AN ASSESSMENT OF THE VIABILITY OF MARKETABLE PERMITS

Thesis by

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to my parents

"Theory," said Leonardo da Vinci, "is the general; experiments are the soldiers." Economic science has already well-trained generals, but because of the nature of the material in which it works, the soldiers are hard to obtain.

-- A.C. Pigou

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Having proffered thanks to the deserving, it's time to take the blame for what remains.

ABSTRACT

The literature on the use of economic incentives to deal with environmental problems makes a persuasive case that policy tools such as emissions taxes or tradable emission permits have important potential advantages compared to source-specific technical standards. Despite the apparent advantages of incentive-based methods, some questions have been raised about the feasibility of their implementation. This thesis is part of a larger research project that addresses these feasibility questions. The principal task undertaken here is to gather the information needed to evaluate the applicability of a marketable permit scheme for dealing with a particular pollution problem (sulfur oxides emissions) in a particular place (the Los Angeles Basin).

The analysis begins with a description of the concept of marketable permits and how it differs from existing regulatory approaches. An agenda for research on transferable permits is outlined. Some of the potential problems in making the transition from the current approach to a market approach are then discussed.

The next part of the analysis focuses on some of the key empirical issues. The effects of changing the natural gas supply are quantified. Static efficiency gains in moving from the status quo to a market approach are also estimated. This is followed by an analysis of the gains from having several markets corresponding to different receptor points. A key result is that the payoff to having several markets, when measured in terms of abatement cost savings, is quite small for this particular example.

The final part of the analysis is devoted to a discussion of theoretical issues that might arise in designing a market. First, the comparative statics results relating to the control of sulfur oxides emissions are derived. Next, a more general model is used to address the issue of how a firm might influence the equilibrium achieved in the permits market. Finally, some issues in identifying cost-effective solutions to problems with multiple objectives are addressed.

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CHAPTER 1

INTRODUCTION

The mathematical analysis of economic problems can be usefully divided into three steps. The first part of the analysis usually develops an abstract theoretical model of agents interacting in one or several markets. Frequently, the model is based on the assumption that firms and individuals exhibit maximizing behavior. For example, producers may maximize profits while consumers typically maximize their happiness or utility. Once the model is formulated, the next step is to focus on the assumptions that are necessary to imply a certain set of outcomes. In the case of transferable licenses, we will see that producer cost functions must exhibit a special shape to ensure that a market in tradable licenses yields a specified level of air quality at least cost. The third step in the analysis is probably the most critical for determining the usefulness of a model for making policy prescriptions. It requires a careful analysis of the empirical validity of the assumptions underlying the model along with an informed assessment of the relevance of the model, taking into account the differences between the formal analysis and the "real world." Indeed, while this inductive approach of moving from the simple to the complex is one of the cornerstones of scientific analysis, its applicability to social problems has been less than an unabashed success. In defense of this approach, Dales offers the following rationale:

> Economists have found that it is usually very helpful to attack complex problems like pollution by assuming away all their complexities and then solving the artificially simplified problems that remain. The value of the technique lies not in the answer to the artificial problem (ask an artificial question and you'll get an artificial answer) but in the making of the assumptions that allow us to solve it, for these assumptions help us to identify what features of the original problem make it complex and difficult. And it is only when we know exactly what the difficulties are that we can begin to zero in on them. Let us, then, begin our study of the economics of pollution with a very simple problem, taking great care to note exactly why it is so simple.[1]

As a model of analysis, the approach has much to recommend for it. However, it can be easily misused if one is not careful. Economic models of pollution problems have tended to be overly simplistic in their assumptions regarding firm behavior and have, in general, devoted little study to the actual implementation of various methods for improving environmental quality. This study is an attempt to bridge the gap between existing theoretical literature on markets for tradable emission licenses and the question of when such markets can provide a cost-effective means of limiting pollution. The analysis consists of four parts shown in Table 1.1.

Table 1.1

Principal Components of Thesis

		Chapters
1.	Introduction to Marketable Permits and Research Design	1,2
2.	Empirical Findings	3,4
3.	Theoretical Issues	5,6,7
4.	Future Research Areas and Conclusion	8,9

The first part of the thesis provides a definition of the problem. The theory of markets in transferable emission rights is reviewed in Chapter 2. The objective is to review the nature of the work which has been completed, and outline areas of research which will be useful in assessing both the feasibility and relative merits of a marketable permit scheme.

Empirical issues are addressed in the second part of the thesis. Chapter 3 examines some of the key concerns in implementing a market designed to limit pollution. The issues are brought into focus by considering a particular example—the control of sulfur oxides emissions in Los Angeles. In Chapter 4, the market is characterized by combining abatement cost data and an air quality model. Quantitative estimates of a permit price are obtained and the sensitivity of price to the supply of natural gas and the choice of an air quality target are examined.

The discussion of the empirical findings is followed by a rigorous treatment of some of the principal theoretical concerns which arise in designing incentive-based systems for controlling pollution. Chapter 5 analyzes how a firm with inputs of variable quality will react in a market for transferable emissions permits. This is followed in Chapter 6 by a discussion of the relationship between market power and transferable property rights. A theoretical model is developed in which the initial distribution of permits has a systematic effect on the market equilibrium. Chapter 7 considers some of the problems which may arise in extending the analysis to the case of controlling several pollutants simultaneously.

The empirical and theoretical results are reviewed in the final two chapters. Areas for future research are outlined in Chapter 8, and the principal results of the analysis are summarized in Chapter 9.

Footnotes for Chapter 1

1. Dales (1968), p. 27.

CHAPTER 2

IMPLEMENTING A MARKETABLE PERMIT SCHEME: THE ROAD AHEAD

One of the most frequently heard criticisms of the current standards-based approach to environmental regulation is that it fails to meet prescribed environmental objectives in a cost-effective manner. If this is in fact true, it would seem incumbent upon those bent on improving the environment to provide alternatives which would be less expensive than the current approach, but also have the possibility of being adopted. This paper examines one candidate which has been suggested as a viable alternative to the existing mode of environmental regulation. The general idea is to set up a market where rights to emit one or several pollutants can be bought and sold. This approach has been referred to by several names including tradable permits, transferable licenses and marketable permits. The principal objective of this essay is to outline the nature of the work which has been completed on tradable permits and, in so doing, point out areas of research which might be of some benefit in assessing both the feasibility and relative merits of a marketable permit scheme.

Before discussing the details involved in the tradable permit approach, it is useful to consider what objectives we should place importance on in designing an environmental policy. At a minimum, it would seem reasonable to design a program which would meet the prescribed environmental quality objectives, or at least allow for meeting objectives in a timely manner. A second desirable feature of an environmental strategy is that it use a minimum amount of resources in achieving its goals, where resources are defined broadly to include both administrative costs and direct expenditures on abatement. If possible, such a policy should not stand in the way of economic progress. Finally, to be more than an intellectual curiosity, the approach should have some possibility of appealing to politicians or regulators who are responsible for developing environmental policy.

The traditional standards approach to regulation is clearly a political favorite, but does not seem to fare well in terms of efficiency. In the case of uniform standards, it is usually possible to achieve significant cost savings by redistributing the burden of cleaning up so that firms for whom it is cheaper will abate more than firms who have very high abatement costs. Even in the case where standards are designed to approximate a least-cost solution, it is quite likely that the regulator will lack the information to identify the solution. In particular, one would expect that several industries possess information on process modifications useful for abatement which are proprietary, and hence, typically not available to the regulator. It would be desirable to develop a mechanism for inducing industry to actively pursue these abatement options when they are cost-effective.

Another more serious flaw of the standards approach is that firms have no reason to abate more than the standard. In the most idyllic of worlds, where standards are treated as a given, firms may have an incentive to search for lower cost alternatives for meeting the standard; however, this will not always be the case since some standards are technology-based. If instead of a standards approach, some pricing mechanism were used to reduce pollution, then, at least in theory, firms would have a continuous incentive to innovate -- not only to find lower cost methods of achieving a given standard, but also to search for ways to reduce emissions.

Three general approaches for providing continuous incentives for searching for new pollution abatement methods are taxes, subsidies and marketable permits. The virtues of emissions taxes are well known. If firms are cost minimizers, Baumol and Oates (1975) have shown that imposing such taxes can lead to a cost-minimizing solution. However, taxes are not without their problems. One difficulty is that it is virtually impossible to predict the level of emissions which would result upon imposing a tax. To partially circumvent this problem, some people have suggested that taxes could be adjusted until the desired outcome is attained. There are three basic problems with this suggestion: First, it may be quite expensive for firms to adjust to wide fluctuations in taxes; second, it is unlikely that the regulatory authority would be given that much discretion in adjusting the tax; and third, firms are likely to respond strategically if their response affects how taxes would be adjusted.

A more serious problem with emissions taxes would seem to be their widespread unpopularity among industry. While they confer benefits on the general public, they force firms to foot both the abatement costs and the tax bill. The extent to which firms pay taxes out of profits depends on whether the increase in taxes can be passed along to consumers. Nevertheless, for the case in which total emissions are similar, it is usually in industry's interest to oppose taxes in comparison with standards because the latter avoid the tax.

Providing subsidies for reducing emissions is yet another way to deal with pollution. Subsidies have the advantage that they have met with considerably less political resistance than taxes. In fact, this instrument has been widely used in the construction of municipal sewage treatment plants. Aside from the advantage of political feasiblity, however, subsidies have few good points. Their most serious drawback is that they usually fail to provide an incentive to keep expenditures on abatement down. Like taxes, subsidies also have the problem that the level of resulting emissions is very uncertain.

Marketable permits suffer few of the drawbacks of the other tools discussed thus far while enjoying many if not all of the advantages. The idea was popularized by Dales (1968) who argues that a market approach has the potential to meet environmental quality objectives at the lowest possible cost while allowing for economic growth. Dales envisioned a hypothetical pollution control board specifying the total number of permits, and hence, the overall level of emissions allowed in a given region. Rights of different duration could be bought and sold through the board by anyone who wished to participate. To accommodate growth some permits might be withheld initially. A critical question is whether the idea of marketable permits could ever win favor in the political arena. One potential advantage that permits have over taxes is that they can avoid net payments to the government if they are initially given away rather than auctioned. If permits were given away to industry, then at least some firms might favor marketable permits over the conventional standards approach because of the wealth transfer they would receive in the form of valuable permits.

Dales offers a very general discussion of how a market in tradable permits would work. A more rigorous analysis of the issue is contained in Montgomery (1972), who shows conditions under which tradable permits will be an efficient mechanism for attaining a least-cost solution. Montgomery raises an important problem in defining a permit by drawing a distinction between emissions and ambient pollutant concentrations. Defining permits in terms of emissions may not be the cost-minimizing strategy for achieving a given air quality target. The reason is that the same amount of emissions may have a different effect on ambient air quality if emitted at different locations. If so, charging firms the same price for a "unit" of emissions will typically imply that the marginal cost of improving the level of air quality will differ across firms. This result holds because firms are being charged a uniform price for emissions and not for pollution.

In theory, permits could be defined in terms of ambient air quality at different receptors, but to ensure an efficient solution, this would require the creation of several permit markets in a given air quality region. The extent to which such fine tuning is justified on a purely economic basis is an open question. Initial research indicates that savings could be quite large. However, in my opinion, the likelihood of instituting several markets to deal with a single pollutant in a given airshed is next to nil. Rather than search for the optimum, it would perhaps be more fruitful to consider the effects of a single market with some trading restrictions, or the effects of defining two or three markets within a geographical region.

Applied research on marketable permits has followed two lines of inquiry. The first focuses on problems encountered in market design and the definition of a permit. One difficult problem is what to do in the event the equilibrium price of a permit is much higher than anticipated. Firms could conceivably balk at paying such high prices, or even be put on the verge of bankruptcy, in which case the marketable permit scheme might be terminated. To deal with such a contingency, Roberts and Spence (1976) suggest the use of a mixed system of permits and fees, where the quantity of pollution would be fixed, unless the equilibrium permit price exceeds a certain level. In the latter case, firms would be charged a fee for emissions not accounted for by existing permits. The fee would provide firms with a continuous incentive to reduce emissions until the overall emissions objective was met. The use of such a mixed system makes sense in theory, but in practice it might be difficult to implement because it explicitly raises the issue of taxing, and it may be too complex for the political process to digest. A more workable alternative would be to adjust the level of permits over time by issuing at least some permits of limited duration, and giving the regulatory authority some discretion over the number of permits issued over time.

Another problem which has received little attention in the literature is whether it makes sense to have firms with vastly different degrees of market power participate in the same market. Mar (1971), in designing a system of water rights, suggests using two separate markets -- one for large institutions and one for individuals or small institutions. The rationale for this approach is unclear. There are several commodity and stock markets currently in existence which manage to accommodate both large and small investors. If a few firms are expected to dominate a market in tradable permits, then there are two options. One is to abandon the marketable permit approach. The second is to design institutional safeguards which guard against contingencies such as thin markets and cornering. While several authors have recognized the possibility of a market which is not competitive, little effort has been devoted to addressing the issue in a concrete policy application.

The second general approach to analyzing the market for tradable permits is simulation of the equilibrium permit price using mathematical programming techniques. DeLucia (1974) analyzes the case of eight Mohawk river municipalities and concludes that a marketable permit approach is a viable alternative for achieving significant cost savings in water pollution. Even in the case where one of the firms can exert control over market price, DeLucia finds that the effect on the price and distribution of permits is minimal. This result is due to the shape of the treatment cost functions. DeLucia's general systems approach of considering the technical, legal and economic dimensions of the problem represents a quantum leap over previous efforts to demonstrate the viability of a permit scheme. Nevertheless, the analysis is less than convincing on one crucial point — why it is reasonable to assume that municipalities will run their waste treatment facilities in a cost-minimizing mode.

Other studies of permit markets in the early seventies are similar in approach, but narrower in scope. For example, Taylor (1975) uses a linear programming model to appraise a regional market in fertilizer rights aimed at reducing water pollution. Mackintosh (1973) considers a hypothetical air rights market in New Orleans and develops a simulation model to illustrate the effect it has on a local petroleum refinery. He concludes that marketable permits are an attractive alternative for meeting environmental quality objectives.

The early studies which simulate the workings of a market in tradable permits generally define a right in terms of emissions. As noted above, it would be useful to know if significant savings result from defining permits in terms of ambient concentrations. Atkinson and Lewis (1974) attack this problem from a slightly different perspective for the case of airborne particulate matter in the St. Louis Air Quality Region. Using a linear program which minimizes control costs, the authors found that exploiting the difference in contributions to ambient concentrations from different sources can lead to a 50 percent savings over a strategy which treats all emissions alike. While the potential savings are great, according to the model, nine markets (corresponding to the different receptors) would be needed to realize the full cost savings.

The most comprehensive study to date on the feasibility of marketable permits was completed by Anderson et al. (1979). The analysis examines alternative policies for attaining a short-term NO_2 standard in Chicago, and concludes that marketable permits present the most attractive alternative. A calculation similar to the one done by Atkinson and Lewis reveals that cost savings on the order of 90 percent could be obtained by using source-specific charges instead of a uniform emissions tax. Even if charges were based on source categories, the authors estimate savings in the neighborhood of 50 percent. While differential charges may lead to a lower cost solution, it is also quite probable that they would lead to unnecessary regulatory delay resulting from differences of opinion over the appropriate charge. In any event, it is unlikely the political system would accept such a complex pricing scheme.

From the perspective of the policymaker, a serious omission in the analysis by Anderson et al. is that the air quality modeling of NO_2 formation does not incorporate what is currently understood about atmospheric processes. For example, their model does not adequately describe the highly nonlinear chemical conversion processes which lead to NO_2 formation. When coupled with the fact that the pollutant dispersion model is designed primarily for applications involving nonreactive pollutants, their air quality results require careful scrutiny. If further modeling studies are to be performed which may have an impact on policy, they should reflect the current understanding of atmospheric processes as well as a reasoned analysis of the key economic and political questions.

CONCLUSIONS

The U.S. Environmental Protection Agency and state and local environmental regulatory agencies are increasingly being confronted with the harsh reality that the current standards system is not working very well. Not only are critics pointing to the whopping price tags on many projected investments designed to curb pollution, but in some instances, it can also be shown that environmental quality is deteriorating. While the environmental regulatory agencies are hardly to blame for this alleged state of affairs, they are in the unenviable position of having to take the political flak.

As the debate intensifies, it appears that agencies at both the federal and state level are willing to experiment with alternative modes of environmental regulation. In some cases, such as the Connecticut plan, the regulation is designed primarily to ensure that standards will be met.[1] Other tools, such as bubbles and offsets are aimed at both reducing environmental control costs while making marginal strides in the direction of improving environmental quality. The bubble focuses on a single firm with one or several plants with several emissions sources. It is designed to allow the firm to increase emissions beyond the current standard at one location if it makes a greater reduction in emissions somewhere else. Offsets are similar, but typically apply to more than one firm. They allow a firm to add new emissions if it pays for a greater reduction in emissions somewhere else in the same area.[2]

With the stepped-up search for viable alternatives, the time would seem ripe for a detailed evaluation of the feasibility of a tradable permit scheme for a particular pollution problem in a well defined region. A careful comprehensive analysis will require several components drawing on different disciplines. In the case of air pollution, a model needs to be used which links emissions and resulting air quality both spatially and temporally. For an actual application, it is imperative that the model be validated. All past studies which I have seen give scant attention to this issue. This is actually somewhat ironic given the amount of effort devoted to demonstrating the increased gains from exploiting the emissions-air quality relationship. If the model is not validated, there is no way of guessing the errors associated with estimates of potential cost savings.

The air quality model must be linked with abatement cost data to determine the quantity of permits to be issued and the appropriate definition. To be relevant, practical issues such as monitoring, enforcement, and administrative costs must be considered. The study by Anderson et al. (1979) exemplifies the type of work that needs to be done in these areas. The issue of ensuring a competitive market or at least a workable market must be carefully assessed. To date little work has been done which examines how different types of trading rules may serve to promote a viable market. Several authors do not see competition as a problem. For example, Teitenberg (1980), in his survey of the literature, asserts "anti-competitive effects of a TDP [transferable discharge permit] system are not likely to be very important in general."[3] Be that as it may, this is a very real concern to most policymakers which should be given adequate consideration.

The current mode of environmental regulation is rather crude. Loosely, it can be viewed as a give-and-take process where regulators attempt to clamp down tighter on source emissions as new technologies become available. It would be naive to presume that this system will be replaced with a finely tuned complex market mechanism which is cost-effective. It would be more realistic to strive for a system which redirects incentives away from large legal expenditures aimed at fostering regulatory delay, and towards a system which enlists the aid of polluting industries in searching for less expensive ways to meet prescribed environmental quality objectives. To move industry in this direction, it is incumbent upon the researcher to not only outline desirable economic alternatives, but also to outline proposals which will receive the backing of a majority of the participants. Such proposals should be easy to understand and give careful consideration to how the spoils will be distributed.

Footnotes for Chapter 2

1. See Clark (1978) for a summary of the Connecticut plan.

2. Payment is not formally required, and sometimes offsets are given away by local or state governments in an attempt to induce firms to locate there. Liroff (1980) provides a more precise definition of these terms along with a discussion of how these policy tools evolved.

3. Teitenberg (1980), p. 414.

CHAPTER 3

MARKETABLE PERMITS: WHAT´S ALL THE FUSS ABOUT?

Recently, both state and federal pollution control agencies have begun to direct their attention towards more economical alternatives which would meet environmental objectives.[1] While it has been shown that schemes which offer firms greater choice in selecting abatement alternatives have the potential to significantly reduce the overall cost of meeting prescribed environmental goals, the response of industry, the public and even regulators has been, at best, lukewarm. What might be the cause of this less-than-overwhelming response to new approaches for controlling pollution such as bubbles, offsets or marketable permits? There would appear tc be two key reasons for the cool reception. The first results from a lack of familiarity with the new regimes. The "command and control" technique currently employed is a well-seasoned approach which industry, regulators, and the public have dealt with on many occasions. It is possible that, in moving to an incentive-based approach, significant transitional costs would be incurred. A second reason for not adopting such schemes is that distributional issues may take precedence over efficiency considerations for many of the key industrial participants.

This paper examines the problem of implementation for one particular alternative for dealing with pollution problems—marketable permits. The first part of the essay develops a simple framework for identifying implementation problems and points out several potential problem areas which need to be addressed. The second part of the essay addresses these issues using the specific example of setting up a market for controlling sulfur oxides emissions (SO_x) in a well defined air quality region.

3.1 Developing a Framework

As a starting point it is useful to construct a situation in which all firms would prefer a marketable permit scheme to a standards regime. The next step is to examine how real world considerations are at variance with the assumptions used to construct the example.

Figure 3.1 illustrates the relationship between levels of abatement and control cost for a composite variable called "air pollution". The curve passing through points B and C represents the minimum total cost of achieving a given level of abatement. Because of the difficulties in obtaining information on the nature of the least cost solution, it is typically thought that regulation leaves us at an inefficient point such as A. Since pollution associated with the existing situation usually exceeds the prescribed standard, let point C correspond to the target level of air pollution.

We wish to consider whether it is possible to devise a marketable permit scheme which allows us to move from point A to point C, and which would be preferred by all industrial participants. First consider the simpler problem of moving to a marketable permit scheme at the current level of pollution. This is represented by a move from A to B in the diagram. If transitional and administrative costs could be

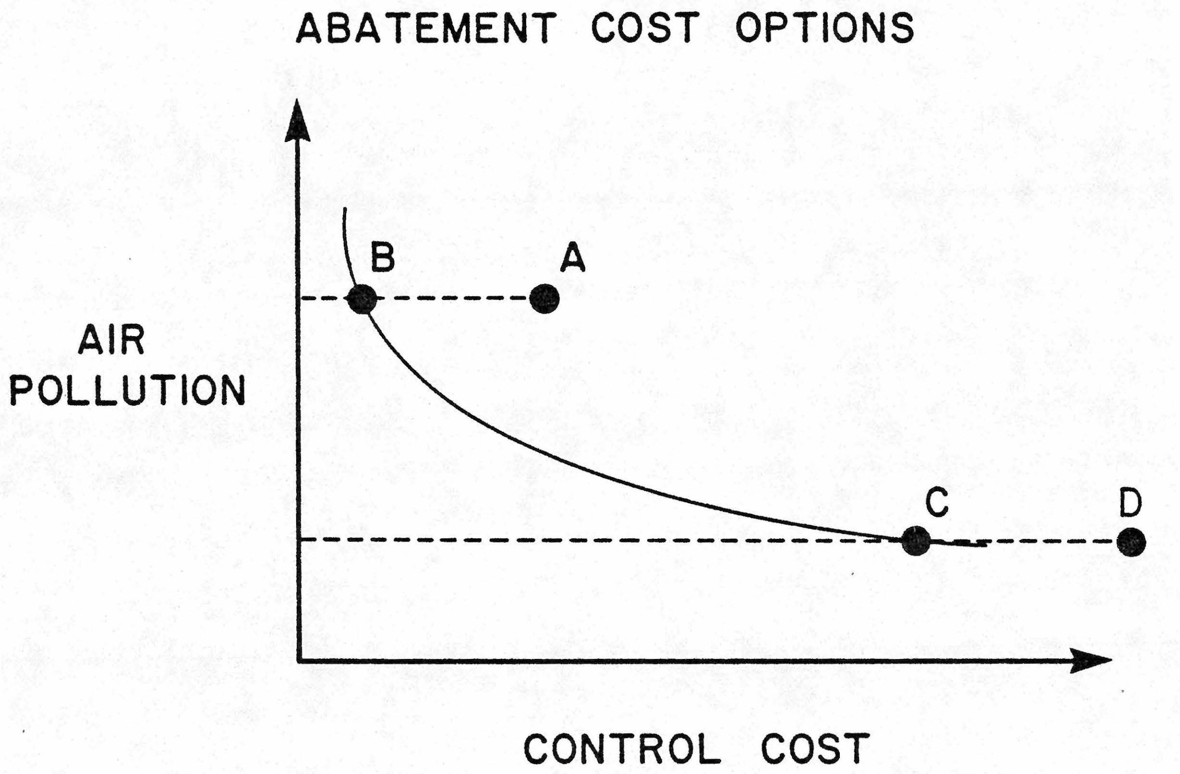

FIGURE 3.1

ignored, then it would be possible to move to a transferable rights scheme by issuing each firm an amount of permits which just equals their current level of emissions. This system of "grandfathering" the rights would be at least as good as the outcome under standards for some firms and unambiguously better for at least one firm (since the move from A to B implies that the overall level of abatement expenditures would be reduced).

The analysis of the situation in which the target air quality standard is more stringent (e.g., moving from A to C) is essentially similar to the argument given above, but requires one further assumption. We must assume that the distribution of rights under the standards approach is known for the level of pollution associated with C. With this assumption, it is sufficient to grandfather the rights in amounts which equal what they would have been under the standards regime. Under such a market scheme, all firms could be made at least as well off as they would be under a standards regime in which the rights to emit are nonnegotiable, since in the latter case, the air quality standard would be reached at a higher cost such as point D.

Two important factors ignored in the above analysis are the implications of uncertainty surrounding the rules to be promulgated by the agency, and the possibility that interested groups could influence the outcome. When these features are considered, the case for convincing industry that it is in their interest to adopt a marketable permit scheme is considerably weakened.

For the case in which the level of air pollution remains unchanged and rights are grandfathered, industry might balk at the marketable permit idea for several reasons. One reason mentioned earlier is that use of a market to reach environmental goals is vastly different from the standards approach. Another possible objection is that grandfathering the rights is unfair because it tends to penalize those groups who have worked hardest to reduce their emissions. Finally, industry might argue that restrictions on trading combined with regulatory delay might lead to a system no better than the present situation, just different.[2]

If a marketable permit system is used to improve air quality over current levels, this introduces additional grounds for objecting to such a system. For example, industry might feel that the pollution level associated with points C and D might never be met under a standards approach or that it would take a much longer time to reach the target. In either case, the discounted present value of staying at inefficient point A, with perhaps some chance of moving to inefficient point D in the future, could be less than the cost of immediately moving to C. Decreasing the level of pollution also makes the initial distribution problem that much more difficult, since it is virtually impossible to know how firms would have fared if standards had remained in place.

Movement to a marketable permit scheme also raises significant issues for regulators and the public. The regulatory agency must be capable of making the transition. Resistance to change can be expected. The agency may have to augment its monitoring and enforcement staff to obtain more accurate measurements of emissions which could stand up in court. The economic tradeoff which must be considered is whether the increased administrative costs would be offset by the expected cost savings in abatement.[3] For the market to work, the agency would have to develop trading rules which are comprehensible and allow several firms to participate.

The preceding list of objections might lead to the conclusion that the prospects for adopting this alternative in the near future are bleak. On the contrary, the prospects for adopting this alternative are very good indeed. This is especially true for pollutants which are not heavily regulated. A case in point would be nonaerosol chlorofluorocarbons.[4]

The basic reason for the growing possibility of actually experimenting with marketable permits is the increasingly widespread dissatisfaction among environmentalists, industry and regulators with the existing standards regime--that is, if point A is bad enough, the objections can be overcome. Industry finds the red tape and uncertainty very costly while regulators and environmentalists are dissatisfied with the progress in abating pollution. Since marketable permits are known to possess desirable properties in theory and appear to be workable for several practical applications, experimentation with this approach may be just around the corner.

The Environmental Protection Agency has developed several limited variants of a tradable permit system that are being applied experimentally around the nation. These are:

(1) _Bubbles_: a single plant that has several emissions sources may be permitted to increase emissions beyond the current standard at one location if it makes a greater reduction in emissions somewhere else at the same facility;[5]

(2) _Offsets_: a firm may add new emissions in a geographic area if it pays for a greater reduction in emissions somewhere else in the same area; and

(3) _Banks_: a firm that reduces its emissions below the applicable standard may deposit as a credit some fraction of its excess emissions reductions in an emissions bank. These banked emission credits can then be sold to some other firm that seeks emission permits.

All of these policies are designed to introduce some flexibility into the means by which firms comply with environmental regulations by introducing the possibility of trading emissions at one place for emissions somewhere else. In this sense they are conceptually similar to tradable permits, but all retain important elements of the standard-setting approach as well. Each trade requires regulatory approval, and the source using the traded permit assumes a burden of proof that the trade is consistent with overall environmental policy.

Current distinctions in the stringency of regulations between new and old sources are retained in all of these policies. Thus, firms seeking to locate an environmentally significant new source of emissions by acquiring offsets must still operate at lowest attainable emission rates. For new sources, the trading policies are regarded as a means for providing one additional possibility for entry where even compliance with new source performance standards would be insufficient to allow it.

The new policies do not yet have well-defined rules and procedures governing transactions, nor in most cases a convenient institutional arrangement for facilitating them. The offset policy provides no formal procedure for informing prospective participants in an offset about the identity of potential partners, the likely cost of reducing their emissions, nor the expected price of their emissions permits. Each offset transaction is the result of bilateral negotiations outside of any formal institutional structure established by the government, except that the terms of the deal must be approved by environmental regulators. Emissions banks do have a formal record-keeping method for tracking the amount and source of marketable emissions credits, but at present the formal rules and procedures regarding trades are still being worked out.

A final problem with all three methods is that the long-term status of traded permits is not clear in any program. If environmental quality in any area falls short of the policy target, all permits--

traded or not—are subject to revision; however the credits from sources that reduced emissions below standards requirements appear more likely to be confiscated or severely reduced in value than other permits do. For example, in listing the options available to a local air pollution control authority should a revision in permits be necessary, the EPA manual for setting up an emissions bank cites four alternatives:

(1) A moratorium on the use of permits obtained from the emissions reduction credit bank;

(2) On a source by source basis, a revision in the number of permits from the bank that are necessary to produce a unit of emissions at that source;

(3) An across the board reduction in the amount of emissions permitted for a permit acquired through the bank; or

(4) A forfeiture of all traded permits.[6]

Thus, a traded emissions permit may have secondary regulatory status in comparison with an untraded permit, making the former less valuable. The possibility that traded permits will be treated this way will make firms reluctant to reduce emissions beyond current requirements in order to create marketable permits out of concern that their additional emissions reductions will be confiscated rather than made available to others. Potential trading partners will be equally reluctant to make long-term capital investments on the basis of emissions permits that have such an uncertain status.

The tradable permits system examined in the next section is a more radical institutional change than has thus far been contemplated by regulatory authorities. It would eliminate distinctions among sources because of age, ownership, industry or method of acquiring permits. It would simply establish a ceiling on total emissions within a geographic area, and it would allow the allocation of emissions among sources in the area to be determined solely by the market. No regulatory review of the methods used by any source or of the distribution of emissions permits among the sources would be undertaken.

3.2 A Potential Application

To demonstrate the viability of marketable permits without actually implementing the alternative requires selecting a specific pollutant, identifying the key implementation problems, and then designing a market which will address these issues. As an example, the problem of controlling particulate sulfates in the Los Angeles region was selected.[7] This problem was chosen because it appeared to be a likely candidate for marketable permits. The scientific aspects of the problem are well understood. Data on sulfur oxides abatement costs are available or can be constructed for most of the key sources, and monitoring and enforcement problems appear tractable.

The question at hand is whether such a market could actually work. First, the criteria for measuring the success of a market need to be specified. For this specific case we would like to design a market that will meet air quality goals in a more cost-effective manner than the current system of source-specific standards, that will encourage investment in finding new abatement technologies for the future, and that will be legally and politically feasible. Legal feasibility means that the market must meet the requirements of relevant constitutional and statutory constraints. Political feasibility means that the regulatory agency should be capable of administering the program and that the approach has a reasonable chance of being acceptable enough to industry, the public and regulators that it stands a chance of being enacted by political officials.

To meet air quality goals requires a good technical understanding of the problem. The particulate sulfate problem in Los Angeles is caused primarily by the combustion of sulfur-bearing energy products. Particulate sulfates are an important concern because they tend to reduce visibility, acidify rainwater, and may also have harmful health effects. The conversion of sulfur oxides emissions to sulfates in Los Angeles can be thought of as proceeding in three stages. First, sulfur enters the air basin. Virtually, all of the sulfur which man uses in the Los Angeles area enters in a barrel of crude oil. Second, when oil products are refined or burned, some of the sulfur contained in them is converted to SO_2 and SO_3 which is released to the atmosphere. Finally, the SO_x compounds react to form sulfates through a series of atmospheric chemical processes. Cass (1978) has shown that the relation between sulfur oxides emissions and sulfate air quality in Los Angeles is approximately linear and, in addition, can be modeled as if it were largely independent of the level of other key pollutants. Given a sulfate air quality objective, it will be possible to use an environmental model to compute the corresponding level of permissible emissions.[8]

The current approach towards controlling sulfur oxides emissions relies on standards and an offset policy. New sources of pollution must trade off the uncontrolled portion of their emissions by effecting further reductions at existing sources in the Los Angeles Basin. The owner of an existing source is thus vested with a valuable property right which can be sold in whole or in part to new source owners. The owner also has the option of holding onto his current abatement possibilities to facilitate subsequent expansion.

The offset policy is one limited form of a market in transferable licenses to emit air pollutants. Its principal drawbacks are that the costs of negotiation are excessive and the number of trades which can be made by new sources are limited. Negotiation costs are high because new entrants must first identify existing sources of pollution where emissions reductions are feasible, then try to estimate a reasonable charge for the offset, and finally perhaps have to purchase the entire business operations of some polluter. Purchases of offsets by new firms are limited by the requirement that new firms must reduce emissions to the lowest achievable level before being allowed to enter the offset market. Presumably, in a full-blown marketable permit scheme, all specific source by source restrictions on burning fuels containing sulfur would be lifted. This would tend to increase the number of mutually beneficial trades. In addition, the market obviates the need for bilateral bargaining, which is cumbersome and unnecessary. By conveying a uniform price for a permit, the market also ensures that rights will go to the highest bidder, and the marginal value of a right owned by a firm will approximate the market price.

While a marketable permit approach can attain a least cost solution, this cannot be assumed. In constructing a market in sulfur oxides emissions permits for Los Angeles, care has to be taken to ensure that a few firms will not be able to dominate. Table 1 gives some indication of the relative market shares of sulfur oxides emissions in 1973 and projected shares for the early 1980s under a low natural gas scenario. The low natural gas scenario is essentially a worst case because the absence of industrial natural gas means that fuel with higher sulfur content will be burned. If this pattern of emissions is accurate, the electric utilities can be expected to account for the largest share of emissions. Note that mobile sources account for more than one-fourth of the total in the 1980s scenario. To force all mobile sources to participate in the market would, needless to say, be quite expensive. Fortunately, it may be possible to transfer this responsibility to local oil companies since they make the gasoline, diesel oil, jet fuel, and bunker fuel burned by mobile sources.

TABLE 3.1

PAST AND PROJECTED "MARKET SHARES" FOR SULFUR OXIDES EMISSIONS BY SOURCE TYPE FOR THE SOUTH COAST AIR BASIN[a]

1973 Emissions		1980s Projection - low natural gas scenario and 1977 emissions control regulations	
Source Type	% of Total Emissions[b]	Source Type	% of Total Emissions[b]
Utility	28	Utility	31
Mobile Sources	16	Mobile Sources	27
Utility	11	Utility	10
Oil Company	8	Oil Company	4
Steel Company	7	Coke Calcining Company	4
Oil Company	3	Oil Company	3
Coke Calcining Company	3	Steel Company	3
Oil Company	3	Oil Company	3
Oil Company	2	Oil Company	2
Oil Company	2	Oil Company	2

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[a] These figures are based on sources located within the 1974 definition of geographic boundaries of the South Coast Air Basin (which was subsequently revised).

[b] Emissions are rounded to the nearest percent.

Source: Based on author's calculations from data used to compile Cass (1978) and Cass (1979).

While a transition to a permit market will almost certainly imply different market shares from those presented above, the electric utilities can still be expected to have the largest share of the market. This presents some difficulties because even if the utilities act as cost minimizers their interaction with the public utilities commission rate-setting process might provide incentives towards investing in permits that differ from more conventional privately-held firms. The problem of predicting utility behavior in a permit market is currently being investigated by examining how utilities treat other durable assets such as real estate, and by observing utility behavior under the current system of offsets and banking.

Given that competition in such a market is not a foregone conclusion, it is important to ask what happens if some of the safeguards don´t work and some of the firms successfully manipulate the price of a permit. While this would certainly affect the distribution of income and should be avoided if possible, it by no means renders the system a complete failure. In fact, so long as the market provides greater flexibility for firms wishing to locate in Los Angeles while maintaining the current level of air quality, this will be a big step forward over current policy.

Some critics fear the market may not have a sufficient number of trades to be competitive. In the jargon of the economist, this is the problem of "thin" markets. The extreme case of a thin market is when no trading occurs. From a practical point of view, this lack of trading would be a concern even if firms in the area were at an equilibrium which minimized aggregate abatement costs. The concern stems from the observation that new firms wishing to enter the area would receive little information on the cost of entry. The solution to this problem is to devise a system which will give potential entrants a price signal when the market becomes too thin. One alternative whose properties are currently being investigated, is to have existing firms put a small percentage of their permits up for sale. Anyone wishing to bid on these permits, including existing participants, would be encouraged to do so. Under such a scheme, new entrants would have a better idea of the cost of emitting sulfur oxides in Los Angeles.

While questions of efficiency are important, distributional issues must also be addressed if the market is to become a politically viable entity. One important concern in moving to a market to control sulfur oxides air pollutants is the transitional costs which firms will face. Some firms or industries may be forced to shut down. For example, if a firm competes in a national market and faces an elastic demand for its product, it may be the case that the costs of entering a permit market could force it to move to another area where environmental regulations are less costly. Estimates of the likelihood of firm closings obtained so far indicate that plant closure will not be a problem in this specific case.[9] If the policy maker wishes to avoid plant closings, this issue can be addressed through a suitable initial distribution of permits.

To gain some perspective on the distribution problem, it is useful to have a qualitative estimate of the size of the "pie." Preliminary estimates of the total annual value of emissions (i.e., the price of a permit multiplied by the quantity issued) are in the neighborhood of 150 million dollars per year.[10] Assuming there are roughly 10 million people in the South Coast Air Basin implies that each person could receive 15 dollars per year if the permits were auctioned and the proceeds were distributed to the public. Some critics have argued that the magnitude of the potential wealth transfers involved does not bode well for marketable permits in the political arena. While problems with distribution can be viewed as a barrier to implementation, there is an alternative view that control over the distribution of permits makes it that much more likely that a politically acceptable solution can be found.

What is really at issue here is who will be given the property rights to the air, and for how long. It is quite likely that a large part of the resistance to emissions tax proposals is related to the realization that under most taxation schemes, emissions rights will revert back to the public domain.[11] This is, in essence, the nature of the excess burden or double taxation argument which states that it is unfair for industry to have to pay the tax and pay to clean up as well. The alleged inequity of the excess burden can be directly addressed in a marketable permit scheme. In the extreme case, all permits could be given to industry if that were deemed fair or necessary to enlist industry's cooperation. Alternatively, some or all of the permits could be auctioned with proceeds returned to the public or used to finance administrative costs. The basic point is that adopting a marketable permits approach provides a great deal of flexibility in addressing distributional issues.

The final question which needs to be addressed is whether the infrastructure exists to handle a marketable permits scheme. There is currently a nominal emissions fee system in place for the South Coast Air Basin. Each firm is required to complete a form analogous to an income tax form which gives annual emissions for air contaminants which are subject to the fee. The principal purpose of the fee system is to cover a part of the operating cost of the South Coast Air Quality Management District (AQMD). For example, during the 1980-81 fiscal year, fees can be expected to cover about 30 percent of the projected 20 million dollar budget.[12] Sulfur oxides emissions are one of five air pollutants which come under the fee system. The charge for emitting a ton of sulfur oxides is $21.[13] This can be compared with a permit price which is estimated to be in the neighborhood of $1,000 per ton for the case in which sulfur oxides emissions remain at their present levels. Though the AQMD currently handles all disputes over emissions fees within the agency, when the price of emissions increases by one or two orders of magnitude, it is quite likely that the courts will play some role in settling disputes.

The problem is to figure out how to minimize the role of the courts. One way is by carefully defining a permit in terms which can be monitored. Two obvious choices are to define a permit in terms of a short-term maximum emissions rate such as a pound per hour, or in terms of a cumulative measure of emissions over a longer time interval. For the case of sulfur oxides emissions it would probably be preferable to define a permit in terms of cumulative emissions over a time interval such as a week or a month, but there is a problem in monitoring sources that do not route all of their sulfur input to the air. Integrated stack monitors do not exist which would provide the necessary information to demonstrate that a violation has actually occurred. On the other hand, the technology for determining whether such sources have violated a short-term maximum emission rate does exist. This can be accomplished by a team of 4 or 5 technicians performing a source test.

The monitoring and enforcement of a marketable permit scheme to control sulfur oxides emissions is within the grasp of the AQMD. It is a relatively straightforward matter to monitor cumulative emissions for utilities and the majority of industrial sources who do not use any abatement equipment for reducing sulfur oxides emissions. The only information that is required to estimate emissions is the quantity of fuel burned and the sulfur content of the fuel. For those sources who do not route all of the sulfur input into the air, the task is less straightforward. The major sources in this category include the oil refiners, coke calciners, glass manufacturers and steel manufacturers. There are two basic approaches which can be used to monitor stack emissions. One is the source test performed by technicians. The second is to install monitoring equipment which indicates the concentration of sulfur oxides within a small area in the stack. Unfortunately, without some measure of the exhaust gas flow rate, it is impossible to know the cumulative emissions. While the use of stack monitors for measuring SO_x is still in its infancy and the estimates are not always reliable, they may be used as a continuous check to determine when a firm's emissions appear to exceed the quantity of permits it holds.

There are currently about 20 continuous stack monitors in place and 100 are expected to be in place by the end of 1980 in the South Coast Air Basin.[14] One possibility for enforcing the SO_x permit scheme is to sample firms at random to see if they are in violation. This random sampling approach could be augmented by a program which uses the information provided by the continuous monitoring system installed in many of the larger sources.

There are some legal problems which need to be addressed in the implementation phase. For example, it is not clear whether under current law the AQMD can penalize violators by fining them in accord with the severity of the violation. It would be desirable to have a system of fines which could be administratively imposed in order to minimize the role of the courts. In addition, the question of who should be given the burden of proof needs to be addressed. The current reporting system for emissions is analogous to federal income tax reporting with the polluter responsible for substantiating his claims when the AQMD estimates differ with those submitted by the polluter.

The exact form of the fine raises some interesting issues. First, consider the objectives in designing a penalty system. The basic objective is to provide firms with a strong incentive to play by the rules so the air quality target will be met. But, how strong an incentive? Clearly, if the penalties were made high enough and there were some probability of getting caught, all firms would play by the rules. There is a question, however, both from a legal and an administrative perspective, as to how high you can make the penalties and still have them be workable. If the penalties far exceed the estimated damages, the courts are not likely to uphold them and the regulators might be reluctant to impose them. Such might be the case if all violations were to be punished by closing down the plant. Thus, in addition to providing an incentive for firms not to exceed their allowed emissions, a penalty scheme should be enforceable.

There are no magic formulas for determining an appropriate penalty scheme. The basic theoretical approach is to try to maximize the difference between social benefits and social costs. Operationally, this is not very helpful. If the firm's violation is viewed as marginal, then a less grandiose objective might be to equate the firm's marginal benefit from the violation with the marginal cost to society of allowing such a violation. The firm's marginal benefit can be estimated by members of the firm, but, in all likelihood, is not public information. The marginal damage to society of such a violation is anybody's guess, but can usefully be separated into two components: the probability of getting caught, p, given that a firm is in violation, and the damage due to a violation, D.

Quantification of damages is always difficult. For illustrative purposes suppose that damages are a function, f, of the size of the difference between monitored emissions and permits currently held by the firm. Call this difference x so that damages are represented by $D=f(x)$. Let F be the size of the fine in dollars and let ℓ be the price of a marketable permit. Equation (3.1) represents a preliminary attempt to link the fine to damages, the probability of getting caught when in violation and the existing price for polluting, ℓ.

$$F = \frac{f(x)\ell}{p} \qquad (3.1)$$

The numerator of equation (3.1) represents an estimate of the monetary value of damages. Dividing through by p gives a measure of expected damages. Thus, the firm is supposed to compare its expected marginal benefits with expected damages.

Equation (3.1) suffers from one serious flaw. Such a penalty system can be circumvented by driving down the price of a permit. This situation could arise if a sufficiently large number of firms chose not to participate in the market, and pay the penalty instead. Equation (3.1) is easily modified to deal with this issue. Let "a" be a parameter set by the regulator which could reflect the expected market price of a permit if all firms were to participate in the market. This gives rise to equation (3.2) which captures the spirit of (3.1), but does not fall prey to manipulation as easily.

$$F = \frac{f(x)\ \mathrm{Max}(a,\ell)}{p} \qquad (3.2)$$

In Equation (3.2), "Max" denotes the maximum of a and ℓ. Thus, at a minimum, a firm caught in violation would have to pay $f(x)a/p$.

If damages are measured in terms of emissions, then a second potential difficulty with equations (3.1) and (3.2) is that profit maximizing firms may be indifferent between obeying and not obeying the terms of a permit. The nature of the damage function, f(x), needs to be spelled out. If the objective is to keep firms close to their permit levels, then it makes sense to increase the marginal cost when the size of the violation increases. This is easily accomplished by letting $f(x) = Kx^n$ where K is an arbitrary constant and n exceeds unity. Substitution into (3.2) yields:

$$F = \frac{Kx^n \operatorname{Max}(a,\ell)}{p} \qquad (3.3)$$

Equation (3.3) is offered merely as one possibility for designing a penalty scheme. It has the virtue that it is simple, and all the parameters can be estimated, at least roughly. Furthermore, it crudely relates benefits to costs, and also would appear to be consistent with the postulated objectives for a penalty system.

The point of going through this exercise of designing a fee was to demonstrate a general approach to the problem as well as to note some of the difficulties in moving from theory to practice. The above formulation is simplistic. It assumes away many of the measurement problems. For example, there is obviously some uncertainty in measuring x. Nevertheless, it is our belief that source tests are sufficiently accurate to warrant a penalty design which assesses fines which are commensurate with the size of the violation. Another problem is that p is really an endogenous variable, which depends on the penalty scheme actually adopted, making it difficult to estimate before implementation begins. In addition, the probability of detection may vary with the size of the violation, and the resources devoted to monitoring and enforcement.

The detailed design of a penalty system will require further distinctions not made here. For example, firms who report violations should be subject to less severe penalties than firms who do not. In particular, the costs of monitoring and enforcement should fall more heavily on those firms who do not truthfully report their emissions. One possibility would be to set p equal to unity for firms reporting violations. In actuality, firms caught cheating on their reported emissions could be subject to other civil or criminal sanctions, similar to those imposed by the Internal Revenue Service.

The first objective in designing a penalty scheme was to induce firms not to exceed the allowable level of emissions most of the time. However, it was recognized that there may be unforeseen circumstances, such as an equipment failure, when a firm might violate its emission limit for a short time. Just as it is important to identify extenuating circumstances for the individual firm, it is also important to identify situations where a marketable permit scheme may be inappropriate. For the case of SO_x emissions in Los Angeles, there are two types of uncertainty which can be expected to strain the system. The first is the unpredictability of the natural gas supply. The permit scheme can handle this uncertainty in two ways: either by forcing industry to deal with this uncertainty or providing some relief in the form of issuing temporary permits should a crisis situation arise. The second major area of uncertainty is the problem of air pollution episodes which require dramatic action on the part of all participants. Because such events are very difficult to predict in advance, the best way of handling these situations is probably to suspend the permit system and invoke tighter regulations during these brief periods.

The preceding discussion indicates that it will be possible to design a market in tradable SO_x emission permits for Los Angeles. Monitoring and enforcement capabilities currently exist, but will probably have to be expanded. A fee system needs to be worked out in detail which will induce firms not to exceed their allowed level of emissions. In addition, the problem of obtaining revenues to administer the market must be addressed. One simple solution is to set a nominal fee on SO_x emissions analogous to the 21 dollar/ton fee which is applied now. Such a fee could be expected to lower the permit price by the discounted value of the fee.

3.3. Conclusions

In a world not beset by uncertainty, but befuddled by pollution problems, it was possible to construct an example in which marketable permits were preferable to standards. In the real world in which we live, the comparison is less straightforward. There are transitional costs in moving to a new system. Not all firms will necessarily be winners in moving to a marketable permit scheme. It is possible that firms may face higher abatement costs than under standards for the simple reason that the air quality goals may be reached more quickly.

Despite these objections, there appears to be an increasing willingness on the part of all groups to experiment with new kinds of environmental regulation. This enthusiasm is derived, in part, from the observation that the command and control approach is not working for many problems. It is burdensome administratively, and even though industry can sometimes foster delays in enacting regulations, the attendant uncertainties can be very expensive for firms who have long-term planning horizons. It might be the case that coalitions can be formed which are willing to consider alternatives such as marketable permits which can provide greater certainty.

If regulatory agencies decide to experiment with marketable permits, it is of paramount importance that some assurances be placed on the minimum duration of a permit. In addition, trading rules need to be spelled out clearly. If environmental agencies adopt a marketable permits approach and change the rules capriciously, they run the risk of losing support for a tool which can be a most-effective means of controlling pollution problems.

The importance of selecting the right problem cannot be overemphasized. It is helpful to have an understanding of the relationship between emissions and ambient pollutant levels so the target can be attained without having to iterate frequently. A monitoring and enforcement capability is imperative. Many environmental regulatory agencies currently do not have the resources or the expertise to successfully monitor and implement a marketable permit scheme. The final element necessary to assess the viability of the marketable permit alternative is an estimate of what it will cost industry to clean up the problem. This information can be used to identify implementation problems and design a market which will address these issues.

Footnotes for Chapter 3

* The work reported here was supported in part by the California Air Resources Board. This paper has benefited from discussions with Jim Krier, Eric Lemke and Roger Noll. The views expressed herein, including any remaining errors, are solely the responsibility of the author.

1. Krier and Bell (1980) provide an insightful discussion on the relationship between some of the new approaches being proposed such as bubbles, offsets and marketable permits, and the traditional approaches to environmental regulation.

2. A summary of industry's skeptical perspective on the bubble policy which supports this view is contained in Environment Reporter (1980).

3. Both the study by Anderson et al. (1979) and the study by Palmer et al. (1980) indicate that expected cost savings are much greater than any expected increase in administrative costs. It should be noted that in some cases administrative costs could actually decrease. One potentially important source of savings for the application considered here is the decrease in resources devoted to evaluating whether a proposed source would meet the standard.

4. This is the subject of the Rand study prepared for the U.S. Environmental Protection Agency.

5. Recently, the U.S. Environmental Protection Agency has extended this concept to include "multi-plant" bubbles, which is conceptually similar to the offset method.

6. ICF (1980), p. 26.

7. The Los Angeles region refers to the South Coast Air Basin and a part of Ventura County. The current definition of the South Coast Air Basin includes all of Orange County, the majority of Los Angeles County and parts of San Bernardino and Riverside County. See Cass (1978) for a more precise definition.

8. See Cass (1978) for a description of the model and the validation procedure.

9. There are two possible exceptions to this conclusion—a large steel manufacturer which may close down before the system could get underway, and the glass manufacturers who account for less than 1% of current emissions, but have very high abatement costs. It appears that both of these problems could easily be handled through a distribution scheme that is politically acceptable.

10. The calculations and methodology for obtaining these estimates are explained in Hahn (1981).

11. This point may need further clarification for readers with a legal perspective on the issue. In a legal sense, it may be true that the public has a claim on such rights. The point made here is that regardless of who has the claim, industry is, de facto, exercising the right whenever it spews forth emissions which are sanctioned by law.

12. Based on interview with Eric Lemke (1980).

13. Small emitters as defined in Rule 301 of the Rules and Regulations of the South Coast AQMD are exempted. SO_x is measured in equivalent tons of SO_2.

14. Based on interview with Eric Lemke (1980).

15. This upper bound estimate is based on the assumption that up to 25 or 30 more technicians might need to be hired.

CHAPTER 4

DESIGNING MARKET MECHANISMS TO CONTROL POLLUTION*

4.1 Introduction

A conventional economic analysis of the standards approach to environmental regulation indicates that it falls short on two counts. In the short run, standards fail to meet environmental objectives in a cost-effective manner because regulators do not have sufficient information on feasible abatement strategies and their attendant costs. In the long run, standards provide little incentive for firms to search for innovations in abatement technology. With such telling criticisms, the question naturally arises as to whether there might be some better way of meeting a prescribed set of environmental policy objectives that is politically feasible. This paper examines one candidate which has been suggested as a viable alternative to the existing mode of regulation. The general idea is to set up a market where rights to emit one or several pollutants can be bought and sold, in much the same way shares of General Motors stock are exchanged on Wall Street. The rules of the market would require that firms hold a quantity of permits equal to or in excess of their emissions. This approach has been referred to by several names including marketable permits, transferable rights and tradable licenses. The principal objective of this essay will be to characterize how such a market might work in a specific application and, in so doing, point out areas of research which might be helpful in assessing both the feasibility and relative merits of a marketable permit scheme.

The scholarly literature on the properties of a system of tradable emissions permits has examined in detail the theoretical advantages and problems of this approach. Examples include Dales (1968), Montgomery (1972), Roberts and Spence (1976), and Teitenberg (1980). A competitive market in emissions permits will achieve the given emissions target at minimum cost (assuming that the permits can be enforced) and will provide a continuing incentive to pursue cost-reducing innovations in abatement technology, advantages that are also characteristic of emissions taxes. In addition, they do not necessarily require that the government collect fees for allowable emissions (the permits can be given away), and they cause the uncertainties associated with environmental policy to be focused more on the total costs of the policy and less on the equilibrium quantity of emissions, in contrast with emissions taxes. Finally, in comparison to other methods of environmental regulation, they generally impose less demanding information requirements on regulators.

A major question concerning the feasibility of an efficient permits market is whether a competitive market can be established. One potential problem is that one or a few sources of pollution will account for such a high proportion of emissions that the permits market will be imperfectly competitive, preventing the market from allocating permits in a manner that minimizes total abatement costs due to strategic market behavior by the major polluters. Another potential problem arises from the geographic specificity of both emissions and damages from pollution. Each receptor is polluted by numerous sources whose emissions interact to produce unique effects at every receptor point. To achieve maximum efficiency (ignoring transactions costs), a separate market would have to be established for pollution at each receptor, and each firm would have to know the effects of its emissions on every receptor in order to buy the appropriate combination of permits.

This essay will focus on the key empirical results which emerge from an analysis of the cost and air quality data for a particular problem--the control of sulfur oxides emissions in the Los Angeles airshed. The central issue is whether a market for emissions permits can be established that produces a more efficient combination of emissions and abatement strategies than the traditional regulatory approach. Because this is an empirical question, it is examined in the context of a particular example. Nevertheless, the analysis should be of general interest because it addresses a set of questions that must be answered in order to make a tradable permits system a practical alternative anywhere.

The tradable permits system examined here is a more radical institutional change than has thus far been adopted by regulatory authorities. The "controlled trading options" developed by EPA since the passage of the Clean Air Act amendments of 1977--so-called bubbles, offsets and emissions banks--start with the existing regulatory structure as a baseline, and overlay the possibility of trades on it (see Hahn and Noll (1981)). Detailed regulatory reviews of each source and of emissions trades are obtained. Moveover, traded permits have a somewhat clouded, secondary status in relation to untraded permits.

The approach examined here replaces the existing regulatory system with a far more flexible system. It would eliminate distinctions among sources because of age, ownership, industry or method of acquiring permits. It would simply establish a ceiling on total emissions within a geographic area, and it would allow the allocation of emissions among sources in the area to be determined solely by the market. No regulatory review of the methods used by any source nor of the distribution of emissions permits among the sources would be undertaken. Policy issues relating to the differential air quality effects of different geographical distributions of emissions permits would be dealt with by the way in which trading regions were defined, and by the rules for trading across regional boundaries, as will be discussed below. The role of the government would be reduced to the following activities: (1) establish ambient air quality standards; (2) determine the total amount of emissions that is consistent with the air quality standard; (3) issue permits and maintain a market for them; and (4) enforce the emissions limits by ascertaining whether each source is emitting pollutants at a level at or below the quantity of permits it holds, and by imposing noncompliance penalties.

Regulators also may wish to use direct regulation, rather than a tradable permits system, to deal with air pollution "episodes." Meteorological conditions have an important effect on the relationship between emissions and air quality. One approach to this problem is to have several different permit systems, each of which pertains to a particular weather pattern. The separate permits systems would correspond to the present multiple stage "alert" system. Alternatively, the tradable permits system could apply only to normal conditions, and direct regulation could be used to deal with emergency conditions. Our study has assumed the latter approach for the present simply to avoid unnecessary complexity. Later, if and when the feasibility of tradable permits is demonstrated for the normal case, attention can be turned to a special permit system for emergency conditions.

Ideally a market in permits would have a large number of buyers and sellers who actively trade permits, quickly establish a market price for permits that is close to the long-run equilibrium, and take actions that minimize abatement costs and distribute emissions geographically and temporally such that ambient air quality standards are met. As a practical matter, certain tradeoffs may have to be made in terms of the design features of the system.

For example, a fairly fine-tuned definition of the times and places at which a permit can be used may produce too few participants in each market to guarantee an efficient outcome; however a broader geographic and temporal definition of a permit may be consistent with numerous substantially different patterns of pollution from the same amount of total emissions. Consequently, in defining the boundaries within which a permit will be valid, it is useful to have both a good model of the relationships between emissions and ambient air quality, and a good approximation of how the market is likely to distribute permits among sources. This enables one to predict the air quality results that are likely to come about from alternative ways of organizing the permits market.

In order to predict how permits—and, therefore, emissions—are likely to be distributed, one needs to know the demand for permits by each source. This requires being able to make a reasonable estimate of the abatement cost function faced by each major source. From this information, one can derive the cost-minimizing combination of permits and abatement that would result from different long-run prices for permits. This yields a demand curve for permits for the cost-minimizing firm.

Similar types of calculations are needed to answer questions about market structure issues. In order to determine whether the market will be sufficiently competitive to produce an efficient result, one needs to be able to forecast the final distribution of permits. If one or a few sources can be expected to hold a large fraction of the permits, the market for permits may have monopolistic features that undermine its efficiency. To predict the concentration of ultimate permits holdings also requires solving the cost-minimizing problem for participants in the market. From this, one can predict the equilibrium price of a permit. Knowing the price, one can then use the abatement cost functions to predict a final distribution of the permits. In similar fashion, cost data are essential for determining whether cost-minimizing abatement will alter the industrial structure of an area. They are also needed to figure out whether a short-run disequilibrium in the permits market could force relocation or bankruptcy of some firms that would continue to operate locally if the equilibrium price were established quickly.

4.2 Is Implementation Feasible?

To demonstrate the viability of marketable permits without actually implementing the alternative requires selecting a specific pollutant, identifying the key implementation problems, and then designing a market which will address these issues. As an example, the problem of controlling particulate sulfates in the Los Angeles region was selected.[1] This problem was chosen because it appeared to be a likely candidate for marketable permits. The scientific aspects of the problem are well understood. Data on sulfur oxides abatement costs are available or can be constructed for most of the key sources, and monitoring and enforcement problems appear tractable.

The current approach towards controlling sulfur oxides emissions in Los Angeles relies on standards, an offset policy, and a modest emissions fee. New sources of pollution must adopt the best available technology, and must trade off the uncontrolled portion of their emissions by effecting further reductions at existing sources in the Los Angeles Basin. The owner of an existing source is thus vested with a valuable property right which can be sold in whole or in part to new sources. The owner also has the option of retaining the opportunity for further abatement to facilitate subsequent expansion.

As discussed above, the offset policy is one limited form of a market in transferable permits to emit air pollutants. Its principal drawbacks are that the costs of negotiation are excessive and the number of trades which can be made by new sources are limited, and, in any case, sources must satisfy technical standards before and after trades. Negotiation costs are high because new entrants must first identify existing sources of pollution where emissions reductions are feasible, then try to estimate a reasonable charge for the offset, and, finally, perhaps have to purchase the entire business operations of some polluter to obtain its emissions rights. Moreover, gains from trade are limited to the extent that differences in technical standards after trades among source categories produce substantial differences in marginal abatement costs.

The question at hand is whether a market for sulfur emissions permits could improve matters. First, the criteria for measuring the success of a market need to be specified. For this specific case we would like to design a market that will meet established air quality goals for particulate sulfates in a more cost-effective manner than the current system of source-specific standards, that will encourage investment in finding new abatement technologies for the future, and that will be legally and politically feasible. Legal feasibility means that the market must meet the requirements of relevant constitutional constraints, and be implementable without fundamental changes in the performance objectives of existing statutes. Political feasibility means that the regulatory agency should be capable of administering the program, and that the approach has a reasonable chance of being sufficiently acceptable to industry, the public and regulators that it stands a chance of being enacted by public officials.

To demonstrate feasibility requires a good technical understanding of the problem. The particulate sulfate problem in Los Angeles is caused primarily by the combustion of sulfur-bearing energy sources. Particulate sulfates are a regulatory concern because they reduce visibility, acidify rainwater, and may have harmful health effects. The conversion of sulfur oxides emissions to sulfates in Los Angeles can be thought of as proceeding in three stages. First, sulfur enters the air basin. Virtually all of the sulfur which is emitted in the Los Angeles area enters in a barrel of crude oil. Second, when oil products are refined or burned without controls, some of the sulfur contained in them is converted to SO_2 and SO_3 and released to the atmosphere. Finally, the SO_x compounds react to form sulfates through a series of atmospheric chemical processes.

Cass (1978) has succeeded in constructing an emissions/air quality model for sulfate particulates in Los Angeles. He has shown that the relation between sulfur oxides emissions and sulfate air quality in Los Angeles is approximately linear and, in addition, can be modeled adequately as if it were largely independent of the level of other key pollutants. One feature of Cass's model is that mobile sources are treated as stationary sources by converting them to traffic densities over the airshed. Because the most likely strategy for reducing sulfur oxides emissions from mobile sources is to reduce the sulfur content of fuels, regulation of mobile sources can be done indirectly by placing the responsibility on refiners. A tradable permits system could then require refiners to add refinery emissions to sulfur oxides emissions from mobile sources to determine the number of permits they must hold.

A major task of the project was to estimate abatement cost functions for the primary sources of sulfur oxides emissions in Los Angeles. Over twenty-five source categories were identified, and abatement costs were estimated for each. The published literature, regulatory proceedings, and interviews with representatives of local industry and state and local regulatory personnel were relied upon to generate preliminary cost estimates. The information typically obtained from a particular source was a point estimate: the cost at some historical date of using a particular method to obtain a specific rate of emissions from a particular kind of facility. These were integrated to produce a step function for abatement costs for representative facilities in each source category based on 1977 regulatory conditions, with corrections made to put the costs in 1977 dollars. The results of these analyses were submitted as industry studies to the relevant firms operating in Los Angeles, with requests for comments. The additional data received in this manner are being used to produce a final emission control cost study, including indications of the amount of disagreement about costs among the sources of information.

A number of factors make these cost estimates upwardly biased as estimators of the costs that would be experienced if a system of tradable permits were instituted. First, for source categories for which no control cost estimates could be found, emissions were assumed to be uncontrollable. Second, production and energy use at emitting facilities were assumed to be independent of the amount of control. In reality, firms with especially high emissions and stiff abatement costs are likely to reduce output or to make more efficient use of energy. Third, although several process changes are available to many firms, they are reluctant to reveal them because they are trade secrets that may confer significant competitive advantages upon these firms in a more stringent regulatory environment. No allowance for these process changes is made in the study, although an effort is now being made to model the possibility of changes in refinery product mix in the oil industry as one means of changing emissions from refineries and refined products.

Because SO_x emissions in Los Angeles result largely from the combustion of petroleum products, the availability of natural gas, which contains negligible amounts of sulfur, can significantly affect SO_x emissions. This, in turn, will affect the demand for permits and, hence, their price. For this reason, three separate cases were analyzed: one which assumes a low level of natural gas availability; a second which corresponds to a historical supply year (1973) which provides an intermediate supply assumption; and a third which assumes a high supply of natural gas. All three cases are based on emissions projections for the early 1980s with 1977 regulations assumed to be in place. In all cases, allocation priorities that are established by regulators, rather than the market, are assumed to determine access to the use of natural gas. This has an important effect on the results since regulatory allocation priorities are not related to the value of natural gas either in terms of its direct use or in terms of the effects of its use on air quality.

With these caveats in mind, the cost data were used to estimate the demand for emissions permits and the distribution of permits that an efficient market would produce. The remainder of the paper will analyze the results of simulating the equilibrium of feasible permits markets.

4.3 The Competitive Model

In all of the models discussed, it is assumed that firms attempt to minimize the sum of abatement costs plus permit costs. In this section, a baseline competitive equilibrium distribution of permits is simulated. Firms are assumed to be price-takers, which is to say they assume that the equilibrium price of a permit is unaffected by their actions. A permit will be defined as the right to emit one ton SO_2 equivalent of sulfur oxides per day anywhere in the airshed. After examining the baseline case, the results will be compared to a fine-tuned definition of permits that takes account of geographical locations of sources and receptors, and to a simulated distribution of emissions when the permits are monopsonized. All calculations here are discussed in Hahn (1981), unless otherwise noted.

To simulate the market, it is necessary to specify an air quality target. For the purposes of analysis, four possible emissions targets are examined which vary from no further net emission control down to about a 70 percent reduction in emissions, needed to meet the California sulfate standard. The four cases are summarized in Table 4.1.

The calculations in Table 4.1 are based on a linear rollback model. The estimates of the emissions/air quality relationship would probably change if a more sophisticated air pollution model were employed, but the rollback model suffices for the purpose of showing how the permit price and abatement costs vary with the choice of an air quality target. Figure 4.1 illustrates the equilibrium price of a permit to emit one ton/day of SO_x in Los Angeles for the case in which there is a low natural gas supply. All price and cost estimates are given in 1977 dollars.

The decreasing step function in Figure 4.1 represents the derived demand curve for permits over the range of interest. The curve was drawn as a step function because most of the engineering cost estimates which were used to generate the demand curves were given in this form. The four vertical supply constraints in Figure 4.1 correspond to the four air quality targets presented in Table 4.1. The market price of a

TABLE 4.1

Selected Air Quality Targets for the South Coast Air Basin in Tons SO_x/day[a]

TARGET	ALLOWABLE EMISSIONS
1. Achieve California Sulfate Air Quality Standard of 25 micrograms/cubic meter over a 24 hour averaging time.	149
2. Violate California Sulfate Air Quality Standard 3-5% of the time.	238
3. No additional controls with an above average natural gas supply.	335
4. No additional controls with a low natural gas supply.	421

[a] Sulfur oxides emissions are measured as tons of SO_2 equivalent.

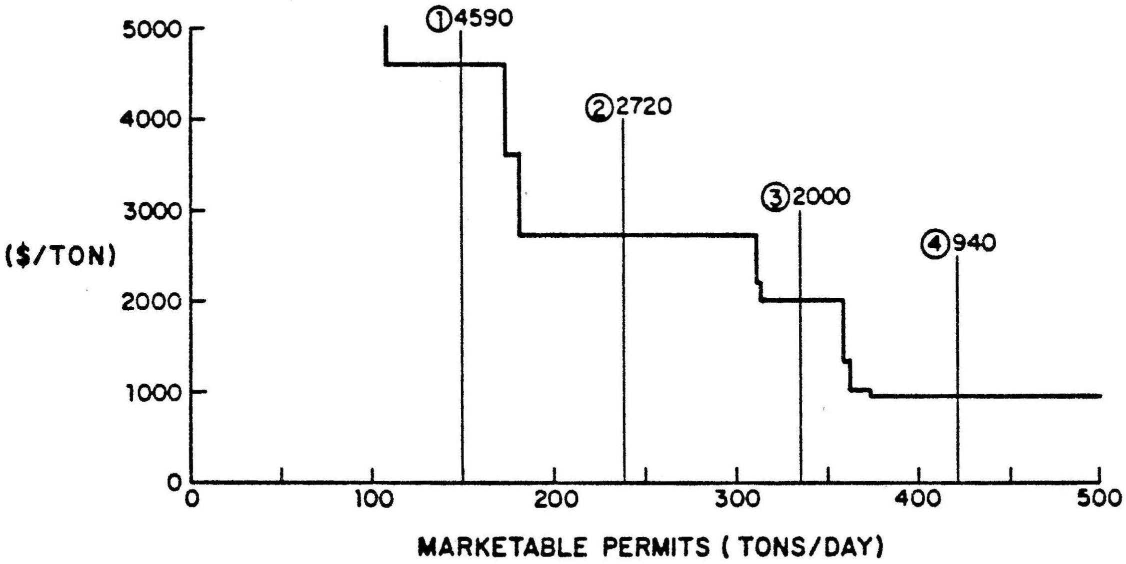

FIGURE 4.1

The Demand for Permits with Low Availability of Natural Gas permit is drawn next to each intersection. Thus, for the first case in which the California sulfate standard is met, the point estimate for the price of a permit is 4,590 dollars. From this graph, it is also possible to calculate two other potentially interesting numbers. The annual abatement cost for any level of air quality can be computed by integrating the area under the demand curve and to the right of the air quality target. The amount of money which could conceivably change hands in a permit market can be calculated by multiplying the number of permits issued by the equilibrium price. The significance of these numbers is discussed below.

The price of an emissions permit is highly sensitive to the availability of natural gas and to the choice of an air quality target. A graphical illustration of this fact is shown in Figure 4.2, which illustrates the derived demand for permits under high and low natural gas availability. Note the wide disparity in price for any given emissions target. Table 4.2 relates the supply of natural gas to the equilibrium permit price for the four air quality targets specified previously. The table exhibits two interesting features. First, it can be seen that the price of a permit can vary by an order of magnitude depending on the assumptions concerning natural gas supply and the air quality target. Second, a comparison of the first two columns indicates that a fairly small change in air quality standards can cause a substantial change in the price of a permit. This reflects the fact that the marginal cost of sulfur oxides abatement changes rapidly at the upper end of the air quality spectrum.

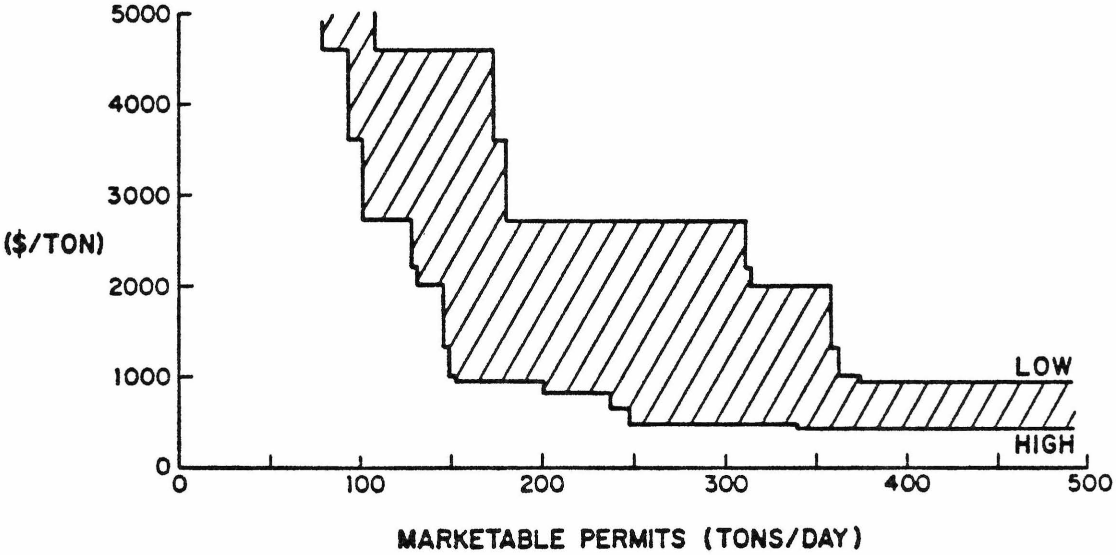

FIGURE 4.2

The Demand for Permits with Low and High Natural Gas Availability

Table 4.2

Price Sensitivity Analysis

NATURAL GAS SUPPLY	AIR QUALITY TARGET			
	1	2	3	4
Low	4,590[a]	2,720	2,000	940
Historical	2,720	2,000	940	810
High	1,320	650	470	420

[a] All prices in $ 1977. A permit entitles the user to emit one ton of SO_x for one day.

The total annual cost of abatement varies considerably both as a function of the natural gas supply and the air quality target. The data are presented in Table 4.3. The estimates of abatement cost do not include the effect of abatement equipment installed in response to rules adopted prior to 1978. Consequently, the changes in abatement cost between different categories are probably the most meaningful figures. Even without estimates of some abatement equipment in place, abatement costs are in the hundreds of millions of dollars annually, except for the case in which natural gas is in plentiful supply.

The most important point to be derived from Table 4.3 is that the availability of natural gas has a marked effect on the cost of reducing SO_x emissions. The only difference between the situations of low and high natural gas supply is that the latter substitutes natural gas for 100 million barrels of residual and distillate fuel oil. Dividing the difference in abatement costs between the two cases by the difference in the amount of oil used yields an average cost saving per barrel-equivalent of natural gas between 4 and 6 dollars, depending on the air quality target. The cost savings result from the substitution of natural gas for high-sulfur fuel oil, rather than using low-sulfur oil or extensive abatement investments to meet emissions targets.

Another way of illustrating the critical importance of the natural gas supply is to ask what firms would be willing to pay for having natural gas substituted for one barrel of residual fuel oil. Assume that the marginal value of natural gas equals the full marginal cost of burning residual fuel oil. The full cost includes the price of

TABLE 4.3

Annual Abatement Costs (in millions of 1977 dollars)

NATURAL GAS SUPPLY	AIR QUALITY TARGET			
	1	2	3	4
Low	684	576	487	447
Historical	400	315	280	252
High	112	83	66	53

a barrel of oil plus the cost of holding permits to emit the associated sulfur oxides. Performing the calculation for all twelve cases reveals that firms would be willing to pay anywhere from 107 percent to 130 percent of the price of the residual fuel oil for a BTU equivalent amount of natural gas.

The last key point which the analysis of the competitive case raises is the magnitude of the sums of money which could conceivably change hands if a market were to be implemented. Define the total annual value of the permits as the number issued multiplied by the annual price people are willing to pay to hold a permit for one year. (This price is obtained by multiplying the data in Table 4.2 by 365.) For the twelve cases examined here, the total annual value of the permits varies between 65 and 250 million dollars with an average of just under 150 million dollars. With approximately 10 million people in the Los Angeles area, this implies that each resident could receive 15 dollars per year if the permits were auctioned and the proceeds were distributed to the public. Some critics have argued that the magnitude of the potential wealth transfers involved does not bode well for marketable permits in the political arena. While problems with distribution can be viewed as a barrier to implementation, there is an alternative view that control over the distribution of permits makes it that much more likely that a politically acceptable solution can be found.

To justify tackling a difficult distributional issue, the expected cost savings from a marketable permit system must be substantial. The estimation of these savings is the subject of the next two sections. First, the expected savings from maintaining the same level of emissions under a marketable permit system are estimated. Then, a system of undifferentiated emission permits (which takes no account of the location of each source) is compared with the case of fine-tuning on a geographic basis.

4.4 Standards vs. Tradable Emissions Permits

Many of the relative costs and benefits of different approaches to regulation are not easily quantified. For example, it is clear that the tradable emission permit system suggested here will tend to reduce existing barriers to entry that industry faces under the current emission standards approach; yet, placing a meaningful dollar estimate on the expected net benefits from such a change is difficult. It is also difficult to know to what extent the marketable permit system will induce process changes and innovations in abatement technology over time. Because of the problems in estimating dynamic efficiency gains, this section will focus on static efficiency gains which can accrue from using a market mechanism. For the specific case of controlling SO_x emissions in Los Angeles, the gains from using an incentive-based approach to maintain the status quo can be expected to be relatively small in comparison to other applications which have been examined. This is because the local pollution control agency has attempted to use cost-effectiveness as a major criterion in promulgating rules.

The specific problem is to examine how the competitive equilibrium under a tradable emissions permit system compares with the current standards approach to regulation. The first step in the analysis is to project the level of expected emissions under standards. This calculation is performed for all three levels of natural gas supply, and two sets of standards. The first set of standards consists of those in place by the end of 1977. The second set consists of those expected to be in place by 1985. The projected emissions for the six cases are shown in Table 4.4. Note that the projected emissions for the low natural gas scenario under 1977 standards correspond to case 4 in Table 4.1. The predicted emissions in 1985 are lower than 1977 sulfur oxides emissions under standards because more stringent controls are placed on three source categories: petroleum coke calciners, fluid catalytic crackers and residual fuel burning by refiners.

The next step in the analysis is to simulate the competitive equilibrium for an emissions permit market for the six cases shown in Table 4.4. The expected annual savings in moving from standards to tradable emissions permits are then computed. These are shown in Table 4.5.

An inspection of Table 4.5 reveals that significant cost savings exist even in the case where a pollution control agency has specifically tried to implement cost-effective control strategies. Moreover, it is likely that such savings would increase as the constraint on permissible emissions were tightened. The savings would

TABLE 4.4

Sulfur Oxides Emissions Under Standards
(Tons SO_x/Day)

NATURAL GAS	STANDARDS 1977	 1985
Low	421	364
Historical	298	250
High	211	167

TABLE 4.5

Annual Cost Savings with an Undifferentiated Tradable Permit System (in millions of 1977 dollars)

NATURAL GAS	STANDARDS 1977	 1985
Low	23	22
Historical	17	15
High	10	8

result, in part, from a lessening of the administrative burden of having to repeatedly search for cost-effective control strategies. It is also probable that political factors would be more likely to constrain the feasible set of individual source standards as abatement costs rise dramatically with the introduction of tighter standards.

In addition to the magnitude of expected cost savings in moving to a tradable permits market, it is of some interest to consider their origin. For example, does a consistent pattern emerge as to which activities are "overregulated" relative to the cost minimum? An examination of all six cases reveals that the category of residual fuel burning for both refiners and utilities faces more stringent controls than would result if the cost minimum were achieved. This implies that under a tradable permit system residual fuel burners would tend to burn higher sulfur fuel than they are currently burning, while other sources would add control equipment to maintain current total emission levels.

Finally, a word needs to be said on the general problem of comparing different regulatory systems on the basis of potential cost savings. The typical approach that is taken, and the one employed here, assumes that the cost estimates developed for a given study are, in some sense, the appropriate standard of comparison. Why this should be the case is usually unclear given the uncertainty surrounding the cost estimates. While it may be useful to employ cost data in estimating static efficiency gains, the potential pitfalls of this approach need to be clearly stated.

The preceding analysis deals with the case in which emissions permits are freely tradable throughout the airshed, with no account taken of the differences among sources in the impact of emissions on ambient air quality. In practice, a fine-tuned permits market would be difficult to implement; however, the outcome of such a system, assuming it could be implemented, can be simulated in the same fashion as the case of a competitive market for geographically unspecified permits. The results of these simulations are discussed in the next section.

4.5 The Gains from Fine Tuning

Instead of having a single market where permits are undifferentiated, imagine a case where there are several markets corresponding to each of the receptors within an air quality region. Assume further that firms would have to participate in all markets where their individual emissions affect air quality. This is the essence of the "fine-tuning" problem. In this section, the gains from moving to a finely-tuned permit system are examined.

The benchmark for purposes of comparison is the undifferentiated permits market. This will be compared with a case in which there are 17 markets corresponding to the 17 receptors illustrated in Figure 4.3.

The calculation of annual abatement costs are presented in Table 4.6. All calculations are based on the low natural gas case. Column (1) lists six alternative levels of total emissions for the airshed. Column (2) lists the associated average air quality based on the cost-minimizing pattern of emissions which result from an

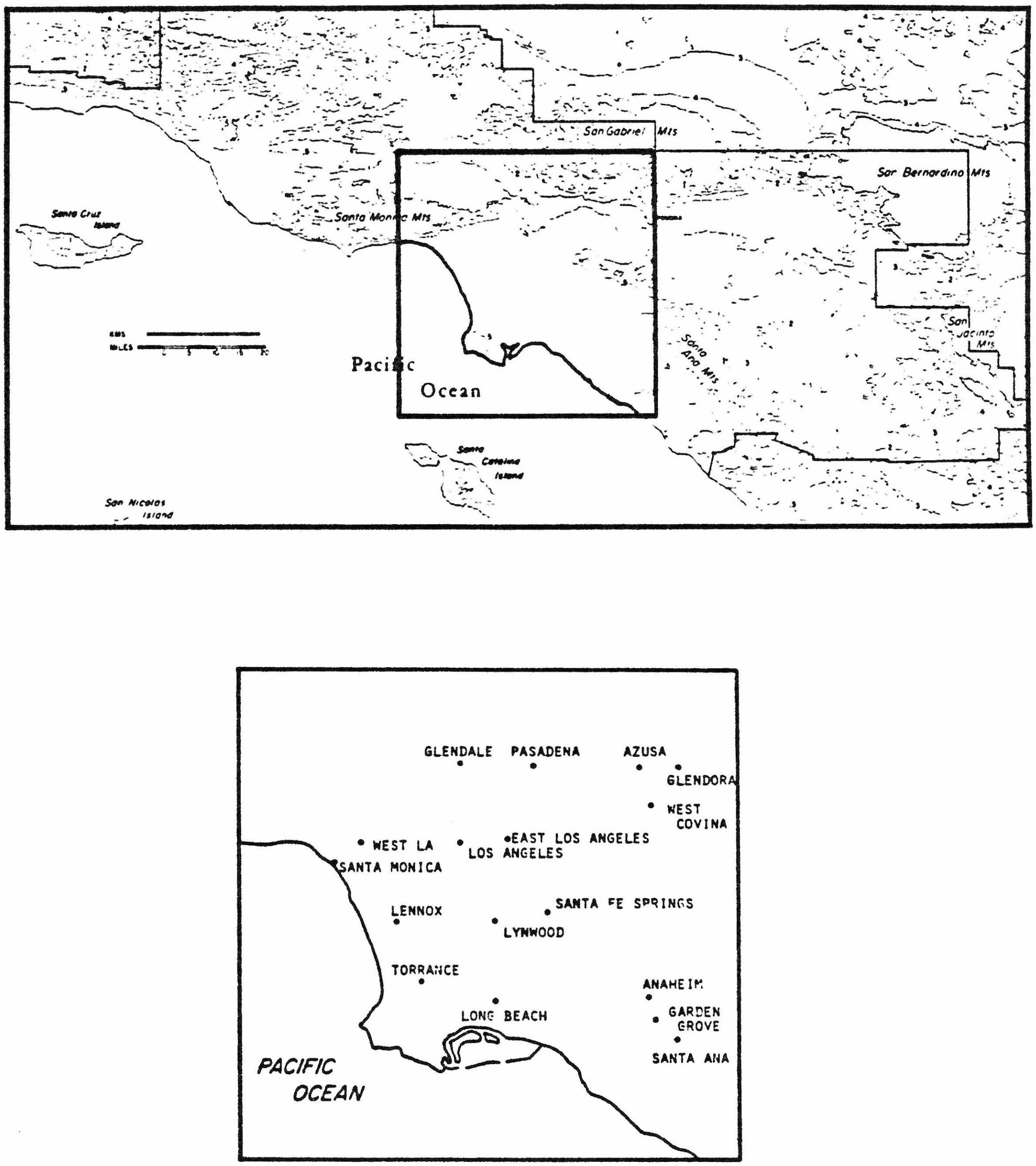

FIGURE 4.3

Location of Receptors in the Fine-Tuning Simulation

TABLE 4.6

Annual Abatement Costs and Market Arrangements

(costs in $ millions)

(1) BASELINE EMISSIONS TARGET (TONS/DAY SO_2 EQUIV)	(2) AVERAGE AIR QUALITY (gm/m^3)	(3) COSTS FOR SINGLE MARKET IN EMISSIONS PERMITS	(4) COSTS FOR EQUIVALENT MULTIPLE AIR QUALITY MARKETS	(5) COSTS FOR "ADJUSTED" MULTIPLE AIR QUALITY MARKETS
150	7.0	682	682	682
200	7.8	614	606	594
250	8.4	565	557	545
300	8.9	515	513	505
350	10.1	476	473	464
400	11.1	455	448	436

undifferentiated permit market. Average air quality represents the arithmetic mean of annual sulfate concentrations at the 17 monitoring sites. Column (3) shows the abatement costs for achieving these levels assuming a competitive permits market.

Associated with the competitive distribution of each of the emissions levels in column (1) is a set of annual concentrations of sulfates at each point in the region at which air quality is monitored. Suppose that instead of setting a limit on total emissions, regulators issue permits to pollute at each receptor point in an amount that would result in the competitive equilibrium in the emissions permit market. Each source of emissions would then need to acquire separately permits for the pollution its emissions caused at every monitoring station. Because the location of the emission sources matters in affecting measured air pollution, this approach could produce additional rearrangements of emissions — and some increase in total emissions — that resulted in lower abatement costs but did not degrade air quality at any measuring station. Column (4) shows the costs associated with the competitive equilibrium distribution of emissions under this system.

Finally, suppose regulators are concerned only with air quality at the worst measuring station, and that they create pollution permits for each station that allow pollution at every monitoring station to equal the pollution measured at the worst station under the competitive equilibrium distribution of emissions permits in column (1). This would allow further trades and increases in emissions as long as air quality did not deteriorate at the location with the worst pollution, and did not force some other station to have its air quality deteriorate beyond the level at the worst-case station. The abatement costs associated with the competitive equilibrium distribution of these permits is shown in column (5).

The result of these simulations is that defining permits in terms of ambient pollutant concentrations, and geographically differentiating the permits for each monitoring location, has relatively little effect on the efficiency of the market. The differences in annual abatement costs under the three systems vary from zero to four percent of the total, amounts that are surely small compared to the difficulties of trying to implement a more complicated system.

The robustness of this result was checked by altering two sets of parameters in the simulation. First, because the abatement cost curve for residual fuel users plays a crucial role in determining price and total abatement cost, this marginal cost was increased and decreased by 50 percent. The savings in abatement cost were quite similar to the results in Table 4.6. As a second check on robustness, source/receptor air quality relationships were altered to represent meteorological patterns observed in 1974 rather than the base case which was associated with 1973. Again, it was found that potential savings were quite small.

There are two qualifications to the basic result that a finely-tuned system may not be warranted on the basis of cost savings. First, it should be noted that air quality is measured in terms of annual concentrations. If a shorter averaging time is used, the result may not obtain. Second, the result speaks to the present. These calculations are based upon the abatement possibilities and emissions inventories of existing firms in their current locations. Future economic change in the airshed conceivably could alter the pattern of emissions such that a more complicated system would provide substantial benefits. But at present, there does not appear to be a serious loss in efficiency associated with adopting the simplest approach of making SO_x emissions permits freely transferable throughout the Los Angeles airshed.

4.6 The Effects of Market Power

Thus far, the analysis has been restricted to the case in which firms act as price-takers in the permits market. One potential problem with a marketable permits system is that one or a few firms may be able to manipulate the market to their advantage and, in the extreme, destroy its efficiency advantages over standards. This problem cannot be dismissed lightly for the case at hand.

Table 4.7 gives the estimated market share for the largest permit holder, which happens to be a utility. The market share of a firm is defined to be the percentage of the total number of permits that it holds. A casual inspection of the numbers reveals that under competition, the firm holding the largest market share will probably own somewhere between one-fourth to one-half of the permits. Whether

TABLE 4.7

Market Share of the Largest Permit Holder Under Competition

(Percent of Total Permits)

NATURAL GAS SUPPLY	AIR QUALITY TARGET			
	1	2	3	4
Low	31	43	45	41
Historical	32	43	48	48
High	23	29	40	47

this will, in fact, allow this firm to dominate the market is an open question which is currently being investigated. For the present, it will be assumed that the sizable market share may allow this firm to exercise market power.

The market power of the firm with the largest market share could manifest itself in several ways. It is not even clear without further specification of the conditions of the market whether a firm with market power will act as a monopolistic seller of permits or as a monopsonistic buyer. Here we will analyze a case that appears plausible in its initial conditions, yet extreme in the assumption about the strength of market power. We assume that the firm in question initially will be given fewer permits than it is expected to want to hold after the market in permits is opened. This is consistent with present policies that tend to force utilities to levels of abatement having higher marginal abatement cost than is common for most other industries. Thus, we assume that the utility will be the only purchaser of permits; that is, the initial distribution of licenses is such that the utility will be able to exercise maximal market power. In such a market, the equilibrium price will equal the marginal abatement cost of the sellers of permits, but not of the monopsonistic buyer. In purchasing permits, the monopsonist will take account of the fact that as it increases its purchases of permits, it will drive up their price. Hence, it will buy fewer permits at a lower price than would be the competitive, cost-minimizing solution. In other words, the monopsonist will abate too much in relation to other firms, and the latter will have lower marginal abatement costs than the former. To the monopsonist, some additional, uneconomic abatement will be worthwhile because of its depressing effect on the price paid for the permits that it acquires from other firms.

Table 4.8 shows the simulated market share of the firm holding the most permits, assuming that it achieves the profit maximizing monopsony equilibrium. A comparison of Tables 4.7 and 4.8 illustrates the additional abatement that the monopsonist will undertake if it has market power. The two tables also reveal one other interesting fact. The market share of the largest firm is highest at an intermediate natural gas supply and does not differ much between high and low gas supply. This reflects the fact that at the extremes natural gas is either used sparingly or extensively by almost all sources, while the intermediate case reflects the fact that utilities will be among the last to be allowed to switch to gas from low-sulfur fuel oil under the current scheme for gas allocations.

The decrease in market share is typically accompanied by a decrease in the price of a permit. This can be seen by comparing Table 4.9 with Table 4.2. As in the competitive case, the permit price still varies over an order of magnitude, depending on the air quality target and the supply of natural gas.

Although the differences between the competitive and monopsonistic case appear large, whether they cause a major loss of efficiency in achieving abatement targets remains an open question.

TABLE 4.8

Market Share of the Largest Permit Holder Under Market Power

(Percent of Total Permits)

NATURAL GAS SUPPLY	AIR QUALITY TARGET			
	1	2	3	4
Low	20	31	37	41
Historical	32	40	33	44
High	23	25	39	32

TABLE 4.9

Permit Prices Under Market Power

NATURAL GAS SUPPLY	AIR QUALITY TARGET			
	1	2	3	4
Low	2,720[a]	2,000	1,000	940
Historical	2,720	1,000	650	470
High	1,000	470	420	210

[a] All prices are in \$ 1977. A permit entitles the user to to emit one ton of SO_x per day.

The appropriate measure of inefficiency is neither price nor market share, but the differences in total abatement costs under the two situations. If at the competitive equilibrium all firms face a fairly flat marginal abatement cost over a wide range of emissions reductions, a large shift of emissions from the monopsonist to the rest of the firms might entail relatively little loss of efficiency. As can be seen in Figure 4.1, all of the choices of alternative ambient air quality standards happen to fall within relatively flat portions of the demand curve for permits, and therefore in areas in which the abatement cost function obeys essentially constant marginal costs. Calculations of the efficiency loss of market power were made in each case, and the loss was determined to be relatively small, ranging from zero to ten percent depending upon the particular combination of assumptions about natural gas supplies, ambient air quality standards, and the method used for estimating the abatement cost functions. The estimated loss in efficiency due to market power is quite sensitive to small changes in the cost functions. Consequently, considerable thought must be given to the possibility of building in protections against monopsonistic market power into the tradable permits system.

4.7 Conclusions

This essay has focused on examining the results from feasible permits markets. The analysis of the competitive case for an emissions permit market demonstrated that the equilibrium price is very sensitive to the desired level of air quality. In addition, the effect of changes in the supply of natural gas was shown to be considerable. The next issue which was raised was how the current standards regime compares with a permits market. It was found that the current standards may place excessive controls on residual fuel burners when compared with the competitive equilibrium solution. The final phase of the competitive analysis compared an emissions permit market with the case of fine-tuning. The payoff to fine-tuning was relatively small in the short run, when estimated using annual air quality data. The question of an appropriate averaging time for air quality data deserves further study, particularly because of its relationship to "hot-spots" —areas with abnormally high pollutant concentrations.

The analysis of the competitive case was followed by an analysis of a case in which the largest firm could exercise monoposony power in the permits market. The effect of market power on efficiency was relatively small for the cases examined here. Nevertheless, care should be exercised in selecting particular trading institutions and initial allocations in this market. The potential for exercising market power is there, but can probably be addressed directly through a judicious selection of institutions, and a careful analysis of how the initial distribution of permits could affect the long-term equilibrium price and distribution of permits.

Footnotes for Chapter 4

* The work reported here was supported in part by the California Air Resources Board. There are three individuals who were instrumental in developing the ideas contained in this paper. Roger Noll aided in the final phase of writing and analysis; Glen Cass developed the emissions/air quality data; and Richard Hanson provided data management support which made the calculations tractable. While I gratefully acknowledge this support, I must also claim responsibility for the views expressed herein, including any remaining errors.

1. The Los Angeles region refers to the South Coast Air Basin and a part of Ventura County. The current definition of the South Coast Air Basin includes all of Orange County, the majority of Los Angeles County and parts of San Bernardino and Riverside County.

CHAPTER 5

A THEORETICAL ANALYSIS OF THE DEMAND FOR EMISSION LICENSES*

This paper examines the qualitative effects that a market in transferable licenses in emissions will have on a firm's input decisions and its expenditure on abatement equipment. The case of the competitive firm is examined in detail, and this is compared with a firm which can exert monopoly power in product and factor markets. The model employed here differs from previous work in that the price of the variable input is explicitly related to its quality. This can be compared with the more conventional approach which treats the pollutant as a factor of production.[1] Several authors have shown that the derived demand for inputs of fixed price and quality are downward sloping.[2] In Section 1, this result is extended to the case where input quality can be varied. Section 2 compares the demand for licenses under competition with the demand for licenses when a firm can exert power over product or factor markets. In Section 3, the role of other traders and the authority issuing licenses is explicitly included in the analysis. Section 4 summarizes the results.

5.1 The General Problem

Attention is focused on the problem of controlling emissions associated with the use of productive inputs. When the relationship between emissions and ambient pollutant concentrations is linear, then the subsequent analysis obtains for the control of secondary pollutants as well as the control of primary emissions.

The control of sulfur oxides emissions is one example for which the model would be appropriate. Sulfur enters into the production process through the use of natural resources that contain it, usually coal and petroleum used as energy inputs. When these inputs are burned some of the sulfur contained in them is converted to SO_2 and SO_3. For a given abatement technology, the relationship between sulfur entering the production process and resulting emissions of sulfur oxides is approximately linear.

The firm may adopt two basic approaches to reducing emissions. It can either reduce emissions directly by purchasing equipment such as scrubbers and baghouses or it can reduce the level of pollutant entering into the production process. This latter reduction is normally accomplished by purchasing higher quality inputs, which typically cost more, by curtailing output, or by varying the amount of inputs used per unit of output in production. For simplicity, the last method for reducing emissions will be ignored. Suppose that the firm has a production function f(E), where E represents the level of inputs. The function f is assumed to be twice differentiable and strictly concave so that $f' > 0$ and $f'' < 0$.

Let X(R,s,E) characterize the firm's abatement opportunities. X is the total annual emission rate; R is the total annual expenditure on abatement; and s is the amount of the pollutant contained in a unit of the input stream, E. Emissions are assumed to decrease with greater abatement expenditures, but there are decreasing returns to such endeavors, (i.e., $X_1 < 0$ and $X_{11} > 0$). On the other hand, annual emissions will increase if the firm chooses lower quality inputs or increases the level of its inputs (i.e., $X_2 > 0$ and $X_3 > 0$). Furthermore, it will be assumed that increasing inputs will not improve the marginal effect of a given pollutant content, and may make it worse (i.e., $X_{23} \geq 0$).[3] The firm's problem is to maximize profits, or the difference between total revenues and the sum of input costs, abatement costs and license costs. Formally, we have:

$$\underset{R,s,E}{\text{Maximize}}\ pf(E) - e(s)E - wX(R,s,E) - R \tag{5.1}$$

where

p = price of output,

e(s) = unit price of inputs; $e' < 0$ $e'' > 0$, and

w = license price.

The price of inputs is presumed to be a convex function of the pollutant content. From this, it immediately follows that a firm would never wish to use two or more different quality inputs simultaneously, where such inputs are defined solely in terms of pollutant content.[4] Empirically, this relationship has been shown to hold approximately for heavy fuel oil prices in Los Angeles.[5]

First-order conditions for an interior solution are given by:

$$-wX_1 - 1 = 0 \tag{5.2}$$

$$-e'E - wX_2 = 0 \tag{5.3}$$

$$pf' - e - wX_3 = 0 \tag{5.4}$$

Equation (5.2) says that at the margin, an additional dollar spent on abatement equipment will be exactly offset by the savings resulting from decreased emissions. Equation (5.3) balances the reduction in emissions from buying higher quality inputs against the increase in the cost of buying licenses. Equation (5.4) equates the marginal revenue product of using an additional unit of inputs with the increase in the cost of input, which consists of two components: the direct cost of inputs, e, and the indirect cost due to having to purchase more licenses, wX_3.

The interesting comparative statics questions revolve around the effect of a change in the license price on abatement expenditures, the pollutant content of inputs, the level of inputs, and hence, the ultimate level of emissions which is chosen. Totally differentiating the first order conditions gives rise to the following Hessian matrix, C:

$$C = \begin{bmatrix} -wX_{11} & -wX_{12} & -wX_{13} \\ -wX_{12} & (-e''E-wX_{22}) & (-e' -wX_{23}) \\ -wX_{13} & (-e' -wX_{23}) & (pf'' -wX_{33}) \end{bmatrix}$$

Let C_{ij} denote the ijth cofactor of C and [C] denote the determinant. Performing the comparative statics yields expressions for the effect of a change in license price on the endogenous variables:

$$\frac{\partial R}{\partial w} = \frac{1}{[C]}[C_{11}X_1 + C_{12}X_2 + C_{13}X_3] \qquad (5.5)$$

$$\frac{\partial s}{\partial w} = \frac{1}{[C]}[C_{12}X_1 + C_{22}X_2 + C_{23}X_3] \qquad (5.6)$$

$$\frac{\partial E}{\partial w} = \frac{1}{[C]}[C_{13}X_1 + C_{23}X_2 + C_{33}X_3] \qquad (5.7)$$

$$\frac{\partial X}{\partial w} = X_1\frac{\partial R}{\partial w} + X_2\frac{\partial s}{\partial w} + X_3\frac{\partial E}{\partial w} \qquad (5.8)$$

Assume that sufficiency conditions for an interior maximum are met.[6] This implies that C is negative definite. Even with this assumption, $\frac{\partial R}{\partial w}$, $\frac{\partial s}{\partial w}$ and $\frac{\partial E}{\partial w}$ cannot be signed unambiguously. However, it is possible to show that the demand for licenses is downward sloping (i.e., $\frac{\partial X}{\partial w} < 0$). Substituting equations (5.5) - (5.7) into (5.8) yields:

$$\frac{\partial X}{\partial w} + \frac{1}{|C|}\left[(X_1, X_2, X_3)\begin{bmatrix} C_{11} & C_{21} & C_{31} \\ C_{12} & C_{22} & C_{32} \\ C_{13} & C_{23} & C_{33} \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix}\right] \qquad (5.9)$$

Because C is negative definite, this implies C^{-1} is negative definite. Thus, equation (5.9) indicates that $\frac{\partial X}{\partial w} < 0$.

While the sign of the terms in equations (5.5) - (5.7) cannot be determined exactly, it is possible to infer from equation (5.9)

5.2 A Comparison of Competition with Market Power

A simple case to analyze is where the pollutant in the inputs just equals emissions; that is, no abatement can be achieved through expenditure on equipment. In this case, reductions can be achieved by reducing the pollutant content of inputs and/or reducing the level of inputs. One example would be the containment of sulfur oxides through the purchase of lower sulfur fuels. Formally, the firm's problem may be written as follows:

$$\underset{s,E}{\text{Maximize}}\ pf(E) - e(s)E - wsE \tag{5.10}$$

First-order conditions for an interior maximum are given by:

$$-e'E - wE = 0 \tag{5.11}$$

$$pf' - e - ws = 0. \tag{5.12}$$

Equation (5.11) indicates that s should be chosen so as to equate the cost of polluting more, w, with the marginal cost of buying higher quality inputs, $-e'(s)$. Equation (5.12) balances the marginal revenue product with an increase in input costs.

Define B to be the Hessian associated with (5.10). Then,

$$B = \begin{bmatrix} -e''(s)E & 0 \\ 0 & pf'' \end{bmatrix} \tag{5.13}$$

From the assumptions on e and f, B is negative definite. An examination of the effects of a change in the price of a license on pollutant content and the overall level of inputs yields:

$$\frac{\partial s}{\partial w} = -\frac{1}{e''(s)} < 0 \qquad (5.14)$$

$$\frac{\partial E}{\partial w} = \frac{s}{pf''} < 0 \qquad (5.15)$$

Equation (5.14) says that the pollutant content decreases with an increase in the price of a license while (5.15) says that the level of inputs also declines. Since the overall level of emissions is given by sE, it is readily seen that emissions decrease in response to an increase in the price of a license.

It is possible to compare the situation when the firm can exert market power with the competitive case by making suitable changes in (5.10) and carrying out the required optimization. Three cases will be considered: first, the case of pure monopoly; next, the case when a firm exerts some influence over the energy market and finally, the case when a firm can dominate the license market. The monopolist's problem is the same as above, except now $p = p(f(E))$, which gives:

$$\underset{s,E}{\text{Maximize}}\; p(f(E))f(E) - e(s)E - wsE \qquad (5.16)$$

First-order conditions for an interior maximum are given by:

$$-e'(s)E - wE = 0 \qquad (5.17)$$

$$pf' + fp'f' - e(s) - ws = 0 \qquad (5.18)$$

Equations (5.17) is identical with equation (5.11). From the assumptions on e, the value for s which solves (5.17) (assuming one exists) will be unique.[7] Thus, the monopolist and perfect competitor will choose the same pollutant content. To determine who would pollute more, it is only necessary to consider whether the monopolist will use more or fewer inputs than in the competitive case. Assuming the revenue function for the monopolist is strictly convave and an interior solution to the problem exists, then the monopolist will use less energy and, hence, pollute less than his competitive counterpart. To see this, define the revenue function: $R(E) = p(f(E))f(E)$. The usual differentiability assumptions imply $R' > 0$ and $R'' < 0$. Comparing conditions (5.12) and (5.18), it is clear that setting E at the optimal level in the competitive case will yield the following inequality:

$$pf' + fp'f' < e(s) + ws, \qquad (5.19)$$

since $fp'f' < 0$. The question is whether (5.19) can be brought into equality by adjusting E. From (5.11) and (5.17), we saw that the pollutant content is identical for the two cases, independent of the level of inputs which is chosen. This means that the expression on the right-hand size of (5.19) can be treated as a constant. Noting that the left-hand side of (5.19) equals $R'(E)$, it immediately follows that the only way to bring (5.19) back into equality is to decrease E from the competitive level.

So far, we have derived conditions under which the monopolist will emit less and produce less than in the perfectly competitive case. The key assumption concerned the shape of the revenue function. This assumption is also critical for deriving the comparative statics results given below:

$$\frac{\partial s}{\partial w} = -\frac{1}{e''(s)} < 0 \tag{5.20}$$

$$\frac{\partial E}{\partial w} = \frac{s}{R''(E)} < 0 \tag{5.21}$$

A comparison of Equations (5.14) and (5.20) reveals that the effect of a change in license price on pollutant content will be the same for the monopolist and the competitive firm for a given level of input quality. The effect of a change in license price on input usage will, in general, differ, even for inputs of the same quality. However, the analysis reveals that the qualitative results under monopoly and competition are the same. Both pollutant content and input usage decline with an increase in the price of a license.

The results for the case in which the firm faces an upward sloping supply curve for inputs closely parallel the monopoly case. The problem is the same as the competitive case except e is now a function of s and E. The firm tries to:

$$\underset{s,E}{\text{Maximize}}\ pf(E) - e(s,E)E - wsE. \tag{5.22}$$

The price of inputs is assumed to increase as demand increases

($e_2 > 0$). In addition, it will be assumed that changing the pollutant content will have no influence on the relationship between input demand and price ($e_{12} = 0$). This latter assumption essentially allows the solution to the first-order conditions to proceed in two stages. First, the pollutant content is determined, and then the level of inputs is chosen.

First order conditions for an interior maximum to (5.22) are given by:

$$- e_1E - wE = 0 \tag{5.23}$$

$$pf' - e - Ee_2 - ws = 0 \tag{5.24}$$

Equation (5.23) determines the optimal pollutant content, s. If E is set to the optimal competitive level, this gives rise to the following inequality:

$$pf' - Ee_2 < e + ws \tag{5.25}$$

The problem is to adjust E so as to bring (5.24) into equality so that the first order conditions are satisfied. Assuming that the costs of inputs eE, is a convex function in E (for any given s) is sufficient to insure that the optimal level of inputs will be less than the competitive case.

The problem of assessing the behavior of a firm which can exert control over the market price for emissions licenses is similar to the previous case, but somewhat more complex. The general problem is the same as in the competitive case except now license price is presumed to be negatively related to emissions so that $w=w(sE)$ and $w' > 0$. The conventional approach to such problems is to disregard output effects and solve the following cost minimization.

$$\underset{s}{\text{Minimize}}\ C(s) = e(s)\bar{E} + w(s\bar{E})s\bar{E}, \tag{5.26}$$

where the level of inputs is fixed at $\bar{E}$. There are two basic reasons for ignoring output effects: first, because the comparative statics results are ambiguous when these effects are included, and secondly, because output effects may not be very important in the short-run.

Dividing (5.26) by $\bar{E}$ and solving the equivalent minimization problem yields the following first order condition:

$$e'(s) + w + s\bar{E}w' = 0 \tag{5.27}$$

Equation (5.27) balances the marginal cost of buying more licenses, $w + sEw'$, with the cost of buying lower sulfur fuel. If the cost function, $C(s)$, is convex so that $C''(s) \geq 0$, then the optimal pollutant content chosen will be less than in the competitive case, provided the output produced is the same. The argument parallels the case of monopoly and will not be repeated here. Instead, we turn to an alternative formulation of the market power problem which explicitly considers the role of other agents.

5.3 Market Power: A More General Approach

The subsequent analysis considers the case where one agent exercises market power, while all other agents assume they cannot affect the price of a license or the quantity of licenses issued, L, (i.e., a Stackelberg ''leader and follower'' model). The aggregate reported demand curve for all agents excluding i is denoted by $Q^{-i}(w)$; it is assumed that Q^{-i} is twice continuously differentiable and downward sloping, i.e., $Q^{-i\prime} < 0$. Let Q(w) represent the aggregation of i's true demand for licenses, $Q_i(w)$, with $Q^{-i}(w)$, which i takes as given. The quantity of licenses supplied by the ''center'' is given by C(w) which is presumed to be twice continuously differentiable and strictly increasing, i.e., $C' > 0$. The curves are illustrated in Figure 1.

Agent i is aware that he may choose any point on the center's supply curve above the price of w_o, which represents the equilibrium price if i submits no demand. A price of w_1, assumed to be greater than w_o, would result if i submitted his true demand.

To derive i's best approach to the problem, first note that his effective supply, denoted as S(w) is given by:

$$S(w) = C(w) - Q^{-i}(w) \qquad \text{for } w \geq w_o \qquad (5.28)$$

Because $C' > 0$ and $Q^{-i\prime} < 0$, $S'(w) > 0$, which means that agent i's effective supply curve of licenses to i is strictly increasing.

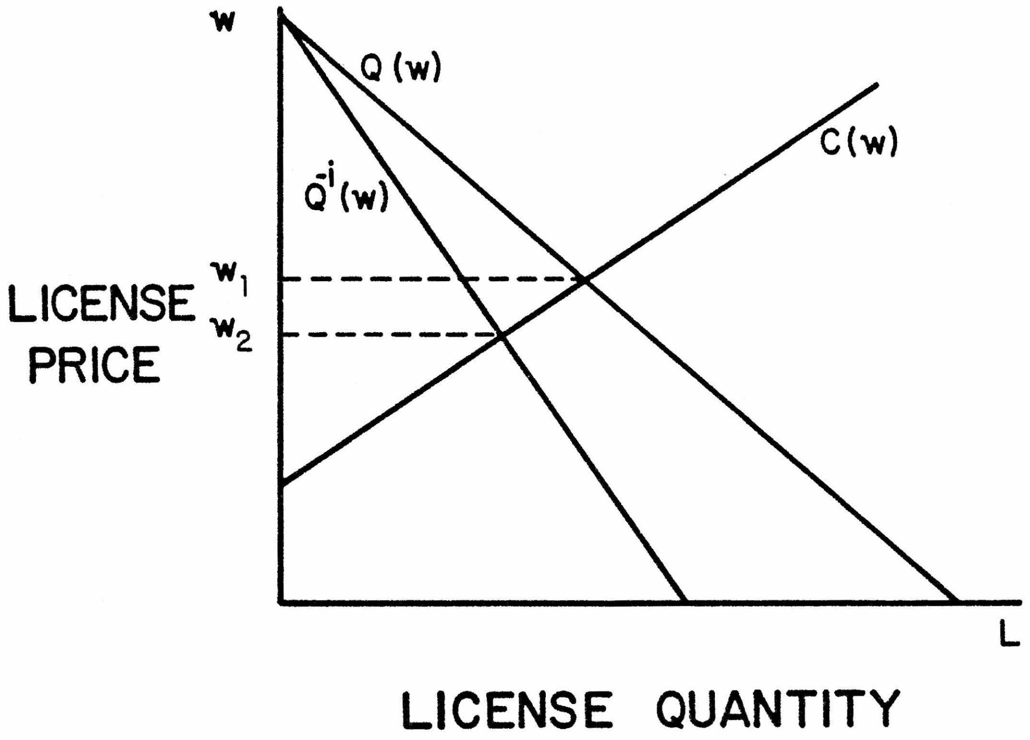

Figure 5.1. The General Supply and Demand Problem.

Define the inverse of S(w) as s(L). Since S is upward sloping, so is its inverse, i.e.,

$$w = s(L) \qquad s' > 0 \tag{5.29}$$

Finally, define agent i's inverse demand function as $d_i(L)$; this function is presumed to be strictly decreasing, i.e., $d_i' < 0$. Agent i's problem is depicted in Figure 2.

L_1 represents the quantity of licenses agent i receives if he reveals his true demand and the market clears at w_1.

The question which i must address is whether it is in his interest to misstate his true demand, and if so, in which direction. To answer this question i's interest is defined as follows:

$$\text{Agent i's net gain} = \int_0^L d_i(q)dq - s(L)L \tag{5.30}$$

Equation (5.3) says that the gain i derives by purchasing L licenses is given by the difference between the area under his inverse demand curve between 0 and L and the costs of purchasing L licenses. With this measure of welfare, it is apparent that agent i will never demand more than L_1 licenses since he not only has to pay more for all inframarginal units, but he also loses on the marginal units as well. The only other possibility is that agent i demands fewer than L_1 licenses. Suppose that he chooses a level of licenses equal to L_2 as illustrated in Figure 2. To compare this outcome to the situation in which i recieves L_1 licenses, it is convenient to sort out his gains

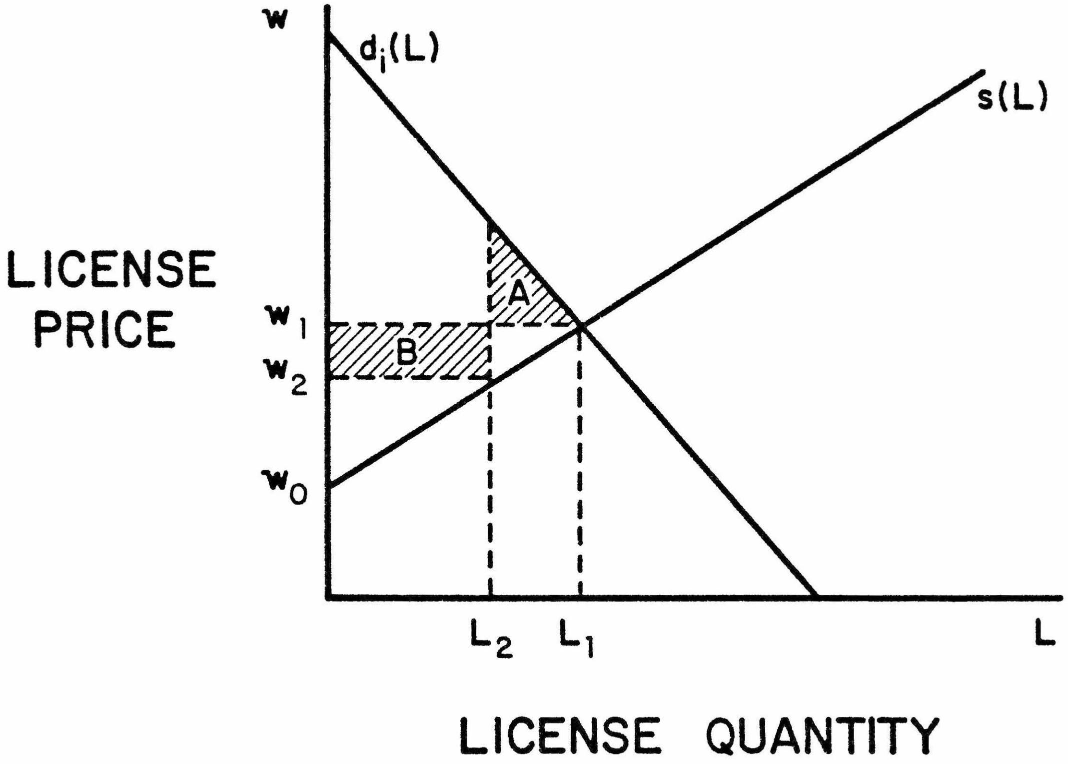

Figure 5.2. Agent i's Problem.

and losses in a systematic manner. The gains to i which result from being charged a price w_2 instead of w_1 are noted by the shaded area B. His losses due to the fact he purchases $(L_1 - L_2)$ fewer licenses are represented by area A. If (B − A) is positive, then we may conclude that i's welfare associated with (L_2, w_2) exceeds that associated with revealing his truthful demand, (L_1, w_1). The problem of showing that it is always in i's interest to overabate is equivalent to showing that there exists an $L \varepsilon (0, L_1)$ for which (B − A) is positive.

Maximizing (5.30) with respect to L and assuming an interior maximum exists yields the following first order condition:

$$d_i(L)(s(L) + Ls'(L)) = 0 \qquad (5.31)$$

Noting $s'(L) > 0$ implies:

$$d_i(L_1) < s(L_1) + L_1 s'(L_1) \qquad (5.32)$$

To bring (5.32) back into equality requires that the L selected be less than L_1. This shows that it is in agent i's interest to underrepresent his demand for pollution emission provided that there is no subsequent trading of licenses, agent i knows the demand curve of all other agents and the supply curve of the center, and the second order conditions are satisfied. It is of some importance to know what conditions on the demand or supply curve would guarantee that the stationary point is a local maximum. The second order sufficiency conditions require:

$$d_i'(L) - 2s'(L) - Ls''(L) < 0 \qquad (5.33)$$

From (5.33), we see that it is sufficient to presume that the rate of change of the slope of the effective supply curve, $s''(L)$, is nonnegative.[8]

The problem analyzed above parallels the case of pure monoposony very closely. The only difference is that agent i is not the only buyer, and hence, must consider how the demand of others will affect his supply. The qualitative results which emerge in the two problems are the same, namely that output and price are both below the level they would have reached in the presence of competition.

The extreme cases were not considered in the analysis. If agent i's effective supply curve does not vary with price, then he will demand L_1 licenses since, by assumption, he cannot exert any downward pressure on the price of a license. In this case i would perceive the license market in the same light as an emissions tax. Another case not considered is when the center fixes the supply of licenses so that $C'(w) = 0$. In this case, the result still obtains that the firms with market power will overabate.

The principal result is called into question, however, when any ''real world'' considerations are brought to bear on the problem. For example, an incomplete knowledge of others' demand curves and the center's supply curve would mean that agent i would have to guess at the equilibrium price in his absence. Of course, knowing the equilibrium price is not enough. Agent i cannot construct his effective supply curve without knowing the center's supply and others' demands over a fairly wide range. The addition of secondary markets further complicates the issue. The clearing price expected in the secondary markets is likely to vary across agents and will affect each individual's behavior in the initial auction. Without explicit modeling of such problems, it is a little premature to conclude that market power will result in overabatement.

5.4 Conclusions

The analysis focused on the derived demand for tradable licenses. In the general case it was found that introducing inputs of different quality did not change the basic result that the derived demand was downward sloping. This holds both for the monopolist and the competitive firm. A comparison of three cases of market power in a more restricted setting revealed that in all three cases, firms would tend to overabate in comparison to the competitive firm. A more general analysis of the case when a firm can dominate the license market indicated that the assumptions required to obtain the overabatement result may be too restrictive. This is one area which merits further thought if marketable permits are to become a reality.

Footnotes for Chapter 5

[*] The work reported here was supported in part by the California Air Resources Board. I wish to thank Roger Noll and James Quirk for providing helpful comments. All views and conclusions expressed herein are my responsibility.

1. For example, see Baumol and Oates (1975), p. 35ff.

2. For examples, see Samuelson (1974), pp. 76-78, Russell (1964) and Winch (1965).

3. This assumption can be explained in terms of the desulfurization of fuel oil. Suppose the effect of desulfurization is to remove a constant fraction $(1 - \frac{1}{n})$ of total potential emissions, sE. Total expenditure on abatement is constant by assumption. The problem is to consider how $\frac{\partial X}{\partial s}$ changes as inputs increase. Consider a discrete change in inputs from E to $(E + \Delta E)$. Before the change, $\frac{\Delta X}{\Delta s} = \frac{1}{n}\Delta sE$. After the change $\frac{\Delta X}{\Delta s} = \frac{1}{n}\Delta s(E + \Delta E)$. In the limit, it is apparent that $X_{23} \geq 0$.

4. The proof is straightforward. Suppose the firm wishes to use two different inputs with respective costs $e(s_1)$ and $e(s_2)$. Let λ equal the fraction spent on the first type and $(1-\lambda)$ be the fraction spent on the second. Then, the average cost of inputs would be $[\lambda e(s_1) + (1-\lambda)e(s_2)] > e(\lambda s_1 + (1-\lambda)s_2)$. Thus, using inputs of the same quality with the equivalent pollutant content would be cheaper. If the firm wishes to purchase n different quality inputs, where n is arbitrary, the same line of reasoning holds.

   The proof assumes, of course, that any convex combination of pollutant contents are available for values of λ on the unit interval. In the case of sulfur in fuel oil, this is a reasonable approximation.

5. On this point, see Chapter 3 of ''Implementing Tradable Emission Licenses: Sulfur Oxides in the Los Angeles Air Shed,'' written by William Rogerson.

6. For the problem to make sense, R, s, and E must be nonnegative. These constraints are assumed to be ineffective.

7. For example, if $\lim_{s \to 0} e'(s) = +\infty$ and $\lim_{s \to +\infty} e'(s) = 0$ (i.e., e is a ''neoclassical'' function), then for any $w > 0$, (5.17) has a unique positive solution in s.

8. In the economics literature the abatement cost function for all firms is typically presumed to be twice differentiable and strictly convex. Accepting this assumption would mean that a sufficient condition for a global maximum on $(0,L_1)$ would be that $C''(w) \geq 0$. For a specific example, see Ackerman, p. 279.

CHAPTER 6

MARKET POWER AND TRANSFERABLE PROPERTY RIGHTS

6.1 Introduction

The idea of using the market to ration a desired quantity of inputs among producers and consumers is by no means novel. Working examples include markets for taxi medallions and liquor licenses. Suggested applications for this construct abound in the economics literature, especially in the fields of air and water pollution.[1] Why has the idea of setting up a market in transferable property rights received so much attention? One key reason, and the reason which motivates this paper, is that such markets have the potential to achieve a given objective in a cost-effective manner. Whether this potential is realized depends, among other things, on the design of the market and the extent to which individual firms can exert a significant influence on the market.

The purpose of this paper will be to analyze the problem of "market power" in a rigorous framework. Section 2 develops the basic model for the case in which one firm can influence the market. Section 3 extends the analysis to the case of two firms with market power. In Section 4, the results of the theoretical analysis are compared with the conventional wisdom and directions for future research are discussed.

6.2 The Basic Model

A critical assumption underlying the competitive model is that firms act as if they were price takers. In the model developed below, it will be assumed that all firms except one are price takers. The basic question to be answered is how (and whether) the equilibrium price and quantities will vary as a function of the initial distribution of permits among firms.

Consider the case of m firms with firm 1 designated as the firm with market power. A total of L permits are distributed to the firms, with the ith firm receiving Q_i^o permits. Firms are allowed to trade permits in a market which lasts for one period. The number of permits which the ith firm has after trading will be denoted by Q_i. All firms except the market power firm are assumed to have downward sloping inverse demand functions for permits of the form $P_i(Q_i)$ over the region $[0,L]$. P_i represents firm i's willingness to pay. All trades in the market are constrained to take place at a single equilibrium price, P. For concreteness, we shall consider the case of a classical pollution externality. All price-taking firms attempt to minimize the sum of abatement costs and permit costs. For the case of pollution, the assumption of downward sloping demand curves is equivalent to the assumption that marginal abatement costs are increasing. Let $C_i(Q_i)$ define the abatement cost function for firm i, where $C_i' < 0$ and $C_i'' > 0$ for $i = 2,\ldots,m$. Price takers solve the following optimization problem:

$$\underset{Q_i}{\text{Minimize}} \quad C_i(Q_i) + P(Q_i - Q_i^o) \qquad (i=2,\ldots,m). \tag{6.1}$$

The first order condition for an interior solution is:

$$C_i'(Q_i) + P = 0. \tag{6.2}$$

This merely says that price takers will adjust the quantity used, Q_i, until the marginal abatement cost equals the equilibrium price, P.[2] Equation (6.2) implicitly defines a demand function $Q_i(P)$ which is downward sloping on [0,L] for i=2,...,m. Furthermore, note that the number of permits the ith price-taking firm will use is <u>independent</u> of its initial allocation of permits.

The analysis of the firm with market power is less straightforward. Begin by defining an abatement cost function $C_1(Q_1)$ where $C_1' < 0$ and $C_1'' > 0$. This says that the firm with market power faces increasing marginal abatement costs. Firm 1 has the power to pick a price which will minimize its expenditure on abatement costs and permits subject to the constraint that the market clears. Formally, the problem is to:

$$\underset{P}{\text{Minimize}} \quad C_1(Q_1) + P(Q_1 - Q_1^o) \tag{6.3}$$

$$\text{Subject to: } Q_1 = L - \sum_{i=2}^{m} Q_i(P).$$

Direct substitution of the constraint into the objective function gives the following equivalent problem:

$$\underset{P}{\text{Minimize}} \quad C_1(L - \sum_{i=2}^{m} Q_i(P)) + P(L - \sum_{i=2}^{m} Q_i(P) - Q_1^0). \qquad (6.4)$$

The first-order condition for an interior minimum is given by the following equation:

$$(-C_1' - P) \sum_{i=2}^{m} Q_i' + (L - \sum_{i=2}^{m} Q_i(P) - Q_1^o) = 0. \qquad (6.5)$$

Equation (6.5) reveals that the only case in which the marginal cost of abatement, $-C_1'$, will equal the equilibrium price is when firm 1's distribution of permits just equals the amount it chooses to use. In effect, this says that the only way to achieve a cost-effective solution, where marginal abatement costs are equal for all firms, is to pick an initial distribution of permits for firm 1 which coincides with the cost-minimizing solution.

This gives rise to the following result:

Proposition 1: Suppose there is one firm with market power. If it does not receive an amount of permits equal to the number which it elects to use, then the total expenditure on abatement will exceed the cost-minimizing solution.

The key point to be gleaned from the analysis is that the distribution of permits matters, with regard not only to equity considerations but also to cost. Traditional models of such markets view problems of permit distribution as being strictly an equity issue.[3] With the introduction of market power, it was shown that the distribution of permits may also impinge on efficiency considerations.

The next logical question to explore is how the market equilibrium will vary as a function of firm 1's initial distribution of permits. Doing the necessary comparative statics yields:

$$\left.\frac{\partial P}{\partial Q_1^o}\right|_{L=\text{constant}} = \frac{1}{(-C_1' - P)\sum_{i=2}^{m} Q_i'' + \sum_{i=2}^{m} Q_i^2 C_i'' - 2\sum_{i=2}^{m} Q_i'} . \tag{6.6}$$

The expression for the denominator is the second order condition for the cost minimization and will be positive if the second-order sufficiency condition for a minimum obtains. For example, in the case of linear demand curves (i.e., $Q_i'' = 0$), the expression will be positive. Thus, for the case when a regular interior minimum exists, a transfer of permits from any of the price takers to the firm with market power will result in an increase in the equilibrium price. An immediate corollary to this result is that the number of permits that the firm with market power uses will increase as its initial allocation of permits is increased. Formally, the problem is to show $(\partial Q_1/\partial Q_1^o) > 0$. By the chain rule,

$$\frac{\partial Q_1}{\partial Q_1^o} = \left(\frac{\partial Q_1}{\partial P}\right)\left(\frac{\partial P}{\partial Q_1^o}\right). \tag{6.7}$$

It suffices to show $(\partial Q_1/\partial P)$ is positive. By direct substitution for Q_i,

$$\frac{\partial Q_1}{\partial P} = \frac{\partial(L - \sum_{i=2}^{m} Q_i(P))}{\partial P} . \tag{6.8}$$

The expression on the right-hand side of (6.8) equals $-\sum_{i=2}^{m} Q_i'(P)$, which is positive, because demand curves are presumed to be negatively sloped.

One question which arises in this model is whether there is any systematic relationship between the distribution of permits to the firm with market power and the degree of inefficiency. If inefficiency is measured by the extent to which abatement costs exceed the minimum required to reach a stated target, then it is possible to show the following result:

> Proposition 2: Let Q_1^* denote the distribution of permits for the case when permit distribution equals permit use for the firm with market power. Then inefficiency increases both as Q_1^o increases above Q_1^* and as Q_1^o decreases below Q_1^*.

The proposition is verified by determining how total cost, TC, varies as a function of Q_1^o.

The efficient solution is derived from the following minimization:

$$\underset{Q_1,\ldots,Q_m}{\text{Minimize}} \quad TC = C_1(Q_1) + \sum_{i=2}^{m} C_i(Q_i) \tag{6.9}$$

$$\text{Subject to:} \quad Q_1 + \sum_{i=2}^{m} Q_i = L.$$

First order conditions imply:

$$-C_i'(Q_i) = P_i(Q_i) = P. \qquad (i=2,\ldots,m) \tag{6.10}$$

Differentiation with respect to total cost yields:

$$\frac{\partial TC}{\partial Q_1^o} = C_1' \frac{\partial Q_1}{\partial Q_1^o} + \sum_{i=2}^{m} C_i' \frac{\partial Q_i}{\partial Q_1^o}$$

$$= - C_1' \sum_{i=2}^{m} \frac{\partial Q_i}{\partial Q_1^o} + \sum_{i=2}^{m} C_i' \frac{\partial Q_i}{\partial Q_1^o}$$

$$= \sum_{i=2}^{m} (C_i' - C_1') \frac{\partial Q_i}{\partial Q_1^o} \quad . \tag{6.11}$$

The above expression can be simplified by noting:

$$\frac{\partial Q_i}{\partial Q_1^o} = - \frac{\partial P}{\partial Q_1^o} / C_i'' \, . \tag{6.12}$$

Equation (6.12) is obtained by differentiating (6.10) with respect to Q_1^o. Substituting equation (6.12) into (6.11) yields:

$$\frac{\partial TC}{\partial Q_1^o} = - \frac{\partial P}{\partial Q_1^o} \sum_{i=2}^{m} \frac{(C_i' - C_1')}{C_i''}$$

$$= - \frac{\partial P}{\partial Q_1^o} \sum_{i=2}^{m} \frac{(-P - C_1'')}{C_i''} = \frac{\partial P}{\partial Q_1^o} (P + C_1') \sum_{i=2}^{m} \frac{1}{C_i''} \tag{6.13}$$

Equation (6.13) implies:

$$\frac{\partial TC}{\partial Q_1^o} > (<)\ 0 \quad \text{as } (P + C_1') > (<)\ 0. \tag{6.14}$$

Combining (6.14) with equation (6.5) yields the result that total cost achieves a minimum at Q_1^* and will increase as the permit distribution deviates from Q_1^* in either direction.

In addition to determining how inefficiency varies with the initial distribution of permits, it is also of some interest to know when the level of inefficiency can be related to observable variables such as the quantity of permits which are exchanged. Placing restrictions on the demand for permits by price takers yields the following result:

> Proposition 3: The degree of inefficiency will increase as the amount the firm with market power decides to buy or sell increases, provided the demand for permits by price takers is linear.

To see this result, first note that any price not equal to the competitive equilibrium price will cause efficiency losses. Second, note that as the deviation between the competitive equilibrium and the observed price increases, the degree of inefficiency increases. This result follows immediately from the assumption that all firms face increasing marginal abatement costs. It remains to be shown that trading increases as the size of the deviation between the actual price and the competitive equilibrium price increases.

The size of the deviation between the actual price and the competitive price is governed by the initial distribution of permits to the firm with market power, Q_1^o. The amount of net buying, $(Q_1 - Q_1^o)$, is also governed by Q_1^o. At the competitive equilibrium, the firm with market power does not trade -- $Q_1 = Q_1^o$. If it can be shown that an increase in Q_1^o leads to an increase in the price of a permit and a decrease in net buying, then Proposition 2 will have been verified. Formally, the problem is to show $\partial P/\partial Q_1^o > 0$ and $\partial(Q_1 - Q_1^o)/\partial Q_1^o < 0$.

The assumption of linear demand implies $Q_i'' = 0$ for all price takers. Inspection of equation (6.6) reveals $\partial P/\partial Q_1^o > 0$ for this case. The relationship of net buying by the firm with market power to its initial distribution is derived below:

$$\frac{\partial(Q_1 - Q_1^o)}{\partial Q_1^o} = \frac{\partial Q_1}{\partial Q_1^o} - 1$$

$$= \frac{- \sum_{i=2}^{m} Q_i'}{\sum_{i=2}^{m} Q_i^2 C_i'' - 2 \sum_{i=2}^{m} Q_i'} - 1 < 0. \qquad (6.15)$$

The second equality is based on substitution of equations (6.6) through (6.8). Based on the signs of Q_i' and C_i'', it follows that $\partial Q_1/\partial Q_1^o < 1$ for this case, which immediately yields the desired result.[4]

Other analysts have considered the possibility of market power, but generally restrict themselves to a special case. For example, Ackerman et al. (1974) consider the problem for a specific hypothetical case, but do not deal explicitly with the effect of permit distribution.[5] DeLucia (1974) considers a numerical example in a simulation of a water rights market in which the rights are auctioned. The firm with market power plays the role of a monopsonist, restricting its demand for permits in an effort to keep the permit price low. The situation analyzed by DeLucia corresponds to the case when the firm with market power receives no permits initially.

While concern that a firm or group of firms can influence such a market has been expressed, relatively little thought appears to have been given to exactly what is meant by market power and how to devise institutions which would yield a desirable set of outcomes. The simple model developed above indicates that market power is related not only to concepts of stock, but also to those of flow. The analysis reveals two essential points. Just because a firm is a large polluter, this does not necessarily mean it can exercise market power in the permit market. Secondly, if a firm does have market power in the permit market, its effect on price (assuming there is one firm with market power) varies with its excess demand for permits. That is to say, once the potential for market power has been ascertained, it is a flow -- net excess demand of the firm with market power -- which determines the equilibrium.

The importance of the flow has immediate implications for market design. In particular, with full knowledge of demand functions, a central authority could effectively pick the quantity of permits it wanted the market power firm to use through a suitable initial allocation. The limits to the discretion of the authority would be dictated by two extreme cases: pure monopsony in which all permits are distributed to the price takers, and pure monopoly in which all permits are distributed to the firm with market power.

With only one firm having market power, the analysis is fairly straightforward. The existence of two or more such firms with power complicates matters. The next section extends the basic result to deal with the case of duopoly.

6.3 Duopoly and Market Power

Notation will be carried over from the basic model developed in the previous section. In this case, two firms will be allowed to exercise market power. Let $C_2(Q_2)$ be firm 2′s cost function, assumed to have the same qualitative property as firm 1′s ($C_2' < 0$ and $C_2'' > 0$). Define $\bar{Q}_2$ as the quantity of permits firm 1 thinks firm 2 will use and $\bar{Q}_1$ as the quantity of permits firm 2 thinks firm 1 will use. Firm 1 and firm 2 face the following minimization problems:

Firm 1′s Problem:

$$\underset{Q_1}{\text{Minimize}}\ C_1(Q_1) + P(Q_1 - Q_1^o) \tag{6.16}$$

$$\text{Subject to: } L = Q_1 + \bar{Q}_2 + \sum_{i=3}^{m} Q_i(P).$$

Firm 2′s Problem:

$$\underset{Q_2}{\text{Minimize}}\ C_2(Q_2) + P(Q_2 - Q_2^o) \tag{6.17}$$

$$\text{Subject to: } L = \bar{Q}_1 + Q_2 + \sum_{i=3}^{m} Q_i(P).$$

Because the two problems are the same conceptually, attention will be focused on the solution to firm 1′s problem. The constraint in (6.16), which says that all licenses be used, implicitly defines the permit price, P, as a function of $(Q_1 + \bar{Q}_2)$. Formally, define $P = P(Q_1, \bar{Q}_2)$;

note that $(\partial P/\partial Q_1) = (\partial P/\partial \overline{Q}_2) > 0$ over $[0,L]$. Substitution into (6.16) yields an equivalent problem for firm 1:

$$\underset{Q_1}{\text{Minimize}}\ C_1(Q_1) + P(Q_1,\overline{Q}_2)(Q_1 - Q_1^o). \tag{6.18}$$

The first order condition for an interior solution is:

$$C_1' + P + (Q_1 - Q_1^o)\frac{\partial P}{\partial Q_1} = 0. \tag{6.19}$$

This implicitly defines a reaction function $Q_1 = f(\overline{Q}_2)$. Note that, as in the simple market power case, the marginal cost of abatement will equal the equilibrium price if and only if the initial distribution to firm 1 is the optimum choice for Q_1 at an equilibrium. Similarly, the first order condition for firm 2 is:

$$C_2' + P + (Q_2 - Q_2^o)\frac{\partial P}{\partial Q_2} = 0. \tag{6.20}$$

This implicitly defines a reaction function $Q_2 = g(\overline{Q}_1)$.

The concept of an equilibrium needs to be defined. The concept used here is a Cournot-Nash equilibrium. Firm 1 minimizes its costs for any given level of Q_2 and firm 2 minimizes its costs for any given level of Q_1. A pair (Q_1^*,Q_2^*) is defined to be an equilibrium if $Q_1^* = f(Q_2^*)$ and $Q_2^* = g(Q_1^*)$.

Equations (6.19) and (6.20) reveal that marginal abatement costs will be equal across firms if and only if $Q_1 = Q_1^o$ and $Q_2 = Q_2^o$. Thus, a similar efficiency result arises for the duopoly case -- namely:

Proposition 4: Suppose there are two firms with market power. If both firms do not receive an amount of permits equal to the number each elects to use, then the total expenditure on abatement will exceed the cost-minimizing solution.

The critical question to be examined is how the equilibrium or equilibria will vary as the distribution of permits varies.[6] There are two approaches to this problem. One is to consider each reaction function separately and examine its attributes. A second is to consider comparative statics around an equilibrium when both first order conditions are satisfied. These will be considered in turn. Totally differentiating equation (6.19) yields the following expressions:

$$\frac{\partial Q_1}{\partial Q_2} = \frac{-(\frac{\partial P}{\partial Q_2} + (Q_1 - Q_1^o)\frac{\partial^2 P}{\partial Q_1 \partial Q_2})}{C_1'' + 2\frac{\partial P}{\partial Q_1} + (Q_1 - Q_1^o)\frac{\partial^2 P}{\partial Q_1^2}} \tag{6.21}$$

$$\frac{\partial Q_1}{\partial Q_1^o} = \frac{\frac{\partial P}{\partial Q_1}}{C_1'' + 2\frac{\partial P}{\partial Q_1} + (Q_1 - Q_1^o)\frac{\partial^2 P}{\partial Q_1^2}} \tag{6.22}$$

Equation (6.21) gives the slope of firm 1's reaction function. Equation (6.22) considers how the reaction function will shift with a change in the initial distribution of permits. For the general case, the signs of $\partial Q_1/\partial Q_2$ and $\partial Q_1/\partial Q_1^o$ are ambiguous. The analysis is the same, mutatis mutandis, for firm 2's reaction function. Rather than impose restrictions on the individual reaction functions, it will be more useful to examine the equilibrium comparative statics. The cases examined below will reveal how the individual reaction functions can be analyzed if the objective is to define conditions under which they will exhibit certain properties.

Total differentiation of the first order conditions for the two market power firms yields:

$$\begin{bmatrix} C_1'' + 2\frac{\partial P}{\partial Q_1} + (Q_1 - Q_1^o)\frac{\partial^2 P}{\partial Q_1^2} & \frac{\partial P}{\partial Q_2} + (Q_1 - Q_1^o)\frac{\partial^2 P}{\partial Q_1 \partial Q_2} \\ \frac{\partial P}{\partial Q_1} + (Q_2 - Q_2^o)\frac{\partial^2 P}{\partial Q_1 \partial Q_2} & C_2'' + 2\frac{\partial P}{\partial Q_2} + (Q_2 - Q_2^o)\frac{\partial^2 P}{\partial Q_2^2} \end{bmatrix} \begin{bmatrix} dQ_1 \\ dQ_2 \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial Q_1}\, dQ_1^o \\ \frac{\partial P}{\partial Q_2}\, dQ_2^o \end{bmatrix} \tag{6.23}$$

The effect of a change in permits on usage cannot be predicted without further assumptions. Let D denote the (2x2) matrix on the left hand side of (6.23). The determinant of D will be positive if $(\partial^2 P/\partial Q_1^2)$ $\geq (\leq)$ 0 and $[(Q_1 - Q_1^o) + (Q_2 - Q_2^o)]$ $\geq (\leq)$ 0. If $|D| > 0$ and the second order sufficiency conditions for a minimum to (6.19) and (6.20) are satisfied this implies D^{-1} will have the following sign pattern:

$$\text{sgn } D^{-1} = \begin{bmatrix} (+) & ? \\ ? & (+) \end{bmatrix} \tag{6.24}$$

This, in turn implies that $(\partial Q_1/\partial Q_1^o)$ and $(\partial Q_2/\partial Q_2^o)$ are positive. This is the analogue of the result obtained earlier with the basic model. The firms with market power will increase their use of permits as permits are redistributed from the price takers to the market power firms.

Further insight can be gained into the duopoly problem by examining three cases. First, consider the case when the aggregate demand by price takers is linear. This implies $P(Q_1,Q_2) = A + B(Q_1+Q_2)$ where both A and B are positive. Substitution into (6.19) gives the following expression:

$$\begin{bmatrix} C_1'' + 2B & B \\ B & C_2'' + 2B \end{bmatrix} \begin{bmatrix} dQ_1 \\ dQ_2 \end{bmatrix} = \begin{bmatrix} BdQ_1^o \\ BdQ_2^o \end{bmatrix} \tag{6.25}$$

For this case, it is readily seen that $|D| > 0$. The comparative statics results for firm 1 are computed below:

$$\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\Bigg|_{Q_2^o = \text{constant}} = \frac{1}{|D|}(C_2'' + 2B)B > 0 \tag{6.26}$$

$$\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\Bigg|_{dQ_2^o = -dQ_1^o} = \frac{1}{|D|}[(C_2'' + 2B)B - B^2] > 0 \tag{6.27}$$

$$\left(\frac{\partial Q_1}{\partial Q_2^o}\right)\Bigg|_{Q_1^o = \text{constant}} = \frac{1}{|D|}(-B^2) < 0. \tag{6.28}$$

Equation (6.26) states that a transfer of permits from the price takers to firm 1 will result in an increase in the number of permits firm 1 holds after trading. Transfering a permit from firm 2 to firm 1 has the same qualitative effect; however, as can be seen from a comparison of equations (6.26) and (6.27), the effect is smaller in absolute value. Equation (6.28) says that transfer of a permit from the price takers to firm 2 will result in a decrease in the number of permits firm 1 uses. The same results hold, mutatis mutandis, for firm 2.

This example also permits analysis of how the equilibrium price will vary under different distribution schemes. For example, suppose firm 1 is given all L permits. Now, consider the following two distribution patterns:

1. Firm 1's initial distribution decreases and firm 2's distribution increases commensurately;
2. Firm 1's initial distribution decreases by, say, x and firm 2's increases by ax ($0 < a \leq 1$), with the remainder being distributed to the price taker.

The qualitative implications for the two cases are illustrated in Figure 6.1. All that can be said is that the price trajectory for the second case will be below that of the first case because the total permits used by firms 1 and 2 will be less in case 2 for any given value of Q_1^o not equal to L. The actual shape of the curves in the figure would be dictated by the derivatives of the marginal cost functions for the two firms.

If the price-taking firms are initially vested with all the permits, then the question arises as to how price will vary as permits are transferred to firm 1 and/or firm 2. For example, if x permits are transferred from the price takers to the market power firms, is the equilibrium price of permits affected by the division of permits between the two firms? The answer is that the price will be affected, but without further assumptions on the third derivative of the cost functions, the relationship is indeterminate. All that can be said is

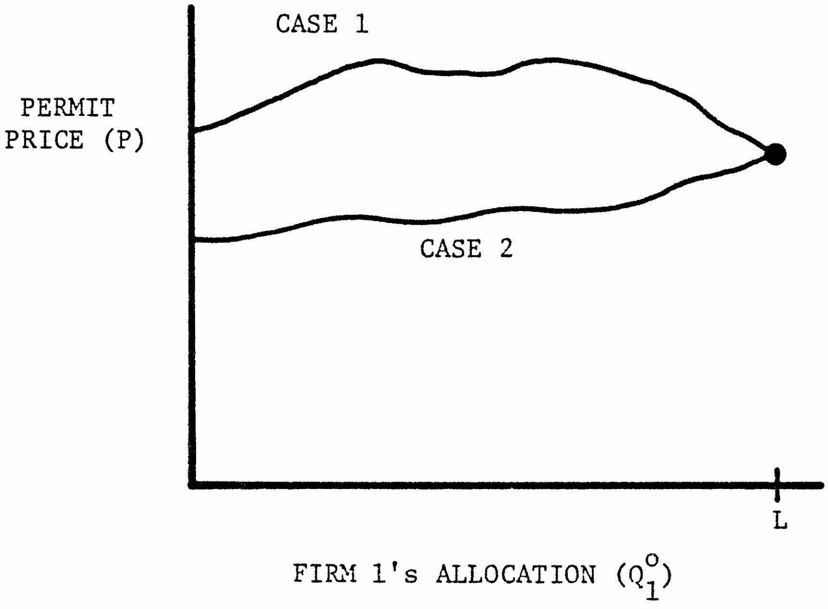

Figure 6.1

Comparing Distribution Patterns

that in distributing permits from the price takers to the two firms with market power, the equilibrium price will increase because the two firms will elect to use more permits.

Two other cases can be analyzed which yield similar qualitative results to those obtained in the linear case. The first of these cases corresponds to the case where firms 1 and 2 are not buyers, and the aggregate demand by price takers is concave to the origin. The second of these cases considers the opposite situation when firms 1 and 2 are not sellers, and the aggregate demand curve by price takers is convex to the origin. The results are summarized in Table 6.1. They are verified in the appendix to this chapter.

The signs of the partial derivatives are given in the six cells of the table. They agree with equations (6.26) through (6.28). In addition, it can be shown for these two cases that the effect of transferring a permit from firm 2 to firm 1 is smaller in absolute value than the effect of transferring a permit from the price takers to firm 1.

The purpose of this analysis of a Cournot duopoly model is to see how the results of the basic model might change with the introduction of more than one firm with market power. While the analysis tends to support the view that permit use will increase with the initial allocation to the duopolists, how the equilibrium price will vary with different patterns of distribution is generally ambiguous without making some fairly restrictive assumptions. The only unambiguous

TABLE 6.1

Summary of Two Special Cases of Duopoly

COMPARATIVE STATICS	MARKET POWER FIRMS NOT BUYERS AND $\frac{\partial^2 P}{\partial Q_1^2} < 0$	MARKET POWER FIRMS NOT SELLERS AND $\frac{\partial^2 P}{\partial Q_1^2} > 0$
$\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\Big\vert_{Q_2^o=\text{constant}}$	(+)	(+)
$\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\Big\vert_{dQ_2^o = -dQ_1^o}$	(+)	(+)
$\left(\frac{\partial Q_1}{\partial Q_2^o}\right)\Big\vert_{Q_1^o=\text{constant}}$	(-)	(-)

results arise when the aggregate demand by price takers is linear or both firms with market power are on the same side of the market.

The question might arise as to what happens in the case of two firms with market power on different sides of the market. In this situation, models of bilateral monopoly may be more appropriate than duopoly models. For example, suppose the two firms attempt to jointly minimize the product of their objective functions as suggested by the Nash bargaining problem.[7] Formally, this yields:

$$\underset{Q_1,Q_2}{\text{Minimize}} \quad (C_1(Q_1)+P(Q_1,Q_2)(Q_1-Q_1^o))(C_2(Q_2)+P(Q_1,Q_2)(Q_2-Q_2^o)) \tag{6.29}$$

First order conditions for an interior minimum are:

$$C_2C_1' + C_1'P(Q_2 - Q_2^o) + C_2P + 2P\,\frac{\partial P}{\partial Q_1}\,(Q_1 - Q_1^o)(Q_2 - Q_2^o) + P^2(Q_2 - Q_2^o) = 0 \tag{6.30}$$

$$C_1C_2' + C_2'P(Q_1 - Q_1^o) + C_1P + 2P\,\frac{\partial P}{\partial Q_2}\,(Q_1 - Q_1^o)(Q_2 - Q_2^o) + P^2(Q_1 - Q_1^o) = 0 \tag{6.31}$$

The first order conditions to this problem reveal that if $Q_1 = Q_1^o$ and $Q_2 = Q_2^o$, then the solution to this problem will be efficient; however, for the case when the two firms are on different sides of the market, the comparative statics remain ambiguous because of the rather complex nature of the first order conditions. This leaves the question of bilateral monopoly unresolved, which is perhaps as it should be given the inherent difficulties in arriving at credible behavioral assumptions for this case.

6.4 Conclusions

The formal analysis in the previous two sections indicates the range of potential outcomes that might arise when firms can exert rather specific types of influence in markets which ration a fixed supply of intermediate or final goods. There are clearly other strategies which large firms might pursue, particularly when the market is just getting under way. For example, it is quite likely that the total number of permits issued and the pattern of distribution could be affected by the behavior of such firms. In the case of pollution rights, some firms might refuse to play the game if they do not care for the new set of rules. Such actions are difficult to model explicitly, which is why the focus here has been on the potential for gain within a well-defined set of rules. Even within this setting, further research is warranted.

One avenue for further research would be to extend the basic model to consider other forms of duopoly and oligopoly behavior. Another potentially fruitful area of investigation is to test the theory of the basic model in a small-group experimental setting and determine when, and under what types of institutions, it is supported. Finally, the magnitude of the result could be examined using data from a proposed market in property rights.

The key result obtained here, that it is the net excess demand that ultimately determines the extent of a firm's market power, does not appear to be widely recognized. One reason is that many people feel that market power in such markets will not be a problem. For example, Teitenberg (1980), in surveying the literature on air rights markets, expresses the view that "the anti-competitive effects of a TDP [transferable discharge permit] system are not likely to be very important in general."[8] For several applications such as the one considered by DeLucia (1974) and the one considered by Hahn (1981), the assumption that the market will approximate the competitive solution would appear to depend critically on how the institutions are designed. Because there is a very real possibility that several markets in transferable property rights could be subject to different kinds of systematic manipulation, there is a need to further explore the ramifications of such problems in theory and applications.

APPENDIX TO CHAPTER 6

This appendix derives the results contained in Table 6.1. Assuming D has an inverse, equation (6.15) can be rewritten as:

$$\begin{bmatrix} dQ_1 \\ \\ dQ_2 \end{bmatrix} = \frac{1}{|D|}\begin{bmatrix} C_2'' + 2\frac{\partial P}{\partial Q_2} + (Q_2-Q_2^o)\frac{\partial^2 P}{\partial Q_2^2} & -(\frac{\partial P}{\partial Q_1} + (Q_2-Q_2^o)\frac{\partial^2 P}{\partial Q_1 \partial Q_2}) \\ \\ -(\frac{\partial P}{\partial Q_2} + (Q_1-Q_1^o)\frac{\partial^2 P}{\partial Q_2 \partial Q_1}) & C_1'' + 2\frac{\partial P}{\partial Q_1} + (Q_1-Q_1^o)\frac{\partial^2 P}{\partial Q_1^2} \end{bmatrix}\begin{bmatrix} \frac{\partial P}{\partial Q_1}\, dQ_1^o \\ \\ \frac{\partial P}{\partial Q_2}\, dQ_2^o \end{bmatrix} \tag{6.32}$$

Note that $\frac{\partial P}{\partial Q_1} = \frac{\partial P}{\partial Q_2}$ and $\frac{\partial^2 P}{\partial Q_1^2} = \frac{\partial^2 P}{\partial Q_1 \partial Q_2} = \frac{\partial^2 P}{\partial Q_2 \partial Q_1} = \frac{\partial^2 P}{\partial Q_2^2}$. This is because the equilibrium price is a function of the sum of the permits used by the two firms with market power.

There are two cases to consider:

Case 1: $\frac{\partial^2 P}{\partial Q_1^2} < 0 \;;\; Q_1 \leq Q_1^o \;;\; Q_2 \leq Q_2^o$.

Equation (6.32) yields the following results:

$$\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\Bigg|_{Q_2^o = \text{constant}} = \frac{\frac{\partial P}{\partial Q_1}\left(C_2'' + 2\frac{\partial P}{\partial Q_2} + (Q_2-Q_2^o)\frac{\partial^2 P}{\partial Q_2^2}\right)}{|D|} \quad > 0 \tag{6.33}$$

$$\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\Bigg|_{dQ_2^o = -dQ_1^o} = \frac{\frac{\partial P}{\partial Q_1}\left(C_2'' + \frac{\partial P}{\partial Q_2}\right)}{|D|} \quad > 0 \tag{6.34}$$

$$\left(\frac{\partial Q_1}{\partial Q_2^o}\right)\Bigg|_{Q_1^o = \text{constant}} = \frac{-\frac{\partial P}{\partial Q_2}\left(\frac{\partial P}{\partial Q_1} + (Q_2-Q_2^o)\frac{\partial^2 P}{\partial Q_1 \partial Q_2}\right)}{|D|} \quad < 0 \tag{6.35}$$

A comparison of equations (6.34) and (6.35) reveals that:

$$\left.\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\right|_{Q_2^o = \text{constant}} > \left.\left(\frac{\partial Q_1}{\partial Q_1^o}\right)\right|_{dQ_2^o = -dQ_1^o} \qquad (6.36)$$

The assumptions for the second case are just the opposite of the first:

Case 2: $\frac{\partial^2 P}{\partial Q_1^2} > 0$; $Q_1 \geq Q_1^o$; $Q_2 \geq Q_2^o$.

The reader can verify that equations (6.33) through (6.36) hold for Case 2.[9]

Footnotes for Chapter 6

* I would like to thank Jim Quirk, Ed Green, Roger Noll and Jennifer Reinganum for providing useful input to this effort. Any remaining errors are solely the responsibility of the author.

1. Teitenberg (1980) provides a comprehensive survey of the application of marketable permits to the control of stationary source air pollution. A general list of references to potential applications in air and water pollution is provided in the study by Anderson et al. (1979).

2. The assumption of increasing marginal abatement costs implies that the firm attains a regular minimum in solving the problem (6.1).

3. The analysis by Montgomery (1972) is one such example. In this analysis, firms are assumed to be price takers. For the case of one pollutant, one market and a linear relationship between source emissions and environmental quality, Montgomery finds that the distribution of permits will have no effect on achieving the target in a cost-effective manner.

4. Proposition 2 will also hold if $(Q_1 - Q_1^o) \geq (\leq)\ 0$ and $Q_i'' \geq (\leq)\ 0$.

5. See Ackerman et al. (1974), p. 279.

6. An equilibrium will exist if the reaction functions are continuous on [0,L]; however, the possibility of multiple equilibria cannot be ruled out.

7. See Luce and Raiffa (1957), pp. 124-128.

8. Teitenberg (1980), p. 414.

9. The comparative statics results derived here obtain globally because all principal minors of the matrix D are positive on [0,L] x [0,L]. A proof of this result is given in Gale and Nikaido (1965).

CHAPTER 7

ON RECONCILING CONFLICTING GOALS: APPLICATIONS OF MULTIOBJECTIVE PROGRAMMING*

7.1 Introduction

Decision makers typically have several objectives in mind when choosing among different policy alternatives. While these objectives are sometimes associated with target values, it is frequently the case that the objectives are viewed as choice variables which are to be jointly maximized in some manner. There are two basic approaches to such problems. Treating the objectives as targets permits the decision maker to minimize costs over a feasible region. If, instead, the objectives are viewed as control variables, then an alternative approach is to maximize some function of the objectives subject to a set of feasibility constraints which usually includes a limitation on expenditures. This latter approach falls under the general heading of multiobjective programming.

While the two approaches to the problem can yield the same solution, this need not be true, especially for cases in which the tactics available for meeting the proposed objectives have an adverse impact on some subset of those objectives. An example would be the problem of increasing automobile fuel efficiency while decreasing emissions. Several control tactics aimed at reducing emissions can have an adverse impact on fuel economy. This problem is complicated further by the introduction of safety considerations. Lave (1980) analyzes the explicit tradeoffs that result from existing legislation in this area, and provides a cogent analysis of the difficulties inherent in reconciling the objectives of improved safety, better fuel economy and reduced emissions. His conclusion that secondary impacts of automobile regulation may be quite important indicates that this may be a potentially fruitful application for multiobjective programming techniques. The particular problem raised by Lave will be illustrated in greater detail in the conclusion, after the approaches for meeting objectives are analyzed more formally.

The objective of this paper is to compare the two approaches for achieving policy objectives. For illustrative purposes, the problem of meeting environmental objectives is examined in detail. The relative merits of the two approaches for decision making are addressed in the conclusions.

7.2 Application to Environmental Problems

The traditional approach to the problem of finding cost-effective solutions to environmental problems has been to specify an emissions target and then compute the minimum cost associated with meeting the objective. The choice of an emissions target is usually predicated on some hypothesized relationship between emissions and environmental quality. When the relationship between emissions and air quality is linear, as is assumed in the models developed by Kohn (1971) and Atkinson and Lewis (1974), then the general problem of meeting an environmental quality objective can be solved directly through the use of linear programming. A non-linear relationship between emissions and air quality may mean that the only part of the problem amenable to solution by linear programming is the relationship between control costs and emissions. Such is the case, for example, in the analysis of the Los Angeles smog problem undertaken by Trijonis (1974).

This analysis specifically focuses on the relationship between costs and emissions. As an alternative to minimizing costs subject to achieving a prescribed reduction in emissions, an approach which treats emissions as the choice variable and cost as a parameter is examined. The analysis reveals two essential points: first, that the alternative approach yields a straightforward method for generating isocost curves and second, that an optimal solution to the traditional cost-minimizing formulation need not coincide with a point on an isocost curve.

7.3 The Traditional Approach

The problem of selecting a set of control tactics which minimize the cost of meeting a given emissions target is set forth in the following linear program which was applied by Trijonis (1974):

The Cost-Minimizing Approach (CM1)

$$\min_{x} \; cx \tag{7.1}$$

$$\text{Subject to:} \quad Bx = E \tag{7.1a}$$

$$Ax \leq S \tag{7.1b}$$

$$Dx \leq L \tag{7.1c}$$

$$x \geq 0 \tag{7.1d}$$

where x is the (r x 1) vector of activity levels for the r control methods,

c is a (1 x r) vector of control costs,

B is an (n x r) matrix whose element b_{ij} represents the reduction of pollutant i resulting from one unit of control activity j,

E is the (n x 1) vector indicating the required reduction in emissions,

A is an (s x r) matrix whose element a_{ij} represents the number of units of source i controlled by one unit of control activity j,

S is the (s x 1) vector of source magnitudes,

D is a (p x r) matrix whose element d_{ij} represents the amount of limited supply input i used by one unit of control activity j,

L is the (p x 1) vector specifying the magnitudes of the limited supply inputs.

The CM1 approach minimizes control costs subject to a set of constraints. Equation (7.1a) states that the vector of emissions be reduced by E units. The second set of constraints (7.1b) places limitations on the level at which different sources can be controlled. The third set of constraints (7.1c) places limits on the use of certain fixed inputs in control activities, while (7.1d) states that all control activities be set at some nonnegative level.

7.4 The Multiobjective Formulation

An alternative approach to identifying cost-effective control strategies is to consider the problem of maximizing the reduction in emissions subject to capacity constraints, supply constraints and a budget constraint. Formally the problem can be stated as follows:

The Multiobjective Approach (MO)

$$\underset{x}{\text{Maximize}}\ Bx \tag{7.2}$$

$$\text{Subject to:}\quad cx \leq \overline{C} \tag{7.2a}$$

$$Ax \leq S \tag{7.2b}$$

$$Dx \leq L \tag{7.2c}$$

$$x \geq 0 \tag{7.2d}$$

where $\overline{C}$ is a scalar which fixes the annual expenditure on pollution control at some prescribed value.

The constraints in the CM1 formulation are similar to those contained in the multiobjective formulation; however, there are two important differences. A budget constraint (7.2a) is added and the constraint on emissions reductions is dropped.[1]

As stated, the MO problem needs some further clarification, since the concept of maximizing a vector may not be clear. The vector x is defined to be an efficient solution to (7.2) if and only if the following two conditions hold:

1. x must be feasible, i.e., it must satisfy the constraint set, and
2. there does not exist a feasible solution, x′ such that $Bx' \geq Bx$ and $Bx' \neq Bx$.

While the solution of the MO formulation may appear, at first glance, to present a difficult problem, the formulation can be simplified considerably by applying the following lemma which allows the problem to be converted to a linear program.

Lemma 1: The vector x* is an efficient solution of the MO problem if and only if there is a (1 x n) vector q > 0 for which x* optimizes the following linear program:[2,3]

The Corresponding Multiobjective Linear Program (MOLP)

$$\underset{x}{\text{Maximize}} \quad qBx \tag{7.2′}$$

Subject to: (7.2a)-(7.2d).

Lemma 1 makes it possible to generate isocost curves (or at least very good approximations thereto) by carefully selecting several values for q and solving the MOLP problem.

7.5 The Relationship Between the Two Approaches

Comparing the CM1 linear programming formulation with the MOLP, one might think that the two are equivalent in some sense, since the former minimizes costs subject to a given level of emissions reductions while the latter takes expenditures as given and maximizes a linear combination of emissions reductions. Surprisingly, the relationship between the two approaches is not obvious. The following two examples will serve to highlight the differences between the two problems. In Example 1, we consider a case where the solution to (7.1) does not exist, but a solution to (7.2′) exists for any given level of expenditures.

> Example 1: Suppose there is one control strategy x_1 with $c_1 = \$1$, $b_{11} = 1$ and $b_{21} = 1$, with the constraint set only requiring that x_1 be nonnegative. A graph of this strategy is shown in Figure 7.1.

Let the objective for reducing emissions be given by point B with coordinates (4,2). The 45^o line represents the control strategy x_1. Note that as you move down the line towards the origin, the level of costs decrease in a linear fashion. For example, at (4,4), $x_1 = 4$ and the cost (c_1x_1) also equals 4. Reducing both types of emissions by one unit each so that $(E_1,E_2) = (1,1)$ implies $x_1 = 1$ and the cost is \$1.00. Using the original CM1 formulation, the prescribed goal of (4,2) is infeasible. This suggests an extension of the CM1 formulation which would permit reductions greater than or equal to the stated targets.[4] Formally the problem can be stated as follows:

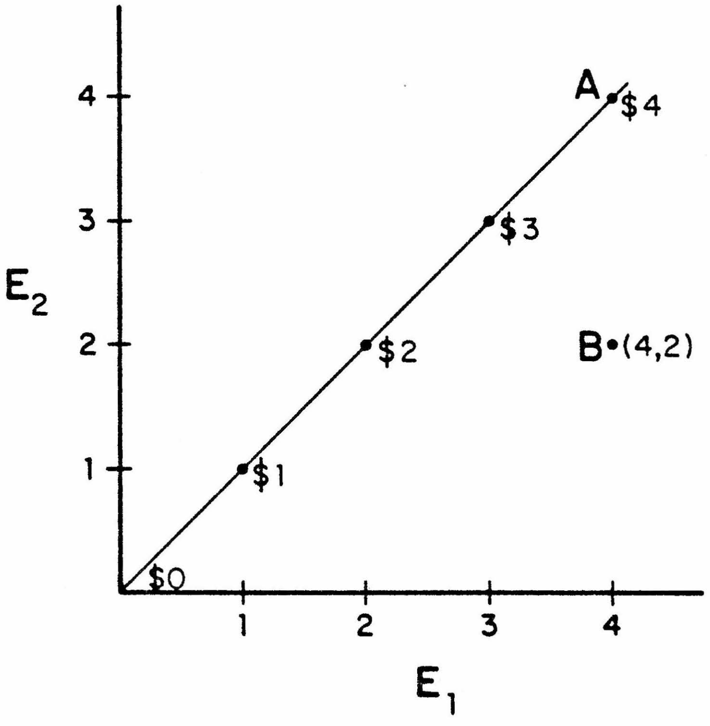

FIGURE 7.1

Illustration of Feasible Emissions Reductions
and Associated Costs

A Revised Cost Minimizing Approach (CM2)

$$\underset{x}{\text{Minimize}}\ cx \tag{7.3}$$

$$\text{Subject to:}\quad Bx \geq E \tag{7.3a}$$

$$Ax \leq S \tag{7.3b}$$

$$Dx \leq L \tag{7.3c}$$

$$x \geq 0 \tag{7.3d}$$

Viewing Example 1 in terms of the CM2 approach, the solution set consists of point A in Figure 7.1. If $\overline{C} = 4$, then point A would also be optimal in terms of the MO formulation.

Example 1 illustrates a case where no feasible solution exists to the original CM1 problem and the solution to the CM2 and MO problems are identical. Next, we consider a problem which has an infinite number of solutions for the CM2 program, only one of which is optimal for the multiobjective program.

Example 2: Suppose there are two control strategies x_1 and x_2 with the following data:

$c_1 = 3 \quad b_{11} = 1 \quad b_{12} = 3$

$c_2 = 1 \quad b_{21} = 3 \quad b_{22} = 1$

$E_1 = 12 \quad E_2 = 12$

The problem is to reduce each type of emissions by at least 12 units, subject to the constraint that nonnegative levels of x_1 and x_2 be chosen. Since there is only one feasible solution to the original CM1 formulation, it must be optimal. The solution is $(x_1,x_2) = (3,3)$, which results in a cost C = \$12.00. Setting $C = \overline{C}$, and considering the multiobjective program, it is easily seen that sole use of the control activity x_2 will result in a higher value for E_2, leaving E_1 unchanged, thus showing the solution to the CM1 problem is not optimal for the multiobjective problem. The problem is illustrated in Figure 7.2.

The feasible region in Figure 7.2 corresponds to the revised cost minimizing problem. For the original cost minimizing problem, the feasible region reduces to the point K with $(x_1, x_2) = (3,3)$. There is an infinite number of solutions to the revised cost minimizing problem characterized by segment $\overline{JK}$; however, of these solutions, only point J is optimal for the multiobjective problem when $\overline{C} = 12$.

The conclusion to be drawn from this analysis is that the CM1 formulation can generate points which are inefficient in the sense that lower emissions may be attainable at the same cost. The CM2 program poses similar problems; however, because the CM2 approach covers a larger feasible region, we are assured that if the solution set to the CM2 formulation is not empty, it contains at least one point which will be an optimal solution to the multiobjective program.[5]

While a solution to the original or revised cost minimizing problem need not be optimal for the multiobjective program, it is

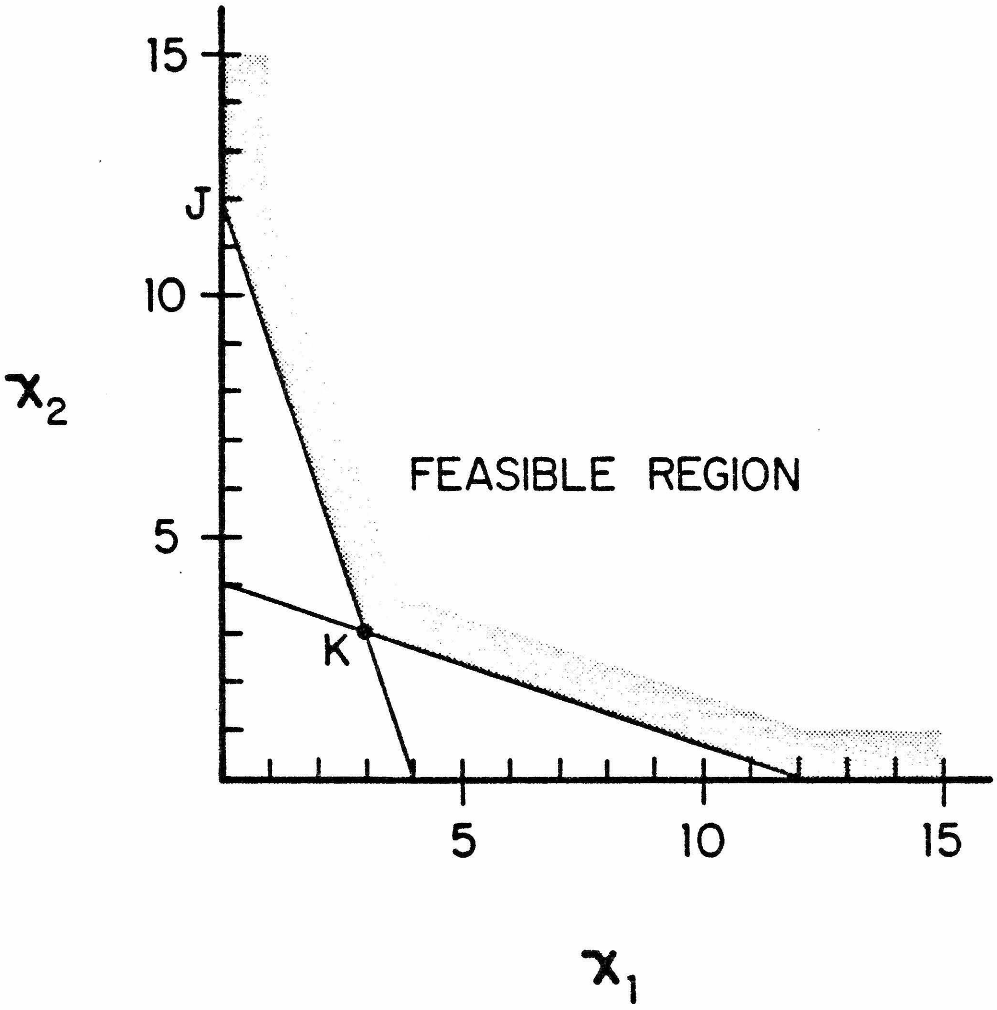

FIGURE 7.2

A Graphical Comparison of Approaches for Finding Efficient Environmental Controls possible to develop a sufficient condition under which a solution for the cost minimizing formulations will also solve the multiobjective program.

In order to economize on notation, the source and supply constraints are merged. Without loss of generality, let

$$Fx \geq P \tag{7.4}$$

represent constraints (7.2b) and (7.2c) or (7.3b) and (7.3c).

Because the theory of duality plays a central role in subsequent results, it will be useful to consider the dual formulations of the revised cost minimizing and the multiobjective linear programming problems. The dual to the CM2 problem is:

$$\underset{y^1, y^2}{\text{Maximize}} \quad y^1 E + y^2 P \tag{7.5}$$

$$\text{Subject to:} \quad y \begin{bmatrix} B \\ F \end{bmatrix} \leq c \tag{7.5a}$$

$$y \geq 0. \tag{7.5b}$$

The solution to the problem is given by the dual row vector $y = [y^1, y^2]$.

The dual to the MOLP problem is constructed in a similar manner, yielding the following expression:

$$\underset{z^1, z^2}{\text{Minimize}}\ z^1\overline{C} - z^2P \tag{7.6}$$

$$\text{Subject to:}\quad z\begin{bmatrix}-c\\ F\end{bmatrix} \leq -\,qB \tag{7.6a}$$

$$z \geq 0 \tag{7.6b}$$

In this case, the solution to the problem is given by the dual vector $z = [z^1, z^2]$.

Two theorems will be developed. The first provides a basis for checking whether a solution to the cost minimizing problem is necessarily a solution to the multiobjective formulation. The second theorem turns the question around, identifying when a solution to the multiobjective problem will necessarily be optimal for the cost minimizing approach.

Theorem 1: Suppose CM2 has an optimal solution x^* with an associated dual solution y^*. Consider the MO problem with $\overline{C} = cx^*$. Then x^* is <u>efficient</u> for the MO problem if $y^{1*} > 0$.

Proof: Suppose that x^* is not efficient. Then there exists an x such that $Bx \geq Bx^*$ and $Bx \neq Bx^*$. This implies:

$$\begin{aligned} cx &\geq [y^{1*}, y^{2*}] \begin{bmatrix} B \\ F \end{bmatrix} x \\ &= y^{1*}Bx + y^{2*}Fx \\ &> y^{1*}Bx^* + y^{2*}Fx \\ &\geq y^{1*}E + y^{2*}P \\ &= cx^*. \end{aligned}$$

The first inequality is obtained from (7.5a) by postmultiplying by x. This expression is simplified in the next step. The strict inequality is based on the supposition. Expressions (7.3a) and (7.4) are used in the subsequent inequality. Finally, the equilibrium theorem of linear programming is applied to obtain the desired result.

Two comments are in order. First, note that the proof also works for the CM1 formulation (i.e., with $Bx = E$). Second, note that the result has a straightforward intepretation when the dual variables are viewed as shadow prices. In short, the theorem says that as long as it costs more to get a reduction in all types of emissions (at the optimum) the cost minimizing solution will be efficient.

The next problem is to identify when an efficient solution will be cost minimizing. This problem is resolved in the following theorem:

Theorem 2: Let x* be an efficient solution to the MO problem and set Bx* = E. Then, x* is optimal for the CM2 problem if $z^{1*} > 0$.

Proof: By contradiction: suppose there exists an x such that cx < cx* which also satisfies (7.3a)-(7.3d). Then,

$$\begin{aligned} -qBx &\geq [z^{1*}, z^{2*}] \begin{bmatrix} -c \\ F \end{bmatrix} x \\ &= -z^{1*}c\ x + z^{2*}Fx \\ &> -z^{1*}cx^* + z^{2*}Fx \\ &\geq -z^{1*}\overline{C} + z^{2*}P \\ &= -qBx^*. \end{aligned}$$

The first inequality is obtained from (7.6a) by postmultiplying by x. Simplifying the expression and applying the supposition yields the strict inequality. This is followed by a substitution using expressions (7.2a) and (7.4). Applying the equilibrium theorem of linear programming yields the desired result.

This result holds for the original cost minimizing problem as well. It shows that an efficient solution to the MO problem will be optimal for CM1 and CM2 provided that, at the margin, an extra dollar will increase qBx. This in turn, implies that at at least one type of emissions can be further reduced at the optimum. Note also that $z^{1*} > 0$ implies that the budget constraint is effective at the optimum, i.e., $cx^* = \overline{C}$.

It is not obvious that the above results will always obtain. In particular, there are several pollution control activities which lead to decreases in one type of emissions at the expense of increasing other types. A case in point were the automobile exhaust emission controls for reactive hydrocarbons and carbon monoxide introduced in California in 1966 and in the remainder of the country in 1968. Unfortunately, the technological modifications adopted by American car manufacturers produced higher engine combustion temperatures which in turn dramatically increased the emissions of another pollutant—nitric oxide. While this problem has been corrected, it highlights the need to understand the likely impact of any new control technique when formulating the mathematical programming problem.

Fortunately, it is a simple matter to check whether, in fact, the above relationships do obtain by generating the appropriate dual variables. Of course, since the conditions are sufficient and not necessary, if they are not satisfied, one may have to resort to a direct computational method by substituting the proposed solution into the problem and checking to see if it works. This can be done in moving from the MO to the CM formulation, but I am not aware of any simple way to move in the reverse direction if the assumptions of Theorem 1 do not hold.

7.6 Conclusions

The analysis in the foregoing paper focuses on the problem of achieving a cost-effective solution to the problem of reducing emissions. The formal comparison of the multiobjective and cost-minimizing approaches has served to illustrate that the traditional cost minimizing solution generated by a linear program will not necessarily be efficient. That is to say, it may be possible to achieve greater emissions reductions than specified in the cost-minimizing formulation at the same cost. The multiobjective approach solves this problem by directly minimizing emissions subject to a budget constraint.

One potential application where the multiobjective approach may yield different solutions than the cost minimizing approach can be illustrated for the case of automobile regulation, which was introduced in Section 7.1. Figure 7.3 provides a stylized representation of the tradeoffs among air quality, fuel economy and safety. There are two control activities, x_1 and x_2. The first activity corresponds to an inspection and maintenance program aimed at improving the safety and reducing emissions of vehicles currently in use. The second activity corresponds to installing improved bumpers on new and/or used cars. The effects of these two activities on the objectives can be seen by noting that the line segments in Figure 7.3 represent constant levels of safety, air quality and fuel economy for the fleet as a whole. The direction of improvement is given by the vector perpendicular to each of the segments. Thus, for example, safety can be improved by increasing x_1 and/or x_2.

Suppose this problem were cast in terms of a cost minimization where the objective is to find the minimum cost of achieving or

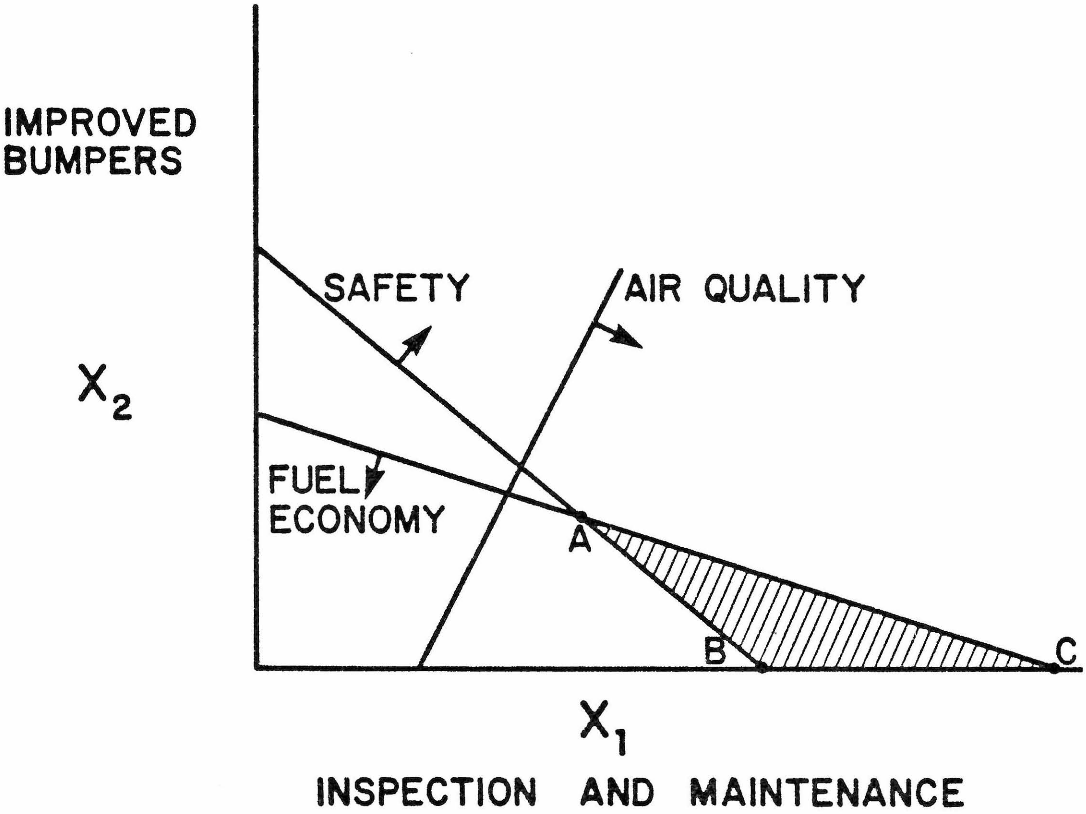

FIGURE 7.3

Illustration of the Tradeoffs among
Safety, Fuel Economy and Air Quality

exceeding the constant levels of safety, fuel economy and air quality shown in the diagram. The feasible region would then correspond to triangle ABC. Now, suppose further that the isocost curves were parallel to segment $\overline{AB}$, which means that the set of cost minimizing solutions corresponds to the segment. It should be clear that any point on the segment other than B is dominated in the sense that better fuel economy and improved air quality can be achieved at the same cost without sacrificing safety considerations. Unfortunately, there is no guarantee that the program will yield point B as the solution. This potential pitfall can be overcome simply by reformulating the problem as a multiobjective program.

Given the potential for differences between the solution sets to the two approaches, the question naturally arises as to which approach would be more useful to the policy maker. The answer is that it depends. If the policy maker has already decided on target levels for the objectives, then the cost minimizing approach is tailor made for this problem. If, on the other hand, the policy maker is less certain of the overall objectives, then the multiobjective programming approach would probably be more appropriate since it is designed to identify the range of options available at a given level of expenditures.

Footnotes for Chapter 7

* This paper has benefited from discussions with Joel Franklin, Gregory McRae, and James Quirk. The views expressed herein, including any remaining errors, are solely the responsibility of the author.

1. This formulation does not explicitly preclude the possibility of a new level of emissions with some negative components. This situation can be handled by identifying a baseline level of emissions, say E^o, and then constraining E^o-E to be nonnegative. Introduction of this constraint does not substantively affect the analysis and is rarely, if ever, binding in actual applications.

2. An asterisk will be used to denote an optimal solution to a given program. $q > 0$ implies each element of q is positive.

3. A proof of this lemma for the case of equality constraints is presented in Franklin (1980). The extension to inequality constraints follows immediately upon introducing slack variables.

4. This is the basic approach taken by Kohn (1971).

5. The proof is straightforward. Let x^* be a solution to the CM2 formulation, and define $\bar{C}=cx^*$. This implies x^* is feasible for the MO problem. If x^* is optimal for the MO problem we are done. Suppose x^* is not optimal. Then there exists a solution x' such that $Bx' \geq Bx^*$ and $Bx' \neq Bx^*$. But, by construction x' would also be a solution to CM2.

CHAPTER 8

AREAS FOR FUTURE RESEARCH

The analysis presented in the preceding chapters points to several avenues for further research. Rather than review all the earlier suggestions, this section will present a few of the more important research areas that can be expected to provide further insights into the immediate problem. These areas are selected because they should be of general interest to researchers and environmental policy makers.

The first area which needs to be explored further is the potential for exploiting the relationship between emissions and air quality. One question which might be examined is whether there are significant savings in overall abatement costs to defining permits seasonally. A second important topic for further study is to consider the possibility that some areas will experience abnormally high pollutant levels under an incentive-based system. As a first step, the idea of a "hot-spot" needs to be defined more carefully. Then, if the problem is expected to arise, thought must be given to building safeguards into the system. For example, it might make sense to place restrictions on where and when large fuel burners with more than one plant are permitted to burn certain types of fuel. A third topic in this area, about which little has been written, is the effect of uncertainty in linking emissions to air quality. A reasonable starting point here would be to estimate how the expected savings from fine-tuning the definition of a permit are related to meteorological conditions.

A second area of research relates to the problem of demonstrating, in some sense, that the system under study dominates the status quo. This is frequently difficult to do using "hard" data because several of the potential gains and losses are difficult to quantify. The traditional approach has been to estimate the static efficiency gains on the basis of available abatement cost data. Applying this approach in Chapter 4 gave rise to potential savings in abatement costs on the order of 10 million dollars annually. This issue is currently being explored along slightly different lines. We are attempting to introduce the possibility of refinery process changes into the model and estimate how this will affect abatement costs and the equilibrium price and distribution of permits.

A final area of interest that is a key concern in implementing a market is the issue of institutional design. Major design criteria for a tradable permits market would include: equity in the initial distribution of permits; sufficient early transactions to produce a price for permits that is close to the long-run equilibrium; and attainment of an equilibrium price and distribution of permits that is close enough to the competitive case to assure attainment of air quality objectives at close to minimum costs.

Two methods for initially distributing the permits appear to have the strongest equity claims. One would base permit distribution on emissions as they existed prior to the attempt to control them, with perhaps some additional provision for firms that have entered the airshed or expanded capacity since that time. The other would base the distribution of permits on the projected equilibrium distribution that would result from a competitive market in permits. Any other method that is based upon historical emissions performance raises the objection that people who were early to comply with regulations would be punished for cooperating. Any method that is not based on emissions raises the objection that it is arbitrary, and, in any case, is more vulnerable to becoming bogged down in a contest between competing claims for redistributing wealth that have nothing to do with air pollution policy.

Basing the initial distribution on the projected competitive equilibrium has a serious defect in terms of efficiency of the permits market. To the extent that the initial distribution succeeded in finding the competitive equilibrium, it would also succeed in avoiding the necessity for any transactions among present sources. Only in the case of new sources or expansions of existing facilities would a demand for trades arise. Thus, a relatively speedy attainment of a stable, competitive price for permits would not be likely under this mechanism. Indeed, much the same problems as confront the current banking and offset policies could be expected: a slow development of the market owing to the difficulties of finding trading partners and negotiating a price.

The other seemingly most attractive alternative on equity grounds is to base initial allocations on pre-regulatory emissions. Unfortunately, this raises two problems: one of data availability, and a second related to the possibility that the largest firm might exert market power.

The dilemma in organizing the permits market under study here is that there is a seeming inconsistency in getting the single largest source of emissions to engage in transactions so as to get the market started quickly on a course that provides stable price signals to firms making abatement and location decisions, and in preventing the market from becoming monopolized. While we have not resolved the problem, several approaches are currently being investigated.

One approach is to have different methods for the largest emissions source and other sources in terms of the initial distribution of permits, allocating to the potential monopsonist something like the competitive equilibrium estimate while using the historical basis for allocating permits to others. This would probably produce a situation in which the largest source was not a participant in the early stages of the market; however the remaining sources would have an incentive to engage in trades, and would be more likely to produce a competitive outcome.

A second approach is to make a distinction between the most important sources as a group and the remaining sources, allocating permits initially so that all of the former are equally interested in acquiring more permits, while all of the latter want to sell. Thus, each of the half-dozen most important sources of emissions could be allocated a number of emissions permits that falls short of the competitive equilibrium by the same absolute amount, while the other firms could be given permits that exceeded the estimated equilibrium by some proportion that is consistent with the first allocation. In such a situation, the largest source of emissions would hold the largest number of permits, but would not account for an especially large fraction of the transactions on its side of the market.

Another approach is to allocate only some fraction of the permits on the basis of historical or projected emissions, and let the state auction the rest. All firms could, say, be allocated 80 or 90 percent of their projected equilibrium emissions, and the remaining permits would be sold. This has the objection that, like an emissions tax, the state ends up collecting revenues, so that the costs of the system exceed abatement costs; however if the fraction of permits sold were small enough, the efficiency gains to industry in rationalizing abatement control strategies would offset the revenues lost to the auction. By placing all firms on the same side of the market (buyers), and by the appropriate choice of an auction institution, the largest firm, even with a market share of forty percent, is not likely to be able to be effective in exercising market power.

The value of investigating these organizational issues goes beyond our particular concern about market power in the context of the case study that we are currently undertaking. While potential monopolization of permits may not be a common problem, all potential applications of tradable permits involve the selection of an institution for allocating the permits in a manner that satisfies equity constraints and still promotes an efficient market. Whereas we expect that the nature of the problems to be overcome in facing a trade-off between these objectives will differ from case to case, we anticipate that conflicts between efficiency and the political perception of equity will be common. The substantial differences in regulatory standards among industries and between new and old sources is a manifestation of the same kinds of conflicts in the current system. Thus, specification of the properties of different methods for distributing permits and organizing trades is an important general issue for making feasible the adoption of tradable permits.

CHAPTER 9

CONCLUSIONS

The principal findings of this thesis fall into three general areas: the first related to empirical findings; the second related to market power and efficiency; and the third related to the current understanding of market mechanisms and their applicability to pollution problems.

The key empirical results from the market simulation are discussed in Chapter 4. The effects of changes in the natural gas supply were quantified. Not surprisingly, it was found that this strategy for reducing sulfur oxides emissions would be quite attractive, even at natural gas prices significantly above those observed in intrastate markets. A second result was that current standards may place excessive controls on residual fuel burners when compared with the competitive equilibrium solution. A third result, and perhaps the most interesting, that emerged from the market simulation data was the estimate of the gains from fine-tuning. The payoff to having several different markets corresponding to distinct receptor points was found to be relatively small in the short run.

In addition to the empirical results, there is one theoretical result which deserves mention. The result emerges from the analysis of market power. Simply stated, it says that the distribution of permits is not only a question of equity, but can also affect whether the competitive equilibrium is achieved. Hopefully, this result will be examined in an experimental setting in the near future.

A final point which needs to be addressed relates to the applicability of market mechanisms to environmental problems. Given a physical and chemical understanding of the environment, this project has attempted to integrate legal, political and economic concerns in an effort to consider the feasibility of different alternatives for controlling pollution problems. Once these alternatives are evaluated, the next logical step is to develop a pilot experiment aimed at bringing some of the more attractive policy alternatives to fruition. It is in this area that the greatest challenges are likely to arise.

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