\frac{de_1}{dt} < 0, \quad \frac{de_2}{dt} < 0 \tag{2.40}$$

(ii) Here

$$(\frac{de_1}{dt}e_2 - e_1\frac{de_2}{dt}) = e_1 c''(e_1)\frac{N}{M} > 0$$

given A.2.1 and (2.35). Using lemma 2, the result follows.

(iii) Change in total profit can be written as

$$\frac{d\Pi_i}{dq} = \frac{\partial \Pi_i}{\partial e_1}\frac{de_1}{dq} + \frac{\partial \Pi_i}{\partial e_2}\frac{de_2}{dq} + \frac{\partial \Pi_i}{\partial q}, \quad i = 1, 2; \; q = t, s \tag{2.41}$$

and

$$\frac{\partial \Pi_1}{\partial e_2} = -(1-t_1)\frac{\overline{\theta}^2}{R}\frac{(2e_1 + e_2)4e_1^2}{(4e_1 - e_2)^3}$$

$$\frac{\partial \Pi_2}{\partial e_1} = (1-t_2)\frac{\overline{\theta}^2}{R}\frac{(2e_1 + e_2)e_2^2}{(4e_1 - e_2)^3}$$

From equations (2.24) and (2.25) in the text, part (i) of Proposition 1, and using envelope theorem, we obtain

$$\frac{d\Pi_1}{dt} = -(2e_1+e_2)\frac{4e_1^2\overline{\theta}^2}{R(4e_1-e_2)^3}\frac{de_2}{dt} > 0$$

$$\frac{d\Pi_2}{dt} = (1-t)\frac{\overline{\theta}^2(2e_1+e_2)e_2^2}{R(4e_1-e_2)^3}\frac{de_1}{dt} - \frac{\overline{\theta}^2 e_1e_2(e_1-e_2)}{R(4e_1-e_2)^2} < 0$$

(iv) Observe that

$$\frac{d\Sigma}{dt} = \frac{\partial\Sigma}{\partial e_1}\frac{de_1}{dt} + \frac{\partial\Sigma}{\partial e_2}\frac{de_2}{dt} \tag{2.42}$$

$$= \left[\frac{\overline{\theta}^2}{R}\frac{e_1(8e_1^2-6e_1e_2-5e_2^2)}{(4e_1-e_2)^3}\right]\frac{de_1}{dt} + \left[\frac{\overline{\theta}^2}{R}\frac{e_1^2(28e_1+5e_2)}{2(4e_1-e_2)^3}\right]\frac{de_2}{dt}$$

From part (i) of the current Proposition, (de_1/dt) and (de_2/dt) are both negative. Their coefficients are both positive if $4e_1^2 - 7e_1e_2 > 0$, which is the case for e_2 to be interior (see (2.15) in the text). Thus, consumer surplus falls. *QED.*

Proof of Proposition 2:

Here,

$$\pi_1(s) = (1+s)p_1\alpha_1$$

$$\pi_2(s) = p_2\alpha_2$$

which implies p_1 and p_2 are the same functions of e_1 and e_2 as in (2.9) and (2.10) in the text.

Plugging $t_1 = -s < 0 = t_2$ in (2.35), we obtain

$$\frac{de_1}{ds} = \frac{V(H+c''(e_2))}{I} \tag{2.43}$$

$$\frac{de_2}{ds} = \frac{VJ}{I} \tag{2.44}$$

$$(\frac{de_1}{ds}e_2 - e_1\frac{de_2}{ds}) = \frac{Ve_2c''(e_2)}{I} \tag{2.45}$$

where $I = (1+s)Ec''(e_2) + Hc''(e_2) + c''(e_1)c''(e_2) > 0$.

(i) & (ii) Proceeding in the same manner as before,

$$\frac{de_1}{ds} > 0, \quad \frac{de_2}{ds} > 0 \tag{2.46}$$

$$\frac{d\theta_2}{ds} > 0 \tag{2.47}$$

(iii) Since $(de_2/ds) > 0$, the sign of the following expression is ambiguous, implying that profit can move in either direction.

$$\frac{d\Pi_1}{ds} = \frac{4e_1^2\overline{\theta}^2}{(4e_1 - e_2)^2R}[(e_1 - e_2) - \frac{(1+s)(2e_1+e_2)}{4e_1 - e_2}\frac{de_2}{ds}] \tag{2.48}$$

However, the profit of firm 2 increases unambiguously with a subsidy.

$$\frac{d\Pi_2}{ds} = \frac{e_2^2(2e_1+e_2)\overline{\theta}^2}{(4e_1-e_2)^3R}\frac{de_1}{ds} > 0$$

(iv) Using the expressions for changes in consumer surplus from the proof of part (iv) of Proposition 1, and (2.46), it is immediate that

$$\frac{d\Sigma}{ds} > 0$$

QED.

Proof of proposition 3:

(i) By definition

$$\Phi_1 = \Pi_1 + B_1 = \Pi_1 - S$$

where

$$S = s\frac{4e_1^2(e_1 - e_2)\overline{\theta}^2}{(4e_1 - e_2)^2R}$$

is the amount of subsidies.

$$\begin{aligned}\frac{d\Phi_1}{ds} &= [\frac{\partial\Pi_1}{\partial e_2} - \frac{\partial S}{\partial e_2}]\frac{de_2}{ds} - \frac{\partial S}{\partial e_1}\frac{de_1}{ds} + [\frac{\partial\Pi_1}{\partial s} - \frac{\partial S}{\partial s}] \\ &= -\frac{4e_1^2(2e_1+e_2)\overline{\theta}^2}{(4e_1-e_2)^3R}\frac{de_2}{ds} - s\frac{(16e_1^3 - 12e_1^2e_2 + 8e_1e_2^2)\overline{\theta}^2}{(4e_1-e_2)^3R}\frac{de_1}{ds} + 0\end{aligned}$$

which is less than zero from (2.46). *QED.*

Proof of Proposition 4:

(i) By definition

$$\Phi_2 = \Pi_2 + B_2$$

where $B_2 = t\frac{e_1 e_2(e_1-e_2)\overline{\theta}^2}{(4e_1-e_2)^2 R}$ is the amount of taxes collected.

$$\Phi_2 = \frac{e_1 e_2(e_1-e_2)\overline{\theta}^2}{(4e_1-e_2)^2 R} - c(e_2)$$

$$\frac{d\Phi_2}{dt} = \frac{e_2^2(2e_1+e_2)\overline{\theta}^2}{(4e_1-e_2)^3 R}\frac{de_1}{dt} + \frac{t}{1-t}c'(e_2)\frac{de_2}{dt} \quad < 0$$

from (2.40). *QED.*

Proof of Proposition 5:

From (2.27), $W = \Pi_1 + \Pi_2 + \Sigma + G - Z$.

Recall G takes a positive value in case of a tax and a negative value in case of a subsidy.

Using the first order conditions,

$$\begin{aligned}\frac{dW^q}{dq} &= \left[\frac{\partial \Pi_2}{\partial e_1} + \frac{\partial \Sigma}{\partial e_1} + \frac{\partial G}{\partial e_1}\right]\frac{de_1}{dq} + \left[\frac{\partial \Pi_1}{\partial e_2} + \frac{\partial \Sigma}{\partial e_2} + \frac{\partial G}{\partial e_2}\right]\frac{de_2}{dq} \\ &+ \frac{\partial}{\partial q}(\Pi_1 + \Pi_2 + \Sigma + G) - \frac{dZ}{dq}\end{aligned} \tag{2.49}$$

where superscript q refers to the aggregate welfare under q, $q = t, s$. Using part (iii) of the proof of Proposition 1 and (2.35) from above, we get

$$\begin{aligned}\frac{dW^s}{ds} &= \left[\frac{\partial \Sigma}{\partial e_1} + \frac{\overline{\theta}^2}{R}\frac{e_2^2(2e_1+e_2)}{(4e_1-e_2)^3} - \frac{s}{1+s}c'(e_1)\right]\frac{de_1}{ds} \\ &+ \left[\frac{\partial \Sigma}{\partial e_2} - \frac{\overline{\theta}^2}{R}\frac{4e_1^2(2e_1+e_2)}{(4e_1-e_2)^3}\right]\frac{de_2}{ds} - \frac{dZ}{ds} \\ \frac{dW^t}{dt} &= \left[\frac{\partial \Sigma}{\partial e_1} + \frac{\overline{\theta}^2}{R}\frac{e_2^2(2e_1+e_2)}{(4e_1-e_2)^3}\right]\frac{de_1}{dt} \\ &+ \left[\frac{\partial \Sigma}{\partial e_2} - \frac{\overline{\theta}^2}{R}\frac{4e_1^2(2e_1+e_2)}{(4e_1-e_2)^3} + \frac{t}{1-t}c'(e_2)\right]\frac{de_2}{dt} - \frac{dZ}{dt}\end{aligned}$$

Using part (iv) of the proof of Proposition 1,

$$\begin{aligned}
\frac{dW}{dq}|_{q=0} &= \left[\frac{\partial\Sigma}{\partial e_1} + \frac{\overline{\theta}^2}{R}\frac{e_2^2(2e_1+e_2)}{(4e_1-e_2)^3}\right]\frac{de_1}{dq} + \left[\frac{\partial\Sigma}{\partial e_2} - \frac{\overline{\theta}^2}{R}\frac{4e_1^2(2e_1+e_2)}{(4e_1-e_2)^3}\right]\frac{de_2}{dq} - \frac{dZ}{dq} \\
&= \left[\frac{\overline{\theta}^2}{R}\frac{e_1(8e_1^2-6e_1e_2-5e_2^2)}{(4e_1-e_2)^3} + \frac{\overline{\theta}^2}{R}\frac{e_2^2(2e_1+e_2)}{(4e_1-e_2)^3}\right]\frac{de_1}{dq} \\
&\quad + \left[\frac{\overline{\theta}^2}{R}\frac{e_1^2(28e_1+5e_2)}{2(4e_1-e_2)^3} - \frac{\overline{\theta}^2}{R}\frac{4e_1^2(2e_1+e_2)}{(4e_1-e_2)^3}\right]\frac{de_2}{dq} - \frac{dZ}{dq} \\
&= \frac{\overline{\theta}^2}{R}\frac{8e_1^3-6e_1^2e_2-3e_1e_2^2+e_2^3}{(4e_1-e_2)^3}\frac{de_1}{dq} \\
&\quad + \frac{\overline{\theta}^2}{R}\frac{e_1^2(12e_1-3e_2)}{2(4e_1-e_2)^3}\frac{de_2}{dq} - \frac{dZ}{dq} \\
&= \frac{\overline{\theta}^2}{R}\left[\frac{(4e_1^3-7e_1^2e_2)+(4e_1^3-3e_1e_2^2)+e_1^2e_2+e_2^3}{(4e_1-e_2)^3}\right]\frac{de_1}{dq} \\
&\quad + \left[\frac{\overline{\theta}^2}{R}\frac{3e_1^2}{2(4e_1-e_2)^2}\right]\frac{de_2}{dq} - \frac{dZ}{dq} \qquad (2.50)
\end{aligned}$$

The expressions enclosed in the parenthesis in the first and second terms in the above equation are positive and the third term depends upon whether a tax or a subsidy is being considered.

Thus in the case of a subsidy, each term in (2.50) has a welfare improving effect. While in the case of taxes, the first two terms have welfare reducing effect but the direction of change of total welfare is not clear. Proposition 7 ensures that with a specific cost function (as assumed in A.2.3) even if total pollution decreases, the decrease is less than the subsidy case. Thus, in terms of aggregate welfare, the subsidy policy dominates the tax policy under A.2.3. *QED.*

Proof of Proposition 6:

(i) From (2.35), for $t_1 = t_2 = t$, we can write

$$\frac{de_1}{dt} = \frac{-1}{\Delta}[(1-t)VH + Vc''(e_2) + (1-t)NF] < 0 \qquad (2.51)$$

$$\frac{de_2}{dt} = \frac{-1}{\Delta}[(1-t)VJ + Nc''(e_1) + (1-t)NE] < 0 \qquad (2.52)$$

where

$$\Delta = (1-t)[Hc''(e_1) + Ec''(e_2)] + c''(e_1)c''(e_2) > 0.$$

Substituting the expressions for V and N, as given in the definitions of (2.35), the above equations can also be written as

$$\frac{de_1}{dt} = -\frac{c'(e_1)[H + \frac{c''(e_2)}{1-t} + \frac{c'(e_2)}{c'(e_1)}F]}{(1-t)c''(e_1)[H + \frac{c''(e_2)}{1-t} + \frac{c''(e_2)}{c''(e_1)}E]} \qquad (2.53)$$

$$\frac{de_2}{dt} = -\frac{c'(e_2)[E + \frac{c''(e_1)}{1-t} + \frac{c'(e_1)}{c'(e_2)}J]}{(1-t)c''(e_2)[E + \frac{c''(e_1)}{1-t} + \frac{c''(e_1)}{c''(e_2)}H]} \qquad (2.54)$$

Using $e_2H - e_1J = e_2F - e_1E = 0$, (2.51), (2.52), and the expressions for V and N, as given in (2.35), we can write

$$\begin{aligned}
&\frac{de_1}{dt}e_2 - e_1\frac{de_2}{dt} \\
&= \frac{1}{\Delta(1-t)}[-e_2c'(e_1)c''(e_2) + e_1c'(e_2)c''(e_1)] \\
&= \left[\frac{1}{\Delta(1-t)}\right]e_1e_2c''(e_1)c''(e_2)\ \left[-\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2}\right]
\end{aligned}$$

where

$$\epsilon_i = \frac{e_ic''(e_i)}{c'(e_i)}, \quad i = 1, 2$$

is the elasticity of the marginal (cleanup) cost curve. Observe that, if this elasticity is a constant, then, from Lemma 2, the change in total demand is zero for changes in a uniform tax. This is satisfied with the cost curve $c(e) = a + (1/2)ke^2$, $a \geq 0$, $k > 0$. In general, if the elasticity of the marginal cost curve is rising (falling), total demand falls (rises) with an increase in uniform tax.

(ii) Using the expression for changes in profit from the proof of part (iii) of Proposition 1 and part (i) of the current proposition, we obtain

$$\frac{d\Pi_1}{dt} = \left[-(1-t)(2e_1+e_2)\frac{4e_1^2\overline{\theta}^2}{R(4e_1-e_2)^3}\right]\frac{de_2}{dt} - \frac{\overline{\theta}^2 4e_1^2(e_1-e_2)}{R(4e_1-e_2)^2}$$

is ambiguous since the first term on the right is positive ($(de_2/dt < 0)$ from part (i)), and given $e_1 > e_2$, the second term is negative.

By the same reasoning as above

$$\frac{d\Pi_2}{dt} = (1-t)\frac{\overline{\theta}^2(2e_1+e_2)e_2^2}{R(4e_1-e_2)^3}\frac{de_1}{dt} - \frac{\overline{\theta}^2 e_1 e_2(e_1-e_2)}{R(4e_1-e_2)^2} < 0$$

$QED.$

Proof of Corollary 1:

(i) Follows from part (i) of the proof of Proposition 1.

(ii) Using $c(e) = a + (1/2)ke^2$, in (2.53), (2.54), we get

$$\frac{de_i}{dt} = \frac{e_i}{1-t}, i = 1, 2 \tag{2.55}$$

Using (2.55) in part (ii) of the proof of Proposition 1, the result follows.

(iii) Follows trivially from part (i) of Proposition 1 and part (ii) of Corollary 1. $QED.$

Proof of Proposition 7:

For $c(e) = a + \frac{k}{2}e^2$, $c'(e) = ke, c''(e) = k$. We know that

$$Z = \alpha_1(D - e_1) + \alpha_2(D - e_2)$$

Lemma 2 shows that $\alpha_1 = \alpha_2$. Thus

$$Z = (3D - 2e_1 - e_2)\alpha_2$$

$$\begin{aligned} \frac{dZ}{dq} &= \frac{d}{dq}\Big[(3D - 2e_1 - e_2)\alpha_2)\Big] \\ &= ((3D - 2e_1 - e_2)\frac{d\alpha_2}{dq} - \alpha_2(\frac{2de_1}{dq} + \frac{de_2}{dq}) \quad q = t, s \end{aligned} \tag{2.56}$$

Change in α_2 can be written as

$$\frac{d\alpha_2}{dq} = \frac{\partial \alpha_2}{\partial e_1}\frac{de_1}{dq} + \frac{\partial \alpha_2}{\partial e_2}\frac{de_2}{dq} \quad q = t, s$$

Using (2.37), (2.38), (2.39), (2.40), (2.43) and (2.44),

$$\frac{d\alpha_2}{dt} = \frac{-\overline{\theta}}{R(4e_1 - e_2)^2} e_1 c''(e_1)[\frac{N}{M}]$$

and

$$\frac{d\alpha_2}{ds} = \frac{-\overline{\theta}}{R(4e_1 - e_2)^2} e_2 c''(e_2)[\frac{V}{I}]$$

Observe that $c''(e_i) = k$, and, at $s = t = 0$, $I = M$ and $e_2 V = e_1 N$. Thus

$$\frac{d\alpha_2}{ds}|_{s=0} = \frac{d\alpha_2}{dt}|_{t=0} < 0$$

From (2.40), (2.46) and (2.56), it follows

$$\frac{dZ}{ds}|_{s=0} < \frac{dZ}{dt}|_{t=0} \tag{2.57}$$

QED.

Chapter 3

Market versus Socially Optimal Provision of Environmental Quality: Policy Alternatives

3.1 Introduction

In the last chapter, the cost of cleanup activity was assumed to be independent of the volume of output. Under such costs, a market equilibrium with fully covered markets and both firms producing positive cleanup levels, does not exist (Lemma 1 of chapter 2). In this chapter, we generalize the cost assumption by assuming that the cost of cleaning increases with the volume of production.[1] This cost assumption enables us to study an equilibrium, where the entire market is served (fully covered market) by the two firms. This formulation is especially relevant for the study of polluting commodities, like fuel, which are essential for

[1] Cremer and Thisse (1999) assume a similar condition on cost and analyze fully covered markets. They focus on the implications of commodity taxation on the market structure. Assuming that if all variants are priced at their marginal cost, each consumer's most preferred quality is the highest feasible quality, they find that a commodity tax may change the market structure, may increase the number of firms entering the market and thus may be welfare improving.

any household regardless of their income levels. Poor consumers collect firewood, others may use cleaner variants like kerosene or still cleaner varieties of kerosene.

For an economy, the marginal damage from an increase in pollution depends upon several factors, e.g., existing levels of pollution, sensitivity of the society towards pollution, etc. The societies may, therefore, differ in terms of damage from additional units of pollution. In this chapter, we highlight the role played by the intensity of environmental externality in determining the optimal policy. We find that the relationship between the affordability of clean environment (determined by income distribution) and the damage parameter plays an important role in deciding the appropriate environmental policy.

The chapter first solves for the socially optimal cleanup levels and then the market solution. It shows that the market equilibrium can sustain two qualities, even when the market is fully covered. While comparing, the market solution with the first best, it finds that though consumers' concern for the environment induces firms to abate pollution, the provision of environmental quality may still be sub-optimal. Other things being equal, consumers prefer (are willing to pay more for) clean goods to polluting goods and hence, internalize a part of the pollution externality. As a result firms gain market share by investing in cleaner activities. Moreover, by providing a good that is cleaner than that of its rival, a firm can strengthen its market position. Hence cleaning up becomes a strategic variable. In the market with oligopolistic competition, a firm may even clean up more than a social planner would prefer. In such a world, environmental policy works out fundamentally different than in the standard model in the literature.

We, therefore, explore the implications of various government policies adopted to control pollution. Specifically we study commodity tax, commodity subsidy, emission tax and specific tax. We find that the provision of a uniform commodity subsidy improves the cleanup levels adopted by firms and reduces total pollution, while a uniform commodity tax has an opposite effect. While doing welfare analysis, we find that *the pollution damage parameter* crucially decides whether a commodity tax is welfare improving or welfare reducing. A small uniform commodity tax is welfare improving, if and only if the pollution damage parameter is sufficiently small. Otherwise, a small uniform commodity subsidy is welfare improving. Further, total pollution increases with a tax policy and reduces with a subsidy policy. The chapter also argues that a uniform tax/subsidy policy cannot reach the first best levels.

A commodity tax reduces the marginal benefit of cleaning for both firms. This induces them to reduce the cleanup levels to bring marginal cost in line with marginal benefit. Thus quality deteriorates in equilibrium. Since we are focusing on fully covered markets, the aggregate demand is totally inelastic and therefore, total pollution is determined solely by per unit pollution.

There are two sources of distortions that make the market solution different from the social optimum, viz., market imperfection and the environmental externality. The effect of these distortions in bringing a divergence between the market solution and the social optimum is in the opposite direction.[2] The welfare effects of any policy instrument depend upon its effect on the interplay of these two distortions. A commodity tax reduces the distortion caused by the duopoly market but increases the distortion due to the externality. The optimal policy is determined by examining which one of the two (distortions) dominates. When intensity of negative externality is sufficiently small, the distortion due to the duopoly power of the firms dominates the distortion due to the externality factor and a small commodity tax is welfare improving. However, as the intensity of negative externality increases from a low to a high value (i.e., when distortion due to the externality dominates the other distortion) the optimal policy shifts from a tax to a subsidy policy.

Cremer and Thisse (1999) have a similar model where the tax operates through increasing the number of firms and, hence, reducing the distortion caused by oligopolistic markets. However, what we are arguing is that with little, or no negative externality, the tax is sufficient to get rid of the distortion through its effect on the quality of the environment good produced. Allowing entry reinforces this effect. On the other hand, in our model, we get the additional result that when negative externalities are strong, subsidies are better

[2]Contrast this with the previous chapter, where both the distortions were in the same direction and reinforced each other.

than taxes.

In the environment literature, a major focus has been on emission tax. It is a natural policy option when the only distortions present in the economy are generated by pollution externalities. However, in the presence of more than one source of distortions, it may not be the best policy instrument. Imposition of an optimal emission tax in our model, removes completely the distortion due to the externality and keeps the distortion due to the duopoly power of the firms unaffected. We demonstrate conditions under which a commodity tax dominates an emission tax. Thus emission tax may not always be the best policy in the class of second best instruments.

Rest of the chapter is planned as follows. The model is described in section 3.2. Section 3.3 solves for the constrained social optimum. The market equilibrium is analyzed in section 3.4. Section 3.5 examines government intervention in the form of commodity tax/ subsidy and solves for the optimal second best policy. Emission tax and specific tax are studied in sections 3.6 and 3.7 respectively. Section 3.8 contains the concluding remarks. The Appendix contains the proofs.

3.2 The Model

Except for a few assumptions and notations, the model formulation is the same as in chapter 2. Instead of repeating the model, we highlight the difference from the last chapter. For completeness, we restate the assumptions.

A.3.1: $C(e,q) = qc(e)$, *where* $c(e) = ke^2/2, \quad k > 0,\ 0 \leq e \leq D.$

where $C(e,q)$ denotes the total cost of the cleaning activity, where q is the output of a firm.

A.3.2: *θ is distributed uniformly over $[\underline{\theta}, \overline{\theta}]$, and the distribution of θ is denoted $F(\theta)$.*

A.3.3: $(9/5)\underline{\theta} > \overline{\theta}$.

A.3.1 is a generalization of A.2.1. Recall that in chapter 2, the cost of cleanup activity was independent of the output produced and further, $c(0) \geq 0$. In this chapter, the cost of cleaning activity increases with the number of units produced and $c(0) = 0$. It would become evident later that A.3.3 along with A.3.1, guarantees that the market is fully covered for any quality choice of duopolists.

Utility of a consumer is given by

$$U = y + v + \theta(y)e_i - p_i - \xi Z(.) \tag{3.1}$$

In the current formulation, the indicator function (as defined in equation (2.1)), always takes value 1. This is because, this chapter focuses on fully covered markets. For the market to be fully covered, the consumer with the least income, should enjoy a non-negative surplus from buying this product. We will show that in equilibrium this is true. $\xi \geq 0$ is the marginal negative externality, i.e., the disutility or the damage caused by a unit increase in the level of pollution. In equation (2.1), ξ takes value 1.

Without loss of generality, we assume that $e_1 \geq e_2$. We proceed by first solving the planner's problem and then the market equilibrium.

3.3 Constrained Social Optimum

While analyzing planner's problem, we restrict the number of qualities produced to two, and also assume that all the consumers are served. This is because, while solving for the market outcome, we are analyzing a duopoly, in a situation where the market is fully covered.[3] Since we have imposed these constraints on the optimization exercise of the planner, we call the solution as *the constrained social optimum.*

The planner maximizes aggregate welfare, given the utility function of the consumers and the cleanup costs. Aggregate welfare is defined as the aggregate of utilities derived by

[3]The assumption of two qualities in the market can be supported by assuming that fixed costs are such that a maximum of two qualities can be sustained in equilibrium (Shaked and Sutton, 1982).

consumers (inclusive of the negative externality caused by pollution) less the cost incurred on cleanup. The planner determines the proportion of consumers buying each quality and the cleanup levels.

Define θ_H as the marginal consumer, for whom the society is indifferent between which variant of the product she consumes. It follows that all consumers with $\theta > \theta_H$ contribute a higher surplus to the welfare by consuming the better quality product. For the description of θ_H to be meaningful, the following inequality must hold:

$$\underline{\theta} \leq \theta_H < \overline{\theta} \tag{3.2}$$

The measure of consumers, consuming the product with cleanup level e_1 is given by $\int_{\theta_H}^{\overline{\theta}} dF(\theta)$, and that of e_2 is given by $\int_{\underline{\theta}}^{\theta_H} dF(\theta)$. The aggregate welfare is given by

$$W(\theta_H, e_1, e_2) = \int_{\underline{\theta}}^{\theta_H} (\theta e_2 - c(e_2))dF(\theta) + \int_{\theta_H}^{\overline{\theta}} (\theta e_1 - c(e_1))dF(\theta) - \xi Z \tag{3.3}$$

Using A.3.2, Z, is measured by

$$Z = \frac{\overline{\theta} - \theta_H}{\overline{\theta} - \underline{\theta}}(D - e_1) + \frac{\theta_H - \underline{\theta}}{\overline{\theta} - \underline{\theta}}(D - e_2) \tag{3.4}$$

where $(D - e_i)$, $i = 1, 2$, is the pollution generated per unit of output by firm i with cleanup e_i. The pollution level Z, uniformly damages each consumer. This is evident in the externality parameter ξ, which is the same for all consumers. Notice that consumers' perception about ξ remains passive as it is not taken into account when they exercise their choice, whereas the planner takes explicit account of ξ while formulating its policies. Substituting the expression for Z from (3.4) in (3.3), and using A.3.2, welfare can be written as

$$\begin{aligned} W = \frac{1}{R}\Big[&\frac{e_2}{2}(\theta_H^2 - \underline{\theta}^2) - c(e_2)(\theta_H - \underline{\theta}) + \frac{e_1}{2}(\overline{\theta}^2 - \theta_H^2) - c(e_1)(\overline{\theta} - \theta_H) \\ &-\xi\Big((D - e_1)(\overline{\theta} - \theta_H) + (D - e_2)(\theta_H - \underline{\theta})\Big)\Big] \end{aligned} \tag{3.5}$$

where

$$R \equiv \overline{\theta} - \underline{\theta} \tag{3.6}$$

The planner maximizes W with respect to θ_H, e_1 and e_2, subject to the constraints

$$0 \leq e_i \leq D, \ \ i = 1, 2 \tag{3.7}$$

$$\underline{\theta} \leq \theta_H < \overline{\theta} \tag{3.8}$$

Assuming interior solutions, the necessary first order conditions are [4]

$$\frac{\partial W}{\partial \theta_H} = 0 \Rightarrow -\theta_H(e_1 - e_2) - \xi(e_1 - e_2) + c(e_1) - c(e_2) = 0 \tag{3.9}$$

$$\frac{\partial W}{\partial e_1} = 0 \Rightarrow \frac{\overline{\theta} + \theta_H}{2} - c'(e_1) + \xi = 0 \tag{3.10}$$

$$\frac{\partial W}{\partial e_2} = 0 \Rightarrow \frac{\theta_H + \underline{\theta}}{2} - c'(e_2) + \xi = 0 \tag{3.11}$$

The solution to the above system of equations is

$$\theta_H^* = \frac{\overline{\theta} + \underline{\theta}}{2} \tag{3.12}$$

$$e_1^* = \frac{1}{b}(\frac{3\overline{\theta} + \underline{\theta}}{4} + \xi) \tag{3.13}$$

$$e_2^* = \frac{1}{k}(\frac{\overline{\theta} + 3\underline{\theta}}{4} + \xi) \tag{3.14}$$

where * denotes the value of the variable in equilibrium. This solution will be referred to as *constrained social optimum (CSO)* in rest of the chapter.

Proposition 1: *Let A.3.1-A3.3 hold.*

(i) There exists an interior solution for low values of ξ.

(ii) In the interior solution, two qualities are produced and the proportion of consumers consuming the two qualities are the same.

However for sufficiently high values of ξ, it is socially optimal to cleanup the entire amount of pollution.

Proof: The proof is in the Appendix.

[4]It can be checked that second order conditions are met at the equilibrium.

For rest of the analysis, we focus on interior solutions. Let e^a denote the average cleanup level. The average cleanup level in the CSO is given by

$$e^{a^*} = \frac{1}{k}(\frac{\overline{\theta} + \underline{\theta}}{2} + \xi)$$

The total pollution in the CSO is given by

$$Z^* = D - \frac{1}{k}(\frac{\overline{\theta} + \underline{\theta}}{2} + \xi) \tag{3.15}$$

From (3.13) and (3.14), it is straightforward to obtain the degree of differentiation between two qualities.

$$e_1^* - e_2^* = \frac{\overline{\theta} - \underline{\theta}}{2k} \tag{3.16}$$

The welfare at the optimal cleanup levels can be evaluated by plugging the values of e_1^*, e_2^*, θ_H^*, and Z^* from (3.13), (3.14), (3.12) and (3.15) respectively, in the expression for welfare as given in (3.5),

$$W^* = \frac{1}{32k}(5\overline{\theta}^2 + 5\underline{\theta}^2 + 6\overline{\theta}\underline{\theta}) - \xi(D - \frac{\overline{\theta} + \underline{\theta}}{2k}) + \frac{\xi^2}{2k} \tag{3.17}$$

The CSO given in this section serves as the benchmark case for comparisons in later analysis. In the next section we describe the market equilibrium with two firms.

3.4 Market Equilibrium

Suppose in equilibrium, all the consumers buy good x. This means that the equilibrium prices are such that even a consumer with the least preference parameter enjoys a positive surplus from buying the good. As will become evident later, this is guaranteed by A.3.3.

The consumer may buy either from firm 1 or firm 2. A consumer of type θ is indifferent between the two qualities at the prevailing prices, if $\theta e_1 - p_1 = \theta e_2 - p_2$. Let $\theta_1 \equiv [(p_1 - p_2)/(e_1 - e_2)]$. It follows that all $\theta > \theta_1$ consumers will prefer the output from firm 1 to firm 2. Given that the total population of consumers is normalized to unity, the market share of each firm is the proportion of people buying from that firm. Using A.3.2, $e_1 \geq e_2$, and the definition of θ_1, the market share of firm i, α_i, $i = 1, 2$, is given by

$$\alpha_1 = \int_{\theta_1}^{\overline{\theta}} dF(\theta) = \frac{1}{R}(\overline{\theta} - \theta_1) = \frac{1}{R(e_1 - e_2)}(\overline{\theta}(e_1 - e_2) - p_1 + p_2) \tag{3.18}$$

$$\alpha_2 = \int_{\underline{\theta}}^{\theta_1} dF(\theta) = \frac{1}{R}(\theta_1 - \underline{\theta}) = \frac{1}{R(e_1 - e_2)}(p_1 - p_2 - (e_1 - e_2)\underline{\theta}) \tag{3.19}$$

where $R = \overline{\theta} - \underline{\theta}$ as defined in section 2.

We solve for the equilibrium, exactly in the same way as in section 2.2 of chapter 2. That is, we first solve the second stage equilibrium prices and then first stage choice of cleanup levels.

The Second Stage Price Game

Let π_i be the second stage profit of firm $i, i = 1, 2$. In this stage, firms compete in prices, for given choices of e_1 and e_2.

$$\pi_i = \alpha_i(p_i - c(e_i)), \quad i = 1, 2 \tag{3.20}$$

Following a similar line of argument as in Lemma 1 of chapter 2, it can be shown that $e_1 > e_2$ in the first stage equilibrium. Therefore, now on $e_1 > e_2$.

The necessary conditions for an interior solution are, $(d\pi_i/dp_i) = 0$, $i = 1, 2$. Using (3.18) and (3.19),

$$\overline{\theta}(e_1 - e_2) - 2p_1 + p_2 + c(e_1) = 0 \tag{3.21}$$

$$p_1 - 2p_2 - (e_1 - e_2)\underline{\theta} + c(e_2) = 0 \tag{3.22}$$

Equilibrium prices in the second stage, given the emission levels, are

$$p_1 = \frac{(e_1 - e_2)(2\overline{\theta} - \underline{\theta}) + 2c(e_1) + c(e_2)}{3} \tag{3.23}$$

$$p_2 = \frac{c(e_1) + 2c(e_2) - (e_1 - e_2)(2\underline{\theta} - \overline{\theta})}{3} \tag{3.24}$$

The First Stage Choice of Abatement Levels

Let Π_i denote the first stage profit expression for firm $i, i = 1, 2$. In the first stage, the firms choose the emission levels. Using (3.23) and (3.24) in (3.18)-(3.20), we can write the first stage demand and profit for each firm wholly in terms of e_1 and e_2.

$$\alpha_1 = \frac{1}{6R}\Big((4\overline{\theta} - 2\underline{\theta}) - k(e_1 + e_2)\Big) \tag{3.25}$$

$$\alpha_2 = \frac{1}{6R}\Big(k(e_1 + e_2) - (4\underline{\theta} - 2\overline{\theta})\Big) \tag{3.26}$$

$$\Pi_1 = \frac{1}{36R}(e_1 - e_2)[4\overline{\theta} - 2\underline{\theta} - k(e_1 + e_2)]^2 \tag{3.27}$$

$$\Pi_2 = \frac{1}{36R}(e_1 - e_2)[k(e_1 + e_2) - 4\underline{\theta} + 2\overline{\theta}]^2 \tag{3.28}$$

Assuming interior solutions, the necessary and sufficient conditions for profit maximization. $[d\Pi_i(e_1, e_2)/de_i] = 0,\ i = 1, 2$, imply the following expressions:

$$(4\overline{\theta} - 2\underline{\theta}) - 3ke_1 + ke_2 = 0$$

$$(4\underline{\theta} - 2\overline{\theta}) + ke_1 - 3ke_2 = 0$$

Let a superscript ^ denote the value of the variable in equilibrium. The solution to the above system of equations gives us the equilibrium cleanup levels

$$\hat{e_1} = \frac{5\overline{\theta} - \underline{\theta}}{4k} \tag{3.29}$$

$$\hat{e_2} = \frac{5\underline{\theta} - \overline{\theta}}{4k} \tag{3.30}$$

Given A.3.3, it can be easily verified that $\hat{e_1} > \hat{e_2} > 0$.[5]

The degree of differentiation, given by the gap between the two variants is given by

$$\hat{e_1} - \hat{e_2} = \frac{3(\overline{\theta} - \underline{\theta})}{2k} \tag{3.31}$$

[5] In the Appendix (just after the proof of Proposition 1), we show that in equilibrium the market is fully covered.

The equilibrium prices can be obtained by using A.3.1, (3.29) and (3.30) in (3.23) and (3.24)

$$\hat{p_1} = \frac{1}{32k}[49\overline{\theta}^2 + 25\underline{\theta}^2 - 58\overline{\theta}\underline{\theta}] \qquad (3.32)$$

$$\hat{p_2} = \frac{1}{32k}[25\overline{\theta}^2 + 49\underline{\theta}^2 - 58\overline{\theta}\underline{\theta}] \qquad (3.33)$$

Substituting e_1 and e_2 from (3.29) and (3.30), in (3.25)-(3.28), we get the demand for two firms as well as profit obtained by them,

$$\alpha_1 = \alpha_2 = \frac{1}{2}$$

$$\Pi_1 = \Pi_2 = \frac{3}{8k}(\overline{\theta} - \underline{\theta})^2$$

Thus

Proposition 2: *Let A.3.1-A.3.3 hold. In equilibrium, the firms share the same size of the market and enjoy the same level of profit.*

It is interesting to note that irrespective of the quality produced, price and cleanup levels adjust in such a manner that both firms share the market equally and also enjoy the same profit. The result can be explained by noting that if the firm with a better cleanup level tries to capture a greater size of the market, its costs also increase proportionately. This dampens its incentives to cover a larger size of the market. Note that the nature of competition is such that firms differentiate because the duopoly competition demands it and not because the cleaner firm obtains a higher profit by producing the better quality product. Thus firms are indifferent as to which quality variant of the product they are producing as long as they are differentiating their product.

Consumer Surplus and Consumer Welfare

The consumers get segmented by θ_1. Consumer surplus Σ can be measured as the sum of the surplus enjoyed by the consumers with $\underline{\theta} \leq \theta < \theta_1$ and $\theta_1 \leq \theta < \overline{\theta}$. Thus

$$\Sigma = \int_{\theta_1}^{\overline{\theta}} (\theta e_1 - p_1) dF(\theta) + \int_{\underline{\theta}}^{\theta_1} (\theta e_2 - p_2) dF(\theta) \qquad (3.34)$$

Substituting the values for $e_i, i = 1, 2$ from (3.29)-(3.30) and $p_i, i = 1, 2$ from (3.23)-(3.24) and using A.2, Σ takes the following value in the equilibrium,

$$\begin{aligned}\hat{\Sigma} &= \frac{1}{64k}(62\overline{\theta}\underline{\theta} - 19\overline{\theta}^2 - 27\underline{\theta}^2) + \frac{1}{64k}(62\overline{\theta}\underline{\theta} - 27\overline{\theta}^2 - 19\underline{\theta}^2) \\ &= \frac{1}{32k}(62\overline{\theta}\underline{\theta} - 23\overline{\theta}^2 - 23\underline{\theta}^2) \qquad (3.35)\end{aligned}$$

Observe that consumers consuming the low-quality good (i.e., consumers at the lower end of the income distribution) derive a lower consumer surplus as compared to the consumers consuming the high-quality good. This can be explained by the difference in their incomes.

In equilibrium, the total pollution generated is

$$\hat{Z} = \alpha_1(D - e_1) + \alpha_2(D - e_2) = D - \frac{\overline{\theta} + \underline{\theta}}{2k} \qquad (3.36)$$

Comparison of Market Outcome with the CSO

Proposition 3: *Let A.3.1-A.3.3 hold. In the market solution:*

(i) For $\xi = 0$, the cleaner firm overcleans and the dirty firm undercleans compared to the CSO; however, the total pollution is the same as in the CSO,

(ii) For $\xi > 0$, cleaner firm may or may not overclean, but the dirty firm always undercleans, and the total pollution is always higher,

(iii) The degree of differentiation is higher than in the CSO for all values of ξ.

Competing in a duopoly market, firms differentiate themselves to maximize profit. Thus degree of differentiation is much higher in a market solution. Surprisingly for $\xi = 0$, the total pollution generated (or the average cleanup levels) in a market solution is same as that generated in the first best. It can be explained by noting that when $\xi = 0$, there is only one source of distortion, i.e., the oligopoly power of firms and the distortion due to the externality factor is absent. Thus there is no discrepancy in the level of pollution. However similar level of pollution is achieved at a much higher cost, lowering the welfare.

The other source of distortion is the externality caused by pollution. While maximizing utility, consumers do not take into account the effect of their actions on the utility of other consumers. This causes an externality and therefore, all the consumers suffer a utility loss. Also we find that for low levels of ξ ($\xi \leq [(\overline{\theta} - \underline{\theta})/2]$), e_1^* continues to be lower than $\hat{e_1}$, but for $\xi > [(\overline{\theta} - \underline{\theta})/2]$, e_1^* is higher than $\hat{e_1}$. However $\hat{e_2}$ is always less than e_2^*. Moreover the gap between the two qualities is always higher in the market solution as compared to the CSO. We also find that the higher the value of ξ, greater is the divergence between the market and the socially optimal level of pollution. This can be better understood through Figure 3.1.

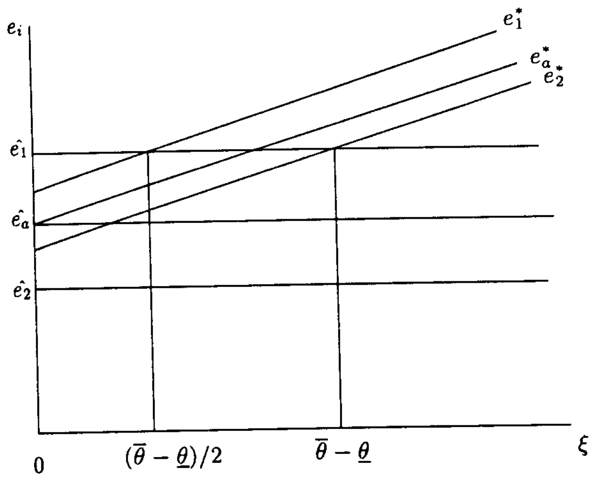

Figure 3.1: Comparing market solution with the socially optimal outcome

This comparison brings to the surface, the conflict between the environmentalists and the benevolent governments. Each agent looks from the point of view of her own objective and the objectives may not coincide. Figure 3.1 shows that from a social point of view, for low values of ξ, the cleanup level of the high quality firm should actually be brought down rather than being raised. However the preoccupation of environmental lobbies is to pressurise for policies, which improve the cleanup levels. Improving the environmental quality, in general, may not always be welfare improving. Thus environmental regulation is a much more complex process than it may initially seem and requires a sophisticated analysis. There is a need to study various government policies and their implications on the environment as well as welfare. Recall ξ is the externality caused by a unit of pollution, and θ captures the extent of internalization. It will be shown that the relationship between ξ

and θ, or the extent to which the environmental externality is internalized, is an important factor in determining the optimal policy.

One can find a role for government due to the mentioned distortions in the market solution. In subsequent sections, we first examine the implications of various government policies on environment as well as welfare, then, we make an attempt to rank these instruments. Specifically we consider commodity tax/subsidy, emission tax and specific tax. Along with environmental and welfare implications, we also highlight political economy issues associated with each instrument. In the next section, we examine commodity taxes and subsidies.

3.5 Commodity Tax/Subsidy

In this section, we examine implications of two government policies, viz., imposition of commodity taxes and provision of commodity subsidies to the firms.

Let t_i be a commodity tax (i.e., a per-unit tax, which is proportional to the price level) on firm i, $i = 1, 2$. The profit functions become

$$\begin{aligned} \Pi_1(t_1) &= [(1 - t_1)p_1 - c(e_1)]\alpha_1 \\ \Pi_2(t_2) &= [(1 - t_2)p_2 - c(e_2)]\alpha_2 \end{aligned}$$

Assuming markets are fully covered, $\alpha_i, i = 1, 2$ are same as in (3.18)-(3.19). Following Cremer and Thisse (1999), these equations can also be written as

$$\begin{aligned} \Pi_1(\tau_1) &= \frac{1}{\tau_1}(p_1 - \tau_1 c(e_1))\alpha_1 \\ \Pi_2(\tau_2) &= \frac{1}{\tau_2}(p_2 - \tau_2 c(e_2))\alpha_2 \end{aligned}$$

where $\tau_i \equiv [1/(1 - t_i)], i = 1, 2$. The use of τ_i instead of t_i simplifies the presentation. Also, we can generalize the description by using τ_i. For instance, $\tau_i = 1, i = 1, 2$ corresponds to the no intervention case. $\tau_i > 1$ implies a positive tax on firm i, while $\tau_i < 1$ corresponds to a subsidy provided to firm i.

From now on, we will represent (τ_1, τ_2) by τ. Proceeding in the same fashion as in the previous section, we first solve for the second stage equilibrium prices and then for the first stage equilibrium choices of $e_1(\tau)$ and $e_2(\tau)$.

Solving for the second stage equilibrium prices in the same way as in section 3.4, equations (3.23), (3.24) and substituting them in the first stage profit expression, we obtain

$$\Pi_1(e_1, e_2, \tau) = \frac{1}{36R(e_1 - e_2)}[(e_1 - e_2)(4\overline{\theta} - 2\underline{\theta}) - k\tau_1 e_1^2 + k\tau_2 e_2^2]^2 \quad (3.37)$$

$$\Pi_2(e_1, e_2, \tau) = \frac{1}{36R(e_1 - e_2)}[k\tau_1 e_1^2 - k\tau_2 e_2^2 - (e_1 - e_2)(4\underline{\theta} - 2\overline{\theta})]^2 \quad (3.38)$$

The necessary first order conditions for an interior solution are

$$\frac{\partial \Pi_i}{\partial e_i} = 0, i = 1, 2$$

which imply the following equations:

$$(e_1 - e_2)(4\overline{\theta} - 2\underline{\theta}) - 4k\tau_1 e_1(e_1 - e_2) + k\tau_1 e_1^2 - k\tau_2 e_2^2 = 0 \quad (3.39)$$

$$(e_1 - e_2)(4\underline{\theta} - 2\overline{\theta}) - 4k\tau_2 e_2(e_1 - e_2) + k\tau_1 e_1^2 - k\tau_2 e_2^2 = 0 \quad (3.40)$$

With a general τ, we cannot explicitly solve for equilibrium e_1 and e_2. As a special case, let us consider $\tau_1 = \tau_2 = \tau_u$. This corresponds to the adoption of a uniform government policy.

Plugging $\tau_1 = \tau_2 = \tau_u$ in (3.37) and (3.38), and noting that $e_1 > e_2$, the first stage profit functions are[6]

$$\Pi_1(e_1, e_2, \tau_u) = \frac{(e_1 - e_2)}{36R}[2(2\overline{\theta} - \underline{\theta}) - k\tau_u(e_1 + e_2)]^2 \quad (3.41)$$

$$\Pi_2(e_1, e_2, \tau_u) = \frac{(e_1 - e_2)}{36R}[k\tau_u(e_1 + e_2) - 2(2\underline{\theta} - \overline{\theta})]^2 \quad (3.42)$$

Equilibrium choice of cleanup activity is obtained by maximizing Π_1 and Π_2 as given in (3.41) and (3.42), with respect to $e_i, i = 1, 2$, respectively. Let $e_1(\tau_u)$ and $e_2(\tau_u)$ be the

[6]It can be checked that under A.3.3, markets are fully covered with a uniform commodity tax/subsidy imposed on both firms.

equilibrium outcomes. Then

$$e_1(\tau_u) = \frac{5\overline{\theta} - \underline{\theta}}{4k\tau_u} \tag{3.43}$$

$$e_2(\tau_u) = \frac{5\underline{\theta} - \overline{\theta}}{4k\tau_u} \tag{3.44}$$

The degree of differentiation between the two qualities

$$e_1(\tau_u) - e_2(\tau_u) = \frac{3(\overline{\theta} - \underline{\theta})}{2\tau_u k}$$

Proposition 4: *Let A.3.1-A.3.3 hold. An increase in* τ_u

(i) reduces the cleanup efforts by both firms,

(ii) keeps constant the demand for each firm,

(iii) reduces the profit of both firms,

(iv) reduces the consumer surplus enjoyed by the consumers,

(v) increases the total pollution

(vi) reduces the gap between the two qualities.

A reduction in τ *has an opposite effect.*

Proof: The proof is given in the Appendix.

Recall $\tau = 1$, implies no intervention and an increase in τ from this level ($\tau_u > 1$) implies a uniform commodity tax. For the choice of emission levels, an increase in τ_u increases the marginal cost of cleanup, keeping the marginal benefit constant. To equate marginal benefit to marginal cost, firms have to reduce the cleanup levels. Since both firms are taxed at the same rate and the entire market is covered, firms continue to share the market equally. Reduced environmental quality increases total pollution. With the imposition of a tax, prices also fall, however the fall in the prices is less than the fall in quality levels. Consequently consumer surplus also falls. Profits enjoyed by both firms also fall.

Similarly $\tau_u < 1$, implies that the government decides to provide an incentive in the form of a uniform subsidy to both firms. In the case of a subsidy as against a tax, the direction of change of all the variables is reversed. A commodity subsidy provided to both firms reduces the cost, keeping the benefit same. This induces both firms to increase their cleanup levels. Now they can charge a higher price for the improved environmental quality. However the increase in cleanup levels is greater than the increase in prices. Thus consumers enjoy a greater consumer surplus. The improved cleanup levels together with constant output bring down pollution. Thus subsidy policy improves the overall environment and tax policy deteriorates it.

Proposition 4 tells us the direction of change of the various components of aggregate welfare in response to the two policies. The question then arises, does aggregate welfare also move in the same direction with the two policies analyzed?

Recall that the market is fully covered and θ_1 segregates the consumer between two qualities. The expression for aggregate welfare in the current scenario (implementable through market) can be obtained by replacing θ_H by θ_1, in (3.5). Throughout the analysis, it is assumed that collected tax revenue is distributed back to the consumers in a non-distortionary way. Thus

$$\begin{aligned} W &= \frac{1}{R}\Big[(\theta_1 - \underline{\theta})(\theta_1 + \underline{\theta} - ke_2)\frac{e_2}{2} + (\overline{\theta} - \theta_1)(\overline{\theta} + \theta_1 - ke_1)\frac{e_1}{2}\Big] \\ &\quad - \frac{\xi}{R}[(D - e_1)(\overline{\theta} - \theta_1) + (D - e_2)(\theta_1 - \underline{\theta})] \end{aligned} \qquad (3.45)$$

is a generalised welfare function. We can study the effect of different policy instruments on welfare, by plugging in the equilibrium expressions for e_1, e_2 and θ_1 under different policies in (3.45).

Proposition 5: *Let A.3.1-A.3.3 hold. Further, let aggregate welfare be defined as in (3.45)*

[7] Recall that in chapter 2, we had defined aggregate welfare as the sum of the profit obtained by each firm, consumer surplus enjoyed by the consumers and government's budget surplus G less negative externality from pollution. That is

$W = \Pi_1 + \Pi_2 + \Sigma + G - \xi Z$

where G denotes budget surplus. Since, we can get closed form solutions for $e_i, i = 1, 2$, in the current chapter, we can measure aggregate welfare directly. It can be checked that we obtain the same expression for the welfare, using either of these two ways.

and

$$\xi_{min} \equiv \frac{3(\overline{\theta} - \underline{\theta})^2}{4(\overline{\theta} + \underline{\theta})}. \tag{3.46}$$

A small uniform tax improves the aggregate welfare if and only if $\xi < \xi_{min}$.

A small uniform subsidy improves aggregate welfare if and only if $\xi > \xi_{min}$

Proof: The proof is in the Appendix.

It is interesting to note that though cleanup levels adopted by both firms, their profit as well as consumer surplus fall with the imposition of a uniform tax and rise with a uniform subsidy, aggregate welfare moves in the opposite direction for small values of externality parameter ξ.

Recall the comparison of the market outcome with the first best. The market solution is different from the CSO due to two reasons. One is the inefficiency arising from the oligopolistic powers of the firm and the other is the negative (environmental) externality arising from the production of x. It is interesting to find that in this model, the effect of these two distortions is in opposite direction. Welfare effects of a policy depend upon its net effect on the two distortions. Though a commodity tax increases the distortion due to the externality, it reduces the distortion caused by the market imperfection. Therefore, for a sufficiently small intensity of negative externality, a commodity tax is welfare improving. A similar argument explains welfare effects of a subsidy.

Figure 3.2 shows that for a small ξ, aggregate welfare improves with a small tax. However for a large ξ, aggregate welfare falls with the imposition of a tax.

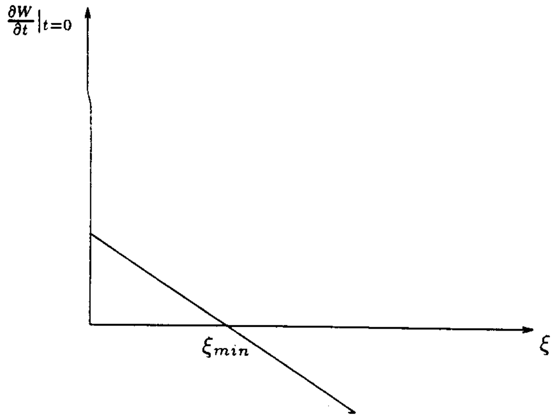

Figure 3.2: Welfare effects of a small tax as a function of pollution damage parameter

Second Best

Proposition 6: *Let A.3.1-A.3.3 hold. The optimal second best policy is a tax for $\xi < \xi_{min}$, a subsidy for $\xi > \xi_{min}$. Further, the optimal policy is given by*

$$\tau_u^* \equiv \frac{13\overline{\theta}^2 + 13\underline{\theta}^2 - 10\overline{\theta}\underline{\theta}}{7\overline{\theta}^2 + 7\underline{\theta}^2 + 2\overline{\theta}\underline{\theta} + 8\xi(\overline{\theta} + \underline{\theta})}$$

The optimal policy follows directly from looking at the welfare effects. While tax is an optimal policy when the distortion due to the oligopoly power of the firms dominates the distortion due to the environmental externality, subsidy is an optimal policy when opposite is the case. It is immediate from (3.66) that for $\xi = \xi_{min}$, the effects due to two distortions offset each other completely, and *no intervention* is the optimal policy. Figure 3.3 illustrates the optimal policy as a function of ξ.

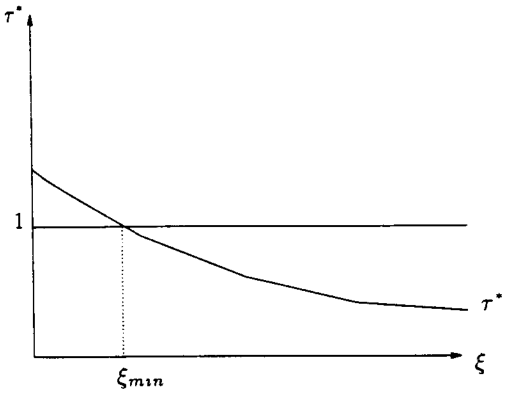

Figure 3.3: Optimal Commodity Policy as a Function of x

For a given income distribution, whether a tax or a subsidy policy is welfare enhancing crucially depends upon the externality parameter ξ. As ξ increases from a low value to a high value, the optimal policy shifts from a tax to a subsidy policy.

Proposition 7: *Let A.3.1-A.3.3 hold. Under welfare maximizing governments, cleanup levels increase as ξ increases.*

Proof: Proof follows from substituting the expression for optimal (second best) policy variable from (3.66) in (3.43) and (3.44).

Proposition 6 shows that whether a tax or a subsidy is an optimal policy, depends upon the relationship between the willingness to pay and the pollution damage parameter. Proposition 7 further argues that irrespective of the fact that whether a uniform tax or a uniform subsidy is an optimal policy, under appropriately set policies, firms adopt cleaner technologies when the externality parameter ξ increases.

With the last two results obtained in this chapter, we can also address the issue of *harmonization of environmental policies* across countries. Often countries' environmental concerns are judged by whether they adopt a tax or a subsidy policy. Typically, subsidies are associated with a lax environmental policy and protection of domestic industries, and taxes are associated with a tough environmental policy. In contrast to this common association, our results suggest that the same instrument may not be appropriate for all societies and countries cannot be termed as tough or lenient based on their environmental policy. An optimal policy depends upon the sensitivity of a society towards pollution (measured by the pollution damage parameter) and its affordability of clean environment (measured by income distribution). In developed nations (local) pollution levels have already been brought under control, therefore, the marginal cost of pollution to the society may be low, resulting in a low ξ. On the other hand, developing countries are facing the problem of heavy pollution, causing ξ to be high. In this scenario, the policy prescriptions for the two sets of countries would differ. A policy instrument, therefore, cannot be considered in isolation and must be evaluated taking into account the overall perspective.

Another strand of comparison is the gap between e_1 and e_2. The gap between e_1 and e_2 reduces with a tax and increases with a subsidy. This is because with the imposition of a uniform tax, both e_1 and e_2 fall, but the absolute fall in e_1 is more than the fall in e_2. Thus gap between the two reduces. In the case of a uniform subsidy, both e_1 and e_2 increase but the absolute increase in e_1 is more than the absolute increase in e_2. Thus the gap between the two increases. Since subsidy is an optimal policy for certain ranges of ξ, it follows that reducing the gap between e_1 and e_2 is not always welfare improving. It should also be noted that ratio of e_1 to e_2 remains constant in a uniform policy regime.

Suppose the environmentalists demand that total pollution should be brought down to the level achieved under the CSO. It is interesting to investigate, does there exist a subsidy rate, which equates the two.

Corollary 1: *Let A.3.1-A.3.3 hold. Define*

$$s^{**} \equiv \frac{\xi}{\frac{\overline{\theta}+\underline{\theta}}{2}} \tag{3.47}$$

With a uniform $\tau_u^{**} \equiv (1/(1+s^{**}))$, *total pollution is equal to that achieved under CSO.*

Proof: Plugging τ_u^{**} in the expression for total pollution, it is easy to check the result. QED.

However, under s^{**}, the cleaner firm is cleaning more than that warranted by the CSO.

and the dirty firm is still undercleaning. The welfare achieved under s^{**} is less than the second best level of welfare. The result again highlights the tussle between environmentalists and benevolent governments.

Observe that as compared to the CSO, the firms differentiate more in a market solution and a uniform subsidy further increases the differentiation. Thus, it is not possible to achieve the cleanup levels achieved under CSO with a policy of uniform subsidy. Similarly we know that the cleanup levels fall with the imposition of a uniform tax and the clean up level of firm 2 is already lower than the socially optimum level, therefore, once again CSO level of cleanup for firm 2 cannot be achieved with a policy of uniform tax. Comparing (3.17) in the text and (3.67) in the Appendix, indeed, it can be checked that $W^* > W(\tau^*)$. We, therefore, continue to be in the second best world with a uniform commodity policy.

3.6 Emission Tax

In the environment literature, the major focus has been on emission taxes as an instrument for correcting environmental externalities. The effect of emission taxes has been analyzed both under perfectly as well as under imperfectly competitive market conditions. The various papers analyzing perfect competition are (Pigou, 1920; Baumol and Oates, 1988; Milliman and Prince 1989; Jung *et al.*, 1996 etc.) The papers dealing with market imperfection are Buchanan, 1969; Katsoulacos and Xepapadeas, 1996; Carraro and Soubeyran, 1996; Parry, Williams and Goulder 1999 etc. (see chapter 1).

Suppose the government imposes an emission tax t_e per unit of pollution as an instrument to control pollution.

Under emission tax, A.3.3 does not guarantee that the market is fully covered. To ensure that the market is fully covered, we assume something similar to A.3.3.

A.3.4: $16\underline{\theta}^2 - 25(\overline{\theta} - \underline{\theta})^2 > \xi[bD - (\xi/2) - \underline{\theta}]$

The first stage profit function, in the presence of an emission tax, becomes

$$\Pi_i(t_e) = \alpha_i[p_i - c(e_i) - t_e(D - e_i)], i = 1, 2$$

The demand for each firm, $\alpha_i, i = 1, 2$ is same as in (3.18) and (3.19).[8]

Solving the two stage non-cooperative Nash equilibrium in the same way as in section 3.3, we obtain a solution for the second stage prices, given by

$$p_1 = \frac{1}{3}\Big((e_1 - e_2)(2\overline{\theta} - \underline{\theta}) + 2c(e_1) + c(e_2) + 2t_e(D - e_1) + t_e(D - e_2)\Big) \quad (3.48)$$

$$p_2 = \frac{1}{3}\Big(c(e_1) + 2c(e_2) + t_e(D - e_1) + 2t_e(D - e_2) - (e_1 - e_2)(2\underline{\theta} - \overline{\theta})\Big) \quad (3.49)$$

The first stage profit functions become

$$\Pi_1 = \frac{1}{36R}(e_1 - e_2)\Big(4\overline{\theta} - 2\underline{\theta} - k(e_1 + e_2) + 2t_e\Big)^2 \quad (3.50)$$

$$\Pi_2 = \frac{1}{36R}(e_1 - e_2)\Big(k(e_1 + e_2) - 2t_e - (4\underline{\theta} - 2\overline{\theta})\Big)^2 \quad (3.51)$$

Assuming interior solution, the closed form solution for e_1 and e_2 are

$$e_1(t_e) = \frac{1}{k}\Big(t_e + \frac{5\overline{\theta} - \underline{\theta}}{4}\Big) \quad (3.52)$$

$$e_2(t_e) = \frac{1}{k}\Big(t_e + \frac{5\underline{\theta} - \overline{\theta}}{4}\Big) \quad (3.53)$$

The degree of differentiation is given by

$$e_1(t_e) - e_2(t_e) = \frac{3(\overline{\theta} - \underline{\theta})}{2k} \quad (3.54)$$

The other variables take the following values in the equilibrium.

$$\alpha_i = \frac{1}{2}, \; i = 1, 2 \quad (3.55)$$

$$\Pi_i = \frac{3}{8k}(\overline{\theta}^2 - \underline{\theta}^2), \; i = 1, 2 \quad (3.56)$$

[8]Recall that the market to be fully covered, the consumer with the least preference parameter enjoys a positive surplus from consuming the good x. To ensure that, A.3.3 is modified as following: $16\underline{\theta}^2 - 25(\overline{\theta} - \underline{\theta})^2 > t_e[kD - (t_e/2) - \underline{\theta}]$. The modification can be interpreted as the left hand side should now be greater than or equal to the net change in consumer surplus due to imposition of an emission tax. This is given by the difference between increase in price of the dirtier quality and increase in utility of the consumer with the least preference parameter due to imposition of an emission tax.

Proposition 8: *Assume A.3.1,A.3.2 and A.3.4. The imposition of a small emission tax* t_e *on both firms*

(i) improves the cleanup levels adopted by both firms, keeping the degree of differentiation constant

(ii) keeps the demand faced by each firm and profit obtained by firms constant

(iii) increases the price of both qualities

(iv) decreases the consumer surplus as well as consumer surplus inclusive of distributed tax revenue.

Proof: The proof follows directly from (3.52)-(3.56).

Observe that though the cleanup levels improve by imposition of an emission tax, profit of each firm remains unaffected. This happens because the firms are able to pass the increased cost of adopting better cleaning technologies to the consumers in the form of increased prices. Consumers enjoy higher cleanup levels by paying a higher price for it. The price-quality pair offered is such that they suffer a loss in consumer surplus.

There are two counteracting effects on welfare. The welfare improves due to the improved environmental quality resulting from the improved cleanup levels. However as seen in proposition 8, the welfare may reduce due to a fall in consumer surplus. Thus overall effect depends upon the relative strengths of these two effects. The next proposition proves that for $\xi > 0$, welfare improves with a small emission tax.

Proposition 9: *Let A.3.1, A.3.2 and A.3.4 hold. Imposition of a small emission tax is welfare improving for* $\xi > 0$. *The optimal tax is equal to the damage parameter* ξ. *The welfare achieved with the imposition of an optimal emission tax is less than that achieved under CSO.*

Proof: The proof is in the Appendix.

While doing welfare analysis, we find that overall welfare increases with the imposition of an emission tax. Producers' surplus remains unaffected and there is a fall in consumer surplus. The only welfare improving effect is in terms of improved environmental quality through the adoption of higher cleanup levels. Thus the optimal level of emission tax depends upon the intensity of negative externality ξ. More specifically, the optimal tax is equal to the externality parameter ξ.

We again refer to the two sources of distortion in the market solution. Imposition of an optimal emission tax completely removes the distortion due to the externality factor and keeps the other distortion, i.e., due to oligopoly power of the firms unaffected. Thus even with an emission tax, first best level of welfare cannot be reached. Notice emission tax is welfare improving if the externality parameter is strictly positive. This is not surprising because an emission tax is aimed at correcting the distortion due to excessive emissions and it is successful in removing that distortion. It does not affect the market otherwise. It is interesting to note that emission taxes were advocated in the literature on the contention that since firms are polluting they should be bearing the cost of cleanup. In a perfectly competitive market, at least a partial incidence of emission tax falls on the firms and they are not able to pass the entire cost of improving the environment to the consumers. However in our setting, we find that in the presence of emission taxes, firms' profits remain unaffected and they are able to pass the entire cost of improving the environment to the consumers. Thus in the presence of environmentally discerning consumers, the cost of improving the environment is borne by the consumers.

Proposition 10: *Let A.3.1-A.3.4 hold. Define* $\tilde{\xi} \equiv \frac{\sqrt{A}-2(\bar{\theta}+\underline{\theta})}{3}$, *where* $A \equiv 13\bar{\theta}^2 + 13\underline{\theta}^2 - 10\bar{\theta}\underline{\theta}$. *The level of welfare achieved with an optimal commodity tax is greater than that achieved by an optimal emission tax if and only if* $\xi < \tilde{\xi}$.

Proof: The proof is given in the Appendix.

A commodity taxation requires information on prices and quantities, whereas emission taxes require information on emission levels. Prices and quantities are more readily observable and verifiable, as compared to emission levels (Cremer and Thisse, 1999). In addition to this, Proposition 10 highlights the fact among the second best instruments, the emission tax may not be the best instrument.

Observe that $\tilde{\xi} < \xi_{min}$. From proposition 6, we know that a commodity tax as opposed to a commodity subsidy is an optimal policy for $0 \leq \xi < \xi_{min}$. In a subset of this range, an optimal commodity tax dominates an optimal emission tax.

3.7 Specific Taxes

For the sake of completion, let us study the effects of a specific tax on equilibrium choices of firms. Let t_i^s be the per unit specific tax imposed on firm i. The profit function of firms in the presence of specific taxes become

$$\Pi_1 = \alpha_1(p_1 - c(e_1) - t_1^s)$$
$$\Pi_2 = \alpha_2(p_2 - c(e_2) - t_2^s)$$

Again we solve for the equilibrium in the same manner as in previous sections. Assuming the market to be fully covered, the expression for demand for two firms is same as in (3.18)-(3.19). The second stage equilibrium prices are given by

$$p_1 = \frac{1}{3}[(e_1 - e_2)(2\overline{\theta} - \underline{\theta})) + 2c(e_1) + c(e_2) + 2t_1^s + t_2^s] \tag{3.57}$$
$$p_2 = \frac{1}{3}[c(e_1) + 2c(e_2) + t_1^s + 2t_2^s - (e_1 - e_2)(2\underline{\theta} - \overline{\theta})] \tag{3.58}$$

Plugging the second stage equilibrium prices in the first stage profit function, and then, maximizing the first stage profit function, we obtain equilibrium choice of cleanup levels as follows

$$e_1(t_1^s, t_2^s) = \frac{5\overline{\theta} - \underline{\theta}}{4k} + \frac{2\Delta t^s}{3kR} \tag{3.59}$$
$$e_2(t_1^s, t_2^s) = \frac{5\underline{\theta} - \overline{\theta}}{4k} + \frac{2\Delta t^s}{3kR} \tag{3.60}$$

where $\Delta t^s \equiv t_1^s - t_2^s$.

The case of uniform specific tax can be now easily analyzed by assuming $t_1^s = t_2^s = t^s$. It is straightforward to check that imposition of a uniform per unit specific tax leaves the equilibrium choice of cleanup levels unaffected. Demand faced and profit obtained by each firm remain unaffected. The higher cost to the firms in terms of tax liability is passed on to the consumers in the form of higher prices. Prices increase by the amount of the tax. Recall the tax revenue collected is distributed back to the consumers in a lump sum way, therefore, even consumer surplus is not affected. Thus uniform lump sum taxes remain ineffective in either reducing the pollution or improving the welfare.

In a similar model, Cremer and Thisse (1999) argue that a commodity tax may alter the market structure by increasing the number of firms and thus reduce the distortion caused by oligopolistic markets. In our model, for a small negative externality, the tax is sufficient to get rid of the distortion through its effect on the quality of the environment good produced. An increase in the number of firms would reinforce this effect and strengthen our result. On the other hand, in our model, we get the additional result that, when negative externalities are strong, subsidies are better than taxes.

Assuming a linear damage function, we have computed ranges for the pollution damage parameter, for which commodity tax or subsidy is an optimal policy. More specifically, we have shown that commodity tax is an optimal policy if and only if the damage parameter is less than ξ_{min} (Proposition 6). However, if the damage function is non-linear, the above ranges alter. If the damage function is convex, i.e., the damage from an increase in emissions increases faster than that in the case of a linear damage function, then ξ_{min} would be revised downwards. For each given level of emissions, the damage and therefore, the distortion due to pollution externality is more than before. A commodity tax reduces the oligopolistic distortion and increases the distortion from pollution externality (since firms respond by lowering cleanup levels). Hence ξ_{min} would be revised downwards. However, if the damage function is concave the above effects work in the opposite direction and ξ_{min} would be revised upwards.

3.8 Conclusion

This chapter examines if there is a role for government intervention, in the presence of environmentally discerning consumers. A possible argument can be that since consumers are environmentally conscious, the entire externality is internalized and therefore, the government need not intervene.

The chapter solves for the socially optimal cleanup levels and finds that there is sub-optimal provision of environment quality in the market solution. It therefore, analyses implications of various government policies on environment as well as welfare. It finds that a small commodity subsidy improves the environmental quality, whereas a small commodity tax deteriorates it. However, welfare effects depend upon the pollution damage parameter. A small uniform commodity tax is welfare improving if and only if the pollution damage parameter is sufficiently small. Otherwise a subsidy is always optimal.

The chapter also attempts to compare various government instruments, viz., commodity tax/subsidy, emission tax and specific tax. In our setting, the adoption of optimal emission tax removes completely the distortion caused due to the negative environmental externality. However it leaves completely unaffected the distortion caused by the oligopoly powers of the firms. Therefore, emission taxes may not be the best instrument when firms are competing in a vertical duopoly. As noted by Cremer and Thisse (1999), the information requirement of output tax is far lower than the emission taxes. We find that the pollution damage parameter, is a crucial factor in deciding the appropriate environment policy. A uniform specific tax is totally ineffective. It leaves the choice of cleanup level and aggregate welfare unaltered.

We can now compare the various instruments discussed in the chapter, in terms of their impact on environmental quality as well as aggregate welfare. Tables 3.1 and 3.2 summarize the results obtained in this chapter. While Table 3.1 summarizes the effect of various policies on the individual components of welfare, Table 3.2 summarizes the effect of various policies on the aggregate welfare.

Table 3.1: Comparison of various government policies

	Producer Surplus	Consumer Surplus	Environmental Quality	Degree of Differentiation
Commodity tax	falls	falls	deteriorates	reduces
Commodity subsidy	rises	rises	improves	increases
Emission tax	remains constant	falls	improves	constant
Specific tax	constant	falls	constant	constant

Table 3.2: Welfare Implications of Various Government Policies

		$\xi = 0$	$\xi < \tilde{\xi}$	$\xi < \xi_{min}$	$\xi > \xi_{min}$
Aggregate Welfare	Commodity tax	rises	rises	rises	falls
Aggregate Welfare	Commodity subsidy	falls	falls	falls	rises
Aggregate Welfare	Emission tax	constant	rises	rises	rises
Aggregate Welfare	Specific tax	constant	constant	constant	constant

Appendix

Proof of Proposition 1:

(i) From (3.13)-(3.14), it is straightforward to see $D > e_1^* > e_2^* > 0$, for $\xi < [kD - (3\overline{\theta} + \underline{\theta})/(4)]$
(ii) The measure of consumers consuming e_1 and e_2 is given by $[(\overline{\theta} - \theta_H)/R]$ and $[(\theta_H - \underline{\theta})/R]$ respectively. Using the expression for θ_H in (3.12), it is easy to see that

$$\frac{\overline{\theta} - \theta_H}{R} = \frac{\theta_H - \underline{\theta}}{R}$$

(iii) For $\xi \geq [kD - (\overline{\theta} + 3\underline{\theta})/4]$, $e_i = D, i = 1, 2.$ *QED.*

We now show that in market equilibrium (without any government intervention), the market is fully covered.

For the market to be fully covered, the consumer with the lowest θ, should enjoy a non-negative surplus from buying the good x. Alternatively $\hat{e_2}\underline{\theta} - \hat{p_2}$ should be non-negative.

From (3.29) and (3.33),

$$\hat{e_2}\underline{\theta} - \hat{p_2} = 16\underline{\theta}^2 - 25(\overline{\theta} - \underline{\theta})^2$$

which is greater than zero, using A.3.3.

Proof of Proposition 3:

Proof: Comparing market solution $(\hat{e_i}, i = 1, 2)$ and the first best $(e_i^*, i = 1, 2)$ as given in (3.29),(3.30) and (3.13),(3.16) respectively, it is straightforward to see that

(i) For $\xi = 0$,

$$\hat{e_1} = \frac{5\overline{\theta} - \underline{\theta}}{4k} > e_1^* = \frac{3\overline{\theta} + \underline{\theta}}{4k}$$
$$\hat{e_2} = \frac{5\underline{\theta} - \overline{\theta}}{4k} < e_2^* = \frac{\overline{\theta} + 3\underline{\theta}}{4k}$$

(ii) The comparison can now be extended to $\xi > 0$. It is easy to see that

$$\hat{e_1} \gtreqless e_1^* \Leftrightarrow \xi \lesseqgtr \frac{\overline{\theta} - \underline{\theta}}{2}$$
$$\hat{e_2} < e_2^* \; for \; \xi > 0$$

$$\hat{e^a} = \frac{1}{2k}(\overline{\theta} + \underline{\theta}) \leq \frac{1}{k}[\xi + \frac{1}{2}(\overline{\theta} + \underline{\theta})] = e^{a*}$$

(iii) It is immediate from (3.31) and (3.16). *QED.*

Proof of Propositions 4:

(i) Follows immediately from (3.43) and (3.44).

(ii)

$$\theta_1 = \frac{p_1 - p_2}{e_1 - e_2}$$

The demand faced by two firms can be obtained by plugging the equilibrium cleanup levels and θ_1 in (3.18) and (3.19)

$$\alpha_1(\tau_u) = \alpha_2(\tau_u) = \frac{1}{2} \tag{3.61}$$

(iii) Similarly, the profit obtained in equilibrium can be obtained by plugging in the equilibrium cleanup levels in (3.41) and (3.42).

$$\Pi_1(\tau_u) = \Pi_2(\tau_u) = \frac{3}{8k}\frac{R^2}{(\tau_u)^2} \tag{3.62}$$

(iv) The consumer surplus

$$\Sigma(\tau_u) = \frac{1}{32k\tau_u}[62\overline{\theta}\underline{\theta} - 23\overline{\theta}^2 - 23\underline{\theta}^2] \tag{3.63}$$

(v) The pollution generated

$$z(\tau_u) = D - \frac{\overline{\theta} + \underline{\theta}}{2k\tau_u} \tag{3.64}$$

The proof follows from (3.43)-(3.64). Observe that in the case of a uniform tax ($\tau_u > 1$), the value of variables in equilibrium is reduced, whereas in the case of a uniform subsidy ($\tau_u < 1$) equilibrium value of all the variables increases. *QED.*

Proof of Proposition 5:

Substituting the equilibrium values of $e_1(\tau_u)$ and $e_2(\tau_u)$ from (3.43) and (3.44) in (3.45), we can obtain the welfare expression under a tax/subsidy policy τ.

$$W(\tau_u) = \frac{1}{16\tau_u k}(7\overline{\theta}^2 + 7\underline{\theta}^2 + 2\overline{\theta}\underline{\theta}) - \frac{1}{32\tau_u^2 k}(13\overline{\theta}^2 + 13\underline{\theta}^2 - 10\overline{\theta}\underline{\theta}) - \xi(D - \frac{\overline{\theta} + \underline{\theta}}{2\tau_u k}) \tag{3.65}$$

Differentiating it with respect to τ,

$$\frac{\partial W(\tau)}{\partial \tau} = -\frac{1}{16\tau^2}(7\overline{\theta}^2 + 7\underline{\theta}^2 + 2\overline{\theta}\underline{\theta}) + \frac{1}{16\tau^3}(13\overline{\theta}^2 + 13\underline{\theta}^2 - 10\overline{\theta}\underline{\theta}) - \frac{\xi(\overline{\theta} + \underline{\theta})}{2\tau^2}$$

No intervention case is characterized by $\tau = 1$.

$$\frac{\partial W}{\partial \tau}|_{\tau=1} = \frac{3(\overline{\theta} - \underline{\theta})^2 - 4\xi(\overline{\theta} + \underline{\theta})}{8k} \gtreqless 0 \Leftrightarrow \xi \lesseqgtr \frac{3(\overline{\theta} - \underline{\theta})^2}{4(\overline{\theta} + \underline{\theta})} \equiv \xi_{min}$$

$QED.$

Proof of Proposition 6:

Maximizing the welfare as given in (3.65), with respect to τ_u, yields the following first order condition, $\frac{\partial W}{\partial \tau_u} = 0$, or

$$-\frac{1}{16\tau^2}(7\bar{\theta}^2 + 7\underline{\theta}^2 + 2\bar{\theta}\underline{\theta}) + \frac{1}{16\tau^3}(13\bar{\theta}^2 + 13\underline{\theta}^2 - 10\bar{\theta}\underline{\theta}) - \frac{\xi(\bar{\theta}+\underline{\theta})}{2\tau^2} = 0,$$

which implies

$$\tau_u^* = \frac{13\bar{\theta}^2 + 13\underline{\theta}^2 - 10\bar{\theta}\underline{\theta}}{7\bar{\theta}^2 + 7\underline{\theta}^2 + 2\bar{\theta}\underline{\theta} + 8\xi(\bar{\theta}+\underline{\theta})} > 0 \tag{3.66}$$

where τ_u^* is the second best policy instrument. Observe

$$\tau_u^* \gtreqless 1 \;\Leftrightarrow\; \xi \lesseqgtr \xi_{min}$$

$QED.$

We can obtain the second best level of aggregate welfare under a uniform tax/subsidy policy by substituting the value of optimal τ_u from (3.66) into (3.65).

$$W(\tau_u^*) = \frac{1}{32k(13\bar{\theta}^2 + \underline{\theta}^2 - 10\bar{\theta}\underline{\theta})}(7\bar{\theta}^2 + 7\underline{\theta}^2 + 2\bar{\theta}\underline{\theta} + 8\xi(\bar{\theta}+\underline{\theta}))^2 - \xi D \tag{3.67}$$

Proof of Proposition 9:

Substituting the values of equilibrium e_1, e_2, and θ_1 in the welfare function (3.45), we obtain

$$W(t_e) = \frac{1}{4k}\Big[\frac{(\bar{\theta}^2 + \underline{\theta}^2 + 14\bar{\theta}\underline{\theta})}{8} - 2t_e^2\Big] - \xi D + \xi\frac{(\bar{\theta}+\underline{\theta})}{2k} + \frac{t_e\xi}{k} \tag{3.68}$$

Differentiating welfare function with respect to t_e, we get

$$\frac{\partial W}{\partial t_e} = -\frac{t_e}{k} + \frac{\xi}{k}$$

$$\frac{\partial W}{\partial t_e}\Big|_{t_e=0} = \frac{\xi}{k} > 0$$

The necessary and sufficient condition for welfare maximization is given by

$$\frac{\partial W}{\partial t_e} = 0 \Rightarrow -\frac{t_e}{k} + \frac{\xi}{k} = 0$$

hence

$$t_e^* = \xi$$

QED.

Proof of Proposition 10:

Substituting $t_e = \xi$ in (3.68), we obtain

$$W(t_e^*) = \frac{1}{32k}(\overline{\theta}^2 + \underline{\theta}^2 + 14\overline{\theta}\underline{\theta}) + \frac{\xi^2}{2k} - \xi D + \frac{\xi(\overline{\theta} + \underline{\theta})}{2k}$$

Comparing welfare under two optimal policies, viz., optimal uniform commodity tax and optimal emission tax,

$$W(\tau^*) - W(t_e^*) = \frac{3(\overline{\theta} - \underline{\theta})^2}{8kA}[3(\overline{\theta} - \underline{\theta})^2 - 12\xi^2 - 8\xi(\overline{\theta} + \underline{\theta})]$$

where $A \equiv 13\overline{\theta}^2 + 13\underline{\theta}^2 - 10\overline{\theta}\underline{\theta}$ and

$$W(\tau^*) - W(t_e^*) \gtreqless 0 \Leftrightarrow 3(\overline{\theta} - \underline{\theta})^2 - 12\xi^2 - 8\xi(\overline{\theta} + \underline{\theta}) \gtreqless 0 \quad (3.69)$$

or alternatively

$$W(\tau^*) - W(t_e^*) \gtreqless 0 \ for \ \xi \lesseqgtr \frac{\sqrt{A} - 2(\overline{\theta} + \underline{\theta})}{3} \equiv \tilde{\xi} \quad (3.70)$$

It can be shown that $\tilde{\xi} < \xi_{min}$ *QED.*

Chapter 4

Change in Income Distribution and Consumer Awareness: Effect on Environmental Quality and Policy

4.1 Introduction

In the previous two chapters, environmental consciousness translated into a positive willingness to pay for an environment-friendly product. Assuming that the consumers' willingness to pay for environmental quality (θ) is a function of income and its distribution for the society remains constant, we examined implications of various regulatory tax-subsidy policies. This chapter serves as an extension to the last chapter. It aims at studying the effects of changes in income distribution on the degree of cleaning.

A change in income distribution changes the distribution of θ as it is a monotonically increasing function of income. We are considering distributional changes such that only the support of the distribution function changes and the distribution continues to be uniform.

An increase in income could either be uniform or heterogeneous across consumers. We analyze both these cases and find that a uniform rise in income improves the quality of both variants of the product, while a heterogeneous rise may improve the quality of one variant and reduce the quality of the other.

When each consumer's income rises uniformly, her willingness to pay for improved quality also rises uniformly. Firms respond to this by improving the quality as well as increasing the price of both variants of the good.

Heterogeneous growth in income may be limited to particular sections of a society. When the growth in income is limited to the upper end of income distribution, willingness to pay of these consumers increases. The cleaner firm responds by improving the quality supplied, and increases its profit by charging a higher price. The lower quality firm faces a situation, where its competitor has differentiated away from it but the willingness to pay of the lower end consumers has not increased. It can lower its quality, and extract greater surplus from the marginal consumers at the upper end. By doing so, it will not lose demand as these consumers cannot move to the cleaner firm. This is because it is more expensive now and their willingness to pay has not increased proportionately. This way the firm is able to retain its demand even by lowering its quality. The price and quality pairs adjust in such a manner that both firms enjoy a higher profit.

Such heterogeneous growth in income, deteriorates the lower quality and may have serious implications for the consumers at the lower end of the income distribution, especially if the product has a direct health or safety hazard for the user. This may cause concern to the planner. We suggest a measure to prevent this deterioration in quality of the inferior variant.

So far we have been concentrating on given levels of consumer awareness. Different societies may have different emphasis on environmental issues and thus differ in their degree of awareness. Within a given society also various consumer activist groups are trying to improve environmental consciousness among the general public through pamphlets, protests, mass campaigns etc. This is having a significant impact on the degree of awareness among consumers. In this chapter, we also attempt to study effect of an increase in consumer awareness on the degree of cleaning.

In our setup, consumers' decisions to buy products with particular environmental characteristics are a function of the net surplus resulting from buying that product. The net surplus is the enjoyment derived from consuming the good minus the price the consumer has to pay. In the previous two chapters, we have used government policy to affect consumer decisions through the prices they pay. Different degrees of consumer awareness, on the other hand, affect the enjoyment a person derives from consuming the product. An increase in consumer awareness increases this surplus, which induces firms to increase their cleanup.

Policy makers are increasingly turning to voluntary measures as an alternative to the traditional legislative or regulatory approaches. It is here that increasing consumer awareness can play an important role.

The rest of the chapter is planned as follows. The model is described in section 4.2. Section 4.3 analyzes uniform increase in income. Greater heterogeneity in income distribution is analyzed in section 4.4. Section 4.5 discusses the effects of increase in environmental as well as social awareness. Finally section 4.6 contains the concluding remarks.

4.2 The Model

The basic model formulation remains the same as in Chapter 3 and, hence, we will not restate it here. Instead we will introduce some new notation that we will use. To take care of economies with varying distribution of income, we will index the economy by the support of the distribution function F. Consider the ordered pair (m, n), $m, n \geq 0$. *We define an economy $E(m, n)$ as one where the distribution $F(.)$ of the willingness to pay, θ, has the support $[\underline{\theta} + m, \overline{\theta} + n]$.* Observe that, if $m = n = 0$, we have the economy, which has been studied in the previous chapters. We will compare the $E(0, 0)$ economy with two particular types of $E(m, n)$ economy. The economy characterized by $m \neq n, m, n \geq 0$ can be distinguished from the $E(0, 0)$ economy as one in which the rise in income among the richer classes (higher θ) is different from the poorer classes. The economy with $m = n > 0$ is one where the rise in income is uniformly higher, among all income classes, compared to the $E(0, 0)$ economy.

We continue with the first assumption in Chapter 3. The other two assumptions have to be modified to take into account the indexed distributions. We state all of them together for completeness. As in the previous chapter, A.4.3 ensures that all consumers are buying the product.

A.4.1: *$C(e,q) = qc(e)$, where $c(e) = ke^2/2, \quad k > 0, 0 \leq e \leq D$.*

A.4.2: *$F(m,n)$ is uniform over $[\underline{\theta} + m, \overline{\theta} + n]$.*

A.4.3: *m and n are such that $(9/5)[\underline{\theta} + m] > \overline{\theta} + n$.*

Before we proceed with the formal analysis, we reproduce (modified versions of) the relevant equations from the last chapter.

(a) The cleanup levels are given by

$$e_1 = \frac{5\overline{\theta} - \underline{\theta}}{4k} + \frac{5n - m}{4k} \tag{4.1}$$

$$e_2 = \frac{5\underline{\theta} - \overline{\theta}}{4k} + \frac{5m - n}{4k} \tag{4.2}$$

(b) The degree of differentiation, given by the gap between the two variants is,

$$e_1 - e_2 = \frac{3(\overline{\theta} - \underline{\theta})}{2k} + \frac{3(n - m)}{2k} \tag{4.3}$$

(c) Recall that θ_1 segregates the consumers between two qualities.

$$\theta_1 = \frac{\overline{\theta} + \underline{\theta}}{2} + \frac{m + n}{2}$$

The demand faced by each firm

$$\alpha_1 = \alpha_2 = \frac{1}{2}$$

(d) Prices charged by the two firms are

$$p_1 = \frac{1}{32k}[49(\overline{\theta} + n)^2 + 25(\underline{\theta} + m)^2 - 58(\overline{\theta} + n)(\underline{\theta} + m)]$$

$$p_2 = \frac{1}{32k}[25(\overline{\theta} + n)^2 + 49(\underline{\theta} + m)^2 - 58(\overline{\theta} + n)(\underline{\theta} + m)]$$

Or alternatively

$$p_1 = \hat{p_1} + \frac{(7n-5m)^2 + 16mn + 2\overline{\theta}(49n-29m) + 2\underline{\theta}(29n-25m))}{32k}$$
$$p_2 = \hat{p_2} + \frac{(5n-7m)^2 + 16mn + 2\overline{\theta}(25n-29m) + 2\underline{\theta}(49m-29n)}{32k}$$

(e) Finally using the demand, price and cost expressions, we obtain profit obtained by two firms

$$\Pi_1 = \Pi_2 = \frac{3}{8k}(\overline{\theta} - \underline{\theta} + n - m)^2$$

4.3 Uniform Increase in Income

In this section, we compare the $E(0,0)$ economy with an $E(m,n)$ economy where $m = n = h > 0$, satisfying A.4.1-A.4.3. For each level of θ in $E(0,0)$, the corresponding person in $E(m,n)$ has a higher income and a higher utility of $\theta + h$ per unit of environmental quality. We term the agents in $E(m,n)$ as having a uniformly higher income compared to the agents in $E(0,0)$.

Proposition 1: *Assume A.4.1-A.4.3, $m = n = h > 0$, and interior solutions. Compared to the $E(0,0)$ economy, in $E(m,n)$*

(i) both firms have higher cleanup efforts and, hence, total pollution is less,

(ii) the gap between the two qualities, measured by the difference $e_1 - e_2$, is the same,

(iii) the proportion of consumers served by each firm is the same,

(iv) the profits of both firms are the same.[1]

Proof: Let a superscript ˜ denote the equilibrium value of the variables for the $E(m,n)$ economy. Plugging $m = n = h > 0$ in (a)-(e) above, it is straightforward to see

(i) The cleanup levels

$$\tilde{e_1} = \hat{e_1} + \frac{h}{k} \tag{4.4}$$

[1]For an interior solution, $h < kD - \hat{e_1}$.

$$\tilde{e_2} = \hat{e_2} + \frac{h}{k} \tag{4.5}$$

Total pollution is

$$\tilde{Z} = \hat{Z} - \frac{h}{k}$$

(ii) The degree of differentiation,

$$\tilde{e_1} - \tilde{e_2} = \hat{e_1} - \hat{e_2} \tag{4.6}$$

(iii) The demand faced by each firm

$$\tilde{\alpha_1} = \tilde{\alpha_2} = \hat{\alpha_i},\ i = 1, 2$$

Prices charged by the two firms are

$$\begin{aligned} \tilde{p_1} &= \hat{p_1} + \frac{h^2}{2k} + \frac{h(5\overline{\theta} - \underline{\theta})}{4k} \\ \tilde{p_2} &= \hat{p_2} + \frac{h^2}{2k} + \frac{h(5\underline{\theta} - \overline{\theta})}{4k} \end{aligned}$$

and

(iv) Profit obtained by the two firms

$$\tilde{\Pi_1} = \tilde{\Pi_2} = \frac{3}{8k}(\overline{\theta} - \underline{\theta})^2$$

QED.

When each consumer's income rises uniformly, firms respond to this by improving the quality as well as increasing the price of both variants of the good. The price-quality pairs alter in such a manner that both firms obtain the same profit as before. Proposition 1 tells us that the $E(m, n)$ economy will be more environment friendly than the $E(0, 0)$ economy. It also tells us that firms are equally well off in both economies (Proposition 1(iv)).

4.4 Greater Heterogeneity in Income Distribution

One of the problems in developing countries is that with economic growth, income disparities increase. It is possible that while population at the upper end of income distribution experiences a large increase in income, that at the lower end gains small amounts. In this section, we analyze the case where growth in income is heterogeneous over consumers.

We first compare the $E(0,0)$ economy with an $E(m,n)$ economy where $m = 0 < n = h$, satisfying A.4.1-A.4.3. The growth in income is heterogeneous, having a higher effect on consumers with a higher θ.

Proposition 2: *Assume A.4.1-A.4.3, $m = 0 < n = h$, and interior solutions.*[2] *Compared to the $E(0,0)$ economy, in $E(0,h)$*

(i) the cleanup effort of the better quality firm is higher and that of the worse quality firm is lower, however, total pollution is lower

(ii) the gap between the two qualities is higher

(iii) the proportion of consumers served by each firm is same

(iv) the profit of both firms is higher.

Proof: The proof follows from plugging $m = 0, n = h$ in (a)-(e) above. Let a superscript $'$ denote the value of the variables in equilibrium.

(i) The cleanup levels

$$e_1' = \hat{e_1} + \frac{5h}{4k} \quad (4.7)$$

$$e_2' = \hat{e_2} - \frac{h}{4k} \quad (4.8)$$

(ii) The degree of differentiation

$$e_1' - e_2' = \hat{e_1} - \hat{e_2} + \frac{3h}{2k} \quad (4.9)$$

(iii) The demand faced by each firm

$$\alpha_1' = \alpha_2' = \frac{1}{2}$$

[2]For an interior solution, $0 < e_i < D$, $i = 1,2$. It can be checked that $h < min[(5\underline{\theta} - \overline{\theta}), (\frac{4}{5}(kD - \hat{e_1}))]$ ensures an interior solution.

Prices charged by the two firms are

$$p_1' = \hat{p_1} + \frac{49h^2}{32k} + \frac{h(49\overline{\theta} - 29\underline{\theta})}{16k} > \hat{p_1}$$
$$p_2' = \hat{p_2} + \frac{25h^2}{32k} + \frac{h(25\overline{\theta} - 29\underline{\theta})}{16k}$$

Finally, profit obtained by each firm

$$\Pi_1{}' = \Pi_2{}' = \frac{3}{8k}(\overline{\theta} + h - \underline{\theta})^2$$

QED.

Since willingness to pay at the upper end of income distribution has increased, the cleaner firm improves the quality supplied, and increases its profit by charging a higher price. Its lower end consumers now enjoy a lower surplus than before as the increase in their willingness to pay is less than that of the upper end consumers. The demand faced by the firm remains constant. The lower quality firm faces a situation, where its competitor has differentiated away from it but the willingness to pay of the lower end consumers has not increased. It can lower its quality, and extract greater surplus from the marginal consumers at the upper end. By doing so, it will not lose demand as these consumers cannot move to the cleaner firm. This is because it is more expensive now and their willingness to pay has not increased proportionately. This way the firm is able to retain its demand even by lowering its quality. The price and quality pairs adjust in such a manner that both firms enjoy a higher profit.

Such heterogeneous growth in income, deteriorates the lower quality or creates fringes of heavily polluted quality. This may have serious implications for the consumers at the lower end of the income distribution, especially if the product has a direct health or safety hazard for the user. Inspite of being aware of these hazards, the consumers at the lower end of income distribution are forced to consume these products due to two reasons. First, the good under consideration is an essential good, and therefore, consumers cannot do without it. Second, the better variant of the product has become more expensive (due to improvement in its quality) and poor consumers are not willing to buy it at that price.

Often developing countries are not applauded for the improved quality of the better products but are blamed for the existence of fringes of heavily polluted products. Rapidly industrializing countries in South-East Asia and Latin America are experiencing pollution ills. Our results suggest that such a situation could be an outcome of increased disparities in income distribution. However, when the gains of economic growth percolate down to the entire economy, and each consumer becomes better off, both qualities improve.

This result of deterioration in the cleanup level of lower quality product, may cause concern for the planner. The question then arises, can governments prevent deterioration in the quality of the inferior product and save its population from such hazardous exposure.

In a similar setting, Arora and Gangopadhyay (1995) suggests that imposing a cleanup standard exceeding the lowest cleanup level produced in the economy improves the environmental quality of both variants of the product. Implementation of such a standard may face resistance from producers on the grounds of stringent environmental policy. The firms may complain about having to bear the cost of environmental protection.

In this chapter, we are interested in a policy, which is voluntarily acceptable to the producers. For that, the policy should not have adverse political economy implications for the firms.

Consider an $E(0,0)$ economy, which is in the process of economic growth. We will restrict ourselves to the economies where the intensity of (negative) environmental externality is sufficiently high (In terms of Chapter 3, it means that $\xi > \xi_{min}$). These economies are characterized by undercleaning in the absence of market intervention. Let the government impose a standard $\overline{e} = \hat{e_2}$. Observe that as of now, this standard is not binding as it does not affect the equilibrium choice of cleanup levels. The adopted standard does not have any political economy implications, and therefore, is not opposed by producers.

The imposed standard assumes significance when the economy experiences economic growth. This increases willingness to pay for the cleaner product. In the initial period, i.e., the intermediate phase, the growth is likely to be heterogeneous and limited to the consumers at the upper end of the income distribution. That is to say that the economy is now characterized as $E(0,h)$ economy. Proposition 2 (i) tells us that the lower quality firm has an incentive to reduce the cleanup level. The standard now becomes binding for it and prevents the firm from lowering the adopted cleanup level.

Using (4.1) and (4.2), we can find the new equilibrium choice of cleanup levels

$$e_1 = \hat{e_1} + \frac{2h}{k};\ e_2 = \overline{e} = \hat{e_2}$$

In the intermediate phase, the standard ($e_i \geq \hat{e}$) on cleanup levels, prevents the lower quality firm to reduce its quality, at the same time, the higher quality firm improves its quality.

The standard would again become ineffective, when the growth in income percolates down to the consumer with the least income. Then, we are in the equilibrium of section 4.3.

It is interesting to analyze the effect of growth in income where the consumers at the lower end of income distribution gain more than those at the upper end. More specifically we consider an increase in income such that $0 < n < m$. From part (b), in section 4.2, we know that such a rise in income reduces the degree of differentiation between the two variant of the products and also increases the cleanup level of the lower quality product. It is easy to see that with a growth in income of ($n < m$) type, profits of both firms are reduced.

In the above analysis, we have changed the distribution of θ through changing income distribution. We can also interpret the change in θ distribution as rise in consumer awareness. In the next section, we examine what happens if consumer awareness of pollution problem rises.

4.5 Rise in Consumer Awareness

In the developed countries, policy makers are increasingly turning to voluntary agreements as an alternative to the traditional legislative or regulatory approaches to environmental protection because of their potential to save on compliance, administration and other transaction costs. Europe has taken a lead in voluntary approaches to pollution control (Commission of the European Countries, 1996). The US 33/50 and Green Lights programs referred to earlier are other such examples.[3]

In developing countries too, there is a move towards adopting voluntary measures as an alternative to traditional legislative approaches. The labeling system called PROPER adopted by the local environmental agency in Indonesia (Afsah *et al.*, 1997) is an example. Hence, we look for an alternative to the regulatory approaches. It is here that raising consumer awareness can play an important role.

Grossman and Krugman (1995) find an inverse relationship between output and environmental deterioration. They argue that economic growth improves the environment quality after a turning point in per capita income has been reached. They point out that as nations experience increased economic prosperity, the society has a greater willingness to bear the costs of environmental protection, and hence citizens demand a cleaner environment from political leaders. One way to interpret the result is that increased income levels make it possible for these societies to afford cleaner environment. While that certainly may be true, an alternative interpretation of the result is that the degree of environmental awareness among consumers is higher in these countries. We do observe that even economies with comparable levels of income, differ in their attitude towards environmentally deteriorating products.

In this section, we are interested in seeing the effect of a rise in *awareness* among consumers of the harmful effects of pollution caused by production process. We'll be examining two ways of increasing consumer awareness– rise in environmental awareness and the rise in social awareness.

Rise in Environmental Awareness

In our first formulation, we model the following scenario. Suppose, in addition to the pollution externality caused by the production of the product, its use causes indoor pollution for the consumers. They, however, perceive that only a part of the indoor pollution is coming from this good, and therefore, internalize only a part of the damage. The extent to which they internalize the externality depends on their awareness of the harmful effects of pollution.

[3]See Arora and Cason, (1995); Bosch, Cook *et al*, (1995); Khanna and Damon, (1997).

For instance, consider the use of firewood as fuel. Consumers' health suffers from the smoke generated by its use. If they have low levels of awareness, they may not be able to attribute the damage to the use of firewood and continue its use. However, if the awareness about this damage increases, they may be inclined to move towards cleaner fuels.

To examine what happens if consumer *awareness* of pollution problem rises, we reformulate the utility function in the following way:

$$U = y + I[v + \beta\theta(y)e_i - p_i] - Z^u - Z \tag{4.10}$$

where $0 \leq \beta \leq 1$ denotes awareness, Z^u is the disutility of pollution (associated with own consumption), the source of which the consumer is unaware of; and Z is the disutility from pollution associated with consumption by others or production. Z^u is taken as given by the agent (as an externality, like Z), but in equilibrium it is given by

$$Z^u = -I(1-\beta)\theta(y)e_i$$

Fraction β of the pollution is perceived to come from the consumption of the good, while the consumer is unaware of the remaining fraction $(1-\beta)$, but she still suffers from this pollution. Observe that in the present formulation, the externality is decomposed into two parts, Z^u and Z. Though an individual consumer suffers from Z^u, she is unaware of its source and therefore, does not internalize it. She does not internalize Z because the effect of her consumption on total pollution is negligible. Carrying out an analysis similar to Chapter 3, we solve for the equilibrium cleanup levels.

Consumers buy the good if they derive a positive surplus from it, i.e., $v + \beta\theta(y)e_i > p_i$. Again, we normalize $v = 0$. The marginal consumer who is indifferent between the two qualities is given by equalizing the net surplus derived from the two variants, i.e., $\beta\theta e_1 - p_1 = \beta\theta e_2 - p_2$, or

$$\theta_1 \equiv \frac{p_1 - p_2}{\beta(e_1 - e_2)}$$

Using the above definition of θ_1, we determine the demand for two firms as

$$\alpha_1 = \frac{1}{R}(\overline{\theta} - \theta_1) = \frac{1}{R}\left[\overline{\theta} - \frac{p_1 - p_2}{\beta(e_1 - e_2)}\right]$$

$$\alpha_2 = \frac{1}{R}(\theta_1 - \underline{\theta}) = \frac{1}{R}\left[\frac{p_1 - p_2}{\beta(e_1 - e_2)} - \underline{\theta}\right]$$

The second stage equilibrium prices are given by

$$p_1 = \frac{1}{3}[\beta(e_1 - e_2)(2\overline{\theta} - \underline{\theta}) + 2c(e_1) + c(e_2)]$$
$$p_2 = \frac{1}{3}[c(e_1) + 2c(e_2) - \beta(e_1 - e_2)(2\underline{\theta} - \overline{\theta})]$$

Plugging these price expressions in the profit functions, the first stage profit expressions for the two firms are obtained as

$$\Pi_1 = \frac{1}{36\beta R}\left[\beta(4\overline{\theta} - 2\underline{\theta}) - k(e_1 + e_2)\right]^2$$
$$\Pi_2 = \frac{1}{36\beta R}\left[k(e_1 + e_2) - \beta(4\underline{\theta} - 2\overline{\theta})\right]^2$$

Maximizing the profit function Π_i with respect to e_i, $i = 1, 2$, we obtain the equilibrium cleanup levels as follows

$$e_1 = \frac{\beta(5\overline{\theta} - \underline{\theta})}{4k}$$
$$e_2 = \frac{\beta(5\underline{\theta} - \overline{\theta})}{4k}$$

With a rise in the awareness parameter β, the cleanup levels adopted by both firms increase. A rise in the awareness increases the net surplus an individual consumer enjoys from buying this good. Since consumers internalize a larger fraction of the pollution externality, firms are induced to adopt cleaner production processes.

Observe that instead of $(1/\tau)$ in the expressions for cleanup levels under tax-subsidy policies (Section 3.5 of Chapter 3), there is a factor β in the current formulation. The effect of an increase in awareness is same as the effect of a commodity subsidy. In Chapter 3, we have shown that when firms are cleaning up less than that warranted by the constrained social optimum, a uniform subsidy regulation can improve the levels of cleanup. Raising resources for subsidies is a difficult problem for developing countries when (economic) developmental expenditures have top priority. Raising consumer awareness can help to avoid the problems of implementing a subsidy.

Rise in Social Awareness

Another justification for consumer willingness to pay for the cleaner good could come from the social interaction among consumers. Specifically, in a society in which there is social awareness, there is social pressure to consume environmentally friendly products. This social pressure may itself be an endogenous pressure. That is, in a society in which there are more people that follow the norm of consuming an environment-friendly good, the social pressure is greater, while in a society in which there are less followers of such a norm the social pressure is less.

In a more advanced model, willingness to pay could be endogenised by making it a function of the percentage of people that follow the norm of consuming an environment-friendly good. That is, the willingness to pay of an individual is a function of the belief about the number of people consuming that variant as well as that of her income. The utility function of an individual would be reformulated as

$$U = y + v + \theta(y, \alpha_i^x)e_i - p_i - \xi Z(.)$$

where α_i^x is the society's belief about the number of people consuming the variant i. The surplus enjoyed by an individual from variant i is given by $e_i\theta(y, \alpha_i^x) - p_i$. The individual will choose the cleaner variant if

$$e_1\theta(y, \alpha_1^x) - p_1 > e_2\theta(y, 1 - \alpha_1^x) - p_2$$

since the market is fully covered, or $\alpha_2^x = 1 - \alpha_1^x$.

Observe that in this formulation, the marginal consumer who is indifferent between the two qualities is no longer uniquely determined by the price-quality pairs offered by the two firms and depends upon the consumers' belief about the percentage of people buying these qualities. The equilibrium will clearly depend upon the prior beliefs of the consumers and, in particular, may not be unique. The equilibrium is characterized by the cleanup levels adopted by two firms, and the consumers beliefs (about the percentage of people buying each quality), which are fulfilled in equilibrium, i.e., in equilibrium $\hat{\alpha}_i = \alpha_i^x$ $i = 1, 2$.

One of the possible solutions is if consumers believe that a smaller number of consumers are buying the cleaner product, then indeed, in equilibrium, a smaller number of people buy the cleaner product. Similarly in a society where consumers believe that a large number of people are consuming the environment-friendly product, a large number of people would do so in equilibrium. Since societies differ in terms of these norms, the achieved cleanup levels would also differ in different societies.

4.6 Conclusion

In this chapter, we examine the effect of growth in income on the cleanup activity of firms. Growth in income affects consumers' willingness to pay for the product, which in turn. determines the qualities that will be served in the market.

The growth in income may take two forms. It can be uniform across all consumers or could be limited to a specific section of the population. Both these forms are analyzed. When the growth in income is uniform for all consumers, cleanup levels rise for both firms, resulting in improved environmental quality.

However, when the growth in consumer awareness is heterogeneous, it may not improve both qualities. In particular, if increase in income is limited to the richer consumers and there is an increase in the disparities in income distribution, the quality of the inferior product gets adversely affected. This causes concern for the government. One of the ways to prevent deterioration in quality is to impose a cleanup standard equal to the quality of the inferior product. Such a standard does not face opposition from firms as it is ineffective at the current levels of income. If there is uniform growth in income, this standard continues to be ineffective. However, if only the rich consumers experience growth in income, and the inferior quality firm has an incentive to reduce the quality further, the imposed standard prevents it from doing so.

The government and non-governmental organizations through information and peer pressure, are making efforts to raise the awareness of the harmful effects of pollution. The decision of consumers regarding the quality of the product is determined also by their knowledge of the environmental bad. If a poor household is aware of the health hazard to children of smoke filled homes, it will be more inclined to move towards cleaner fuels (to kerosene from firewood) even if it cannot afford the cleanest fuel (cooking gas or electricity). Alternatively, if people are aware of the damage caused to future generations (their children) by deforestation, they will be more inclined towards buying kerosene rather than cut trees.

In this chapter, we also discuss effects of increase in the degree of environmental awareness among consumers. The increased awareness results in improvement of environment quality. This means of improving environmental quality serves as an alternative to the traditional legislative or regulatory approaches adopted for environmental protection. The investigation is significant in view of the observation that increasingly governments are moving towards voluntary approaches to environmental protection, as opposed to regulatory approaches like taxes or subsidies etc.

Chapter 5

Inducements for Technological Development: BAT is Bad

Traditional approach to environmental regulation is that environmentalism comes at a heavy cost to industry. Conventional economic theory talks about a trade-off between the benefits of a cleaner environment and the cost of achieving it. An obvious way to relax the trade-off is to find superior technologies that will improve the environment at a lower cost. However such technological improvements require investment in research and development. Regulatory agency, thus, is often concerned with the provision of incentives for technological development.

In all the previous chapters, we analyzed implications of various government policies assuming cleanup technology to be given. In the present chapter, we extend the previous analysis by examining the effect of government regulation on firm's incentive to invest in developing cheaper (cleanup) technologies.

Specifically, we focus on two types of policies: a contingent policy and a non-contingent policy. A contingent policy is one where the regulator re-optimizes environmental regulation in response to new technologies, i.e., the regulation is contingent on the available technology. This we call the *best available technology* (BAT). However, in a non-contingent policy, the regulator announces a regulation and sticks to it irrespective of the firm's adopted technology.

As in earlier chapters, consumers are environmentally conscious agents. i.e., they are aware of the environmental damage caused by the production process. The analysis of the chapter takes into account the fact that a firm's innovation effort is subject to an uncertain outcome. Here the firm can invest in R&D whose outcome is stochastic. If R&D is successful, it can obtain a given level of cleanup at a lower cost. The model formulation in this chapter also incorporates an asymmetry of information between the regulator and the polluting agent.[1] We assume that the regulator cannot observe the R&D effort even when it can observe the technology of cleanup. Thus if the firm is using a high-cost cleanup technology, it does not know if the firm invested in R&D and was unsuccessful or, it did not invest in R&D at all.

It is natural to expect that in the absence of consumer awareness, firms do not have any incentive to produce environment-friendly products. However consumers are showing an increased preference for environmentally friendlier products (low-pollution, energy-efficient, resource-efficient), shifting out the demand for environmentally improved products. Innovations can be used to command price premiums for "green" products and gain international market share. This should induce firms to implement environmentally better technologies. Then, it is not clear, why one needs regulation when consumers are already rewarding producers who are environment friendly. We show that even if consumers are environmentally aware and have a preference for cleaner products, private benefits of (environment friendly) technological change are insufficient.

In this context, Porter and van der Linde (1995) claim that properly designed environmental regulation can trigger innovation that may partially or more than fully offset the

[1]Some of the previous works dealing with asymmetry of information in the context of environment include Roberts and Spence (1976), Kwerel (1977) and Dasgupta, Hammond and Maskin (1980). The first two papers argue that when the regulators are uncertain about firms' cleanup costs, a mixed system of regulation involving effluent charges and marketable licenses is preferable to either effluent fees or licenses used separately. The third paper places some of the earlier work in a more general perspective. However these papers do not address the issue of incentives for technological development and also do not incorporate environmentally conscious consumers.

costs of complying with them. Innovation undertaken to comply with environmental regulation, if successful, often improves either the product quality or the production process. In a dynamic context, there is a possibility that some technological opportunities exist, which firms bypass because success in R&D effort is not guaranteed. The above paper also claims that a policy based on best available technology hampers firms' incentives for developing new and improved technology.

The present chapter shows that whether environmental regulation triggers or prevents innovation depends on the details of the regulation. The central result is that no adoption of cleaner technologies takes place if the government re-optimizes environmental regulation in response to new technologies (i.e., the adopted policy is a contingent or BAT policy). As compared to a contingent policy, welfare is higher with a non-contingent policy. In a non-contingent policy, the regulator commits to a certain level of environmental regulation and does not raise it later. Thus a non-contingent policy is a policy that requires commitment, since without commitment the policy becomes time-inconsistent.

A new technology is modeled as a downward shift in the abatement cost function (reduction in parameter k). The smaller the abatement costs are, the larger the incentives to abate for both the market and the social planner. However, the incentives for the social planner increase faster with the fall in k than the incentives for an unregulated firm, since the former not only takes into account consumers' direct preference for clean goods (as do firms), but also the indirect pollution externality. Hence, if the government wants to impose regulation to induce firms to cleanup as much as in the social optimum, regulation has to be more stringent the lower the abatement cost is. Since this implies lower profits as well (profits fall when regulation becomes more stringent), firms will not adopt technologies with lower abatement costs. A better policy is to announce environmental regulation and stick to this policy after firms have adopted the cleaner technology (non-contingent policy), even if adoption justified more stringent regulation ex-post in a first best world.

Our work relates to the literature addressing the problem of time inconsistency and commitment of environmental regulation (Yao, 1988; Biglaiser, Horowitz and Quiggin, 1995;

Gersbach and Glazer 1999; and Marsiliani and Renstrom, 2000.) A government's policy is dynamically inconsistent when, although being optimal at the outset, it is no longer optimal at a later date — even if no new information has appeared. This means that the government has no incentive to be committed to its original plans. In such a scenario, firms may behave strategically against the regulator.

Yao (1988) analyzes the dynamic interactions between the regulator and industry in the context of standard setting regulation, given technological uncertainty and private information. The information asymmetry about innovation capability of the industry creates incentives for underinvestment in research for all industry types. However, the degree to which industry reduces its investment in order to decrease future expected costs depends on the innovation capability of the industry. Initial period investment increases expected future costs for the low-capability type more than it does for higher capability type. Thus the initial level of R&D activity caused by regulation increases with the intrinsic technical capability of industry. In this chapter, we also analyze a dynamic model of strategic interaction between the regulator and firm. In our setup, if a low-cost (abatement) technology becomes available, unregulated firm will always adopt it due to the presence of environmentally aware consumers. Thus it has an incentive to develop such technologies. However, a firm subject to contingent regulation will not adopt a low cost technology even if it becomes available. Therefore, it does not have an incentive to innovate. We show that commitment to the stringency of environmental regulation takes away firm's incentives to behave strategically against the regulator and ensures a positive investment in R&D.

Biglaiser *et al.* (1995), and Gersbach and Glazer (1999) examine to what extent the problem of time-inconsistency can be resolved through issuing tradeable permits. The first paper addresses the time inconsistency of optimal permit regulation. It shows that tradeable pollution permits may not achieve the social optimum because firms behave strategically against the regulator. The second paper examines the issue of hold-up problems in a situation where firms potentially subject to regulation may behave strategically by not investing in equipment that reduces cost of compliance, thereby forcing the regulator to abandon the proposed regulation. It assumes that the regulator is unable to commit to the stringency of emission tax and can commit to issue marketable permits. The paper argues that emission taxes are less suitable to solve the hold-up problem as investing firms only save part of the emission tax, and are not compensated for their investment. Under permits market, however, investing firms may gain from selling pollution permits to firms that did not invest.

Marsiliani and Renstrom (2000) present an economy in which government policy of environmental tax is dynamically inconsistent. In such a situation, they show that dedicating specific revenues to the financing of specific public services can act as a commitment mechanism and thus partially solves the time-inconsistency problem.

The rest of the chapter is organized as follows. The model is described in section 5.2. Section 5.3 solves for the first best allocation, given the technology. Compliance under different standards and fine rates is analyzed in section 5.4. Section 5.5 examines implications of different policies. Section 5.6 contains the concluding remarks.

5.1 The Model

A firm produces a physically homogenous product x, at zero cost. Production of this output damages the environment at the level $D > 0$. The damage could be in the form of emissions of pollutants or depletion of natural resources. We term it as *environmental bad.* The damage can be reduced by cleaning up the pollution. This could be an end of the pipe cleaning process or a top of the pipe cleaner production process.

For $0 \leq b \leq D$, the cost, $c(b)$, of reducing the environmental damage to the level b from D, is given by

$$c(b) = \frac{1}{4}k(D - b)^2 \tag{5.1}$$

Cost of cleaning the pollution is a one time cost that is incurred prior to the commencement of the production process.

All potential consumers, or economic agents, derive utility, U, from the pollution producing good x and a composite good, *money.* Those consuming x buy one unit or none at all. The good in question has two attributes; a physical attribute and an environmental impact. The physical attribute contributes utility v to a consumer of x; the environmental damage affects the utility of all agents, those who consume x and those who do not. We further assume that all agents are environmentally conscious and, are therefore, aware of the environmental damage caused by the production of x. This awareness is translated into a *net* utility for the consumers of x, which is less than v by the extent of their feeling of "guilt" in supporting the production of an environmentally damaging good. This is reflected in the fact that the higher is b, the lower is the price that consumers are willing to pay for x (Arora and Gangopadhyay, 1995; Cremer and Thisse, 1999).[2] To be more specific, if the aggregate production of x is positive, the utility function of an agent is

$$U = y + I[v(y) - \gamma b - p] - \eta b \tag{5.2}$$

y is the money endowment or income of the consumer and $v(y)$ is the utility derived from one unit of the physical aspect of the good for the consumer with income y. b is the environmental bad caused by the production process, implying that $D - b$ of the bad has been cleaned up by the firm. γ is the weight attached to the disutility caused by the generation of environmental bad, and is a measure of the degree of environmental consciousness of the consumers. p is the price paid by the consumer for the good x, if it is bought. I is an indicator function and takes the value 1 if the good x is bought by the agent, and 0 if it is not bought by this agent. η is the utility loss per unit of damage caused by the production of x. Thus, for a consumer who buys a unit of x, the utility is

$$y + v(y) - \gamma b - p - \eta b;$$

and for the one who does not buy it, it is

$$y - \eta b.$$

[2]Alternatively, if the good in question is a cheap household fuel like firewood, its use not only damages the environment, but also is unhealthy for those who use it in their house, say, for cooking. The damaging effect on personal health reduces the net utility from its consumption.

Observe that the term ηb can be interpreted as the negative externality caused by the production of x. The environmental damage uniformly affects both groups of agents — consumers and non-consumers of x.

The parameter γ can be interpreted as the marginal disutility caused by the consumption of an extra unit of *bad*. It depends upon the consumers' concern, level of awareness or sensitivity regarding the environment. It may differ among different societies. It can also be influenced by propaganda, mass campaigns, boycotts, etc., aimed at increasing consumer awareness.

In our formulation, therefore, the environmental damage caused by the production of x, has a direct and an indirect effect. The former is specific to the consumers and results in a direct utility loss to the consumers. The latter appears as an externality caused by its production and is suffered uniformly by all the agents — consumers, as well as non-consumers. The direct effect, measured by θ can take the form of health hazard, safety risk, guilt or concern due to environmental consciousness. The indirect effect can take the form of atmospheric pollution, depletion of natural resources, productivity of future generation etc. Thus the model formulation covers a broad class of products, the products which have a (negative) externality associated with their production as well as those, which have only a direct hazard associated with their consumption, and the negative externality $\eta = 0$. The various examples of such products are, the use of firewood or kerosene as a fuel that has a direct health effect for the user and also pollutes the atmosphere. While making their choices, the agents take into account the direct effect of the product; however, the indirect effect is treated, as outside their control.

Consumers have different levels of income and the same good may yield different utility to different consumers. In chapters 2-4, v was normalized to 0, however, in this chapter we assume $v'(y) < 0$, that is, v is a monotonically decreasing function of y. The marginal utility of this good falls as income increases. The nature of the good is such that poor consumers derive a higher marginal utility from this good and, despite the environmental bad that the good generates, cannot do without it. Consumers with higher income levels derive a lower marginal utility from this good and are willing to buy the good only if it generates low levels of *bad*. An example where such a specification is relevant, is fuel. Amongst the class of goods that can be used as fuel, some deteriorate the environment as well as have direct harmful effect for the user, for example firewood. It is a necessity good for the poor. Rich people can use other (cleaner) alternatives as fuel.

A consumer will buy the good only if she enjoys a positive surplus from the good. For a consumer with income level y, the surplus generated from buying the good is given by $v(y) - \gamma b - p$. It measures the net addition to utility from buying the good. For the same b and p, different consumers enjoy different levels of surplus due to the differences in their income levels. As income level rises the surplus enjoyed from buying this good falls, since the marginal utility of income is falling. We assume that y is distributed uniformly with support $[\underline{y}, \overline{y}]$; this implies that $v(.)$ is uniformly distributed with support $[\underline{v}, \overline{v}]$ where $\underline{v} = v(\overline{y})$ and $\overline{v} = v(\underline{y})$. We use the following normalization of v :

A.5.1: v is distributed uniformly over $[0, 1]$.

Given the one to one relationship between v and y, we can characterize consumers by v rather than y. From now on, therefore, v will denote the consumer type, with a higher v implying a consumer with a lower money endowment. Henceforth, we will also suppress the argument y from v.

A.5.2: $\gamma D < 1$.

If there is no cleaning done by the firm, then the environmental damage is D. Also, since $v \in [0, 1]$, the highest (marginal) utility derived from the physical properties of x is 1. This utility is obtained by the lowest income earner. A.5.4 implies that the disutility derived from the product with the least environmental quality (i. e., without any cleaning activity) is less than the utility that a consumer with lowest income enjoys by consuming this good. This is to ensure that the consumer with the lowest income always has a positive demand for the product at sufficiently low prices.[3] Alternatively, even for b as high as D, the product commands a positive price.

A.5.3: $kD - 2\gamma - 2\eta > 0$.

Given the cost function in (5.1), the marginal cost of cleaning the last unit of pollution, is $[(kD)/2]$, while marginal utility of the cleanup is $\gamma + \eta$. A.5.4 says that the marginal cost of cleaning the last unit of pollution (i. e., $b \to 0$, and cleanup approaching D) is greater than the gain in utility to the consumer caused by the act of cleaning. It ensures the concavity of the welfare function and hence guarantees interior solution in the social optimum.

Given the utility function, where consumers are environment conscious, the firm may decide on its own to do a positive amount of cleanup, i.e., choose a $b < D$.

The profit to the firm is

$$\pi = \alpha p - c(b); \tag{5.3}$$

where α denotes the aggregate demand of the product. Recall that the surplus enjoyed by a consumer of type v, from the product with emissions b at price p, is given by $v - \gamma b - p$. Let $\hat{v}$ denote the marginal consumer type who is indifferent between buying and not buying the good. Thus, in a situation where x is bought in the market at a price p, the marginal consumer is characterized by $\hat{v} = \gamma b + p$. The product is demanded by all those whose $v \geq \hat{v}$. Thus the aggregate demand (α) is given by $1 - \hat{v} = 1 - \gamma b - p$, thus

$$\pi = (1 - \gamma b - p)p - c(b), \tag{5.4}$$

Observe that, we can compare different technologies by the value of k in equation (5.1).

Lemma 1: *Let A.5.1-A.5.3 hold. Suppose that the firm has access to two technologies, k_0 and k_1, with $k_0 > k_1$. Then the firm chooses k_1.*[4]

[3] However we allow for the consumers at the upper end of the income distribution not to demand it at all. That is to say, the market is partially covered.

[4] The result can be generalised to any set of technologies.

Proof: From equations (5.1) and (5.3), observe that, for a given price and a cleanup level $b < D$, the profit from technology 1 is always greater than that from technology 0, since $c_0(b) > c_1(b)$ for all $b < D$.

We, therefore, need to show that the choice of b by the firm is, indeed, less than D. Consider a technology i, $i = 0, 1$. The first order conditions are

$$\frac{\partial \pi_i}{\partial b_i} = -\theta p_i + \frac{k_i}{2}(D - b_i) = 0 \quad (5.5)$$

$$\frac{\partial \pi_i}{\partial p_i} = 1 - 2p_i - \theta b_i = 0 \quad (5.6)$$

Given A.5.2 and A.5.3, equations (5.5) and (5.6) are necessary and sufficient for a unique solution.[5] Given A.5.2, $p_i > 0$. This implies, $b_i < D$. *QED*.

Denoting the market solutions with the superscript m, from (5.5) and (5.6), we get

$$b^m = \frac{kD - \gamma}{k - \gamma^2} \quad (5.7)$$

$$p^m = \frac{k(1 - \gamma D)}{2(k - \gamma^2)} \quad (5.8)$$

Observe that b^m, $p^m > 0$, using A.5.2 and A.5.3. Also note that

$$\frac{\partial b^m}{\partial k} > 0$$

$$\frac{\partial p^m}{\partial k} < 0$$

If a technology with a lower k becomes available, it will be used (Lemma 1). With the improved technology, the firm generates less pollution and is able to sell its product at a higher price. The first half of the above statement is intuitive and the second half can be explained by the fact that the consumers are willing to pay more for the environmentally better products.

[5]The second order condition for a unique maximum is $k_i > \gamma^2$. A.5.3 and A.5.2 imply $k_i D > 2\gamma > 2\gamma\gamma D$. It now follows that $k_i > 2\gamma^2$ which, in turn, implies $k_i > \gamma^2$.

Substituting the equilibrium value of b and p from (5.7) and (5.8) in the profit expression (5.4), we can obtain the value of monopoly profit in equilibrium.

$$\begin{aligned}\pi^m &= (1-\theta b^m - p^m)p^m - c(b^m) \\ &= \frac{k^2(1-\gamma D)^2}{[2(k-\gamma^2)]^2} - \frac{k}{4}\Big(D - \frac{kD-\gamma}{k-\gamma^2}\Big)^2 \\ &= \frac{k(1-\gamma D)^2}{4(k-\gamma^2)} \end{aligned} \tag{5.9}$$

This also gives us an alternative proof of Lemma 1, since

$$\frac{\partial \pi^m}{\partial k} = -\frac{\gamma^2(1-\gamma D)^2}{4(k-\gamma^2)^2} < 0$$

In this model, there are two reasons why the market solution may not be the first best outcome. One is immediate — the inefficiency resulting from a monopolist producer. The other is the negative (environmental) externality, arising from the fact that even those who do not consume x, are suffering the impact of a depleted environment. Thus, even though buyers are willing to pay for a cleaner environment, not all of the externality is internalized in the price of x.

To see this more clearly, consider $\hat{v}^m$ that determines the proportion of people who are buying in the market.

$$\begin{aligned}\hat{v}^m &= \theta b^m + p^m \\ &= \theta\frac{kD-\gamma}{k-\gamma^2} + \frac{k(1-\gamma D)}{2(k-\gamma^2)} \\ &= \frac{k+\theta kD - 2\theta^2}{2(k-\theta^2)} \end{aligned} \tag{5.10}$$

There are two types of consumers who are not buying this product. For those consumers, whose *net* utility, $v(y) - \theta b$, is negative will obviously, not buy the product at any positive price. However, there is also a second group of people who are not buying x. These are the people for whom $v(y) - \theta b$ is positive but $v(y) - \theta b - p$ is negative. Thus, even though people buying the product are (environmentally) conscious enough to value their utility net of the environmental damage their consumption creates, there are others (the non-buyers) who are indirectly paying for the environmental damage (through a loss in their utility).

Thus, the market solution is expected to be different from the first best solution. We use the term *double distortion* to refer to this simultaneous presence of multiple distortions. Sometimes these effects offset each other, but at other times, the effects may compound each other. An optimal regulation must incorporate a careful analysis of the effect of these two types of distortions. In the next section we solve for the optimal provision of environmental quality.

5.2 Social Optimum: First Best Allocation

Welfare is defined as the total surplus, i.e., the sum of consumer and producer surplus generated by the production of x. It is equal to the utilities derived by the consumers, less the cleanup cost.[6] Thus the welfare w, is given by

$$\begin{aligned} w &= \int_{\hat{v}}^{1}(y+v-\gamma b-p-\eta b)dF(v)+\int_{0}^{\hat{v}}(y-\eta b)dF(v)+\int_{\hat{v}}^{1}pdF(v)-c(b) \\ &= \int_{\hat{v}}^{1}(y+v-\gamma b-\eta b)dF(v)+\int_{0}^{\hat{v}}(y-\eta b)dF(v)-c(b) \qquad (5.11) \end{aligned}$$

where $F(v)$ is the distribution function of v. By A.5.1, $dF(v) = 1.dv$. Using (5.1), A.5.1 and $\hat{v} = \gamma b + p$, in (5.11),

$$\begin{aligned} w &= y+\frac{1}{2}-\gamma b+\frac{\gamma^2 b^2}{2}-\frac{p^2}{2}-\frac{k}{4}(D-b)^2-\eta b \\ &= y+\frac{1}{2}(1-\gamma b)^2-\frac{p^2}{2}-\frac{k}{4}(D-b)^2-\eta b \qquad (5.12) \end{aligned}$$

Observe that the welfare expression is falling in price, therefore, in equilibrium, price should be set equal to zero. A price equal to zero implies that $\hat{v} = \gamma b$, and ensures that all the consumers with $v > \gamma b$ are able to consume x. The social optimum, then is obtained by

[6] We are keeping away from distributional issues and therefore, the division of total surplus between consumer and producer surplus does not matter from the point of view of social optimum.

choosing an optimal level of emission to maximize the welfare. Solving for b, the necessary condition is

$$\frac{\partial w}{\partial b} = 0 \Rightarrow -\theta^2 b - \gamma + \frac{k}{2}(D - b) - \eta = 0$$

which implies

$$b^* = \frac{kD - 2\gamma - 2\eta}{k - 2\gamma^2} \tag{5.13}$$

where a superscript $*$ denotes the first best value of the variable, given technology k. The second order condition $(\partial^2 w/\partial b^2) < 0$, or $k - 2\gamma^2 > 0$, is guaranteed by A.5.2 and A.5.3 (see footnote 6).

Using A.5.3, $b^* > 0$. Also observe that

$$\frac{\partial b^*}{\partial k} = \frac{2\gamma(1 - \gamma D) + 2\eta}{(k - 2\gamma^2)^2} > 0 \tag{5.14}$$

Again, the optimal cleanup level rises as the cleanup technology becomes cheaper.

Substituting the equilibrium value of b^* from (5.13), and $p^* = 0$ in (5.12), we can obtain the value of aggregate welfare in equilibrium for $0 < b^*$,

$$w^* = y + \frac{k(1 - \gamma D)^2}{2(k - 2\gamma^2)} - \frac{\eta(kD - 2\gamma - \eta)}{k - 2\gamma^2} \tag{5.15}$$

This is the first best level of welfare, which the economy with technology k can achieve.

Lemma 2: *Let A.5.1-A.5.3 hold. Suppose that the firm has access to two technologies,* k_0 *and* k_1, *with* $k_0 > k_1$. *Then the welfare is higher with* k_1.

Proof: The proof follows exactly the same steps as the proof of Lemma 1. Alternatively, it is immediate from the sign of the first derivative of w^* with respect to k.

$$\frac{\partial w^*}{\partial k} = -\frac{\gamma^2(1 - \gamma D)^2 + \eta^2 + 2\eta\gamma(1 - \gamma D)}{(k - 2\gamma^2)^2} < 0$$

QED.

Lemma 2 is analogous to Lemma 1. It simply states that welfare can not go down with a technology that has a lower cleanup cost.

Having described the market outcome and the first best, it is now possible to compare the two.

Proposition 1: *Let A.5.1-A.5.3 hold. For any given technology, as compared to the first best, the market outcome*

(i) provides a lower cleanup level

(ii) serves a smaller size of the market.

Proof: (i) Comparing (5.7) and (5.13), it is immediate that $b^m > b^*$. *QED.*

(ii) The size of the market served is given by $1-\hat{v}$. It is straightforward to check that $\hat{v}^m > \hat{v}^*$.

$$\Rightarrow (1 - \hat{v}^m) < (1 - \hat{v}^*)$$

QED.

The inefficiency in the market solution has two effects. One is the underprovision of environmental quality, and the other is, a smaller size of the market is served.

The market inefficiency can be broken down into the inefficiency caused by a monopoly producer and that from the environmental externality. Suppose there were no external damage. Then, the people who were not buying x will not have any utility loss because others were buying. The difference in the first best and the market solution will now be due only to the market structure. The second stage welfare expression (5.11) now becomes

$$w' = \int_{\hat{v}}^{1} (y + v - \gamma b) dF(v) + \int_{0}^{\hat{v}} y dF(v) - c(b) \tag{5.16}$$

Following the same procedure as above, we can again solve for the first best b as

$$b' = \frac{kD - 2\gamma}{k - 2\gamma^2} \tag{5.17}$$

Observe that it is easy to show that $b^m > b' > b^*$ and

$$b^* = b' - \frac{2\eta}{k - 2\gamma^2} \tag{5.18}$$

The second expression on the right hand side of (5.18) is, therefore, the inefficiency caused by the environmental externality.

To complete the comparison, let us also compare the aggregate welfare obtained under the monopoly with the social optimum. Under the monopoly, $\hat{v} = \gamma b + p$. Plugging the value of b^m, and p^m, from (5.7) and (5.8) in the welfare expression (5.12), we obtain

$$w^m = \frac{k(1-\gamma D)^2}{4(k-\gamma^2)} + \frac{k(1-\gamma D)^2}{8(k-\gamma^2)^2} - \eta\frac{kD-\gamma}{k-\gamma^2} \qquad (5.19)$$

The first term on the right hand side of the above equation is the profit obtained by the firm, second term is the consumer surplus and the last term is the negative environmental externality generated by the production of x. The welfare expression confirms that the welfare obtained under a monopoly is below the first best welfare.

Let us now examine how does the degree of inefficiency, i.e., the deviation from the first best cleanup level, varies with a variation in k.

Proposition 2: *Let A.5.1-A.5.3 hold. The degree of inefficiency, i.e., the deviation of the market solution from the first best solution, increases with a lowering of k, the slope of the marginal cleanup cost.*

Proof: Recall

$$\begin{aligned} b^m - b^* &= \frac{k\gamma(1-\gamma D)}{(k-\gamma^2)(k-2\gamma^2)} + \frac{2\eta}{k-2\gamma^2} \\ \frac{\partial(b^m - b^*)}{\partial k} &= -\frac{\gamma(1-\gamma D)(k^2-\gamma^4)}{(k-\gamma^2)^2(k-2\gamma^2)^2} - \frac{2\eta}{(k-2\gamma^2)^2} < 0 \end{aligned}$$

QED.

This is an interesting result. It shows that the incentive to deviate from the first best emission level increases as the cleanup technology improves (or the marginal cost of cleanup falls).

In view of the inefficiencies in the market solution, there is a role for non-market regulation. In the next section, we analyze environmental regulation.

5.3 Environmental Regulation and Compliance

Suppose the regulator knows the optimal emissions that the firm should be generating. It can set a standard and the firm is required to pay a fine if it does not meet the standard. Specifically, let $\hat{b}$ be the exogenous emission standard faced by the firm, and a firm not complying with the standard is required to pay a fine f per unit of deviation from the standard. Note that the firm pays a fine only if it generates emissions more than the set standard. However, if its pollution is less than the imposed standard, it does not pay any fine. The profit is now a function of the regulation, as well as the optimal choices of b and p by the firm. With some abuse of notation, we continue to use π as the notation for profit, but include as arguments, f and $\hat{b}$. Thus, the profit function of the firm in the presence of such an environmental regulation is

$$\pi(., f, \hat{b}) = p(1 - \gamma b - p) - f\ max[(b - \hat{b}), 0] - c(D - b) \tag{5.20}$$

Observe that as long as $b^m \leq \hat{b}$, the government regulation is irrelevant and does not affect the market solution. If, however $b^m > \hat{b}$, the regulation does have an impact on the firm.[7] Then, maximizing π with respect to p and b, gives the following necessary conditions

$$1 - \gamma b - 2p = 0$$
$$-\gamma p - f + \frac{k(D - b)}{2} = 0$$

yielding

$$-\gamma(\frac{1 - \gamma b}{2}) - f + \frac{k(D - b)}{2} = 0$$

implying

$$b = \frac{kD - \gamma - 2f}{k - \gamma^2} \tag{5.21}$$

[7]Note that for $\hat{b} < b^m$, the effect of this regulation on the profit function of the firm is similar to that of an effluent tax. Consider a standard $\hat{b} = b^*$, the first best emission. We will show later that there exists a fine f^*) that implements this first best. Then, the fine f^*, in conjunction with the standard b^*, equates the marginal benefit of pollution to the firm, to the marginal damage caused by it to the society. In this sense it is equivalent to a Pigouvian tax.

$$p = \frac{k(1-\gamma D)+2f\gamma}{2(k-\gamma^2)} \tag{5.22}$$

Lemma 3: *Let A.5.1-A.5.3 hold. If the firm produces, then it complies with the standard* $\hat{b}$ *for all fines* $f \geq f(\hat{b})$, *where* $f(\hat{b})$ *is given by*

$$f(\hat{b}) \equiv \frac{kD-\gamma-\hat{b}(k-\gamma^2)}{2} = \frac{k(D-\hat{b})-\gamma(1-\gamma\hat{b})}{2}. \tag{5.23}$$

Proof: The firm will produce only when it makes non-negative profits.[8] Then the necessary conditions for profit maximization prevail. Plugging the value of $f(\hat{b})$ in the profit function $\pi(.,f,\hat{b})$, it can be easily checked that in equilibrium, $b=\hat{b}$.

We refer to the *minimum* fine because, it is immediate that any fine rate above this minimum, $f(\hat{b})$, will also make the firm meet the standard. *QED.*

Recall that $b^m = (kD-\gamma)/(k-\gamma^2)$. Plugging in this value as $\hat{b}$ in (5.23) gives us $f(b^m)=0$. In other words, $f(\hat{b})>0$, if and only if $\hat{b}<b^m$. Obviously, any standard $\hat{b}\geq b^m$, is irrelevant for the profit maximizing firm and does not require a fine to enforce it. The standard becomes effective only if the required standard is below b^m, and then a positive fine is required to enforce it. Further we are assuming perfect enforcement. That is, once the regulator decides on the standard, it is able to enforce it through an appropriate fine rate.[9]

Observe that the fine which implements the standard is a function of k. Moreover, the first best pollution level is also a function of k. Thus any regulatory mechanism that involves the setting of a standard, and a punishment for deviating from the standard, requires information about the true cost of cleanup. This can lead to a number of problems, since, in reality, it

[8] If the regulation does not allow the firm to make non-negative profit, then it will produce nothing and, hence, no pollution. In this case it overcomplies for all $\hat{b}>0$.

[9] Imperfect enforcement may arise when the regulator is unable to determine whether the firm has maintained the standard. One way to model this is to assume that the fine is imposed with probability $0<h<1$. In this case, the *expected* fine is what matters; otherwise, it does not change our analysis. It can be accommodated by inserting h in the denominator of the expression for $f(\hat{b})$.

is difficult for the regulator to know this cost. From Proposition 2, we know that a lower k produces a greater incentive to deviate from the first best. In other words, a firm with a lower cleanup cost, has an incentive to overstate its costs so that it can induce the regulator to set a weaker standard. Given equation (5.1), we can describe different cleanup technologies by considering different values of k. Suppose the regulator knows that there are two possible cleanup technologies, $0, 1$ with $k_0 > k_1$. It, therefore, knows, from equation (5.21), that the optimal pollution under k_0 is higher than under k_1. Thus, if the regulator believes that the cost of cleaning is higher (k_0) it will want to set a "weaker" standard. The firm is better off if the regulator thinks the technology is k_0 when it is actually k_1. Indeed, firms facing the possibility of environmental regulation clamour about the costs of cleanup.

Another way to see the problem is to consider the fine rate. From equation (5.23), we know that the fine rate is increasing in k since

$$\frac{\partial f(\hat{b})}{\partial k} = \frac{1}{2}(D - \hat{b}) > 0$$

Thus, if the standard is already set, then the firm has an incentive to announce a better (lower cost) technology than it actually has! As we will argue, the different types of misreporting incentives for the standard and the fine rate, have important implications for regulatory policies.

At this stage we introduce some notation to take care of different technologies and an assumption. For any given standard $\hat{b}$, we define $f_j(\hat{b})$ to be the same as equation (5.23) with k_j in place of k, $j = 0, 1$. We will denote the maximized value of profit under this regulation, for firm type i, to be $\tilde{\pi}_i(\hat{b}, f_j(\hat{b}))$, $i = 0, 1$.

A.5.4: $\tilde{\pi}_0(b_1^*, f_0(b_1^*)) > 0$.

This assumption ensures that firm type 0 can make positive profit when the standard is b_1^* and the fine rate forces it to meet the standard. In a sense, this is the strictest possible regulation (lowest level of pollution allowed and the largest possible fine rate); we are assuming that firm 0 will still make positive profit and thus produce positive output. We have the following result.

Lemma 5: *Let A.5.1-A.5.4 hold and $k_1 < k_0$. Then $\tilde{\pi}_0(b_0^*, f_0(b_0^*)) > \tilde{\pi}_1(b_1^*, f_1(b_1^*))$.*[10]

Proof: For a firm type i, $i = 0, 1$, let the set standard be its corresponding first best level, i.e., $\hat{b} = b_i^*$. Suppose the fine set is such that the firm's optimal response is to maintain the standard, i.e., fine rate is equal to $f_i(b_i^*)$. Then, suppressing the subscript, and from (5.4), (5.1) and the definition of $\tilde{\pi}(b^*, f(b^*))$, we can write

$$\tilde{\pi}(b^*, f(b^*)) = p(b^*)(1 - \gamma b^* - p(b^*)) - \frac{k(D - b^*)^2}{4}$$

where $p(b^*)$ is the price chosen by the firm to maximize its profit when it is required to meet b^* under fine rate $f(b^*)$.

Plugging in the expression for b^*, from (5.13), we obtain

$$\tilde{\pi}(b^*, f(b^*)) = \frac{[k(1 - \gamma D)^2(k - 4\gamma^2) - 4\eta^2(k - \gamma^2) - 4\eta\gamma k(1 - \gamma D)]}{4(k - 2\gamma^2)^2} \tag{5.24}$$

It can be checked that

$$\frac{\partial \tilde{\pi}}{\partial k} = \frac{2\gamma^4(1 - \gamma D)^2 + k\eta^2 + \eta\gamma(1 - \gamma D)(k + 2\gamma^2)}{(k - 2\gamma^2)^3} > 0$$

Given $k_1 < k_0$, the Lemma follows immediately. *QED.*

The aggregate welfare when the regulator implements the first best level of emission for a given k is given by

$$w(b^*) = y + \frac{3}{8}(1 - \gamma b^*)^2 - c(b^*) - \eta b^* \tag{5.25}$$

where b^* is the first best level of pollution appropriate to the known value of k. It follows from (5.15) and (5.25) that we are in the second best world, since $w(b^*) < w^*$.[11] This is because b^* is implemented through the market. Recall that the first best, w^*, required the price to be zero; however, at zero price the firm will not operate.

[10] A.5.4 is a stronger assumption for this result. Assuming $\tilde{\pi}_i(b_i^*, f_i(b_i^*)) > 0, i = 0, 1$ is sufficient for the result to go through.

[11] Both $w(b^*)$ and w^* are functions of k.

Before completing this section, we investigate the degree of compliance by the firm under differing (cleanup) technologies. This is non-trivial since the optimal fine that ensures compliance is a function of k.

Proposition 3: *Let A.5.1-A.5.4 hold. Consider a standard $\hat{b}$ and recall that $b_1^m < b_0^m$ for $k_0 > k_1$. Define*

$$g(k, \hat{b}) = \frac{k(D - \hat{b})}{2} - \frac{\theta(1 - \theta\hat{b})}{2}$$

The level of emissions generated by firm with technology i, at a fine rate $f = g(k, \hat{b})$, is given by

$$b_i = min[b_i^m, max(\hat{b}, \hat{b} + \frac{k_i - k}{k_i - \gamma^2}(D - \hat{b}))] \tag{5.26}$$

Proof: (a) Suppose $\hat{b} \geq b_i^m$. Then it is obvious that firm i, would be generating b_i^m for all non-negative fine rates.

(b) Suppose $b_i^m > \hat{b}$.

Replacing f by $g(k, \hat{b})$ in (5.21), we obtain

$$b_i = \hat{b} + max[0, \frac{k_i - k}{k_i - \gamma^2}(D - \hat{b})]$$

Observe that if $k \geq k_i$, $b_i = \hat{b}$, using Lemma 3. *QED.*

This Proposition highlights the fact that, given a standard and a fine rate, firm type 1 will comply whenever type 0 complies. This is because, the fine rate at which 0 complies is greater than that required for type 1 to comply. Alternatively, if the fine rate is such that 1 just complies, type 0 will not comply. In general, with $k_1 < k_0$, for any given standard $\hat{b}$, and any fine rate (common to both firms), the level of emission by firm type 0 will be no less than that of firm type 1, i.e., $b_0 \geq b_1$.

5.4 Policy Alternatives

The analysis so far has assumed the technology to be given. In reality, firms complain about the high costs of cleanup. The regulatory agency, thus, is often concerned with the development of cheaper technologies for cleaning the environment. Development of technologies are determined through the R&D expenditures by the firm. While the regulator may find out the technology once it is in operation, it is much more difficult for it to know the level of effort and resources spent by the firm to develop the technology. Since the outcome of R&D is stochastic, clearly, the regulatory environment has significant effects on the incentive to develop cheaper technologies. This, in turn, has serious implications for the optimal regulatory structure. More specifically, in this section we will study the effects of the environmental regulation on the incentive to invest in technological development.

Consider a three stage game. In the first stage, the government announces the regulatory policy — a standard and a fine rate. In the beginning of the second stage, the firm decides on the investment in R&D. The outcome of the R&D effort is stochastic and this gets resolved at the end of this stage. With probability q, it is successful and the firm develops a new technology where k in equation (5.1) is equal to k_1; with probability $(1-q)$, the R&D effort is a failure, and the firm has the incumbent, or old, technology that has $k = k_0$. Of course, $k_1 < k_0$. In the third stage, the firm decides on the cleanup technology, price, and the level of cleanup. Observe that if the R&D effort has been a failure, the technology choice is trivial. If, however, the R&D effort has been successful, the firm has two technologies to choose from.

The R&D technology is characterized by the probability of success. This probability is a function of the resources spent in R&D. For ease in exposition, we will work with the probability of success as the firm's choice variable in the R&D stage. If q is this probability, then $F(q)$ denotes the cost undertaken.

A.5: $F'(q) > 0,\ F'(0) = 0,\ F''(q) > 0.$

As viewed in the second stage, the total cost to the firm has two components — one, the investment in developing a low cost technology that is undertaken in this stage and the other, the cost of cleaning the pollution that is undertaken in the next stage and the associated fine if the optimal response is not to meet the standard and pay the fine.

Let us first analyze the incentive for technological development for the firm without any regulation. The second stage expected profit function of the firm (Π) is the expected third stage profit less the second stage cost of R&D. From Lemma 1,

$$\begin{aligned} \Pi &\equiv q[(1-\gamma b_1^m - p_1^m)p_1^m - c_1(b_1^m)] + (1-q)[(1-\gamma b_0^m - p_0^m)p_0^m - c_0(b_0^m)] - F(q) \\ &= q\pi_1^m + (1-q)\pi_0^m - F(q) \end{aligned} \tag{5.27}$$

Recall that π_1^m and π_0^m differ not only in terms of clean up cost k, but also in terms of the choice of b.

Proposition 4: *Let A.5.1-A.5.3, A.5 hold. In the presence of environmentally aware consumers, the firm undertakes a positive amount of investment in R&D.*

Proof: Differentiating the expected profit function with respect to q,

$$\begin{aligned} \frac{\partial \Pi}{\partial q}|_{q=0} &= \pi_1^m - \pi_0^m - F'(0) \\ &= \pi_1^m - \pi_0^m > 0 \end{aligned}$$

using A.5 and Lemma 1. At $q = 0$, the firm's profit is increasing in q; therefore, it will invest positively in technological development. *QED.*

The optimal investment in R&D is given by maximizing Π with respect to q. From A.5.3 and A.5, the following condition is necessary and sufficient.

$$\pi_1^m - \pi_0^m - F'(q) = 0 \tag{5.28}$$

The third stage profit is higher with the cleaner technology, but at the same time, the probability of developing a cleaner technology is increasing in the R&D investment. There is a trade-off between the expected third stage profit and the R&D cost. Both are increasing in the cleaner technology. Observe that this result is due to the presence of environmentally aware consumers. In the absence of consumer awareness, the firm does not have any incentive to invest in developing a cheaper (cleaner) technology.

Following a similar procedure, we can obtain the welfare maximizing investment in R&D. Let W be the expected welfare in the first stage. Then,

$$W(q) = qw_1^* + (1-q)w_0^* - F(q) \tag{5.29}$$

Here we are using Lemma 2 to argue that if the R&D effort is successful, welfare maximization demands that the cheaper cleanup technology be used. To define the welfare in the third stage, we are assuming that any fine collected by the government is returned back to the producers and consumers in a non-distortionary manner.

The equilibrium investment in technology development is given by the first order condition obtained by maximizing W with respect to q, which implies

$$w_1^* - w_0^* - F'(q) = 0 \tag{5.30}$$

Since $w_1^* - w_0^* > 0$, it is immediate that in the overall first best, a positive investment is undertaken for developing a cheaper technology. Let us now compare the firm's investment in R&D with the social optimum.

Proposition 5: *Let A.5.1-A3, A.5 hold. There is under investment in R&D in a market solution.*

Proof: The market solution requires

$$F'(q^m) = \pi_1^m - \pi_0^m = \frac{(k_0 - k_1)\gamma^2(1-\gamma D)^2}{4(k_0-\gamma^2)(k_1-\gamma^2)}$$

The welfare maximizing solution requires

$$F'(q^*) = (w_1^* - w_0^*) = \frac{(k_0-k_1)\gamma^2(1-\gamma D)^2 + \eta(k_0-k_1)[\eta + 2\gamma(1-\gamma D)]}{(k_0-2\gamma^2)(k_1-2\gamma^2)}$$

It is straightforward to check that $F'(q^*) > F'(q^m) \Rightarrow q^* > q^m$, using A.5. *QED.*

We have already described the inefficiency in the market solution as compared to the first best (Proposition 1). Proposition 5 strengthens this inefficiency, by stating that in addition to the cleanup inefficiency, there is also an underinvestment in technological development. Thus our contention that there is a role for non-market regulation is strengthened. Further, notice that even in the absence of the externality factor, i.e., $\eta = 0$, there is under investment in R&D in the market solution. The presence of externality increases the extent of underinvestment. Thus the total effect due to these two distortions gets compounded.

The timing of the announcement of the regulation is important. It has implications for the incentives for investing in R&D. If the regulation is announced after the investment in R&D, the firm cannot alter its decision regarding this investment. This uncertainty in innovation benefits is counter productive. We, therefore, assume that the government announces regulation in the beginning of the game, i.e., prior to the investment decision of the firm.

Since the regulator cannot observe the investment in R&D, but observes the realized technology, a natural form of regulation is that the planner makes the regulation contingent on the realized technology. Environmental laws often emphasize phrases like *best available technology* (BAT). We examine the implications of such a regulatory mechanism.

In our setup, we can implement the BAT policy in the following manner. The regulator announces that it will check the cleanup technology that is being used by the firm. By assumption, this inspection technology is perfect.[12] If the technology used is k_i, $i = 0, 1$, the standard imposed will be $\hat{b} = b_i^*$ and the fine $f_i(b_i^*)$. We know that under this regulation the firm of type i will meet the standard. However, Lemma 5 tells us that the profit of firm 1 under this regulation is *lower* than that of firm type 0. Thus, even if technology 1 is available, it pays the firm to implement technology 0. Knowing that it is better off using 0 in the final

[12]If the inspection technology is imperfect in the sense described in footnote 9 earlier, our qualitative results still go through when we make the appropriate changes to the fine as discussed there.

stage, the firm has no incentive to spend anything in developing the new technology! We thus have the following result, stated without proof:

Proposition 6: *Assume A.5.1-A.5. If the regulator announces a policy based on BAT, the firm does not have an incentive to invest in developing a cheaper cleanup technology and, therefore, there is no investment in R&D.*

First, consider the case $\gamma = 0$, or no consumer awareness. Then, it is immediate that $b_0^m = b_1^m = D$ in the third stage, i.e., no cleanup technology will be used. Therefore, the firm will spend nothing on R&D and $q = 0$. In this situation, the BAT policy will make the firm use technology 0, and restrict emissions to $b^* < D$, and therefore, will be better than no policy. However, once $\gamma > 0$, there is an incentive for the firm, *without any regulation*, to invest in R&D (Proposition 4) and the pollution emitted is less than D. Here a BAT based regulation takes away the incentive that the consumer awareness created for the firm!

In most countries non-governmental organizations play a role in informing consumers about the effects of pollution as well as the extent of such pollution generated by firms. This has the effect of raising γ. This has an enabling effect on the reduction of pollution by the firm, as well as on its incentive to develop cheaper cleanup technologies. A BAT-based regulatory policy is counter-productive in this situation.

Observe that we can interpret such a regulation as one that is contingent on the technology being used, treating it as the "best practice" technology. We will now go on to argue that a regulation that is not contingent on the technology being used is better than one that is based on the technology being used. This will be the central result of this chapter. This is non-trivial because even though a BAT may not generate any R&D effort, it can still be a second best policy (as b_0^* could be less than both b_1^m and b_0^m).

There is a major difference between a contingent (BAT) and non-contingent policy. In the BAT, the appropriate standard was contingent on firm type i, $i = 0, 1$. Also, the fine rate for type i is given by (5.23) where $k = k_i$. Thus, conceptually, both type of firms will comply with the standard (appropriate to them). In a non-contingent policy, both the standard and the fine rate is fixed independent of the firm type. Thus, it is possible that one type of firm may not comply while the other type does. As before, the regulator announces an emission standard and a fine rate, which kicks in whenever the firm fails to meet the standard. The total fine paid is the fine rate times the extent of the deviation from the set standard. We have observed that we can define for any standard $\hat{b}$, a fine rate $g(k, \hat{b})$ (see statement of Proposition 3) which collapses to (5.23) for $k = k_i$ if firm type is i (see the paragraph before A.5.4).

Lemma 6: *Assume A.5.1-A.5. A non-contingent regulation,* $(\hat{b}, g(k, \hat{b}))$, *induces the firm to undertake a positive investment in technological development.*

Proof: Consider any given (non-contingent) standard and fine rate, and suppose the cleanup level achieved by the firm is b. The firm has a greater profit for this level of cleanup if it uses technology 1 instead of technology 0 (see equation (5.20)). Therefore, given A.5, it invests a positive amount in developing a cheaper technology. *QED.*

Proposition 6 and Lemma 6 together show that, in terms of investment in R&D, BAT is dominated by a non-contingent policy. An obvious question that arises is, is BAT dominated by a non-contingent policy in terms of aggregate welfare as well. Recall that amongst non-contingent policies, the relevant range for setting emission standards is $b_0^* \leq \hat{b} \leq b_1^*$. We, therefore, first compare BAT with a non-contingent policy, where standard announced is b_0^*, and the associated fine is $g(k_0, b_0^*)$. With this fine rate, firm type 0 will comply since $g(k_0, b_0^*) = f_0(b_0^*)$ (see equation (5.23)).

Proposition 7: *There exists a non-contingent policy, which dominates BAT in terms of aggregate welfare.*

Proof: Observe that aggregate welfare under BAT is $w_0(b_0^*)$, since the firm does not spend any resource in developing a cheaper technology.

Consider the policy $\hat{b} = b_0^*$, $f(\hat{b}) = g(k_0, b_0^*)$. From Lemma 6, it follows that if a cheaper technology is available, it will be used. Also we know from proposition 3 that under this regulation, firm type 0 will comply and type 1 will either comply or overcomply. In other words, $b_1 = min\{b_1^m, b_0^*\}$. The expected welfare under the above policy is, therefore, given by

$$\begin{aligned} W &= qw_1(min\{b_1^m, b_0^*\}) + (1-q)w_0(b_0^*) \\ &= q[w_1(min\{b_1^m, b_0^*\}) - w_0(b_0^*)] + w_0(b_0^*) \end{aligned} \tag{5.31}$$

To prove the proposition , we need to show that $W > w_0(b_0^*)$. From Lemma 6, we know that $q > 0$. Therefore, it is sufficient to show that $w_1(min\{b_1^m, b_0^*\}) > w_0(b_0^*)$.
(i) Suppose $b_1^m \geq b_0^*$. Then

$$w_1(b_0^*) > w_0(b_0^*)$$

since for any given standard, welfare is higher with the use of a cheaper technology.
(ii) Suppose $b_1^m < b_0^*$. Then again, $w_1(b_1^m) > w_0(b_0^*)$, since $b_1^* < b_1^m < b_0^*$ (Proposition 1), and given technology 1, any move towards b_1^* is welfare improving. *QED.*

As already stated, the relevant range for standards is $b_1^* \leq \hat{b} \leq b_0^*$ and for fine rates is $g(\hat{b}, k_1) = f_1(\hat{b}) < f_0(\hat{b}) = g(\hat{b}, k_0)$. Proposition 7 proves that a non-contingent policy consisting of setting emission standard $\hat{b} = b_0^*$, and fine rate $f_0(b_0^*)$ yields a higher welfare than BAT policy. We call this the weakest policy as b_0^* is the optimal level of pollution for the firm with the worst (highest cost) cleanup technology and $f_0(b_0^*)$ is the fine rate that ensures that this firm complies with the set standard. We already know that the strictest possible regulation is standard b_1^* and fine $f_0(b_1^*)$ (see the paragraph discussing A.5.4). Let us now examine whether either of the two extreme policies is the second best policy.

In our analysis, it is the standard, which has welfare effects. A fine by itself, does not affect welfare directly, as it is collected from the firm and distributed to the consumers. The fine affects welfare indirectly through affecting the choice of cleanup level by the firm.

Proposition 8: *Assume A.5.1-A.5.5. A non-contingent welfare maximizing policy standard* $\hat{\hat{b}}$ *must between lie between the two first best levels of emission, i.e.,* $b_1^* < \hat{\hat{b}} < b_0^*$.

Proof: First we examine that for any given standard, how does the welfare change with a change in standard. Given any regulation $\hat{b}, g(k, \hat{b})$, $k_1 \leq k \leq k_0$, type 1 firm always either complies or overcomplies, however type 0 firm may or may not comply, depending upon the factor k in function $g(.,.)$.

$$W = qw_1(min\{b_1^m, \hat{b}\}) + (1-q)w_0(b_0)$$

where q is determined by

$$F'(q) = \pi_1(min\{b_1^m, \hat{b}\}) - \pi_0(b_0) + \frac{k(D-\hat{b}) - \gamma(1-\gamma\hat{b})}{2}(b_0 - \hat{b})$$

Observe that at $g = g(\hat{b}, k_0(\hat{b}))$, type 0 firm also complies with the set standard, i.e., $b_0 = \hat{b}$, thus the last term in the right hand side of above equation drops out. Then, using envelope theorem, we get

$$\frac{\partial W}{\partial \hat{b}} = q\frac{\partial w_1(min\{b_1^m, \hat{b}\})}{\partial \hat{b}} + (1-q)\frac{\partial w_0(\hat{b})}{\partial \hat{b}} \qquad (5.32)$$

At $\hat{b} = b_1^*$, the first term in (5.32) vanishes because, by definition, $w_1(b)$ is maximized at b_1^*. The second term is positive because, $w_0(b)$ is a (strictly) concave function (from A.5.2 and A.5.3) and $b_1^* < b_0^*$. Thus welfare improves when the standard is relaxed at the level b_1^*. Similarly at $\hat{b} = b_0^*$, the second term in (5.32) vanishes and the first term is negative, therefore, a tighter standard is welfare improving. *QED.*

5.5 Conclusion

In this chapter we find that the market solution is inefficient and results in underprovision of environmental quality. The inefficiency is caused by two sources of distortion—one, market imperfection and the other, the negative (environmental) externality associated with the production process. The effects of these two distortions on the choice of the cleanup level are in the same direction, and therefore, reinforce each other.

In addition to the static inefficiency of the market outcome, there is also a dynamic inefficiency. While consumers' willingness to pay a higher price for environmentally better products induces the firm to invest in R&D effort, private benefits of technological change are inadequate. We, therefore, explore implications of various regulatory mechanisms on incentives for R&D effort.

The central result of the chapter is that a policy based on the best available technology, or BAT, takes away the incentive that consumer awareness created for the firm. Hence under such a regulatory mechanism, the firm does not invest any resources in developing a cheaper technology. It is interesting to note that the regulation, which achieves a socially optimal outcome in a static analysis (based on a given cleanup technology), generates perverse incentives for developing a better technology as we extend the period of analysis.

We further find that a non-contingent policy (common to both types of firms), not only induces the firm to make a positive investment in R&D but may also be welfare improving. Specifically, a policy that implements an emission standard optimal for the high cost firm, dominates a BAT policy in terms of welfare as well.

Finally we examine various policies in terms of relative strictness, and find that a second best policy must lie between the two extreme policies, viz., the weakest policy and the toughest policy.

Chapter 6

Conclusion

This thesis studies the provision of environmental quality in imperfect markets, in the presence of environmentally aware consumers. The market solution is expected to be different from the social optimum due to the presence of two sources of distortions, viz., the imperfect market and the environmental externality. Therefore, I examine the effect of regulation on these two types of distortions.

Chapters 2 and 3 analyze a two stage duopoly game, where firms choose cleanup levels in the first stage and compete in prices in the second stage. In chapter 2, the cost of cleanup is independent of the quantity produced, whereas in chapter 3, the cleanup cost increases with the quantity produced. Another difference in the formulation of these two chapters is that in chapter 2, the market is partially covered, whereas in chapter 3 the market is fully covered. Both these chapters focus on studying the effects of commodity tax-subsidy policies.

I find that in equilibrium, firms never choose identical cleanup levels, and differentiate the product quality, under both the cost assumptions. In response to a commodity subsidy, both firms improve the quality of the product and reduce the quality in response to a commodity tax.

In chapter 2, the proportion of consumers served by the cleaner firm is always twice that served by the lower quality firm and also, the cleaner firm always obtains a higher profit than the dirty firm. A discriminatory subsidy unambiguously increases the profit of the dirty firm and has an ambiguous effect on the profit of the cleaner firm. A discriminatory tax increases the profit of cleaner firm and reduces the profit of the dirty firm. Consumer surplus rises with a subsidy and falls with a tax. The size of the market served reduces with both the instruments. While doing welfare analysis of various policies, I assume that all taxes are distributed back to the economy in a non-distortionary way. Aggregate welfare unambiguously improves with a small discriminatory subsidy, while the effect on it due to a small tax is ambiguous. A small commodity subsidy reduces the distortion caused by the market imperfection as well as that caused by the environmental externality. *It, therefore, has the double dividend effect referred to, in section 1.1 in chapter 1.*

Assuming a specific functional form for the cost function, I obtain the following additional results. A uniform tax/subsidy policy neither affects the size of the market served, nor the proportion of consumers served by each firm. Total pollution falls with a uniform subsidy policy and rises with a uniform tax policy. The aggregate welfare improves with a small uniform subsidy and falls with a small uniform tax. A small discriminatory subsidy dominates a small discriminatory tax.

In addition to the differences in model formulation in chapters 2 and 3 mentioned above, I assume a specific functional form for the cost function in chapter 3. I find that the market is equally divided between the two firms. The market intervention in the form of a uniform commodity tax/subsidy policy does not affect the proportion of consumers served by each firm. The total pollution increases with a uniform commodity tax policy and decreases with a uniform commodity subsidy policy.

While doing the welfare analysis, I find that a small commodity subsidy is welfare improving if and only if the intensity of environmental externality is larger than a certain minimum level. Otherwise, a small commodity tax is welfare improving. This result suggests that the double dividend effect of a small commodity subsidy, which was present in chapter 2 is not there under the assumptions of chapter 3.

Chapters 2 and 3 analyzed welfare implications of various tax-subsidy policies, assuming a given income distribution. Chapter 4 studies the effect of growth in income on the cleanup levels chosen by the two firms. A change in income distribution also changes the distribution of the parameter that reflects marginal willingness to pay (θ). We considered distributional changes such that the new distribution continues to be uniform and only the support of the distribution changes. Except for the change in the support of the distribution of θ, the model formulation is similar to chapter 3.

I show that a uniform growth in income among all consumers improves the cleanup levels adopted by both firms and does not affect the profit obtained by the firms. However, a heterogeneous growth in income may result in lowering of one of the two qualities. More specifically, if the growth in income is limited to the rich consumers (who are more likely to gain from economic growth), the quality of the (environmentally) inferior variant is reduced. This has serious implications for the poor consumers. They are now forced to buy a quality, which is even lower than the one they were buying before. This causes concern for the government. The government can prevent the fall in quality by imposing a standard.

If the consumers at the lower end of the income distribution are targeted for an increase in income, then not only does the quality of the inferior variant improve, but the degree of differentiation between the two qualities also reduces. This chapter also analyses economies with varying degrees of consumer awareness. It finds that the cleanup levels improve with an increase in the degree of consumer awareness.

The analysis in all the previous chapters assumed the cleanup technology to be given. In chapter 5, I examine the effect of government regulation on a firm's incentive to invest in R&D effort, to develop environmentally better technologies. The government regulation in this chapter takes the form of the imposition of an emission standard and a fine in case of non-compliance.

Often environmental regulation is based on the currently available technology. In a model, where the outcome of the R&D process is uncertain and the regulator cannot observe the firm's R&D effort, I find that such a policy hampers a firm's incentive to invest in developing new and improved technologies. More specifically, a regulation based on the best available technology guarantees that innovation will not occur. I also find that the optimal regulation should lie between the weakest and the toughest possible regulations.

Bibliography

Afsah, S, B Laplante and Wheeler, 1997, Regulation in the Information Age: Indonesia's Public Information Programme for Environmental Management, *The World Bank*, March.

Amacher, Gregory S., Arun S. Malik, 1998, Instrument Choice when Regulators and Firms Bargain, *Journal of Environmental Economics and Management*, 35, 225-41.

Arora, Seema, 1993, Public Disclosure as a Means of Reducing Industrial Pollution: A Case Study of the US, Draft World Bank Paper

Arora, Seema and T.C. Cason, 1995, An Experiment in Voluntary Environmental Regulation: Participation in EPA's 33/50 Program *Journal of Environmental Economics and Management*, 28, 271-86.

Arora, Seema and Shubhashis Gangopadhyay, 1995, Toward a Theoretical Model of Voluntary Overcompliance, *Journal of Economic Behaviour and Organization*, 28, 289-309.

Barnett, Andy H, 1980, The Pigouvian Tax Rule Under Monopoly, *American Economic Review*, 70(5), 1037-41.

Barrett, S., 1994, Strategic Environmental Policy and International Trade, *Journal of Public Economics*, 54, 325-38.

Barrett, J. and K. Segerson, 1997, Prevention vs. Treatment in the Design of Environmental Policy, *Journal of Environmental Economics and Management*, 33(2), 217-26.

Bator, F. M.,1958, The Anatomy of Market Failure *Quarterly Journal of Economics*, 72, 351-79.

Baumol, W, J., and W.E. Oates, 1971, The Use of Standards and Prices for Protection of the Environment, *Swedish Journal of Economics*, 73, 42-54.

Baumol, W, J., and W.E. Oates, 1988, The Theory of Environment Policy (Cambridge, England, Cambridge University Press)

Biglaiser, G., Horowitz, J. K. and Quiggin, J., 1995, Dynamic Pollution Regulation, *Journal of Regulatiry Economics*, 8, 33-44.

Bohm, P. and C. Russell, 1985, Comparative Analysis of Alternative Policy Instruments, in A. Kneese and J. Sweeny (eds), Handbook of Natural Resource and Energy Economics, New York: Elsevier Publishers, 395-460.

Bosch, D., Z. Cook, and K. Fugile, 1995, Voluntary versus Mandatory Agricultural Policies to Protect Water Quality: Adoption of Nitrogen Testing in Nebraska, *Rev. Agricultural Economics*, 17, 13-24.

Bovenberg, A. L., J. A. Smulders, 1995, Environmental Quality and Pollution-Augmenting Technological Change in a Two Sector Endogenous Growth Model, *Journal of Public Economics*, 57, 369-91.

Buchanan, James M., 1969, External Diseconomies, Corrective Taxes and Market Structure, *American Economic Review*, 59(1), 174-77.

Bulow, J., J. Geanakoplos, and P. Klemperer, 1985, Multimarket Oligopoly: Strategic Substitutes and Complements, *Journal of Political Economy*, 93, 488-511.

Carraro, C. and A. Soubeyran, 1996, Environmental Policy and the Choice of Production Technology, in C. Carraro Y. Katsoulacs and A. Xepapadeas, (eds), Environmental Policy and Market Structure, Kluwer, Boston.

Cason, T. M., and Lata Gangadharan, 1999, Environmental Labelling and Incomplete Consumer Information in Laboratory Markets, The University of Melbourne, Research Paper No. 708.

Clark, Ann Marie, 1995, Non-Governmental Organizations and their Influence on International Society, *Journal of International Affairs*.

Coase, Ronald H., 1960, The Problem of Social Cost, *Journal of Law Economics*, 3, 1-44.

Conrad and Wang, 1993, The Effect of Emission Taxes and Abatement Subsidies on Market Structure, *International Journal of Industrial Organization*, 11, 499-518.

Cremer, H. and Thisse J-F, 1999, On the Taxation of Polluting Products in a Differentiated Industry, *European Economic Review*, 43, 575-94

Cropper, Maureen L. and Wallace E. Oates, 1992, *Journal Of Economic Literature*, 30, 675-740.

Dales, J. H., 1968, Pollution, Property and Prices, Toronto: University of Toronto Press.

Dasgupta, Partha S., Hammond and Eric Maskin, 1980, On Imperfect Information and Optimal Pollution Control, *Review of Economic Studies*, 47, 857-60.

DeCanio, Stephen J., 1993, Why do Profitable Energy Saving Investment Projects Languish?, Paper presented at the Second International Research Conference of the Greening of Industry Network, Cambridge, Mass.

Dorfman, Mark H., Warren R. Muir and Catherine G. Miller, 1992, Environmental Dividends: Cutting More Chemical Wastes, New York: INFORM

Fershtman, C. and Aart de Zeeuw, 1996, Tradeable Emission Permits in Oligopoly, CenTER Discussion Paper No. 9630.

Gabszewicz, J. and J-F. Thisse, 1979, Price Competition, Quality and Income Disparities, *Journal of Economic Theory*, 20, 340-359.

Gangadharan, Lata, 1998, Transactions Costs in Pollution Markets: An Empirical Study, mimeo, University of Melbourne.

Gersbach, H. and Glazer, A., 1999, Markets and Regulatory Hold-up Problems, *Journal of Environmental Economics and Management*, 37, 151-164.

Grossman, S., 1981, The Informational Role of Warranties and Private Disclosure about Product Quality, *Journal of Law and Economics*, 24.

Grossman and Krugman, 1995, Economic Growth and the Environment, *Quarterly Journal of Economics*, 353-77.

Itoh Motoshige, 1983, Monopoly, Product Differentiation and Economic Welfare, *Journal of Economic Theory*, 31, 88-104.

Jaffe, A., Peterson, S., Portney, P. and R. Stavins, 1995, Environmental Regulation and the Competitiveness of U.S. Manufacturing: What does the Evidence Tell us?,*Journal of Economic Literature*, 33, 132-63.

Jung, C., K. Krutilla, and R.Boyd, 1996, Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives, *Journal of Environmental Economics and Management*, 30, 95-111.

Kamien, Morton I., and Daniel R. Vincert, 1991, Price Regulation and Quality of Service, Northwestern University, Evanston, Illinois, Discussion paper no. 920.

Katsoulacos, Y., A. Xepapadeas, 1996, Emission Taxes and Market Structure, in C. Carraro Y. Katsoulacs and A. Xepapadeas, (eds), Environmental Policy and Market Structure, Kluwer, Boston.

Khanna, Madhu and Lisa A. Damon, 1999, EPA's Voluntary 33/50 Program: Impact on Toxic Releases and Economic Performance of Firms, *Journal of Environmental Economics and Management*, 37, 1-25.

Kwerel, Evan R., 1977, To Tell the Truth: Imperfect Information and Optimal Pollution Control, *Review of Economic Studies*, 44, 595-601.

Malueg, D.A.. 1990, Welfare Consequences of Emission Credit Trading Program. *Journal of Environmental Economics and Management*, 18, 66-77.

Marsiliani, L., T. I. Renstrom, 2000, Time Inconsistency in Environmental Policy: Tax Earmarking as a Commitment Solution, *The Economic Journal*, 110 (March), C123-C138.

Meyer, Stephen M., 1992, Environmentalism and Economic Prosperity: Testing the Environmental Impact Hypothesis, Cambridge, Mass.: Massachusetts Institute of Technology.

Meyer, Stephen M., 1993, Environmentalism and Economic Prosperity: An Update, Cambridge, Mass.: Massachusetts Institute of Technology.

Miceli, T.J., and K. Segerson, 1998, Voluntary Environmental Agreements: Good or Bad News for Environmental Protection?, *Journal of Environmental Economics and Management*, 36 (2), 109-30.

Milliman, S. R. and R. Prince, 1989, Firm Incentives to Promote Technological Change in Pollution Control, *Journal of Environmental Economics and Management*, 17, 247-65.

Misiolek, S. W. (1980), Effluent Taxation in Monopoly Markets, *Journal of Environmental Economics and Management*, 7, 103-107.

Montgomery, W. D., 1972, Markets in Licenses and Efficient Pollution Control Programs, *Journal of Economic Theory*, 5, 395-418.

Mussa, Michael and S. Rosen, 1978, Monopoly and Product Quality, *Journal of Economic Theory*, 18, 301-17.

Oates, W., Palmer, K., and P. Portney, 1995, Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm?, *Journal of Economic Perspectives*, 9, 4, 119-32.

Parkinson, Gerald, 1990, Reducing Wastes can be Cost Effective, *Chemical Engineering*, 97:7, 30.

Parry, Ian W. H., R. C. Williams,III and L.H. Goulder, 1999, When can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets, *Journal of Environmental Economics and Management*, 37, 52-84.

Pigou, A. C., 1920, The Economics of Welfare, London: Macmillan

Porter, Michael E., 1990, The Competitive Advantage of Nations, New York: Free Press.

Porter, M., 1991, America's green strategy, *Scientific American*, 264, 168.

Porter, M. and C. van der Linde, 1995, Toward a New Conception of Environment-Competitiveness Relationship, *Journal of Economic Perspectives*, 9, 4, 97-118.

Rauscher, M., 1994, On Ecological Dumping, *Oxford Economic Papers*, 46, 822-840.

Raytheon Inc., 1991, Alternate Cleaning Technology, Technical Report Phase II.

Raytheon Inc., J. R. Pasquariello, Vice President Environmental Quality;Kenneth J. Tierney, Director Environmental and Energy Conservation; Frank A. Marino, Senior Corporate Environmental Specialist; interview, Lexington, Mass., April 4, 1993.

Repetto, Robert, 1995, Jobs, Competitiveness, and Environmental Regulation: What are the Real Issues?, *Washington, D.C.: World Resources Institute.*

Requate, T., 1992, Pollution Control under Imperfect Competition via Taxes or Permits: Cournot Duopoly, *Working Paper 212, University of Bielefeld.*

Rice,Faye, July 1993, Who Scores Best on the Environment?, *Fortune.*

Roberts, Marc J. and Michael Spence, 1976, Effluent Charges and Licenses under Uncertainty, *Journal of Public Economics* 5, 193-208.

Salant, S.W., and Greg Shaffer, 1999, Unequal Treatment of Identical Agents in Cournot Equilibrium, *American Economic Review*, 89, 3, 585-604.

Sen, Partha, and Sjak Smulders, 2000, The Double Dividend and Trade Liberalization, *Center Discussion Paper No. 2000-6.*

Shaked, A., and J. Sutton, 1982, Relaxing Price Competition through Product Differentiation, *Review of Economic Studies*, 49, 3-13.

Sheridan, J.H., 1992, Attacking Wastes and Saving Money ...Some of the Time, *Industry Week*, 241:4, 43.

Simpson, D. and R. Bradford, III, 1996, Taxing Variable Cost: Environmental Regulation as Industrial Policy, *Journal of Environmental Economics and Management*, 30, 282-300.

Smulders, A.,J., 1995, Entropy, Environment, and Endogenous Economic Growth, *International Tax and Public Finance*, 2(2), 319-40.

Stranlund, J. K., 1997, Public Technological Aid to Support Compliance to Environmental Standards, *Journal of Environmental Economics and Management*, 34, 228-39.

The Economist, 1998, The Limits to Growth, July 30th.

Tirole, J., 1988, The Theory of Industrial Organization (Cambridge: MIT Press).

Ulph, Alistair, 1996, Environmental Policy and International Trade when Governments and Producers Act Strategically, *Journal of Environmental Economics and Management*, 30, 265-81.

Ulph, A., 1996, Strategic Environmental Policy, International Trade: The Role of Market Conduct, in C. Carraro, Y. Katsoulacos and A. Xepapadeas (eds.), Environmental Policy and Market Structure, Kluwer, Dordrecht, 99-131.

van der Linde, Claas, 1993, The Micro-economic Implications of Environmental Regulation: A Preliminary Framework, in Environmental Policies and Industrial Competitiveness. Paris: Organization of Economic Co-operation and Development.

van der Linde, Claas, 1995a, Competitive Implications of Environmental Regulation in the Cell Battery Industry, Hochschule St. Gallen, St. Gallen.

van der Linde, Claas, 1995b, Competitive Implications of Environmental Regulation in the Printing Ink Industry, Hochschule St. Gallen, St. Gallen.

van der Linde, Claas, 1995c, Competitive Implications of Environmental Regulation in the Refrigeration Industry, Hochschule St. Gallen, St. Gallen.

Varian, Hal R., 1994, A solution to the Problem of Externalities When Agents are Well Informed, *The American Economic Review*, 84, 1278-93.

Von der Fehr, N.-H.M., 1993, Tradeable Emission Rights and Strategic Interaction, *Environmental and Resource Economics*, 3, 129-51.

Weitzman, M. L., 1974, Price Vs. Quantities, *Review of Economic Studies*, 41, 477-91.

Wheeler, David, and Ashoka Mody, 1992, International Investment Location Decisions: The Case of US Firms, *Journal of International Economics*, 33, 57-76.

Xepapadeas, A. and A. de Zeeuw, 1998, Environmental Policy and Competitiveness: The Porter Hypothesis and the Composition of Capital, CenTER for Economic Research, Discussion Paper No. 9838.

Yao, D. A., 1988, Strategic Response to Automobile Emissions Control: A Game- Theoretic Analysis, *Journal of Environmental Economics and Management*, 15, 419-438.