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PRICES VS. QUANTITIES:
ENVIRONMENTAL REGULATION AND IMPERFECT COMPETITION

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ABSTRACT

In a market subject to environmental regulation, a firm's strategic behavior affects the production and emissions decisions of all firms. If firms are regulated by a Pigouvian tax, changing emissions will not affect the marginal cost of polluting. However, under a tradable permits system, the polluters' decisions affect the permit price. This paper shows that this feedback effect may increase a strategic firm's output. Relative to a tax, tradable permits improve welfare in a market with imperfect competition. As an application, I model strategic and competitive behavior of wholesalers in the Pennsylvania, New Jersey, and Maryland electricity market. Simulations suggest that exercising market power decreased local pollution by approximately nine percent, and therefore, substantially reduced the price of the region's pollution permits. Furthermore, I find that had regulators opted to use a tax instead of permits, the deadweight loss from imperfect competition would have been approximately seven percent greater.

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1 Introduction

This paper examines the welfare implications of strategic behavior in a market subject to environmental regulation. Market-based policies–including some tradable permit systems–appear to be implemented without the consideration of whether or not the polluting markets are competitive. This omission is important because, if firms have market power, they alter the output and emissions of all firms relative to a competitive market. This paper studies the interaction of environmental regulation and imperfectly competitive markets by asking two questions: First, does strategic behavior affect pollution in environmentally regulated markets? Second, how does the choice of environmental policy instrument affect the welfare implications of imperfect competition?

This paper develops a theoretical model of environmental regulation, focusing on the comparison between emissions taxes (*i.e.,* a price instrument) and tradable permits (a quantity instrument). In a classic analysis, Weitzman [34] examines the welfare consequences of price and quantity regulations when abatement costs are uncertain. In contrast to modeling this uncertainty, I examine the welfare consequences of policy instrument choice when firms have market power in selling a polluting good. In a market subject to environmental regulation, a firm's strategic behavior affects the production and emissions decisions of all firms. If firms are regulated by a Pigouvian tax, changing emissions will not affect the marginal cost of polluting. However, under a tradable permit system, polluters' decisions affect the permit price. As shown in this paper, this feedback effect may *increase* a strategic firm's output.[1] Therefore, relative to a tax, tradable permits improve welfare in a product market with imperfect competition.[2]

[1] As discussed below, this will always be the case when the dominant firm is relatively dirty. When the dominant firm is relatively clean, the results depend on the sensitivity of the permit price to the firm's behavior.

[2] To be consistent with the literature on pollution regulation, I use the term "product market" to distinguish markets that produce goods (and pollute in the process) as opposed to a market, like a permit market, where firms trade property rights.

The paper then studies the welfare consequences of policy instrument choice in the context of restructured electricity markets. Regulators restructured power generation with the hopes of providing incentives for better investment and operation of power plants. In general, however, restructuring has enabled wholesalers to exercise market power.[3] I focus on the Pennsylvania, New Jersey, and Maryland (PJM) market, which was restructured in April 1999. During the summer of 1998, before restructuring, wholesale prices were consistent with those of a competitive market, while after restructuring actual prices were substantially higher than simulated competitive prices [22]. Furthermore, after restructuring, firms distorted production and caused welfare losses [23].

At the same time, the PJM market was subject to market-based environmental regulation: the tradable permit system established by the Ozone Transport Commission (OTC) regulates nitrogen oxides (NO_x) emissions by power plants in the Northeast. I simulate the interaction of the PJM and OTC markets to determine the impact of policy instrument choice on welfare. Since 1999, the geographic coverage of both PJM and the regional NOx regulations have changed: the simulation in the paper is based on the old PJM footprint.

In the simulation, I make a few assumptions that differ from the theory section. First, while the theory section allows for the possibility that firms may exercise market power in the input market, this effect is assumed to be relatively minor as it is not the focus of this paper (see Hahn [14] for a discussion of that effect). In the simulation, this is made explicit by assuming that firms take input prices as given. Secondly, the theory focuses on a dominant firm facing a competitive fringe in order to provide the intuition of how strategic behavior in product markets may affect pollution levels. The simulation model uses a Cournot model, which is arguably more appropriate for this application [6]. However, the environmental effects of introducing a dominant firm are more straightforward to model and are the focus of the theory part of the paper.

[3]Numerous studies find large, positive price-cost margins in England and Wales [35],[36],[37], California [3],[16],[27], and New England [7].

Throughout the paper, I define “local” emissions as those occurring in the product market of interest (e.g., PJM).[4] Results imply that the market power introduced by restructuring reduced local emissions by approximately nine percent, and decreased permit prices by 48 percent (relative to simulated competitive prices).[5,6] A tax set assuming a competitive product market would have increased the production distortions of strategic firms. I conclude that the welfare loss from imperfect competition in PJM would have been seven percent larger under a tax than under the permit system.

The paper proceeds as follows. Section 2 briefly discusses how this paper fits into the economics literature. In section 3, I construct a model of optimal environmental regulation for the case of perfectly competitive markets. Section 4 examines the environmental implications of strategic behavior. Section 5 discusses the welfare implications of environmental policy instrument choice. In section 6, I simulate how NO_x permit prices respond to market power in the PJM electricity market and quantify the welfare impacts of the policy instrument choice of taxes versus tradable permits. Section 7 offers concluding remarks.

2 Related Literature

This paper adds to an extensive literature that has examined the theory of environmental regulation in imperfectly competitive markets. As an example of the theory of the second best, a polluting monopoly facing a Pigouvian tax, which is set equal to the marginal ex-

[4] As noted below, when a region is regulated by a cap-and-trade program, local reductions in emissions will result in greater emissions elsewhere in the region (as long as the cap is binding). In this case, the effect will be to lower the permit price. There may be additional welfare effects if the regulated pollutant is not uniformly mixed.

[5] Strategic firms in PJM tend to have higher emissions rates than the fringe [[24]. As discussed below, when a dominant firm is relatively dirty, market power reduces local emissions.

[6] Consistent with this result, Mansur [24] finds emissions measured using a model of competitive behavior exceeded the actual emissions of firms in PJM by approximately eight percent. Chen and co-authors [9],[10] examine the interaction of market power in the PJM and NO_x markets. They note that firms may exercise market power in the permit market, depending on the initial allocation of permits. They find that exercising market power in the electricity market will lower the price of permits. However, their models do not allow for trading of permits outside of PJM so there are no “local” environmental effects as defined here.

ternal cost, may cause more welfare loss than an unregulated competitive market [5].[7] In practice, however, ignoring market structure may lead to small inefficiencies when determining pollution regulation given that these concerns are second order [26]. On the other hand, second-order implications *do* matter in a general equilibrium setting because of distortions in other markets, like labor markets [4].[8]

Monopolies distort overall production but produce using the least costly technology. In contrast, in addition to distorting overall production, oligopolists also cause production inefficiencies by substituting production across firms. In these markets, the pollution implications of market power depend on total production and the technologies employed. Key factors include demand elasticity, the costs and emissions associated with various technology types, the distribution of technologies among firms, and the exact strategic game.

Therefore, determining the optimal environmental regulation in this second-best setting becomes more complicated when polluters behave strategically. Taxes, even when proportional to emissions rates, may increase pollution from an oligopolistic industry with asymmetric cost functions [20]. Since market structure leads to production inefficiencies and distorts the total quantity produced, the second-best tax may exceed the marginal environmental cost [8],[29],[30]. A related literature has examined the importance of strategic behavior in setting environmental policy with international trade [2],[13],[33].

This literature discusses optimal taxation policy assuming regulators observe market structure. However, as discussed below, regulation may be slow to react to changes in market structure or there may be other reasons why environmental regulators do not consider issues of market power in product markets. Thus, in contrast to the existing literature, this paper asks whether ignoring market power in product markets has welfare consequences. In

[7] Due to additional distortion in the product market, the second-best tax for a monopolist is less than the marginal external cost [1],[19].

[8] In general, environmental policy makers may improve welfare by considering: when the product market is economically regulated [11]; when markets are regulatory constructs (such as permit markets) that may be either set sub-optimally initially or cannot respond optimally to market shocks; and when product market regulations or structure have large environmental impacts.

particular I ask, if environmental regulators assume competitive product markets, what type of policy instrument choice will lead to greater social welfare, prices or quantities?

3 Model

3.1 Setup

3.1.1 Product Markets

Suppose that there are several independent product markets comprising N firms that emit pollution into a common airshed. Of these, M firms are located in the product market of interest, which may or may not be perfectly competitive. Their emissions are defined as "local" emissions. The set of $N - M$ firms are located in other product markets, which will be assumed to be perfectly competitive. For each firm i, emissions (e_i) equal the firm's output (q_i) times its emissions rate (r_i): $e_i = q_i r_i, \quad i \in \{1, ..., N\}$. For simplicity, I study just a short-run model. In particular, I assume the following about the product markets:

- Firms cannot change abatement technology: r_i is fixed.[9]
- The number of firms, N, is fixed (firms cannot enter or exit).
- The production costs $(c_i(q_i))$ are convex.

Pollution results in environmental and health damages. Assume a convex damage function that depends only on aggregate emissions and not on their spatial distribution:

$$D = D(\sum_{i=1}^{N} q_i r_i). \tag{1}$$

Regulators can set either an emissions tax or a tradable permits cap to limit pollution in an effort to correct for the externality. In the case of a permit system, firm i is allocated permits

[9] I make this assumption in order to simplify the model. The paper's results also hold if the firms' profit functions are additively separable in choosing production levels and abatement technologies. Furthermore, given reasonable restrictions, the results of this paper can be shown to be robust to the presence of endogenous emissions rates [21].

of amount $\overline{e}_i$. Transaction costs may result from firms trading permits. If any such costs exist, then they will be minimized if permits are allocated such that no trades are needed in order to achieve overall cost minimization [31]. In other words, I assume regulators set $\overline{e}_i$ equal to the level that would be efficient under perfect competition.[10]

3.1.2 Setting Environmental Policy

Throughout this paper, I assume that regulators who set environmental policy fail to account for imperfectly competitive product markets. If regulators correctly model market structure, then we are in a second-best setting. If the absolute slopes of the marginal abatement costs and marginal damages are similar [34], then there will be some level of emissions, which can be obtained by either a tax or permit system, that will minimize welfare loss across the product and abatement markets. However, there are two reasons why we might think that environmental regulation does not account for the current structure in the industry.

First, regulators may be slow to adjust to the introduction of strategic behavior resulting from deregulation, restructuring, mergers, *etc.* As in Weitzman [34] and in the literature on technological change [15], important differences arise between policy instrument choices when regulators are slow to react.

Second, environmental policy may ignore strategic behavior in product markets because of the separation of regulatory obligations in the government. The Environmental Protection Agency and Department of Justice have different mandates. For example, the EPA's Integrated Planning Model assumes a competitive electricity industry.[11]

[10] This assumption can be relaxed. However, by setting permit allocation at this level, I am able to distinguish between the effect that Hahn [14] discusses regarding market power in permit markets from that being observed here: that permit prices might change because of imperfect competition in a product market. The incentives to distort the permit price could be significant and, depending on the distribution of permits, may exacerbate or even contradict the results of this paper. For example, if the dominant firm is relatively dirty and is a large net buyer of permits, it may pollute even more than would occur in a competitive market in order to drive down the permit price. These effects are shown in the first order conditions below.

[11] See section 2 of the description of the Integrated Planning Model, written by ICF, on the electricity market (http://www.epa.gov/airmarkets/epa-ipm/).

3.2 Environmental Regulation in Competitive Markets

3.2.1 Taxation

If product markets are competitive, firm i takes its product market's price (P_i) as given. Under a tax (τ_0), firm i chooses q_i in order to maximize profits (which equal total revenue less total production costs, minus what the firm must pay for polluting):

$$\max_{q_i}\{P_i q_i - c_i(q_i) - \tau_0 q_i r_i\}. \tag{2}$$

The resulting first order condition implies that firms set their marginal abatement cost (MAC_i) equal to the tax:

$$MAC_i \equiv \frac{P_i - c_i'(q_i)}{r_i} = \tau_0.^{12} \tag{3}$$

Therefore, in the case of fixed abatement technology, the marginal abatement cost is exactly the forgone profits associated with emitting an extra ton of pollutant.

Efficiency is achieved by the set of output decisions $\{q_1^*, ..., q_N^*\}$ that equate marginal net benefits of emissions (or equivalently, the marginal abatement costs) and marginal damages for each firm [32]:

$$\frac{P_i - c_i'(q_i^*)}{r_i} = D'(\sum_{i=1}^{N} q_i^* r_i), \text{ for all } i \in \{1, .., N\}. \tag{4}$$

Note that the source of emissions is not relevant to the marginal damage function. Therefore, the social optimum will be attained when regulators levy a tax equal to the marginal damages from emissions where firms produce $\{q_1^*, ..., q_N^*\}$: $\tau_0 = D'(\sum_{i=1}^{N} q_i^* r_i)$.

3.2.2 Emission Trading

Alternatively, regulators could use a tradable permit system to achieve the social optimum. Firm i will take the permit price (τ), as well as P_i, as given. Here, the cost of polluting equals

[12] This assumes an interior solution, an assumption made throughout this paper. Note that the second order condition for profit maximization is met: $-c_i''(q_i) < 0$.

any additional pollution beyond the firm's allocated permits. In a competitive market, firm i solves:

$$\max_{q_i}\{P_i q_i - c_i(q_i) - \tau \cdot (q_i r_i - \overline{e}_i)\}. \tag{5}$$

Since the permit price is not a function of q_i, the first order condition of (5) is similar to (3): the firm sets its marginal abatement cost equal to the permit price. Here, regulators allocate permits in aggregate equal to the optimal level of emissions: $\sum_{i=1}^{N}\overline{e}_i = \sum_{i=1}^{N} q_i^* r_i$. To minimize transaction costs, firm i is allocated permits equal to its optimal level of emissions: $\overline{e}_i = q_i^* r_i$.

4 Environmental Implications of Strategic Behavior

This section examines how production decisions, and therefore emissions, differ when a product market is imperfectly competitive. In the case when regulators levy taxes, I compare the emissions under perfect competition with those of a market dominated by a strategic firm. I show that the implications of strategic behavior depend on the relative emissions rates of the dominant firm and the competitive fringe. Next, for the case of tradable permits, I compare the local emissions from markets that are perfectly competitive with those with strategic firms. Here, I examine how permit prices respond to the degree of market competition.

4.1 Implications Under a Tax

In order to model the equilibrium, I make two simplifying assumptions. First, I assume that the imperfectly competitive product market consists of a single dominant firm (which produces q_m) and a competitive fringe (q_f).[13] The simplicity of the model shown here allows for

[13] One could construct a more complicated model with *multiple* strategic firms, such as a Cournot or Bertrand model. In some cases, it is clear that the strategic interactions of oligopolists will have implications for environmental policy [2]. However, the welfare implications that this paper discusses occur because of indirect effects through the permit market price. In other words, if an alternative model were used, what matters (from the perspective of this paper) is whether the permit price rises or falls when firms exercise market power in the product market. Furthermore, if the permit price changes, does this necessarily result in less of a distortion of the product market? These more complex models will be studied in future work.

ease in exposition. Second, I assume that demand in this product market is perfectly inelastic ($\overline{q}$). This is an assumption common to the literature on wholesale electricity markets.[14] In equilibrium, the quantity supplied equals the quantity demanded: $q_m + q_f = \overline{q}$. Note that assuming demand is perfectly inelastic is not the same as assuming that $P'(q_m) = -\infty$: the dominant firm recognizes that the competitive fringe will change its production depending on the dominant firm's behavior.

For the imperfectly competitive product market facing a tax, the dominant firm recognizes that its output affects $P(q_m)$ and solves:

$$\max_{q_m}\{P(q_m) \cdot q_m - c_m(q_m) - \tau_0 q_m r_m\}. \tag{6}$$

As in (3), the firm cannot affect the regulation price ($\tau_0' = 0$). The first order condition of (6) implies that the dominant firm will set marginal abatement cost equal to the tax:

$$\frac{P(q_m) + P'(q_m) \cdot q_m - c_m'(q_m)}{r_m} = \tau_0.^{15} \tag{7}$$

Let $\widehat{q}_m$ solve (7). Again, the firm's marginal abatement cost equals forgone profits. Proposition 1 states that relative to a competitive market, the dominant firm produces less while the fringe produces more:

Proposition 1 $\widehat{q}_m < q_m^*$ *and* $\widehat{q}_f > q_f^*$.

Proof. See Appendix A. ■

Next, I examine the local pollution implications of introducing strategic behavior–that is, the emissions in the dominant firm's product market. With fixed abatement technology and perfectly inelastic demand, these pollution implications will depend solely upon the relative

[14]Derived demand is nearly completely inelastic for two reasons. First, consumers have no incentive to reduce quantity demanded at higher prices because the regulatory structure of electricity retail markets has kept consumers' rates constant. Second, the firms that procure customers' electricity in the wholesale market are mandated to provide the power at any cost.

[15]The second order condition for profit maximization is the typical condition for strategic firms and is assumed to hold: $2P'(q) + P''(q) \cdot q - c''(q) < 0$.

emissions rates of the dominant firm and of the competitive fringe. The reduction in output by the dominant firm ($q_m^* - \widehat{q}_m$) exactly equals the increase in output from the fringe ($\widehat{q}_f - q_f^*$). Define $\Delta\widehat{q} \equiv q_m^* - \widehat{q}_m$ (which is positive and equals $\widehat{q}_f - q_f^*$). For a given tax, the dominant firm reduces emissions by $\Delta\widehat{q} \cdot r_m$, while the fringe emits $\Delta\widehat{q} \cdot r_f$ more. The net impact on emissions is $\Delta\widehat{q} \cdot (r_f - r_m)$. Hence the environmental effects will depend on whether the dominant firm is relatively dirty (*i.e.*, $r_m > r_f$) or relatively clean (*i.e.*, $r_m < r_f$).

Figures 1 and 2 present the local pollution effects of introducing market power. For a firm in a competitive market, (3) implies that the marginal abatement cost is decreasing in production (and therefore in emissions). Given the convexity assumption, marginal damages are increasing in emissions. The figures display the optimal policy, using taxes or permits, under the assumption of competitive product markets.

Figure 1 displays the case when the dominant firm has a higher emissions rate than the fringe: $r_m > r_f$. When the dominant firm behaves strategically, local pollution falls by $\Delta\widehat{q} \cdot (r_m - r_f)$. The same level of emissions can be achieved with less abatement from firms in other product markets. Thus, the aggregate marginal abatement cost function lies below that of the competitive market. Hence in this case, strategic behavior results in lower emissions than perfect competition when the regulator levies a tax.

Figure 2 presents the converse case when the dominant firm has a lower emissions rate than the fringe: $r_m < r_f$. When the dominant firm exercises market power, local pollution increases. The aggregate marginal abatement cost curve now lies above the competitive market's curve. With a tax, emissions increase under imperfect competition.

4.2 Implications Under a Tradable Permit System

The environmental implications of strategic behavior differ under a permit system. Even though total emissions are fixed, the share of emissions from any one product market changes when the dominant firm exercises market power. In contrast to a tax, this has implications for the price of the regulation. Namely, changes in local pollution affect the permit price.

Under a permit system, a strategic firm recognizes that its output affects prices $P(q_m)$ and $\tau(q_m)$ and solves:

$$\max_{q_m}\{P(q_m)\cdot q_m - c_m(q_m) - \tau(q_m)\cdot(q_m r_m - \overline{e}_m)\}. \tag{8}$$

The first order condition then implies that a strategic firm equates the forgone profits in the product market from abating with the profits it earns from selling a permit, where the permit price is endogenous:

$$\frac{P(q_m) + P'(q_m)\cdot q_m - c'_m(q_m)}{r_m} = \tau(q_m) + \tau'(q_m)\cdot(q_m - \frac{\overline{e}_m}{r_m}).^{16} \tag{9}$$

Let $\widetilde{q}_m$ solve (9).

Note that if there are only two agents (the dominant firm and the competitive fringe) that are in *both* the product and permit markets, then there is only one (q_m, q_f) pair that will solve the two constraints of perfectly inelastic demand for the product and a fixed supply of permits. However, in this model, there are $N - M$ firms in other product markets that are also regulated by the permit market. This relaxes the constraint and allows the dominant firm to exercise market power without violating the two constraints.

In general, a strategic firm considers both: (i) the incentive to increase the product market price; and (ii), in order to minimize regulation costs, the incentive to distort the permit price. Under the assumption that $\overline{e}_m = q^*_m r_m$, the first incentive dominates, or otherwise is consistent with, the second incentive [14]. Hence, a firm acting strategically will produce less than it would have in a competitive market: $\widetilde{q}_m < q^*_m$. (Appendix B provides a general discussion of $\widetilde{q}_m$).

It is important to note that if $\tau'(q_m)$ is small, then there will be little difference between the tax and the permit market. For example, given that there are many firms in the national SO_2 market, this would be less of an issue. As the US moves from small regional NO_x

[16] The second order condition for profit maximization is $2P'(q)+P''(q)\cdot q-c''(q)-2\tau'(q)\cdot r-\tau''(q)\cdot(qr-\overline{e}) < 0$. Note that $P'(q) < 0$ and that $c''(q) > 0$. No restrictions are imposed on $\tau(q)$. As discussed below, the sign of $\tau'(q)$ differs when the strategic firm is relatively dirty from when it is relatively clean.

markets to larger ones (OTC to NO_x SIP Calls to CAIR), this distinction between taxes and permits will be less of an issue.

The abatement decisions are also more complex for a strategic firm facing a permit price. The problem is analogous to the problem of defining a supply function for a monopoly. That said, one could derive the abatement "supply" function from (9). The function would depend on the output and emissions of the dominant firm and its various competitors. Since $\widetilde{q}_m < q_m^*$, the firm's equilibrium $(\tau, \widetilde{q}_m)$ abatement "supply" function (or equivalently, its demand for permits) will lie below that of a competitive market. As with a tax, the aggregate marginal abatement cost function depends on whether the dominant firm is dirty or clean relative to the fringe. As aggregate demand for permits shifts, the equilibrium price will change.

When the dominant firm is relatively dirty (as in Figure 1), then introducing market power reduces local emissions. For the permit market to be in equilibrium, the reduced demand for permits will result in permit prices falling.[17] At the initial permit cap, the marginal damages exceed the new marginal abatement costs. This implies that firms emit more than the new level maximizing surplus in the "market" for abatement (given by e^*). As noted below, in a second-best setting, e^* is not the optimal regulation given that there is deadweight loss in the product market: the shaded areas only show the welfare loss occurring in the abatement market. Alternatively, had regulators established an initially optimal tax instead, strategic behavior would result in less pollution as firms abate to the point were marginal abatement costs equal the tax (given by $\widehat{e}$).

The converse arguments can be made when the fringe is relatively dirty, as shown in Figure 2. For a given permit price, more local pollution occurs when the dominant firm exercises market power. Firms in other product markets must abate more to attain the same level of emissions in the airshed. Therefore, this increase in demand will result in higher permit prices. Now, e^* allows for more pollution than the initial permit cap. In

[17] Here, the marginal abatement cost function includes the feedback effect that permits have on the product market: firms will alter production decisions when marginal costs change, including permit prices.

contrast, if regulators had established an initially optimal tax, then firms would emit more than e^*.

In summary, if the dominant firm is relatively dirty (clean), introducing market power reduces (increases) local emissions. Under a permit system, this will result in a lower (higher) permit price. If demand is not perfectly inelastic, the results are slightly modified.[18]

Note that, in this model, the introduction of strategic behavior is akin to a shock to the marginal abatement cost function. Assuming that regulation is set optimally given some initial conditions, almost any such change in marginal abatement costs results in welfare loss.[19] As an application of the theory of the second best, however, regulators may not want to eliminate this deadweight loss, because additional welfare losses also exist in the imperfectly competitive product market. Next, I examine the conditions under which permit markets are more robust to market power in product markets in comparison to a tax.

5 Theoretical Implications for Policy Instrument Choice

In this section, I examine the welfare implications of policy instrument choice, given that environmental regulators either may not consider the welfare implications in the product market, or simply do not know whether there will be more or less pollution after a dominant firm exercises market power in the product market. When abatement costs are uncertain, the size of the welfare loss from the "mistake" implied by regulators acting on expectations is not equivalent under taxes and tradable permit systems but rather depends on the slopes of marginal abatement costs and marginal damages [34]. In the special case of equal absolute slopes, policy makers should be indifferent between the instruments; both cause the same

[18] If the dominant firm is dirtier, then the effect is unambiguous; less quantity demanded would reinforce the conclusion that overall emissions would go down. However, if the dominant firm is cleaner, then the effect is ambiguous.

[19] In the extreme cases, regulatory mechanisms can mimic society's demand for clean air: if the marginal damages are perfectly inelastic, then a permit system will respond optimally. Alternatively, taxes respond optimally when the marginal damages are perfectly elastic.

environment-related welfare losses given a shock to marginal abatement costs. The social planner will prefer a tax to a quota system when the slope of marginal damages is less, in absolute terms, than that of marginal abatement costs. In contrast, the quota system will be preferred if marginal damages are steeper.

Given Weitzman's findings, I examine whether policy instrument choice has further welfare implications when product markets are imperfectly competitive. For any given abatement and damage functions, the welfare effects will depend on both the arguments of Weitzman as well as those argued here. To separate these effects, I make the following simplifying assumption.

Assume that, under perfect competition, regulators are indifferent between a tax and tradable permits that are set such that the tax equals the expected permit price where marginal damages equal marginal abatement costs. This implies that the slope of the marginal damages equals the absolute value of the slope of the marginal cost of abatement. Thus, any shock to costs will result in welfare loss in the market for abatement that will have the same expectation regardless of instrument choice. This is shown in both Figures 1 and 2 by the shaded areas. The gray area is the welfare loss associated with a tradable permit. The black area is the welfare loss associated with a tax.

The assumptions that (1) regulators set policy optimally and (2) that policy makers are just indifferent to taxes and permits allows me to isolate the specific welfare implication that I want to address. Namely, how does instrument choice affect welfare in an imperfectly competitive product market?[20] The key insight to why instrument choice may matter is to recognize that, relative to a tax, permit prices respond to production decisions. The implications for production, and therefore welfare, can be seen by looking at how profits change when the permit price falls.

[20] These assumptions may suggest that my findings are second order. However, as the literature on the tax interaction effect has found, second order effects can be quite large when a market is previously distorted. For example, if regulation is not set optimally or if policy makers have a tendency to use one type of regulation, then the effects of strategic behavior may be exacerbated.

In order to determine whether a dominant firm will produce more under a permit system or under a tax, I compare the firm's first order conditions under each policy at a specific point. Namely, I examine the conditions at the level of output ($\widehat{q}_m$) where the dominant firm maximizes profits (π) under a tax. The difference between the first order condition under a permit, ($\frac{d\pi(\tau)}{dq}|_{\widehat{q}_m}$), and the first order condition under a tax, ($\frac{d\pi(\tau_0)}{dq_m}|_{\widehat{q}_m}$), can be written as:

$$\frac{d\pi(\tau(q_m))}{dq_m}|_{\widehat{q}_m} - \frac{d\pi(\tau_0)}{dq_m}|_{\widehat{q}_m} = [\tau_0 - \tau(\widehat{q}_m)] \cdot (r_m - r_f) + \tau'(\widehat{q}_m) \cdot (\overline{e}_m + \widehat{q}_m r_f - \widehat{q}_m r_m). \quad (10)$$

See Appendix A for the derivation of (10). Next, I determine the sign of (10) separately for a dominant firm that is relatively dirty from one that is relatively clean.

5.1 Relatively Dirty Dominant Firm

If the dominant firm is relatively dirty ($r_m > r_f$) and exercises market power, then permit prices will fall below the level of the tax ($\tau(\widehat{q}_m) < \tau_0$). In this case, $\tau'(q_m) > 0$ and (by assumption) $\overline{e}_m > \widehat{q}_m r_m$. Therefore, at $\widehat{q}_m$, profits are increasing in q_m under a permit (while $\frac{d\pi(\tau_0)}{dq_m}|_{\widehat{q}_m} = 0$). As stated in proposition 2, the dominant firm produces more if regulated by a permit system than if regulated by a tax.

Proposition 2 *If $r_m > r_f$, then $\widetilde{q}_m > \widehat{q}_m$.*

Proof. Proof follows immediately from the preceding arguments. ■

As a case in point, consider $r_m = 1$ and $r_f = 0$. Now (10) equals:

$$\tau_0 - \tau(\widehat{q}_m) + \tau'(\widehat{q}_m) \cdot (\overline{e}_m - \widehat{q}_m). \quad (11)$$

Figure 3 depicts the welfare implications of this example by plotting residual demand (a function of the fringe's production costs), the marginal revenue of that function, and four cost curves: marginal private costs ($c'_m(q_m)$), marginal social costs ($c'_m(q_m) + D'(q_m) \cdot r_m$), marginal private costs plus the tax ($c'_m(q_m) + \tau_0 r_m$), and marginal private costs plus the permit price ($c'_m(q_m) + \tau(q_m) \cdot r_m$). The shaded area is a measure of welfare loss, not a transfer, as less efficient units (*i.e.*, those with higher marginal social costs) are being used to produce energy when lower cost ones are not producing [23].

As permit prices fall relative to the tax, the strategic firm produces more. This will reduce the dominant firm's production costs relative to a tax, and production for the strategic firm is greater than it would have been under a tax: $\widetilde{q}_m > \widehat{q}_m$. The welfare loss from a dominant firm facing a tradable permit is the area between the residual demand curve and the marginal social costs from the point where the dominant firm opts to produce ($\widetilde{q}_m$) to the optimal point where the lines intersect q_m^* (the hashed area). A tax would result in addition welfare loss (the gray area), as the dominant firm would produce even less ($\widehat{q}_m$).

5.2 Relatively Clean Dominant Firm

If the dominant firm is relatively clean, $r_m < r_f$, and exercises market power, then the dirty fringe produces more and permit prices rise relative to a tax, $\tau(\widehat{q}_m) > \tau_0$. Greater permit prices will result in an increase of production costs for *all* firms. *Ceteris paribus*, greater marginal costs for the dominant firm imply that it would increase profits by reducing output. However, what matters is the relative effect. Namely, if marginal revenue increases *even more* than marginal costs, the dominant firm will increase output. Below I discuss the conditions for this to be the case.

Note that when the dominant firm is relatively clean, the increase in the permit price will cause the fringe's production costs to increase even more so than those of the dominant firm. Returning to (10), this has two potentially offsetting effects on marginal revenue. I examine both parts of (10) separately. First, as the permit price exceeds the tax, $\tau(\widehat{q}_m) > \tau_0$, and the dominant firm is relatively clean, $r_m < r_f$, increasing output *improves* profits under a permit relative to a tax:

$$[\tau_0 - \tau(\widehat{q}_m)] \cdot (r_m - r_f) > 0. \tag{12}$$

Second, the more the dominant firm produces, the permit price exceeds the tax by a smaller amount: $\tau'(q_m) < 0$. Therefore, the second term of (10) is negative, $\tau'(\widehat{q}_m) \cdot (\overline{e}_m + \widehat{q}_m \cdot (r_f - r_m)) < 0$, as $r_f > r_m$. When q_m is near zero (and $\tau'(q_m) \cdot \overline{e}_m$ is insubstantial), the first effect is likely to dominate: the marginal revenue under a permit system will exceed that under a tax. Conversely, at the competitive output level q_m^*, the permit price is assumed to be set equal to the tax, $\tau(q_m^*) = \tau_0$, so the second effect dominates. At this competitive outcome, marginal profits are greater under a tax.

Given that (10) is a continuous monotonic function, there exists some $q_m \in (0, q_m^*)$ where these two effects offset and the marginal revenue under the tax is equal to the marginal revenue under the permit system. Permits will result in more production by the dominant firm than a tax ($\widetilde{q}_m > \widehat{q}_m$) and less welfare loss *only if* the permit price does not respond substantially to changes in q_m around $\widehat{q}_m$, meaning:

$$\frac{[\tau_0 - \tau(\widehat{q}_m)] \cdot (r_m - r_f)}{\overline{e}_m + \widehat{q}_m \cdot (r_f - r_m)} > -\tau'(\widehat{q}_m). \tag{13}$$

Proposition 3 states that–when the dominant firm is relatively clean and conditional on (13) holding–profits are increasing in q_m under a permit at $\widehat{q}_m$. In this case, as in proposition 2, the firm produces more if regulated by a permit system than if regulated by a tax.

Proposition 3 *If $r_m < r_f$ and (13) holds, then $\widetilde{q}_m > \widehat{q}_m$.*

Proof. Proof follows immediately from the preceding arguments. ■

I examine the implications of this proposition using simplifying assumptions: $r_m = 0$ and $r_f = 1$. Also, I assume that the clean dominant firm will not be allocated permits: $\overline{e}_m = 0$. Now the condition (13) can be written:

$$(\frac{\tau(\widehat{q}_m) - \tau_0}{q_m^* - \widehat{q}_m}) \cdot (\frac{q_m^* - \widehat{q}_m}{\widehat{q}_m}) > -\tau'(\widehat{q}_m). \tag{14}$$

The left-hand side of this equation equals the average increase in the permit price from reducing output from the competitive level multiplied by a ratio. The ratio, which is the amount of output reduced over the amount the dominant firm produces, is bounded by zero and one assuming positive marginal costs. The right-hand side is the marginal increase in the price from further reducing output. If the average impact is substantially greater than the marginal effect, then permits are welfare improving. In other words, this constraint will hold if $\tau(q_m)$ is concave.

Figure 4 provides an example of the welfare implications. As in the previous case, the strategic firm produces where marginal revenue equals marginal cost. This figure has four residual demand curves based on the fringe's costs in these cases: marginal private costs ($c_f'(\overline{q} - q_m)$), marginal social costs ($c_f'(\overline{q} - q_m) + D'(q_m) \cdot r_f$), marginal private costs plus the tax ($c_f'(\overline{q} - q_m) + \tau_0 r_f$), and marginal private costs plus the permit price ($c_f'(\overline{q} - q_m) + \tau(q_m) \cdot r_f$). I have drawn the marginal revenue curves for the two policy instruments. I have shown the case when the residual demand with the permit price lies above that with the tax at $\widehat{q}_m$. Therefore, for a given fringe emissions rate, the marginal revenue for the residual demand with permits is greater than that with taxes, implying more welfare loss under the tax (the same area shading is used as in Figure 3).

In summary, the relatively dirty dominant firm produces more under a tradable permit system than under a tax and, therefore, there is less welfare loss. If (13) holds, then the relatively clean dominant firm will also produce more under a permit system and welfare will be improved. All else equal (and if (13) holds), I find that given the presence of strategic firms in product markets, welfare losses will be reduced if environmental policy makers opt for tradable permit systems in comparison to pollution taxes. This finding suggests that, even when the slope of the marginal abatement costs exceed, in absolute values, the slope of the marginal damages, regulators should give some consideration to tradable permits in imperfectly competitive markets.[21]

[21] The policy recommendations of Weitzman [34] could be modified to account for this additional effect. The expected welfare from a given policy will depend on many characteristics of the regulated market and the pollutant's damages.

6 Simulation of Policy Instrument Choice

This section asks whether these welfare effects are of economic significance. Specifically, the question I ask is: what would be the *additional* deadweight loss in the PJM electricity market had a tax been implemented instead of a permit system? Throughout this paper, I assume the tax would have been set optimally assuming competitive behavior. Since strategic firms in PJM are dirtier than those in the fringe, exercising market power will reduce local emissions [24]. If the OTC permit price is endogenous, the decreased demand for permits will result in a permit price below the tax.

As noted in the previous section, this lower permit price gives incentives for the strategic firms to produce more than they would under a tax, and therefore, cause less distortion to the economy. Again, I assume that the slopes of the marginal benefits and marginal costs of abatement are equal so that the welfare implications are solely a function of the impacts on the electricity market.

The calculation of the welfare implications requires modeling the regulators tax level decision and the strategic firms' production behavior under this scenario. This requires a permit supply model for firms that are regulated by the OTC but are outside PJM. From May to September, the OTC NO_x permit market regulates firms in PJM, New England, and New York. During 1999, OTC did not apply to firms in Maine, Maryland, Vermont, Virginia, and Washington, D.C. The number of permits are fixed. If the PJM firms pollute more, the other firms in New England and New York must abate an equal amount.[22] To clear the PJM firms' demand for extra permits with these non-PJM firms' supply, the permit price will rise.

In addition, the simulation uses models of firm behavior in the PJM electricity market. The strategy is first to determine what the permit price would have been had the firms in

[22] This market allows firms to bank permits for future summers. However, this feature would be extremely complex to model as it would require considering multiple years of permit supply and demand.

PJM behaved competitively. In equilibrium, the increase in emissions in PJM as the market changes from a strategic "regime" to a competitive one must equal the increase in abatement by firms outside of PJM. Given the equilibrium price, I assume that regulators would have set the tax at this intended level and then simulate how strategic firms would have produced. As demand is assumed to be perfectly inelastic, the welfare effects of a tax are the extra production costs. These costs include the environmental externality that is valued at the tax level. This assumes optimal regulation whereby the tax equals the marginal external cost.

The section begins by describing the model of abatement supply outside of PJM. Then I model firm behavior in the PJM electricity market for both the competitive and strategic regimes. Finally, the simulation method is discussed and the results are presented.

6.1 Model of Permit Supply

The degree to which the price rises depends, in part, on the elasticity of the non-PJM firms' supply of abatement. NO_x pollution can be abated by installing technologies such as Selective Catalytic Reduction (SCR), by reducing the burning efficiency of a power plant, and by improving the monitoring of the production process. Some of this technology was installed in preparation for this regulation. I assume that these capital investments are fixed in the short run and that firms could not change these investment decisions during the first summer of the regulation. In the short run, firms can abate pollution by not operating. The firm forgoes profits but no longer needs to purchase or to hold on to a pollution permit. It is this trade-off of profits for permits that determines my abatement supply curve.[23]

In order to construct this curve, I model the permit market and the New England and New York electricity markets as competitive. Recall from (3), the marginal cost of abatement (MCA) of a firm taking prices as given is equal to the rents $(P - c'(q))$ divided by the emissions rate (r). For the period of May to September, I construct an abatement supply curve by

[23] In the long run, the permit supply function becomes much more elastic. This will dampen the responsiveness of the permit price to the actions of the dominant firm (*i.e.*, $\tau'(q_m)$ is smaller). This will reduce any differences between the welfare effects of taxes and permits.

measuring the hourly MCA for each power plant regulated by OTC but not in PJM. To measure the market price (P), I use the hourly system-wide price from the New England ISO for the New England firms. New York did not restructure until the following winter. Therefore, I use the New England price as a proxy for the New York electricity price. The price is assumed to be exogenous to individual cost shocks. Further, I do not model the New England electricity price as a function of the permit price. Note that if electricity prices are endogenous, then more abatement will mean higher permit prices and higher electricity prices. This will increase the slope of the abatement supply curve. Ignoring this endogeneity results in a less elastic supply of permits, which in turn results in a smaller difference between the welfare effects of taxes and permits.

The EPA's Egrid database includes information on a power plant's heat input, electricity output, capacity, emissions, primary fuel source, and regulations. The data sources of the New York city gate natural gas spot market and New York oil spot market are discussed in [22], while the EIA's form 767 spot coal prices by power plant are discussed in [[17]. The daily marginal costs ($c'(q)$) are defined as the sum of fuel costs, variable operating and maintenance costs, and SO_2 pollution costs.[24] These costs do not include the costs of the NO_x regulation.

From these data, I construct the abatement supply curve. If the hourly price equals or exceeds a plant's marginal cost, then that plant can abate up to its capacity times its emissions rate that hour. I sort the quantity of abatement by the plant-hour's MCA. Then I calculate a cumulative abatement function, assuming a linear fit of abatement for observations with MCA below $5000/ton. An OLS regression implies that for every additional ton abated by firms outside of PJM, the permit price will increase by $0.1053/ton.[25]

[24]Data on variable O&M costs are not readily available so I assume them to be $2/MWh for all power plants. The SO_2 pollution costs apply to power plants regulated by Phase I of the 1990 Clean Air Act Amendment's Title IV.

[25]The independent variable is the emissions rate times the plant's capacity. In the long run, firms will install abatement technology, changing its emissions rate. This may be correlated with the dependent variable (foregone profits). However, in the short run, this is not likely to be the case as abatement technology and

6.2 Model of Competitive and Strategic Behavior

This section adapts a model of competition and Cournot behavior from Bushnell, Mansur, and Saravia [6] (hereafter BMS). As noted above, some firms in PJM had incentives to increase prices as they sold a substantial amount of energy, q, in the wholesale market. Other firms had obligations to serve large amounts of electricity, or native load, (q^c) to retail customers at fixed rates. These firms may have benefited from lower wholesale prices. The difference between a firm's production of q and retail obligations of q^c, or "net positions," affect firms' incentives. The first order condition is a modification of (9):

$$P(q) + P'(q) \cdot (q - q^c) = c'(q) + \tau(q) \cdot r + \tau'(q) \cdot (qr - \overline{e}), \tag{15}$$

where now firms profit from higher prices only on the amount sold in the market net of the contracts. BMS discuss and account for these net positions. That paper's model uses a firm's first order condition of profit maximization to solve for equilibrium in the PJM electricity market.

Note that firms may have incentives to exercise market power in permit markets directly [14]. If the allocation of permits, $\overline{e}$, is similar to the amount emitting by a strategic firm ($qr \simeq \overline{e}$), then the term last term of (15), $\tau'(q) \cdot (qr - \overline{e})$, will be small. The two firms likely to set prices in the wholesale electricity market are the Philadelphia Electric Company (PECO) and Pennsylvania Power & Light (PPL) [22]. These firms emitted 120 and 74 percent as much NO_x as they were allocated in permits, respectively.[26] In order to focus on the impact of policy instrument choice on welfare in the product market, I assume that firms did not behave strategically in the permit market: $qr \simeq \overline{e}$. For a given permit price, I simulate how much each firm in PJM would have produced under both the competitive and Cournot regimes.

capacity are fixed. For this reason, I assume the independent variable to be exogenous.

[26] Using CEMS data, I calculate that during the period of OTC regulation, PECO emitted 3554 tons of NO_x. In contrast, the firm was allocated permits for 2939 tons of NO_x (See http://www.pacode.com/secure/data/025/chapter123/s123.121.html). PPL emitted 14,785 tons and was allocated permits for 20,027 tons.

Regardless of whether firms take prices as given or act strategically, they will produce a given amount using their least costly generating units. The BMS model includes data on marginal costs, capacity, and emissions rates for all polluting units. Thus, a firm can respond to changes in permit prices by substituting across its units using different fuels or abatement technologies (*i.e.*, fuel switching). For a given permit price, I recalculate the merit order (least costly set of generating units a firm owns). I use these data to determine each firms' hourly emissions. This allows me to compare aggregate emissions across regimes and permit prices.

6.3 Simulation Results

6.3.1 Market Power and Permit Prices

The simulation is solved in several steps. I begin by modeling the permit price assuming firms actually behave as Cournot firms in the PJM electricity market [6]. The actual permit price was volatile during the summer of 1999; the price started near \$5000/ton and eventually settled around \$1000/ton. In comparison, a tax would have been constant throughout this period. It would be difficult to interpret the effects of a volatile permit price relative to a tax. Therefore, I model the permit price as a constant equal to the price that permits were trading at in late September. This is when firms had to demonstrate compliance. I model the permit price as equal to \$1000/ton.

Second, I use the BMS model to estimate firm behavior in PJM for each hour in the summer of 1999 when OTC was in effect.[27] From May 1 to September 30, 1999, the Cournot model simulation predicts that the PJM firms regulated by OTC emit 88,222 tons of NO_x (see Table 1). In contrast, these same firms would have emitted 100,936 tons, an increase of 11 percent, if they had taken prices as given. Therefore, PJM firms in a competitive regime would have demanded 12,713 more permits than those in a Cournot regime. This increase in demand for permits would have resulted in a higher permit price. If the firms in PJM

[27] For greater discussion of the assumptions of this model, see BMS.

behaved the same regardless of the permit price, then based on the permit supply estimates above, the price would have been \$2338/ton.[28] However, the PJM firms do change their production decisions as the permit price increases.

I solve this simultaneity problem by iterating between the two models discussed in sections 6.1 and 6.2. I begin by picking a permit price. Then I measure the quantity of abatement, or number of permits, supplied by firms outside of PJM at that price.[29] Next I determine the amount of permits demanded by competitive firms in PJM at that price and compare that level with the amount demanded in the benchmark case: *Cournot firms at the \$1000 price*. I vary the permit price until one is found that equates supply and demand. At the equilibrium price of \$1934/ton, the firms in the competitive market emit 97,096 tons, which is 8874 more than the Cournot equilibrium emissions. This implies that introducing market power reduced local emissions by approximately 9 percent. To meet this extra demand for permits, the permit price rises by 93 percent, a level well within the range firms actually faced during that summer.

6.3.2 Welfare Effects in PJM

As in section 3, I assume that regulators would have set a tax equal to the marginal external cost of NO_x emissions. If they assumed a competitive PJM market, then (based on the calculations of the permit price above) this tax would be \$1934/ton.[30] As discussed in section 4, deadweight loss is greater under such a tax than under a permit system when firms behave strategically. To quantify this effect, I measure the total variable social cost in the PJM market including production costs and the environmental externalities of NO_x pollution. Note that consumer surplus does not change in the short run given fixed retail prices (see footnote 14).

[28] That is, the initial \$1000/ton plus the slope of \$0.1053/ton times the change in emissions of 12,713 tons.

[29] Note that by changing the permit price for each iteration, this will change the merit order of each firm. For any given permit price, the firm will produce using the least costly generating units.

[30] This first-best solution ignores any tax interaction effect [12].

Over the summer of 1999, the variable social costs for the competitive regime totaled \$1452 million. This is the case for both a permit system and a tax because, *if PJM were a competitive market*, then the permit price would equal the tax of \$1934/ton. The Cournot model predicts costs of \$1565 million given the permit price of \$1000/ton. This simulation predicts that firms exercising market power in PJM cause deadweight loss equal to \$113 million, or 7.8 percent of the variable social costs.

Next, the total variable social costs are estimated assuming a tax. As mentioned, the competitive model costs are the same as above since the tax and permit prices equate. With a tax, the strategic firms distort production even more. The variable social costs, *including* the externality, equal \$1573 million. The higher price of pollution resulted in 2300 fewer tons, a reduction of 2.7 percent. The value of this pollution reduction is \$4.4 million. The benefit of these externalities have been taken into account in the simulation's measure of total cost. In other words, the costs to the firms are \$12.7 million greater under the tax in comparison to the permit system, but society also values the cleaner air under a tax. Thus, relative to a permit system, social costs in PJM have increased by \$8.3 million under a tax even though there is less pollution.

6.3.3 Welfare Effects from Imports

In addition, the equilibrium electricity price under the tax is greater than that under the permit system. The higher prices imply greater imports of electricity, which are costly. The area under the import supply curve between the electricity price with the permit and that with the tax represents additional variable costs. Using the BMS import supply function, I find that these costs total \$3.0 million.

Therefore, a tax would have increased the deadweight loss in PJM by \$11.3 million in one summer. This is equal to 7.4 percent of the total welfare loss associated with strategic behavior in this market. In addition to these welfare effects, retail customers pay more for electricity under a tax. The simulated electricity price for the Cournot regime averages

$52.85/MWh under a tax, slightly more than the $51.89/MWh average under a tradable permit system.[31] If all electricity traded at these prices, then the procurement costs of buyers in the wholesale market would have increased by $102.4 million under a tax relative to a permit system. Recall these costs are for one market and one summer only. If similar margins exist in other pollution regulations, the overall impacts on welfare and transfers may be substantial.

7 Conclusions

Policy makers developing incentive-based environmental regulation should consider the consequences of firms exercising market power in product markets. When dominant firms are dirtier than the fringe, exercising market power reduces pollution from the product market and lowers prices in permit markets. The optimal pollution cap is lower than under perfect competition. When dominant firms are cleaner than the fringe, the opposite conclusions are drawn. However, altering the environmental regulation could increase welfare loss in the product market. In this second best setting, the overall welfare effects must be considered.

Market conditions influence whether a permit system increases welfare in comparison to a tax. In this paper, I suppose that the environment policies optimize welfare assuming perfect competition in all markets. This may result from regulators being slow to adjust to the introduction of strategic behavior. Alternatively, environmental policy makers may ignore issues of competition because of regulatory jurisdiction.

Tradable permits may be preferable to taxes when firms set prices in product markets.[32] When the fringe has lower emissions rates than the dominant firms, permit prices fall as

[31] These prices may seem small in an oligopoly market with perfectly inelastic demand. However, as BMS note, this is because the vertically integrated PJM firms had large retail commitments and had less incentive to set high prices.

[32] If marginal damages and marginal abatement costs have similar slopes in absolute value, these policies would have the same expected welfare loss [34]. Relative to this baseline, I argue that permits are less distortionary.

market power is exercised. A permit system will be preferable to a tax if strategic firms' marginal costs decrease by more than their marginal revenues (which depend on the fringe's marginal costs). In the case in which the fringe is dirtier, strategic behavior increases the permit price. This may increase the dominant firms' marginal revenue more than its costs. As an application of the theory of the second best, when regulators initially determine optimal environmental policy assuming competitive product markets, the presence of strategic behavior in product markets may make tradable permits preferable to a tax.

This paper examines the magnitude of these welfare implications of environmental policy instrument choice. I simulate the OTC permit market and firm behavior in the PJM electricity market. This simulation predicts that strategic behavior reduced local emissions by approximately nine percent. Had the market been competitive, the permit price would have been 93 percent greater than the price given strategic behavior. I then estimate and compare the welfare effects of Cournot behavior at the observed permit price and under a tax. I model regulators as setting the tax optimally given an assumption of competitive behavior in all markets. The deadweight loss from strategic behavior would have increased by seven percent if regulators had chosen a tax rather than a tradable permit system.

These theoretical and simulation results suggest that regulators may improve social welfare by considering the interactions between environmental regulation and firm behavior in product markets. In particular, I find that more consideration should be given to permit markets. However, there are many other factors that must be considered in policy choice, most notably uncertainty [34], transaction costs [31] and tax-interaction effects [12]. The relative significance of these effects will be case specific.

The results have applications beyond the electricity industry. For example, this work may have implications for the regulation of local fisheries, oil refining, and automobile fuel economy standards. While most market based environmental regulation of air pollutants has focused on the electricity industry, there are many examples of environmental regulation in imperfectly competitive markets.

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Figures and Tables

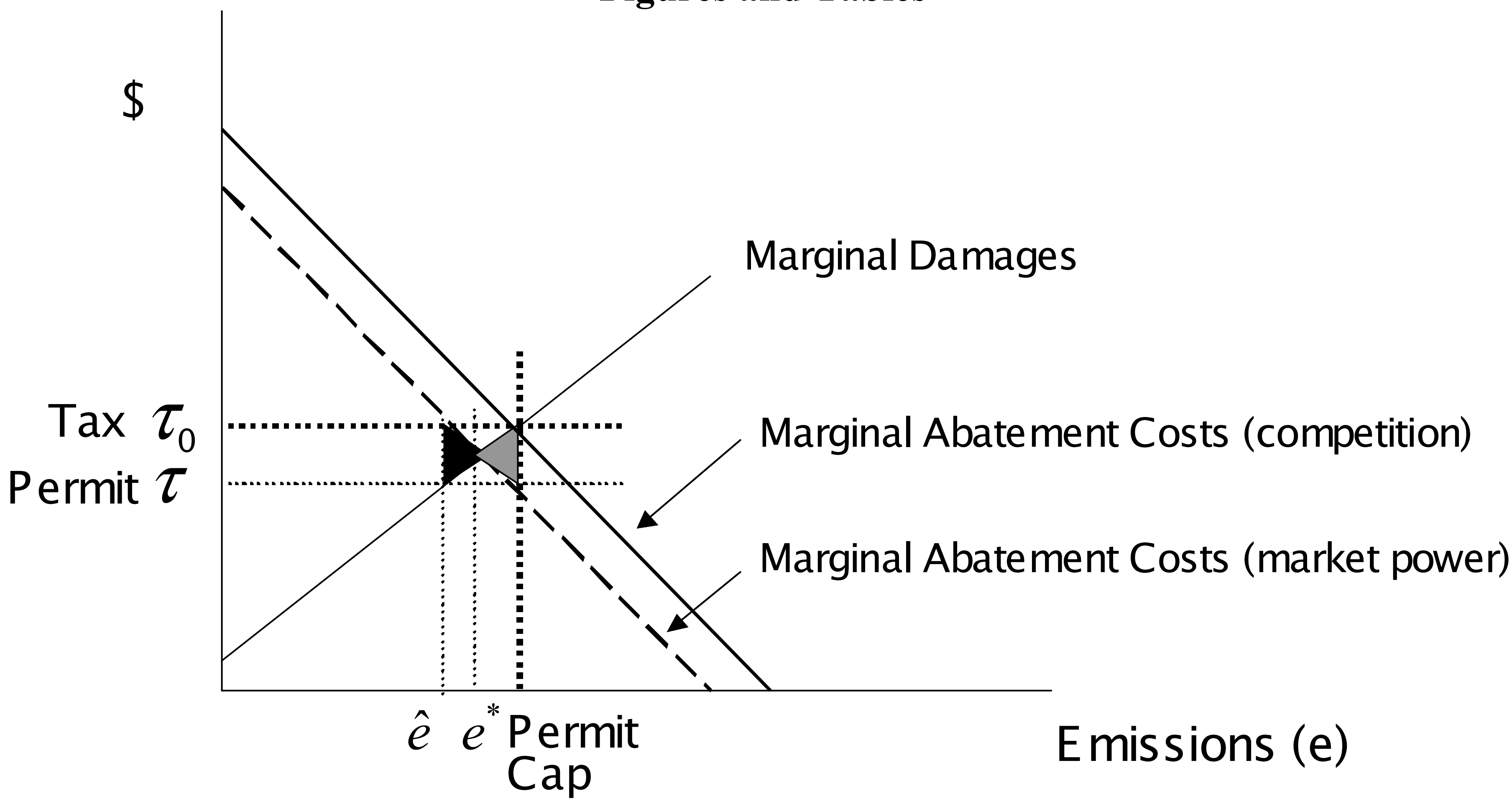

Figure 1: Implications of Strategic Behavior for Environmental Regulations: The Case of a Relatively Dirty Dominant Firm.

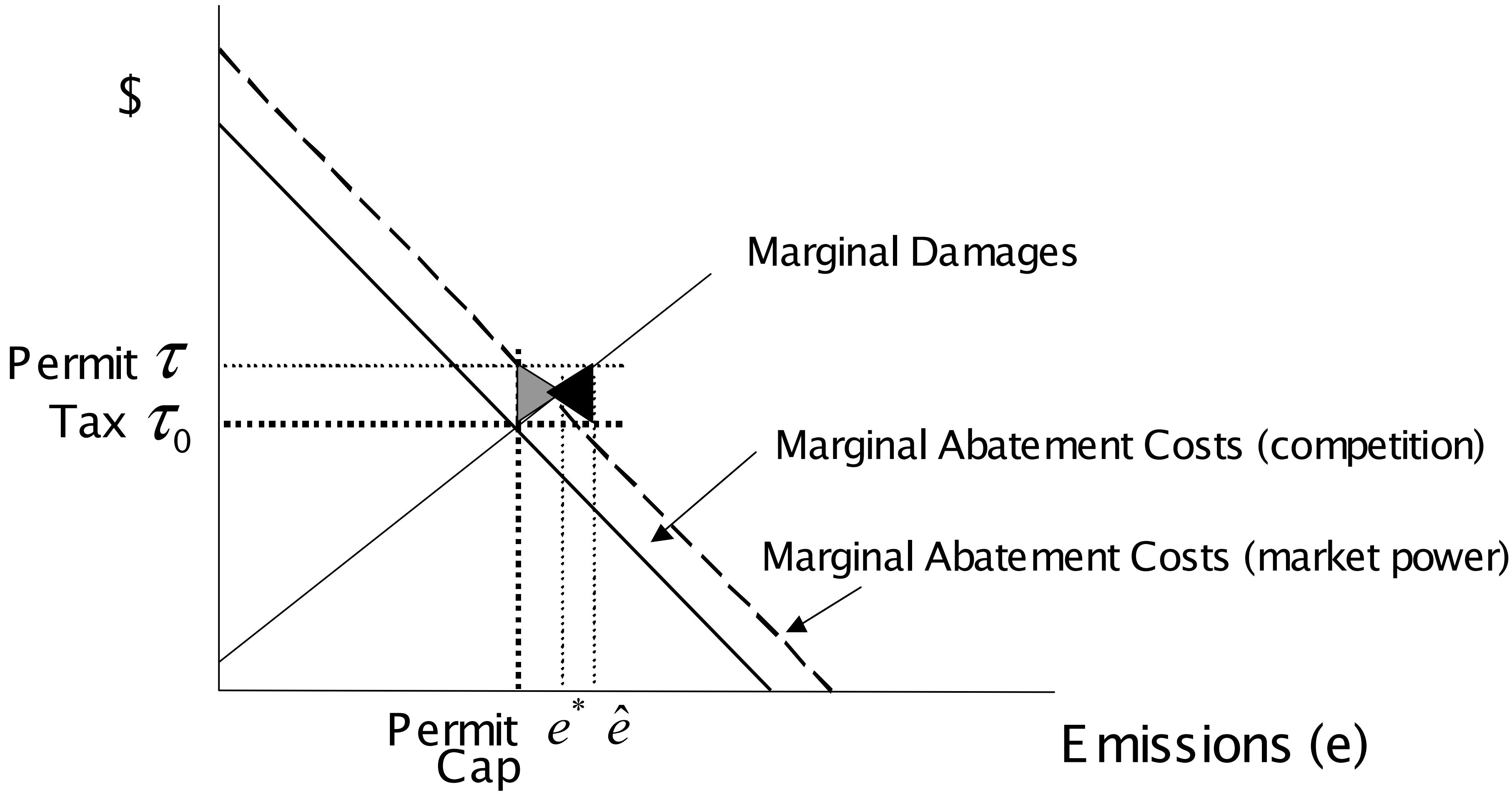

Figure 2: Implications of Strategic Behavior for Environmental Regulations: The Case of a Relatively Clean Dominant Firm.

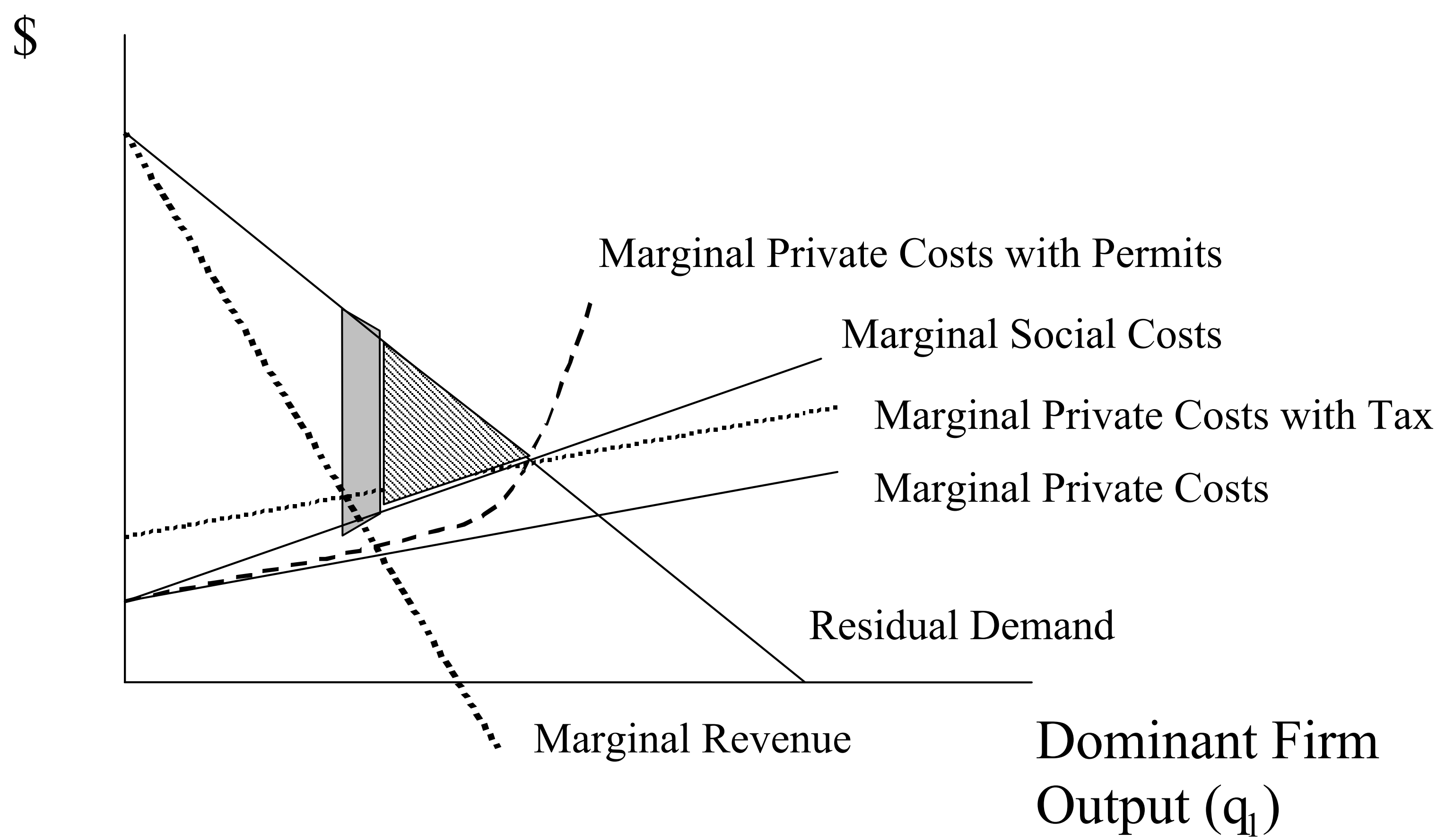

Figure 3: Implications of Strategic Behavior for Production: The Case of a Relatively Dirty Dominant Firm.

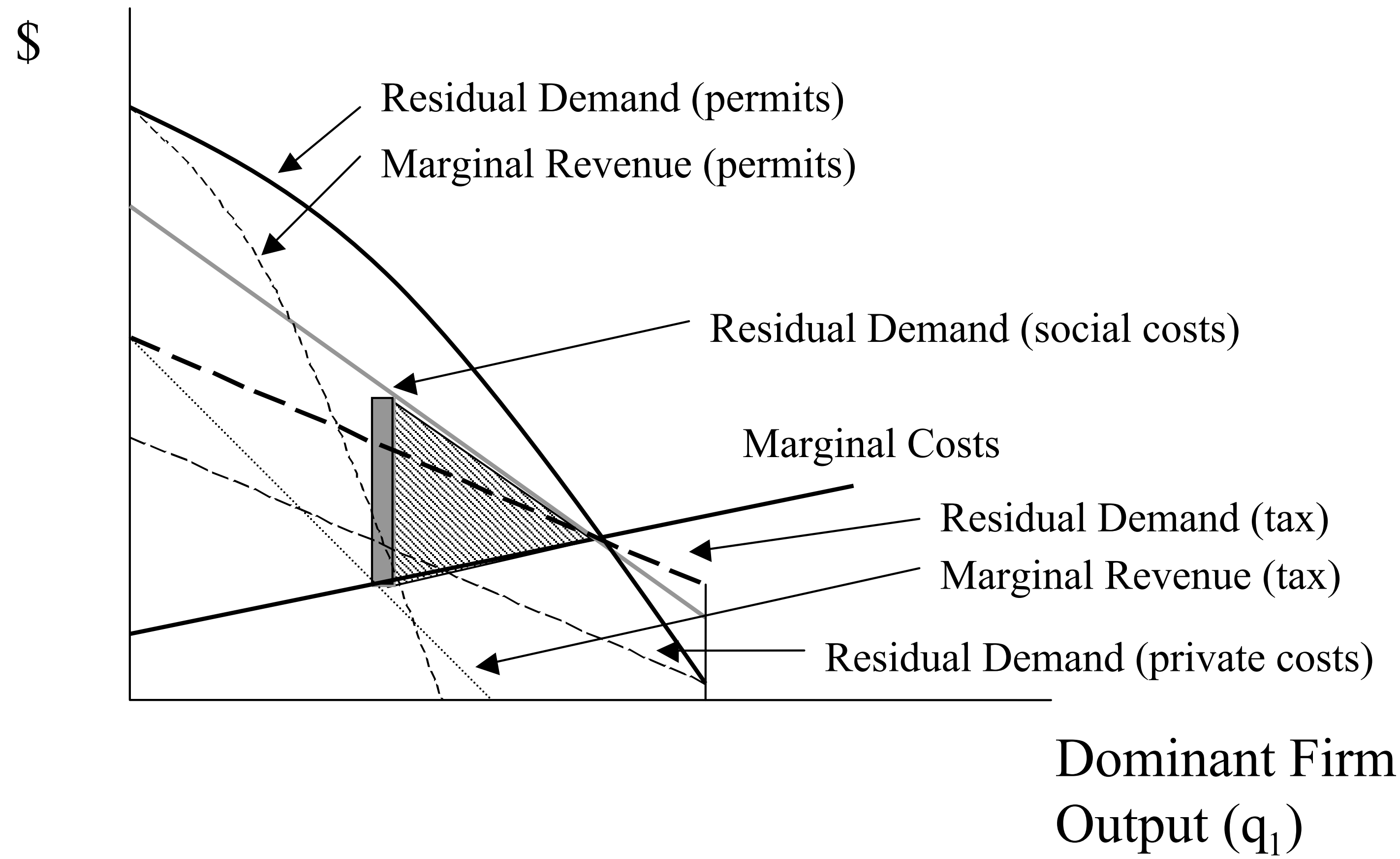

Figure 4: Implications of Strategic Behavior for Production: The Case of a Relatively Clean Dominant Firm.

Table 1

Simulation of Policy Choice Effects on Emissions and Welfare

	Permit System	Tax	Difference	Percent Difference
Marginal private cost of a ton of NO_x pollution	$1,000	$1,934	$934	93%
NO_x emissions (tons)				
Cournot	88,222	85,923	2,300	2.7%
Competitive[a]	100,936	97,096	3,839	4.0%
Difference	12,713	11,174		
Percent difference	11%	12%		
Additional permits[b]			8,874	10.1%
Variable costs ($ millions)				
Cournot	1,565	1,573	8.3	
Competitive	1,452	1,452	0	
Welfare loss				
Emissions component			-4.4	
Firm cost component			11.7	
PJM total	113	121	8.3	7.4%
Percent loss	7.8%	8.3%		
Change in Imports			3.0	
Total			11.3	10.0%
Percent loss				

Notes:

a) Under a permit system, the competitive regime's permit price would equal $1934/ton. The first column holds the price at $1000/ton (the Cournot regime's permit price) for comparison purposes only.

b) "Additional permits" compares the Cournot regime's emissions at a $1000/ton permit price with the competitive regime's emissions at a $1934/ton permit price or tax.

Appendix A

Proof of Proposition 1.

Because demand is perfectly inelastic, the price in the product market $P(q_m)$ is determined by the marginal cost of the fringe. Under a tax, $P(q_m)$ equals:

$$\begin{aligned} P(q_m) &= c_f'(q_f) + \tau_0 r_f \\ &= c_f'(\overline{q} - q_m) + \tau_0 r_f. \end{aligned} \tag{A1}$$

Hence, (7) can be written to define $\widehat{q}_m$ as a function of exogenous parameters:

$$c_f'(\overline{q} - q_m) + \tau_0 r_f - c_f''(\overline{q} - q_m) \cdot q_m - c_m'(q_m) - \tau_0 r_m = 0 \tag{A2}$$

Similarly, for a price taking firm, (3) can be written to define q_m^* :

$$c_f'(\overline{q} - q_m) + \tau_0 r_f - c_m'(q_m) - \tau_0 r_m = 0 \tag{A3}$$

Comparing (A2) and (A3) at q_m^*, and noting that $c_f''(\overline{q} - q_m) > 0$, the strategic firm will always produces less than it would have in a competitive market: $\widehat{q}_m < q_m^*$. With perfectly inelastic demand, the opposite holds for the fringe: $\widehat{q}_f > q_f^*$.

Q.E.D.

Derivation of Equation (10).

As in the proof of proposition 1, residual demand $(P(q_m))$ is defined by the fringe's marginal cost. Under a permit system, this equals:

$$P(q_m) = c_f'(\overline{q} - q_m) + \tau(q_m) \cdot r_f. \tag{A4}$$

This implies that the slope of the residual demand function will be:

$$P'(q_m) = -c_f''(\overline{q} - q_m) + \tau'(q_m) \cdot r_f \tag{A5}$$

The first order condition (9) is modified for the dominant firm as:

$$\begin{aligned} \frac{d\pi(\tau(q_m))}{dq_m} &= [c_f'(\overline{q} - q_m) + \tau(q_m) \cdot r_f] + [-c_f''(\overline{q} - q_m) + \tau'(q_m) \cdot r_f] \cdot q_m \\ &\quad -c_m'(q_m) - \tau(q_m) \cdot r_m - \tau'(q_m) \cdot (q_m r_m - \overline{e}_m) = 0. \end{aligned} \tag{A6}$$

Under a tax, based on (A1), the dominant firm's first order condition (7) is rewritten as:

$$\frac{d\pi(\tau_0)}{dq_m} = [c_f'(\overline{q} - q_m) + \tau_0 \cdot r_f] + [-c_f''(\overline{q} - q_m)] \cdot q_m - c_m'(q_m) - \tau_0 \cdot r_m = 0. \tag{A7}$$

Note that $\frac{d\pi(\tau_0)}{dq_m}|_{\widehat{q}_m} = 0$. Subtracting (A7) from (A6), the cost equations cancel, yielding (10).

Appendix B

For a firm regulated by a tradable permit system, this appendix discusses the relationship between a firm's production in a competitive market (q_m^*) and its production in a imperfectly competitive market ($\widetilde{q}_m$). The strategic firm can affect prices in the product ($P(q_m)$) and permit markets ($\tau(q_m)$). A firm will exercise monopoly or monopsony power depending on whether its sells or buys permits, on net [14]. In comparing (3) and (9), the firm will produce less when acting strategically than it would have in a competitive market as long as, at $q_m = q_m^*$:

$$P'(q_m) \cdot q_m < \tau'(q_m) \cdot (q_m r_m - \overline{e}_m). \tag{B1}$$

This holds when permits are allocated $\overline{e}_m = q_m^* r_m$, as assumed in this paper. To see this, note that when $q_m = q_m^*$, (B1) is simplified to $P'(q_m^*) < 0$. Thus, at q_m^*, the first order incentive to set high prices in the product market dominates the second order incentive to set permit prices.

However, if permits are allocated differently, then the incentives to set permit prices may dominate. As section 4 discusses, increasing output may increase the permit price in some cases, but will decrease it in others. In the case of a positive $\tau'(q_m)$, had the firm been allocated a substantial amount of permits, it would want to produce more in order to drive up the permit price and this inequality would fail. Similarly, in the case of a negative $\tau'(q_m)$, if the firm had been given very few permits, then the firm would increase production and reduce the permit price (as explained in the paper, by reducing demand for other, dirtier firms' production). This would also result in the failure of the inequality.

Another reason firms may have incentives to affect the market price is in order to raise their rivals' costs [25],[28]. Kolstad and Wolak [18] find that firms' behavior in California is consistent with this incentive. However, this is beyond the scope of this paper. In contrast to the previous research on market power in permit markets and raising rivals' costs, this paper focuses on another aspect of permit prices: namely, input prices may be affected by firm behavior, which in turn has welfare implications.