Three Essays on Environmental Policy and Institutions

by

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ABSTRACT

This dissertation examines three topics related to contemporary environmental policy.

The first essay examines the impact of government procurement policies that favor environmentally superior products. If a good is purchased by both the government and the private sector and marginal costs are increasing, private substitution will offset, in whole or in part, government procurement policies. Such crowding out implies that, in the absence of other policy instruments, the optimal price preference for a 'green' product will be less than an optimal Pigouvian tax. If marginal costs are sufficiently decreasing (i.e., economies of scale are sufficiently large), then changes in private consumption may amplify a procurement policy; in such cases, the optimal environmental preference may exceed a Pigouvian tax. When government purchases are funded by distortionary taxes, the optimal environmental preference will be correspondingly lower.

The second essay explores the institutional structure of the waste-to-energy (WTE) and landfill gas recovery (LGR) industries. In particular, it examines various factors that influence government decisions about privatization. A simple accounting model indicates that federal tax policy can create significant capital cost differences between public and private ownership; for most of the period studied, these differences favored private ownership. The temporal pattern of privatization of WTE and LGR facilities indicates that these capital cost differences have had a substantial effect on privatization decisions; private ownership was substantially more common during the favorable tax regime of the early 1980's than before or after. Transaction costs associated with specific assets also influence privatization decisions. Assets that are more specific to a transaction with a local government are more likely to be governed under long-term contracts or by vertical integration (i.e., public ownership) than are less specific assets.

The third essay considers the design of auctions for tradeable pollution permits. Economic analyses suggest that tradeable permit systems can provide substantial efficiency gains compared to traditional command and control regulation. However, it is difficult to design actual permit markets that take full advantage of these gains.

Transaction costs and thin markets, in particular, can undermine market efficiency. This essay describes a category of uniform price combinatorial auctions that can reduce potential market inefficiencies. These auctions are specifically designed for tradeable permit systems that involve multiple types of permits and in which, as a result, polluters will want to buy and sell permit combinations. These auctions may be used both for the initial distribution of permits by the government and for the exchange of permits thereafter. The essay presents both the general design of these auctions as well as an application to the sulfur dioxide permit market currently developing in the United States.

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INTRODUCTION

It has become increasingly common for environmental advocates to couch their arguments in economic terms. Thus opponents of logging on federal lands argue that the Forest Service is losing money on its forest management practices; energy conservation advocates argue that energy efficiency is less expensive than building new power plants; recycling advocates argue that government procurement standards for products made of recycled content will internalize the costs of waste disposal and virgin materials use, and environmental groups argue that the costs of air emissions from utility power plants can be internalized by the use of externality adders in the public utility regulatory process, among many other examples.

While the increasing application of economic concepts to environmental issues is a welcome development, the quality of the underlying economic thought varies widely. In many instances, environmental advocates use economic terms (prices, incentives, externalities, internalization, market imperfections, monopolization, etc.) without fully understanding the economic content of these notions or the implications thereof.

The first two essays in this dissertation derive from a concern that some current environmental policy proposals are of this type: couched in economic terminology yet backed by insufficient economic analysis. These essays find that two proposals - the idea that governments should favor 'green' products in their procurement policies and the assertion that long-term contracts with waste-to-energy facilities monopolize disposal markets, inefficiently discourage recycling, and should therefore be eliminated - are based on an incomplete understanding of economics and economic behavior. The third essay then considers a recent environmental policy innovation, the development of tradeable permit systems, that is based on sound economic reasoning but whose use raises important issues of implementation; this essay suggests a possible approach to market design that may improve the operation of certain permit markets.

Essay 1: Government procurement of 'green' products

The first essay examines the idea that governments ought to structure their procurement policies to favor 'green' products. Advocacy of government procurement standards is a classic instance in which environmentalists have adopted the language of economics. Procurement standards, whether implemented via set-asides (x% of government purchases must be of 'green' goods) or price-preferences (the government is willing to pay more for 'green' goods than 'brown' goods), are said to create market incentives for producers of 'green' products while internalizing the costs of waste disposal and virgin materials use.

This essay examines whether and to what extent these and related claims are supported by some economic models; while these models support some of the general assertions about procurement policies, they also demonstrate some important difficulties with such policies. Under standard conditions of increasing marginal costs and competitive markets, for example, government procurement standards may crowd out private purchases of 'green' products; while the government buys more of the 'green' good, the private sector buys less. As a result, the net effect of a government procurement policy may be substantially smaller than its gross effect on government purchases.

This result is of general import because it exemplifies some important problems with piece-meal environmental policies, of which government procurement policies are only one example. While environmentalists often argue that it is better to regulate at least part of the economy if, for political reasons, they cannot regulate all of it, the crowding out result indicates that the benefits of regulating a portion of the relevant market may be significantly less than a pro-rata share of the benefits of regulating the entire market. Because piece-meal regulation induces distortions in the unregulated portion of the market, both the marginal and the total benefits of such policies are reduced.

Results may differ, however, if production is characterized by decreasing marginal costs and competition is imperfect. Under such conditions, private sector activities may actually amplify the effects of a government procurement policy. This result is more consistent with the claims of environmentalists who often assert that a main benefit of procurement standards is to help 'green' firms take advantage of economies of scale.

Even in this case, however, economic analysis highlights some important subtleties to the argument. First, the analysis shows only that it is possible for private behavior to amplify the government policy; the mere existence of scale economies is by no means sufficient for this result. Second, the analysis indicates that the relevance of the scale economy arguments depends on whether the economies of scale are in production of the 'green' good or the 'brown' good and whether the 'green' good is 'green' because its production avoids a negative externality or because it creates a positive externality. In the case of avoiding a negative externality, it turns out that the crucial economies of scale are those in production of the 'brown' good, while for creating a positive externality the crucial scale economies are in production of the 'green' good. Thus, the scale economies argument must be nuanced to recognize that the identity of the relevant scale economies depends on the type of externality.

Essay 2: Institutional aspects of the waste disposal industry

The second essay in this dissertation applies a very different type of economic reasoning to environmental issues involving the institutional structure of the waste disposal industry. Recycling advocates have recently claimed that long-term contracts with waste-to-energy (WTE) facilities (which they call 'incinerators') and flow control policies guaranteeing waste to these facilities are providing inappropriate disincentives to recycling. Specifically, recycling advocates argue that long-term contracts, minimum take requirements, and flow control ordinances essentially monopolize the waste disposal market, are therefore inefficient, and should therefore be invalidated.

To the economically unseasoned (and, indeed, to many of the economically seasoned), this argument has a ring of plausibility: why should waste be guaranteed to a facility for twenty years or more when it may turn out (as it has in the late 1980's and early 1990's) that the market cost of waste disposal will be substantially less than the contract rates? The long-term contracts, flow control, etc. appear to force uneconomic disposal, relative to current spot market costs, by granting a monopoly to the WTE facility.

Many economists once shared a similarly dim view of such restrictive long-term contracts. As noted by Joskow (1991, p. 60), they often believed that such contracts were "mysterious, suspect, and indicative of market power". In the past two decades, however, an increasing body of literature on institutional choice has illustrated that long-term contracts, vertical integration, and other types of restrictive vertical relationships may instead arise from legitimate economic concerns and may reflect efficient, non-monopolistic choices by the parties to those relationships. A primary example of this reasoning is the paradigm of transaction cost economics (Klein, Crawford, and Alchian 1978; Williamson 1979, 1985) which recognizes that the costs of executing transactions may vary with institutional structure, that certain institutional structures may therefore be more efficient than others, and that, in particular, restrictive vertical relations, including long-term contracts and vertical integration, may be appropriate when long-lived sunk investments are required.

Because WTE facilities involve significant sunk investments, transaction cost reasoning may provide significant insight into the governance issues raised by recycling advocates. Moreover, because these institutional structures involve a choice between public and private ownership of facilities, this reasoning may also provide insight into governments' privatization decisions and, more generally, may help to define the frontier between public and private enterprise. Thus this essay focuses on factors related to the privatization decision, including transaction cost issues and federal tax policy, with an analysis of the environmental aspects of governance following as an important corollary.

The empirical analysis suggests that the governance structures for two types of waste disposal facilities, WTE facilities and landfill gas recovery (LGR) facilities, vary in ways predicted by transaction cost theory. As a result, it is reasonable to expect that long-term contracts and vertical integration (public ownership) will arise in this industry out of purely efficiency-enhancing motivations; such relationships are not obviously monopoly-related. These results are only strengthened by the tax policy analysis, which finds that federal corporate tax policy has had an important impact on ownership decisions over time while between different types of facilities, ownership appears to be driven by institutional concerns.

Essay 3: The design of tradeable permit markets

The third and final essay developed from a somewhat different angle on contemporary environmental economics. It focuses on the design of markets for tradeable pollution permits, a long-time favorite of economists that has recently gained widespread interest in environmental policy circles. Here the issue is not so much one of whether the basic economic ideas are correct (although that is an issue in certain permit systems), but how to implement those ideas in an efficient manner.

This essay considers one important aspect of many real-world permit systems - the need for many different types of permits and the resultant need of polluters to own permit portfolios - and suggests one approach to market design that may be appropriate in such a setting.

While economic analyses suggest that tradeable permit systems can provide substantial efficiency gains, compared to traditional command and control regulation, by encouraging private agents to adopt least-cost pollution control measures, it is difficult to design actual permit markets that take full advantage of these efficiency gains. The experience of some early permit systems (e.g., the bubble and offset systems created under the United States Clean Air Act) indicates that transaction costs and thin markets, for example, can undermine market efficiency (Hahn and Hester 1989; Atkinson and Tietenberg 1991). Such inefficiencies may be particularly likely in systems that involve many different types of permits. The SO_2 trading system, for example, involves different permits for each year (so utilities currently hold portfolios of up to thirty different types of permits), while the trading system in Los Angeles includes at least eight types of permits in each year (two pollutants in two regions with two compliance schedules), leading firms to hold as many as eighty or more different types of credits. In these cases, polluters will hold complex permit portfolios and may need to execute trades that involve many different types of permits.

This essay describes a category of call auctions - uniform price combinatorial auctions - that are explicitly designed for such multi-permit systems. These auctions may be used both for the initial distribution of permits by the government and for the exchange of permits thereafter. The key attribute of these auctions is that they allow participants to define bids, offers, and more complicated orders over multiple permit types. Because similar auctions have performed well in experimental settings and because related, but simpler, auctions have the attractive incentive properties of a second-price auction, the essay suggests that such auctions may be a useful way to trade pollution permits.

Conclusion

While these three essays differ in subject, focus, and style, they share an underlying belief that economic reasoning can improve the design and implementation of environmental policies. That the essays employ quite different modes of economic analysis - theoretical, empirical, institutional, etc. - simply illustrates that economics offers a broad range of analytic methods and insights that are relevant to environmental policy. That the analyses in some cases lead to issues well beyond the scope of environmental issues *per se* (e.g., the determinants of privatization and the design of auctions) simply illustrates the converse, that interesting economics can be motivated by investigation of environmental issues.

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ESSAY 1

BUYING GREEN: GOVERNMENT PROCUREMENT AS AN INSTRUMENT OF ENVIRONMENTAL POLICY

1. INTRODUCTION

In recent years, policy makers have increasingly tried to use government purchasing as an instrument of environmental policy. For example, since 1976 the United States federal government has passed a series of laws designed to favor energy efficient products and recycled products in government procurement. All fifty states and many municipalities have similar laws and policies favoring procurement of goods considered environmentally superior. This paper considers whether such procurement policies can be effective and useful instruments of environmental policy.

Environmental procurement policies are typically justified as a mechanism for internalizing the environmental costs (or, in some cases, the environmental benefits) of producing goods for government consumption. In the absence of policies that internalize these costs (and benefits) throughout the economy, it is argued that the government, at least, should account for these costs (and benefits) in its own purchasing decisions. Procurement policies are also justified as a means of promoting the development and adoption of 'green' technologies (see, e.g., Nader, Lewis, and Weltman 1992). In this perspective, 'green' firms use the government purchases to establish their product, to take advantage of economies of scale, and to begin a process of lowering costs through learning-by-doing. The government purchases thus act as a catalyst for cost reductions and private market acceptance of the environmentally favored product or technology.

This paper will evaluate these arguments by modeling the effects of environmental procurement policies in a variety of market settings (homogenous and differentiated goods in competitive markets, imperfectly competitive markets, and competitive bidding). By considering a range of settings, it will be possible to identify conditions under which procurement policies may be particularly effective or ineffective. These positive analyses will build upon previous studies that have examined the effect of domestic preferences in government procurement (Baldwin 1970, Herander 1982, Miyagiwa 1991, and McAfee and McMillan 1989). The paper will also derive the optimal procurement policy (in terms of an optimal price preference for 'green' products) for a government that has no other policy instruments. This second-best policy analysis will highlight the important differences between environmental procurement policies and first-best policies such as Pigouvian taxes.

While results vary somewhat with the setting, a number of basic findings recur throughout this analysis. First, if the government purchases a product that is also sold to the private sector, then government procurement policies will influence private purchasing decisions. If marginal costs are increasing, private substitution will diminish the effect of the government policy. As the government purchases more of the environmentally superior good and less of the environmentally inferior, price signals will encourage the private sector to substitute in an offsetting manner. The net effect of a procurement policy on overall consumption patterns will therefore be smaller, sometimes significantly, than its gross effect on government consumption. As a result, the optimal price preference for a 'green' product will be less than an optimal Pigouvian tax.

If marginal costs are constant, there is no private substitution, and government procurement policies are completely successful. While marginal costs are typically increasing in the short-run, free entry and exit and the absence of any scarce factors of production imply that long-run marginal costs are constant. In such cases, private substitution will occur in the short-run, but will be eliminated in the long run.

If marginal costs are sufficiently decreasing, price changes may encourage the private sector to substitute in the same direction as the government, thereby amplifying the effect of procurement policy. If a 'brown' good creates a negative externality and is produced with economies of scale or a 'green' good creates a positive externality and is produced with economies of scale, then the optimal environmental preference for the 'green' good may exceed the value of the externality.[1] While most popular discussions of procurement policy focus on economies of scale in production of 'green' goods, this result indicates that economies of scale in production of 'brown' goods also matter.

A second finding is the importance of the cost of raising government funds. Although many policy analyses assume (often implicitly) that government funds can

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[1] Pollution in the production of a 'brown' good is an obvious example of a negative externality. Production of a 'green' good may create a positive externality if, for example, that production uses an otherwise damaging waste product.

be raised through non-distortionary revenue sources[2], in reality government revenues are often raised through distortionary taxes. These distortions should be taken into account in evaluating the costs of government procurement policies. In general, the additional cost of distortions will make procurement policies a less attractive instrument of environmental policy and will imply that optimal price preferences are correspondingly lower.

The paper proceeds in the following manner: Section 2 provides a brief review of environmental procurement policies and their use in the United States. Section 3 then presents a simple model of government procurement policies in a competitive market for an homogenous good that is produced by two technologies, one of which produces a non-internalized externality. This model provides a clean illustration of the importance of private substitution and the cost of government funds. Section 4 extends this model to the more realistic case of differentiated goods. Section 5 considers how results may differ under imperfectly competitive markets (including those characterized by economies of scale). Section 6 considers how results may differ when the government purchases via competitive bidding. Section 7 then summarizes the results and concludes.

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[2] These include lump sum taxes, user fees for government services, and revenues from Pigouvian taxes.

2. ENVIRONMENTAL PROCUREMENT POLICIES

a. Types of policies

There are four basic types of procurement policies. First, and least controversial, are those that attempt to eliminate unnecessary biases against environmentally superior products. In some cases, government procurement guidelines overspecify product requirements in such a way as to exclude some essentially equivalent products. To the extent that the excluded products are environmentally superior (e.g., made of recycled content), removing such exclusions may decrease environmental harms and, in addition, reduce costs to the government (since the government will purchase these alternatives if they are cheaper).

Second, but closely related, are policies that base procurement decisions on life-cycle costs[3] rather than initial purchase costs. For these policies, the concern is that government procurement agents may be unwilling to purchase products with high upfront costs even if they ultimately reduce costs over the lifetime of use.[4] A typical example is the decision to invest in energy efficient devices. More efficient devices typically have greater initial costs but offer the possibility of reduced energy costs (and possibly other benefits) over a lifetime of use. Encouraging procurement agents to purchase cost-effective energy-using devices may thus lead to reduced government

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[3] In this context, life-cycle refers to all costs incurred by the user during product use. It does not refer to all costs of the product life-cycle, which include environmental costs of production.

[4] This unwillingness may stem from myopia, career concerns, or improper incentives from budgetary institutions.

costs and reduced environmental damages associated with energy production.

Third, there are price preference policies in which the government commits to purchasing environmentally superior products so long as their prices do not exceed those of alternatives by more than a specified amount. Typical policies give a 5% to 15% price preference to environmentally superior products.[5]

Fourth, there are set-aside policies that establish specific targets for consumption of the environmentally superior good. For example, many state governments have targets for recycled paper use (e.g., 40% of usage by the year 2000).

This paper will focus on the latter two types of policies. While the first two types may have beneficial effects on the environment, they can be justified purely in terms of minimizing costs to the government. In essence, they fall under the well-studied problem of how to make government procurement more efficient (for the theoretical frontier in this area, see Laffont and Tirole (1993)). Price preference and set-aside policies, on the other hand, explicitly require the government to incur increased costs in order to buy the environmentally superior good; they thus run contrary to the goal of minimizing government costs.

[5] These policies are quite similar to some externality adder programs that have been adopted by state utility regulators. As a result, many of the results presented here will also apply to the case of preference policies applied to regulated firms. The parallels between procurement policy and regulatory policy in general are, of course, quite familiar (see, e.g., Laffont and Tirole (1993)).

b. Policies adopted in the United States

At the federal level, environmental procurement standards date from at least the mid-1970's. The Resource Conservation and Recovery Act (RCRA) of 1976, for example, requires that federal procurement be "effected in a manner that maximizes the use of recovered materials" (Witt 1977). This policy is explicitly intended to "use the stimulus of government procurement to increase the use of these products within both government and private sectors" (EPA 1991).

Under RCRA, the Environmental Protection Agency (EPA) is required to prepare guidelines describing the availability, sources, and potential uses of recovered materials in satisfying government purchasing needs.[6] As of this writing, the EPA has published five such guidelines: paper and paper products, lubricating oils, retreaded tires, building insulation products, and cement and concrete containing fly ash.[7] Additional guidelines are being prepared for geotextiles, compost, and other products.

The procurement guidelines neither include, nor explicitly forbid, a price preference for the favored good. They do suggest that specific minimum content standards be used in agency procurement and they do require that each purchasing

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[6] Procuring agencies can decide not to purchase items specified in the guidelines if "a guideline item's price is unreasonable; applying minimum-content standards results in inadequate competition; obtaining designated items results in unusual and unreasonable delays; or guideline items do not meet all reasonable performance specifications" (EPA 1990).

[7] The first of these did not appear until 1983 (flyash in concrete); the others were issued in 1988 and early 1989.

agency (including essentially all recipients of federal funds) develop an active preference policy for favored goods. RCRA is currently up for reauthorization; there is significant interest in including an explicit price preference policy.

A series of energy bills (dating at least from the Energy Policy and Conservation Act of 1976 to the Energy Policy Act of 1992) have similarly required the government to procure energy efficient products. In some cases, these laws have also required the use of life-cycle costing in procurement decisions.

Procurement policies at the federal level are likely to expand under the Clinton administration. In his 1993 Earth Day address, the President indicated that federal agencies would be instructed to favor products that are made of recycled waste, that are energy efficient, and that do not use ozone-depleting chemicals. Consistent with one of the mandates of the Energy Policy Act, federal agencies will also be required to purchase vehicles that use alternative fuels (e.g., electricity, natural gas, ethanol, or methanol).

In addition to the federal policies, all fifty states have some type of preference policy for products made from recycled content. At least thirty-two of these have explicit price preference policies that apply a 5% to 15% preference to recycled products (Raymond 1992). Additional states also have set-asides specifying particular targets for government use of recycled products. These policies apply to a wide variety of products.[8] In addition, some states also have preferences based on other

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[8] According to Macdonald (1991) and Raymond (1992), products subject to procurement guidelines for recycled content in at least one state include: paper, newspaper, plastic, compost, rubberized asphalt, batteries, fuels, cellulose insulation,

environmental concerns, e.g., policies that favor soy ink and unbleached paper. Raymond (1992) provides a detailed overview of state recycling laws including procurement preferences.

3. PROCUREMENT IN A COMPETITIVE MARKET FOR AN HOMOGENOUS GOOD

To analyze the effect of environmental procurement policies, we begin by considering a competitive market for an homogenous good that can be produced by two technologies. For each unit of output, technology 1 (the 'brown' technology) produces some negative externality (e.g., air pollution); this externality has monetary value $w > 0$. Technology 2 (the 'green' technology) produces no such externality.[9] Firms using technology i ($i = 1,2$) have an aggregate (over all firms) cost function $c_i(Q_i)$; we make the standard assumptions that $c_i' > 0$, and $c_i'' \geq 0$ (declining marginal costs are considered in a later section on oligopoly).

The good is demanded by the government and by the private sector. For simplicity, we assume that the government demands a fixed quantity G. This assumption allows us to focus on the allocation of government purchases among the two technologies while abstracting from the aggregate amount of government

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steel, rubber, tires, paint, antifreeze, air conditioning filters, carpeting, electrical equipment, laser printer cartridges, lubricating oils, solvents, and concrete.

[9] Our primary model thus focuses on procurement policies that attempt to internalize (partially) a negative production externality. The formal analysis of a positive externality in production of the 'green' good is almost identical; the few important differences will be noted where appropriate.

purchases. The private sector has a downward sloping demand curve D(p) and corresponding inverse demand curve P(q). We let G_i denote government purchases, D_i denote private sector purchases, and p_i denote the market price for each good i (we refer to the production of technology i as good i although the goods are physically identical).

To pay for its purchases, the government raises revenue through distortionary taxes. Each dollar spent on government purchases therefore costs society λ, where $\lambda > 0$ is the shadow cost of public funds;[10] we assume that λ is unaffected by government policies in the product market. Firms and consumers in the private sector act as price takers. The government, however, is aware that its purchasing decisions may influence production decisions and, hence, market prices.

a. Equilibrium with no procurement policy

In the absence of an environmental procurement policy, both the government and the private sector purchase the good at the lowest possible price. The market equilibrium is then defined by

[10] Attempts to estimate λ depend heavily on underlying assumptions about tax and expenditure policies and behavioral elasticities; as a result, estimates vary significantly. A reasonable range, at least for illustrative purposes, would be λ in the range .1 to .4; for a review of estimates see Jorgenson and Yun (1992) and references therein.

$$
\begin{aligned}
Q_1^n &= G_1^n + D_1^n \\
Q_2^n &= G_2^n + D_2^n \\
p_1^n &= c_1'(Q_1^n) \\
p_2^n &= c_2'(Q_2^n) \\
p^n &\equiv p_1^n = p_2^n \\
G^n &= G_1^n + G_2^n \\
D(p^n) &= D_1^n + D_2^n,
\end{aligned}
\tag{1}
$$

where the superscript n denotes the no policy equilibrium. Competitive behavior implies that prices are equal to marginal costs. The equality of prices results because the good is homogenous and, therefore, purchasers are indifferent to the production technology.[11]

b. Equilibrium with a procurement policy

As noted earlier, procurement policies can be expressed as price preferences or as set-asides. In the current setting (competitive markets with no uncertainty) the two approaches are, of course, functionally equivalent. Because the positive analysis of procurement policy will focus on quantity outcomes (in particular, crowding-out results), it is useful to model procurement policy as a set-aside that specifies government consumption of the 'green' good (G_2). Each set-aside implicitly defines an equivalent specific price preference $a = p_2 - p_1$; this price preference will play a

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[11] This price equality also assumes that both technologies are actually used, an assumption that we maintain throughout. Formally, we assume that $c_i'(0) < p_i^*$, ($i \neq j$) where p_j^* is the technology j "stand-alone" price defined by

$$p_j^* \equiv c_j'(G + D(p_j^*)) .$$

central role in a later section, when we consider the normative analysis of optimal procurement policy.

The most important aspect of the no policy equilibrium defined by (1) is that it does not uniquely determine the G_i and D_i; because the good is homogenous, only G and $D(p^n)$ are uniquely determined. If total government purchases are less than the no policy production of good 2 (i.e., $G \leq Q_2^n$), then no government procurement policy can increase the amount of production of good 2.[12] A procurement policy could appear completely successful, with 100% 'green' purchases by the government, and yet have no net effect on production because government purchases of the 'green' good crowd out private purchases one-for-one. Of course, the procurement policy would also impose no costs on the government since the price of each good remains at the no policy level.

For procurement policy to have any net effect, we therefore require that $G > Q_2^n$, i.e., government demand is greater than the no policy production of good 2. To influence overall production decisions, government policy must completely crowd out private purchases of good 2 (Herander (1982) also derives this result). Thus, the new market equilibrium will be defined by

[12] Baldwin (1970) and Herander (1982) have previously derived this policy irrelevance result in the context of procurement policies that favor domestic producers.

$$
\begin{aligned}
Q_1 &= G_1 + D(p_1) \\
Q_2 &= G_2 \\
p_1 &= c_1'(Q_1) \\
p_2 &= c_2'(Q_2) \\
G &= G_1 + G_2 .
\end{aligned}
\tag{2}
$$

Note that the market prices for good 1 and good 2 are no longer equal. In order to promote production of good 2, the government must provide a price preference.

We evaluate the effect of procurement policies by considering how a switch in government demand from good 1 to good 2 affects production of both goods. Once private consumption has been crowded out, we have that $dQ_2/dG_2 = 1$; total production of good 2 increases one-for-one with government purchases.[13] To find the effect on good 1, we note that

$$
\frac{dQ_1}{dG_2} = \frac{dD}{dG_2} - 1 = \frac{\partial D}{\partial p}\frac{dp_1}{dG_2} - 1 . \tag{3}
$$

From the equality of price and marginal cost, we have

$$
\frac{dp_1}{dG_2} = c_1'' * \left(\frac{\partial D}{\partial p}\frac{dp_1}{dG_2} - 1\right) \quad \rightarrow \quad \frac{dp_1}{dG_2} = \frac{-c_1''}{1 - c_1''\frac{\partial D}{\partial p}} . \tag{4}
$$

To make this expression more intuitive, we define the following supply and demand elasticities (all elasticities are defined to be positive numbers):

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[13] For the positive externality case, this implies that, in this setting, procurement policy is completely effective at the margin. In the aggregate, the effect of the policy is less than one-for-one, since some portion of the switch in government consumption to the 'green' good is required to crowd out private consumption.

$$\eta_1 \equiv \frac{\partial Q}{\partial p_1}\frac{p_1}{Q_1};\ p_1 \equiv c_1'(Q_1) \quad \Rightarrow \quad \eta_1 = \frac{p_1}{Q_1 c_1''}$$
$$\epsilon_{11} \equiv -\frac{\partial D}{\partial p}\frac{p_1}{D}. \tag{5}$$

Substituting these into (4), we find

$$\frac{dp_1}{dG_2} = -\frac{p_1}{\eta_1 Q_1 + \epsilon_{11} D}, \tag{6}$$

implying

$$\frac{dQ_1}{dG_2} = -\frac{\eta_1}{\eta_1 + \epsilon_{11}\frac{D}{Q_1}}. \tag{7}$$

In general, dQ_1/dG_2 is less than 1 in absolute value. When the government shifts a portion of its demand from good 1 to good 2, it reduces the price of good 1 (because price equals marginal cost and marginal cost is increasing). The reduced price elicits increased consumption of good 1 by the private sector. As a result, the net effect on good 1 is smaller than the reduction in government demand. This is true both at the margin, as illustrated in (7), and in the aggregate.

This private substitution effect exists as long as private demand is positive, the private demand elasticity is positive, and the supply elasticity for good 1 is less than infinity (i.e., marginal cost is strictly increasing). More generally, the private substitution effect increases with the relative size of private demand, increases with the price elasticity of private demand, and decreases with the price elasticity of supply of good 1. These results are intuitive, implying that the private substitution effect is larger whenever private demand is more responsive, and supply of good 1 is less responsive, to a fall in price.

To illustrate the magnitude of the private substitution effect, it is useful to consider some numerical examples using representative values for the elasticities and the ratio of private to total purchases of good 1. Table 1 calculates $-dQ_1/dG_2$, expressed as a percentage, for a range of demand elasticities (0.25 to 2.25), a range of supply elasticities (0.25 to 2.25), and two values for the ratio of private to total purchases of good 1 (90% and 50%).[14] The table illustrates that $-dQ_1/dG_2$ may be significantly less than 1. For the parameter values illustrated here, $-dQ_1/dG_2$ ranges from about 10% to 95%.

c. Procurement policy in the long-run

As just noted, the private substitution effect requires that marginal costs are increasing. This is a reasonable assumption in the short-run, when production capacity is relatively fixed. In the long-run, however, free entry and exit and the absence of scarce factors of production imply that marginal costs will be constant (and equal to minimum average costs; we ignore integer problems). If these conditions hold, then in the long-run there will be no private substitution effect and government procurement will be completely effective. In essence, the assumptions imply that the private sector will build a set of plants of efficient scale to meet the new government

[14] For comparison, note that federal government purchases in the United States are about 8% of GDP, implying that other purchasers make up 92% of the market, on average. Of course, the government share varies significantly across products. State and local governments purchase about 11% of GDP; each individual state's share is, of course, much lower.

Table 1: Government procurement policy in a market for homogenous goods

The reported figures are $-dQ_1/dG_2$ expressed as a percentage; they also represent the optimal environmental preference as a percentage of the externality (if government funds are raised by distortionary taxes, divide these values by $1 + \lambda$ to get the optimal preference).

a. Private demand is 90% of total demand

	Private Elasticity of Demand				
Supply Elasticity	0.25	0.75	1.25	1.75	2.25
0.25	53%	27%	18%	14%	11%
0.75	77%	53%	40%	32%	27%
1.25	85%	65%	53%	44%	38%
1.75	89%	72%	61%	53%	46%
2.25	91%	77%	67%	59%	53%

b. Private demand is 50% of total demand

	Private Elasticity of Demand				
Supply Elasticity	0.25	0.75	1.25	1.75	2.25
0.25	67%	40%	29%	22%	18%
0.75	86%	67%	55%	46%	40%
1.25	91%	77%	67%	59%	53%
1.75	93%	82%	74%	67%	61%
2.25	95%	86%	78%	72%	67%

demand for good 2 and will close a set of plants that previously were used to meet that demand with good 1. Private sector consumption will be unaffected since it is satisfied by a separate set of efficient scale plants.

This reasoning implies that private substitution will be important in the short-run but will be eliminated in the long-run. If any factors of production are scarce, however, then marginal costs will still be increasing in the long-run and the private substitution effect will persist.

d. Optimal procurement policy

Based on the positive analysis, we can now determine the optimal procurement policy for a government that lacks other policy instruments (e.g., Pigouvian taxes). We define a government objective function in which the government's control variable is its purchases of the 'green' good (good 2). The first order conditions for the optimal G_2, i.e., the optimal set-aside, will yield an expression for the optimal price preference a^*.

The government maximizes net welfare, defined as the gross consumer surplus less production costs, the externality, and the distortionary cost of government purchases[15]:

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[15] For simplicity we assume that private sector demand comes from consumers and not firms. In reality, the relevant goods may be used by private firms in the production of consumer goods. The model applies to this case as well if we interpret the demand curve as being the derived demand curve for the intermediate good.

$$\underset{\{G_2\}}{Maximize} \int_0^{D(p_1)} P(q)\,dq - c_1(Q_1) - c_2(Q_2) - wQ_1 - \lambda(p_1G_1 + p_2G_2)$$

subject to:

$$Q_1 = D(p_1) + G_1$$
$$Q_2 = G_2 \tag{8}$$
$$G = G_1 + G_2.$$

This problem has the first order condition

$$\frac{\partial D}{\partial p}\frac{dp_1}{dG_2}p_1 - (c_1' + w)\frac{dQ_1}{dG_2} - c_2' - \lambda(p_2 - p_1 + G_1\frac{dp_1}{dG_2} + G_2\frac{dp_2}{dG_2}) = 0. \tag{9}$$

Substituting the equality of price and marginal cost and the definition of a, we find that the optimal price preference is

$$a^* = \frac{w}{1+\lambda}(-\frac{dQ_1}{dG_2}) - \frac{\lambda}{1+\lambda}(G_1\frac{dp_1}{dG_2} + G_2\frac{dp_2}{dG_2}). \tag{10}$$

To interpret this result, we first consider the case when $\lambda = 0$. In this case, the optimal price preference simplifies to

$$a^* = w\,(-\frac{dQ_1}{dG_2}). \tag{10a}$$

Because $0 \leq -dQ_1/dG_2 \leq 1$ (from (7)), the optimal price preference is positive, but smaller than the externality w.[16] An optimal Pigouvian tax, in contrast, would exactly equal the externality. Because private substitution offsets some of the

[16] For the positive externality case, replace $-dQ_1/dG_2$ in (10) with $dQ_2/dG_2 = 1$. In the absence of tax distortions, the optimal price preference would then equal the externality.

effect of procurement policy, the optimal price preference is smaller than the optimal Pigouvian tax. From the figures in Table 1 (which reports $-dQ_1/dG_2$ for a range of parameter values), it is clear that the optimal price preference may be substantially lower than the externality; an optimal preference on the order of half to two-thirds the externality would not be surprising.

When $\lambda > 0$, the result is more complicated. In the absence of any externality ($w=0$), the optimal price preference is not zero because the government can use its market power to reduce its overall expenditures. The optimal price preference for good 2 may thus be positive or negative depending on the sensitivity of the two prices to the allocation of government demand. In considering the case of $w>0$, it is therefore useful to compare the optimal price preference to that which would hold with $w=0$. In this case, the additional price preference, which we will call the environmental price preference, is similar to that with no tax distortion, except that it is divided by $1 + \lambda$. The shadow cost of government funds thus reduces the optimal environmental preference.[17]

The relationship between the optimal overall price preference and the optimal

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[17] The shadow cost of public funds has additional relevance for environmental policy analysis. The tax distortion implies that, in general, it may be preferable for the government to force the private sector, rather than the government, to pay for environmental clean-up. In particular, rather than applying extra-strong environmental standards to itself, it may be preferable for the government to apply stricter ones to the private sector (Summers 1989 makes a similar argument regarding mandated benefits). The shadow cost of public funds thus provides a normative basis for the common government practice of exempting itself from various laws. Of course the costs of such policies - in particular general skepticism about any legislature that exempts itself from its own laws - may more than outweigh these benefits.

Pigouvian tax is complex in this case. If private demand is inelastic (elastic), an optimal tax may be greater than (less than) the externality in order to raise additional low-distortion revenue. Because the tax raises prices to the government, there is also some reason to lower the tax, relative to w, in order to reduce government expenditures. The net impact of these effects will depend on parameter values.

4. PROCUREMENT IN A COMPETITIVE MARKET FOR DIFFERENTIATED GOODS

While the foregoing analysis generates some interesting results about the effects of procurement policy, it has two significant drawbacks. First, for procurement policy to have any effect, all private consumption of good 2 must be crowded out; this is certainly extreme. Second, the assumption of complete homogeneity is unlikely to hold for most goods. Goods will often differ in some quality attributes (e.g., the difference between recycled and virgin paper, the difference in lighting quality between fluorescent and incandescent bulbs, reliability of renewable energy resources compared to conventional, etc.). In addition, firms, consumers, and government agencies will differ in their preferences for environmentally superior products (e.g., they will differ in the degree to which they value the appearance of environmental awareness; energy users will differ in their usage habits). For all these reasons, it is likely that environmentally friendly and unfriendly products will be imperfect substitutes.

To illustrate how procurement policies work in this more realistic setting, we now develop a model of differentiated goods in a competitive market. The private sector has demands $D_i(p_1,p_2)$ for each good i. These satisfy standard assumptions that

$$\frac{\partial D_i}{\partial p_i} < 0 < \frac{\partial D_i}{\partial p_j}. \tag{11}$$

a. The effect of procurement policy

As before, we begin with a positive analysis of the effect of a procurement policy that switches government demand from good 1 to good 2. The market equilibrium is given by

$$\begin{aligned} Q_1 &= D_1(p_1,p_2) + G_1 \\ Q_2 &= D_2(p_1,p_2) + G_2 \\ p_1 &= c_1'(Q_1) \\ p_2 &= c_2'(Q_2) \\ G &= G_1 + G_2. \end{aligned} \tag{12}$$

To model the effect of policy, we want to know the effect on prices and quantities of the government switching its purchases from good 1 to good 2. Some tedious differentiation and algebra yield

$$\begin{aligned} \frac{dQ_1}{dG_2} &= -\frac{\eta_2 + \frac{D_2}{Q_2}\epsilon_{22} - \frac{D_1}{Q_1}\frac{Q_1}{Q_2}\epsilon_{12}}{\eta_2 + \frac{D_2}{Q_2}\epsilon_{22} + \frac{\eta_2}{\eta_1}\frac{D_1}{Q_1}\epsilon_{11} + \frac{D_1}{Q_1}\frac{D_2}{Q_2}\frac{1}{\eta_1}(\epsilon_{11}\epsilon_{22} - \epsilon_{12}\epsilon_{21})} \\ \frac{dp_1}{dG_2} &= \frac{p_1}{Q_1\eta_1}\frac{dQ_1}{dG_2} \end{aligned} \tag{13a}$$

$$\frac{dQ_2}{dG_2} = \frac{\eta_1 + \frac{D_1}{Q_1}\epsilon_{11} - \frac{D_2}{Q_2}\frac{Q_2}{Q_1}\epsilon_{21}}{\eta_1 + \frac{D_1}{Q_1}\epsilon_{11} + \frac{\eta_1}{\eta_2}\frac{D_2}{Q_2}\epsilon_{22} + \frac{D_1}{Q_1}\frac{D_2}{Q_2}\frac{1}{\eta_2}(\epsilon_{11}\epsilon_{22} - \epsilon_{12}\epsilon_{21})}$$
$$\frac{dp_2}{dG_2} = \frac{p_2}{Q_2\eta_2}\frac{dQ_2}{dG_2}, \tag{13b}$$

where the elasticities are defined by

$$\epsilon_{ii} \equiv -\frac{\partial D_i}{\partial p_i}\frac{p_i}{D_i}; \; \epsilon_{ij} \equiv \frac{\partial D_i}{\partial p_j}\frac{p_j}{D_i}; \; \eta_i \equiv \frac{\partial Q_i}{\partial p_i}\frac{p_i}{Q_i} = \frac{p_i}{Q_i c_i''}. \tag{14}$$

These expressions are more complicated than those for the homogenous case because the private substitution effect now works through the markets for both goods. Note that the expressions for the homogenous case are recovered if we assume that $D_2 = 0$ and $\epsilon_{12} = 0$; these conditions reflect the complete crowding-out of private consumption of good 2.

For simplicity, we will assume that the term $(\epsilon_{11}\epsilon_{22} - \epsilon_{12}\epsilon_{21})$ is non-negative. A sufficient condition for this is

$$\frac{\partial D_i}{\partial p_j} < -\frac{\partial D_i}{\partial p_i}, \tag{15}$$

i.e., the own price effect is larger in magnitude than the cross price effect; this condition will hold if income effects are small.

Given that the term is positive, it follows that both denominators are positive and, as a result, $dQ_1/dG_2 \geq -1$ and $dQ_2/dG_2 \leq 1$. Unlike the homogenous good case, it is possible that $dQ_1/dG_2 > 0$ or $dQ_2/dG_2 < 0$. The former will occur, for example, if the ratio of private to total demand for good 1, the ratio of demand for good 1 to that of good 2, and ϵ_{12} are all sufficiently large. In these cases, procurement policies will actually increase production of the environmentally inferior good.

While such a perverse effect is possible, in typical cases the government procurement policy will push consumption in the intended direction, but private substitution will cause the net effect to be less than one-for-one.[18] Focusing on dQ_1/dG_2, which is the crucial term for reducing negative externalities, we find that the private substitution effect increases (and the efficacy of government procurement decreases) with ϵ_{11}, D_1/Q_1, and Q_1/Q_2 and decreases with ϵ_{21} and η_1. In general, the effects of the other parameters are ambiguous. If all factors are completely flexible then, as in the homogenous case, government procurement policies are completely effective.

It is useful to provide some numerical examples to illustrate the magnitude of the effects discussed here. Unfortunately, the differentiated goods model includes substantially more parameters than did the homogenous good case (10 versus 4 if we treat the quantity ratios as parameters). To simplify the numerical presentation, we impose some symmetry assumptions: equal own price demand elasticities, equal cross price elasticities, equal supply elasticities, and equal ratios of private and public consumption for each good. We further assume that cross price elasticities are half the size of own price elasticities.

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[18] Unlike the homogenous goods case, this is true for the positive externality case as well.

Using these assumptions, Table 2 reports values of $-dQ_1/dG_2$ (as a percentage) for a range of demand elasticities (0.25 to 2.25), a range of supply elasticities (0.25 to 2.25), two values of Q_1/Q_2 (3 and 1), and two values of D_i/Q_i (90% and 50%). Comparing Table 2 with Table 1, we see that the effects of procurement policies are smaller in the differentiated goods case than they were in the homogenous case. This reduction reflects the impact of private substitution through the market for good 2.

b. Optimal procurement policy

In the absence of procurement policies, the government will purchase a mix of goods 1 and 2. As in the private sector, this mix will reflect not only the relative prices of the two goods but also their effect on other costs or on the quality of output. Thus, for example, incandescent and fluorescent lightbulbs will be evaluated not only on their prices but also on their effects on electricity bills and on the quality of light they provide. To focus solely on procurement policy, let us assume that the government, like the private sector, selects an optimal mix of goods 1 and 2 in the absence of a procurement policy.

Table 2: Government procurement policy in a market for differentiated goods

The reported figures are $-dQ_1/dG_2$ expressed as a percentage; they also represent the optimal environmental preference as a percentage of the externality (if government funds are raised by distortionary taxes, divide these values by $1 + \lambda$ to get the optimal preference).

a. Private demand is 90% of total demand; green good is 25%.

	Private Elasticity of Demand				
Supply Elasticity	0.25	0.75	1.25	1.75	2.25
0.25	16%	-3%	-5%	-5%	-5%
0.75	51%	16%	4%	-1%	-3%
1.25	66%	32%	16%	8%	3%
1.75	74%	43%	26%	16%	10%
2.25	79%	51%	34%	23%	16%

b. Private demand is 90% of total demand; green good is 50%.

	Private Elasticity of Demand				
Supply Elasticity	0.25	0.75	1.25	1.75	2.25
0.25	43%	20%	13%	10%	8%
0.75	69%	43%	31%	24%	20%
1.25	79%	55%	43%	35%	29%
1.75	84%	63%	51%	43%	37%
2.25	87%	69%	57%	49%	43%

Table 2 (continued)

c. Private demand is 50% of total demand; green good is 25%.

Supply Elasticity	Private Elasticity of Demand 0.25	0.75	1.25	1.75	2.25
0.25	34%	4%	-2%	-4%	-5%
0.75	68%	34%	18%	10%	4%
1.25	79%	51%	34%	23%	16%
1.75	84%	61%	45%	34%	26%
2.25	87%	68%	53%	43%	34%

d. Private demand is 50% of total demand; green good is 50%.

Supply Elasticity	Private Elasticity of Demand 0.25	0.75	1.25	1.75	2.25
0.25	57%	31%	21%	16%	13%
0.75	80%	57%	44%	36%	31%
1.25	87%	69%	57%	49%	43%
1.75	90%	76%	65%	57%	51%
2.25	92%	80%	71%	63%	57%

An environmental procurement policy will cause the government to deviate from its optimal mix of purchases. To solve for the optimal procurement policy, we therefore need to specify the cost and quality factors that underlie government demand for the two goods (this step was unnecessary in the homogenous case). We assume that the government has a range of applications in which it uses the products and that in each application there is a cost-quality penalty Θ to using good 2 rather than good 1. We allow $\Theta < 0$, in which case good 1 costs more to use than good 2. Government demands for the goods are indexed by Θ, which we assume to be continuously distributed with cdf F on $[\Theta_l, \Theta_u]$; we assume F is differentiable with derivative f.

In the absence of a procurement policy, the government purchases good 2 whenever $p_2 + \Theta < p_1$ and purchases good 1 otherwise. With a preference policy, the comparison is $p_2 + \Theta$ versus $p_1 + a$ (the price preference applies to life-cycle costs, not just purchase costs). For any policy, we can define a cut-off value $\Theta^* = p_1 + a - p_2$ such that good 2 is purchased for all lower Θ. We have that $G_1 = G(1 - F(\Theta^*))$ and $G_2 = GF(\Theta^*)$. From the latter definition, it follows that $\Theta^* = F^{-1}(G_2/G)$.

Given these definitions, the total cost-quality penalty to the government of purchasing G-G_2 of good 1 and G_2 of good 2 is

$$CQP(G_2) \equiv G \int_{\theta_l}^{F^{-1}(\frac{G_2}{G})} \theta f(\theta)\, d\theta. \tag{16}$$

Using Leibnitz' rule and the formula for the derivative of an inverse, it is easy to show that

$$\frac{dCQP}{dG_2} = \theta^* = p_1 + a - p_2; \tag{17}$$

this formula will be used in deriving the government's first order condition for an optimal procurement policy.

The government's objective is to maximize gross consumer surplus less production costs, the externality, the cost of raising government funds, and the cost-quality penalty to the government of using good 2. We assume that the latter cost is monetary and therefore results in both a direct cost and a cost of raising funds to pay for it. The government thus solves

$$\begin{aligned} \underset{(G_2)}{Max}\ & S(D_1,D_2) - c_1(Q_1) - c_2(Q_2) - wQ_1 \\ & - \lambda(p_1G_1 + p_2G_2) - (1+\lambda)CQP(G_2) \\ subject\ to: & \\ & Q_1 = D_1(p_1,p_2) + G_1 \\ & Q_2 = D_2(p_1,p_2) + G_2 \\ & G = G_1 + G_2, \end{aligned} \tag{18}$$

where $S(D_1,D_2)$ is the gross consumer surplus associated with private consumption of D_1 and D_2. By definition of the surplus function,

$$\frac{\partial S}{\partial D_i} = p_i. \tag{19}$$

The government problem has the first order condition (using (17) and (19))

$$p_1\frac{dD_1}{dG_2} + p_2\frac{dD_2}{dG_2} - (c_1' + w)\frac{dQ_1}{dG_2} - c_2'\frac{dQ_2}{dG_2}$$

$$- \lambda(p_2 - p_1 + G_1\frac{dp_1}{dG_2} + G_2\frac{dp_2}{dG_2}) - (1 + \lambda)(p_1 + a - p_2) = 0. \tag{20}$$

Rearranging (20), and using the equality of price and marginal cost, we find that the optimal price preference is given by an equation identical to that of the homogenous good case,

$$a^* = \frac{w}{1 + \lambda}(-\frac{dQ_1}{dG_2}) - \frac{\lambda}{1 + \lambda}(G_1\frac{dp_1}{dG_2} + G_2\frac{dp_2}{dG_2}). \tag{21}$$

Thus the differentiated goods case yields the same qualitative results as the homogenous case.[19] The optimal environmental preference (the first term) is smaller than the externality because of private substitution and because of the cost of government funds. In some cases, moreover, the optimal environmental preference may actually be negative. From Table 2, finally, we see that the optimal environmental preference, expressed as a fraction of the externality, is smaller than in the homogenous case; a value of a quarter to a half the externality would not be surprising.

5. PROCUREMENT POLICIES WITH IMPERFECT COMPETITION

The foregoing results are all based on the assumption of competitive product markets. It is useful to consider whether these results change if we allow for

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[19] As before, replace $-dQ_1/dG_2$ by dQ_2/dG_2 in (21) to get the expression for the positive externality case.

imperfectly competitive behavior. Our analysis will build on the work of Miyagiwa (1991) who studied the effect of discriminatory government procurement in oligopolies.

a. Procurement in a homogenous good oligopoly

The homogenous goods case is not particularly interesting and will not be analyzed formally here. As in the competitive case, procurement policies are irrelevant unless government demand for good 2 completely crowds out private demand. In this case, government procurement policies do increase production of the 'green' good, but its effects are softened by private substitution.

This result assumes that the government pays the same price as private consumers. Miyagiwa (1991) considers a situation in which the government pays more for the desired good than do private consumers. In this case, a specific price preference is irrelevant but an ad valorem price preference changes producer behavior for the worse, causing an increase in production of the undesirable good.[20] This result is unlikely to apply to environmental price preferences. Procurement policies do not require that agencies pay a premium relative to the market price of a good; they require that, if necessary, a premium be paid to the price of an alternative. Throughout this paper we therefore maintain the (reasonable) assumption that the government and the private sector pay the same prices.

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[20] For other analyses of procurement in which government prices differ from private market prices, see Stern (1987) and Finsinger (1988).

b. Procurement in a differentiated goods oligopoly

We now assume, as we did previously, that the two goods are imperfect substitutes. From the private demand functions $D_i(p_1,p_2)$, we derive the inverse demand curves $p_i(D_1,D_2)$. These satisfy the standard assumptions that

$$\frac{\partial p_i}{\partial D_i} < 0; \ \frac{\partial p_i}{\partial D_j} < 0. \tag{22}$$

We assume that one firm produces each good and that they compete in private quantities (they take government demands as given and choose how much more to provide to the private sector); price competition yields the same qualitative results but is somewhat more complicated. For simplicity, we also assume that they choose quantities simultaneously; the qualitative results are the same as for the more general conjectural variations set-up considered by Miyagiwa (1991).

Each firm has a profit function given by

$$\pi_i(D_i;D_j,G_i) = p_i(D_i,D_j)(D_i + G_i) - c_i(D_i + G_i), \tag{23}$$

with associated first-order condition

$$\frac{\partial \pi_i}{\partial D_i} = p_i + (D_i + G_i)\frac{\partial p_i}{\partial D_i} - c_i' = 0. \tag{24}$$

The firm's second-order condition, which we assume to hold, is

$$A_i \equiv \frac{\partial^2 \pi_i}{\partial D_i^2} = 2\frac{\partial p_i}{\partial D_i} + (D_i + G_i)\frac{\partial^2 p_i}{\partial D_i^2} - c_i'' < 0. \tag{25}$$

To analyze the effect of procurement policy, we need to know the effect of government purchases on the marginal profit for each firm; we define

$$\Gamma_i \equiv \frac{\partial^2 \pi_i}{\partial G_i \partial D_i} = \frac{\partial p_i}{\partial D_i} - c_i''. \tag{26}$$

We have that $\Gamma_i < 0$ unless c_i'' is sufficiently negative. For now we assume that $\Gamma_i < 0$ for i = 1,2; in a later section we consider what happens when we allow $\Gamma_i > 0$ (Miyagiwa (1991) does not consider these cases).

We can now determine the effect of government procurement on the private consumption of the two goods. Differentiating the first order conditions, we find

$$\frac{dD_1}{dG_2} = \frac{\Gamma_1}{A_1}; \quad \frac{dD_2}{dG_2} = -\frac{\Gamma_2}{A_2}. \tag{27}$$

Under our maintained assumptions, it follows that

$$\frac{dD_1}{dG_2} > 0; \quad \frac{dD_2}{dG_2} < 0. \tag{28}$$

Thus the private substitution effect occurs in imperfectly competitive markets as well. As noted by Miyagiwa (1991), it can happen that the drop in private consumption of good 2 will more than offset the increase in consumption by the government (all that is required is $0 > \Gamma_2 > A_2$). Thus the government preference may actually cause production of the 'green' good to decrease. In a similar manner, the government preference may also increase production of the 'brown' good.

c. Procurement with economies of scale

The foregoing results are based on the assumption that marginal costs are increasing or, at least, are not decreasing too quickly (so that $\Gamma_i < 0$). If marginal costs for good i are sufficiently decreasing then $\Gamma_i > 0$ and, from (25) and (27), the effects of procurement policies will differ from those described in the previous section. To model these effects, we will say that economies of scale for good i are sufficient if

$$2\frac{\partial p_i}{\partial D_i} + (D_i + G_i)\frac{\partial^2 p_i}{\partial D_i^2} < c_i'' < \frac{\partial p_i}{\partial D_i}, \tag{29}$$

which implies that $A_i < 0 < \Gamma_i$. The second inequality ensures that economies of scale are large enough to change the results of the previous section; the first inequality ensures that the firm's second-order condition is not violated.

From (27), it follows that sufficient economies of scale for good 1 imply that a procurement policy favoring good 2 will decrease both private and government consumption of good 1. Similarly, when sufficient economies of scale exist for good 2, procurement policy will increase both private and government consumption of good 2. When sufficient economies of scale exist, private market behavior can thus amplify the effects of government procurement policies.[21]

d. Optimal procurement policy for an oligopoly

The analysis of optimal procurement policy in this setting follows the same

[21] These results are unambiguous because we have assumed simultaneous quantity selection. In a more complex setting, the qualitative effect of procurement will depend on parameter values. The results presented here thus only illustrate that significant economies of scale can cause private actions to amplify the effect of policy.

form as it did in the competitive case. The only difference is that we can no longer substitute $p_i = c_i'$ in the first order condition. Instead, we have terms that represent the price markup charged by each oligopolist. Manipulating the first order condition (20), we find that

$$a^* = \frac{w}{1+\lambda}\left(-\frac{dQ_1}{dG_2}\right) - \frac{\lambda}{1+\lambda}\left(G_1\frac{dp_1}{dG_2} + G_2\frac{dp_2}{dG_2}\right) + \frac{1}{1+\lambda}(p_1 - c_1')\frac{dQ_1}{dG_2} + \frac{1}{1+\lambda}(p_2 - c_2')\frac{dQ_2}{dG_2}. \tag{30}$$

This is the competitive market formula (21) with two additional terms. These terms, the price-cost markups multiplied by the change in production due to government procurement, reflect the welfare effects of changing production when price is not equal to marginal cost. As in the case of the tax distortion, these pricing distortions are a reason for government price preference policies even in the absence of environmental concerns (assuming the government has no other instruments to deal with oligopoly problems). Like the tax distortion, the pricing distortions could imply a preference for either good depending on the relative size of the two terms.

The effect of environmental concerns is to add the now familiar environmental price preference for good 2. The basic qualitative results for optimal procurement in imperfectly competitive markets are therefore the same as for competitive markets. Note, however, that significant economies of scale for good 1 imply that $-dQ_1/dG_2 > 1$; as a result, the optimal environmental preference can exceed the value of the externality. Thus, when production of the 'brown' good causes a negative externality, the key scale economies are those in its production, not in production of the 'green" alternative.[22]

6. ENVIRONMENTAL PREFERENCE IN PROCUREMENT AUCTIONS

The foregoing analyses have assumed that government purchases take place in traditional microeconomic markets. In reality, many goods are purchased through a process of competitive bidding. To analyze the effects of preference policies in this setting, we rely upon the results of McAfee and McMillan (1989) (MM henceforth) who analyzed the effect of domestic content preferences on competitive bidding for government contracts.

MM consider the case of a good for which the government is the only buyer. The government solicits offers to provide the good from a set of domestic and foreign firms. The government does not know the specific cost structure of each firm but does know the distribution of costs for domestic firms and the distribution for foreign firms. If the domestic and foreign distributions differ, then the optimal auction, from the perspective of minimizing government costs, will typically involve some favoritism towards one of the two groups. In particular, if foreign firms have a comparative advantage, the government will typically want to favor domestic firms.

The rationale for this preference is that it serves to make the auction more competitive. When one group of firms has a comparative advantage over another group, those firms will be able to bid less aggressively than if all firms drew costs

[22] When production of the 'green' good creates a positive externality, then, as before, the $-dQ_1/dG_2$ term is replaced by dQ_2/dG_2. In this case, it is economies of scale in production of the 'green' good that matter.

from the better distribution. By giving a price preference to the disadvantaged firms, the government can increase the competitiveness of the auction and thereby reduce its expected procurement cost. The optimal price preference balances this increase in competitiveness against the increased probability of buying from a firm other than the lowest bidder.

This result carries over directly to the case of environmental preference. If firms using an environmentally beneficial technology have higher costs compared to a more damaging technology, the government may benefit by giving the clean firms some price preference. Of course, this argument is completely symmetric. If the environmentally inferior technology operates at a comparative disadvantage, then the optimal auction will instead give it a price preference.

This rationale for a price preference thus has nothing to do with the environment. It is merely a result about how the government should behave in order to increase the competitiveness of its procurement auctions and thereby reduce its expected procurement cost. If we expect that cleaner technologies will generally have higher costs than less clean technologies, the result does imply that the government should generally favor the cleaner technologies.

MM performed some simple numerical calculations to illustrate the magnitude of optimal price preferences. For relatively small markets (2 to 5 firms of each type), they found that optimal ad valorem price preferences for high cost firms (i.e., preferences expressed as a fraction of the price of low cost firms) are on the order of 4% for a cost differential of 10% and are on the order of 17% for a cost differential of 25%. These preferences are not necessarily decreasing in the number of firms. The absolute price preference declines, of course, with the number of firms (since an increase in the number of firms implies an increase in competitiveness), but such a decline is consistent with a relatively flat or even increasing ad valorem preference.

These results apply to a situation in which the only goal of the government is to minimize its expected purchase cost. When the government also takes into account the externality associated with production from type 1 firms, an additional price preference for clean firms will also be appropriate. In the MM set-up, this preference will equal the externality (or the externality adjusted by the cost of government funds) because the government is the only consumer of the good. In a more general setting, in which the government buys from firms that sell to the private sector, the previous results about private substitution and the cost of government funds would imply an optimal preference that is smaller than the externality.

As a final note, the MM analysis can be used to illustrate a difference between two types of preference policies. As MM demonstrate, an ad valorem price preference can be used to increase the competitiveness of government procurement auctions. This result should be contrasted with the anti-competitive effect of procurement guidelines that set specific content standards or otherwise restrict the pool of eligible bidders (in the competitive market case, we could equate price preference and content standard policies as functionally equivalent). The difference in competitive effects of the two policies parallels the difference between tariffs and import quotas in the trade literature.

7. CONCLUSION

Advocates of procurement policies often point out that ignoring externalities in making government decisions is tantamount to treating them as being zero (see, e.g., Nader, Lewis, and Weltman 1992). As a result, they suggest that the government include these costs in its own purchasing decisions. The results derived here indicate that this reasoning is only partially correct. In the absence of other policy instruments, it is indeed generally optimal for the government to take externalities into account in its purchasing decisions. However, the government should not use an environmental preference equal to the value of the externality. Because of private substitution and the cost of raising government funds, the optimal environmental preference is generally lower, often significantly, than the externality.

When the government substitutes towards environmentally superior products, private substitution may cause private agents to substitute away. Procurement policies thus differ from other environmental policies, in particular taxes and tradeable permits, that encourage all market participants to substitute towards 'green' products and technologies. Procurement policies are likely to be an effective instrument of environmental policy only when private substitution is relatively small and, as a result, the net effect of the policy on total consumption will be close to its gross effect on government consumption. Procurement policies will thus be most successful when the government is a large purchaser of the relevant good, when private demand is relatively inelastic, and when private supply is relatively elastic.

Procurement policies may also succeed if there are significant economies of scale in production; these economies can cause private market responses to amplify a government procurement policy. However, it is important that the economies of scale be correctly matched with the relevant externality. For example, consider the case of procurement policies designed to increase use of recycled materials. If the primary concern is to reduce environmental damages associated with virgin materials use, then the crucial economies of scale are in the production technologies that use virgin materials. If, however, the purpose of such policies is to reduce waste disposal (so usage of recycled materials has a positive externality), then the crucial economies of scale are in production technologies that use the recycled materials.

These results, and the analysis underlying them, are based on an essentially static analysis of procurement policies (with some attention to long-run entry and exit). They can be used, however, to evaluate some of the dynamic arguments made about procurement policies and the development of 'green' technologies and products. The heart of these arguments is the notion that the government can accelerate the development and distribution of 'green' technologies by providing an earlier and larger market for their products. Such a market allows firms to take advantage of static economies of scale as well as the economies that may be achieved through learning-by-doing.

These arguments require that the government is, in fact, successful in increasing the amount of the good produced. Thus procurement policies designed to promote 'green' technologies will likely be successful in the same instances in which a static analysis indicates that they will be successful. While we have not undertaken a detailed or formal analysis of the innovation incentives of procurement policy, we can conjecture that, when they are available, other policies that encourage both the government and the private sector to increase purchases of 'green' products may be more effective in promoting innovation.[23]

This paper has not considered a number of other aspects of procurement policy. First, it has not considered whether such policies are actually followed in the agencies to which they apply. According to industry participants, it may be common for procurement guidelines to be ignored by affected agencies. Even when they are observed, moreover, it may happen that other social goals embodied in other procurement guidelines, e.g., a preference towards purchasing from the handicapped, may take precedence.

Second, this paper has also ignored the possibility that individual citizens actually have preferences over the types of goods used by their governments. Some consumers appear to be willing to pay extra for goods that they believe to be environmentally friendly. If these preferences carry over to government purchases as well, then government procurement may raise social welfare even if its actual effects on environmental quality are small.

Finally, this paper has also ignored the costs required to implement procurement policies. These include both the direct costs of redesigning procurement policies, hiring environmental analysts, etc. and, likely more important, the effect of

[23] See Geroski (1990) for an argument in favor of government procurement as a general instrument of innovation policy.

altering the planning environment within which procurement occurs. During recent years a great deal of effort has been spent worrying about the efficiency of procurement and the problem of how to design procurement policies that minimize costs to the government. Environmental procurement policies run directly counter to the goal of minimizing government costs. As noted by a state procurement official, "since decisions related to procuring recycled products are not driven by costs, buyers need training to become familiar with new priorities and procedures" (quoted in DiPietro (1991)). These "new priorities and procedures" may have significant costs if they undermine the general procurement goal of minimizing government costs.

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ESSAY 2

TAX POLICY, TRANSACTION COSTS, AND PRIVATIZATION: EVIDENCE FROM THE WASTE DISPOSAL INDUSTRY

1. INTRODUCTION

Although economists have long compared the costs and performance of private and public enterprises,[1] they have devoted relatively little effort to explaining how governments, together with firms, choose between them. Economic analyses suggest that this choice is important, because private enterprises tend to incur lower costs, earn higher profits, and provide greater quality of service than their public counterparts. Nevertheless, public enterprises continue to be common in many countries, including the United States.

This paper explores some of the factors that influence the choice between public and private enterprise. It focuses in particular on federal tax policy, which influences the relative capital costs of public and private ownership, and on transaction costs associated with asset specificities, which imply that institutional efficiencies may arise from public ownership of specific assets that produce goods and services for government consumption. Although it focuses on economic factors, the paper also considers, in a preliminary manner, a number of political factors, including community ideology and the power of local government employees, that may also influence the public/private choice.

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[1] For surveys of this literature see Borcherding, Pommerehne, and Schneider (1982) and Vining and Boardman (1992).

To test various explanations of privatization, the paper focuses on two types of waste disposal facilities. Waste-to-energy (WTE) facilities, often known as incinerators, recover energy from the combustion of solid waste. Landfill gas recovery (LGR) facilities collect and process the methane gas that is produced by the decomposition of waste in landfills. Because municipal governments and private firms both own significant numbers of these facilities, they provide a fruitful area in which to explore the privatization decision.

A primary theoretical finding is that, at least until the Tax Reform Act of 1986, federal tax policy provided substantial incentives for private ownership of WTE facilities and, to a lesser extent, LGR facilities. Federal tax policy has long allowed private developers to finance WTE facilities with tax-exempt debt. As a result, private developers have been able to access essentially the same low-cost debt as public developers. At the same time, private developers have also been able to access the tax benefits associated with capital investment - tax credits and accelerated depreciation. During the early 1980's, these tax benefits allowed private WTE developers to have as much as a 35-40% capital cost advantage over public developers. Because of differences in financing arrangements (in particular the limited availability of tax-exempt debt to private developers), the cost advantage for private LGR developers was substantially smaller, on the order of 5-10% (this figure excludes some tax benefits related to facility operations, rather than capital costs, that increase the benefits of private ownership).

The time pattern of ownership decisions for these facilities illustrates that the tax benefits of private ownership have had a significant impact on privatization. Private ownership of both municipally-sponsored WTE facilities and LGR systems on public landfills was significantly more common under the favorable capital recovery provisions of the early 1980's than under the less favorable provisions before and after.

Transaction cost theory suggests that asset specificities may also influence the institutional structure under which WTE and LGR facilities are governed. WTE facilities typically serve the waste disposal needs of one or a few communities; because waste is relatively expensive to transport, these facilities, once constructed, are specific to the communities they serve. This specificity implies that the sponsoring communities will have a certain degree of monopsony power over a WTE developer once the initial capital costs of the facility are sunk. Conversely, if contract negotiations require that government decision-makers also incur sunk costs or if the sunk investment creates barriers to entry for alternative waste disposal providers,then once a facility is built, a WTE developer may also posses some monopoly power over the sponsoring community. Following the transaction cost reasoning of Klein, Crawford, and Alchian (1978) and Williamson (1979, 1985), we therefore expect that these facilities will be governed under long-term relationships (long-term contracts or vertical integration, i.e., public ownership) that can protect specific assets and avoid *ex post* monopsony and monopoly problems. Because WTE facilities have long operating lifetimes and face significant regulatory and economic uncertainties, we further expect that long-term contracts will tend to be incomplete.

As a result, integration may be a particularly attractive form of WTE governance.

While LGR facilities similarly serve individual communities,[2] they are often designed to be portable; thus they are not specific to a single landfill or community. As a result, LGR facilities face much smaller *ex post* expropriation risks than do WTE facilities. Transaction cost theory predicts that long-term contracting and vertical integration (public ownership) of these facilities will be much less common than for the more specific WTE facilities.

The pattern of facility governance structures is consistent with these predictions. WTE facilities are usually developed under long-term contracts or vertical integration; moreover, these facilities are often protected by special contractual provisions or local ordinances that guarantee a sizeable waste stream. WTE facilities are much more likely to be publicly owned than are the less-specific LGR facilities. Moreover, among WTE and LGR facilities, more specific facilities are more likely to be publicly owned.

Besides illustrating that transaction cost reasoning can be applied to privatization, these results shed light on a current environmental debate about the design of governance structures for WTE facilities. Some environmentalists have

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[2] Because the energy revenues from burning waste are substantially smaller than the costs of building WTE facilities, WTE contracts always require that the sponsoring municipality pay a service fee for waste disposal. The methane produced in landfills is sufficiently valuable, relative to the cost of LGR facilities, that they usually turn a net profit. Thus, facility developers often pay royalties to the host landfill. On public landfills, this implies that under a LGR contract, the developer pays revenues to the government and not, as in the case of WTE, vice-versa. Although the direction of payments thus differs between the two types of facilities, the basic governance issues still apply.

argued that long-term contracts and flow control policies allow WTE facilities to inefficiently monopolize waste disposal markets, thereby discouraging recycling efforts,and should therefore be avoided in new facilities and, if possible, eliminated at existing facilities. The transaction cost perspective illustrates that this argument is only partly correct; while the institutional policies may create *ex post* monopolies, the resultant monopolization need not be a sign of inefficiency. To argue that waste disposal markets are monopolized requires an *ex ante* evaluation of the competitive process by which such institutions were developed, not merely an *ex post* evaluation of the specific institutions chosen.

To set the context for developing and analyzing these findings, section 2 discusses various theories of the choice between public and private enterprise and reviews the existing empirical literature. Section 3 then discusses the WTE and LGR industries in the United States. Section 4 develops a simple accounting model to estimate the capital cost differences between public and private ownership under different tax regimes. It illustrates how federal tax policy can provide substantial incentives for private ownership. Section 5 then discusses transaction costs related to asset specificities and the degree to which they are present in the WTE and LGR industries. Section 6 combines the tax policy and transaction cost considerations with political and other variables in an econometric model of institution choice. Section 7 then concludes.

2. THE CHOICE BETWEEN PUBLIC AND PRIVATE ENTERPRISE

Consistent with usual convention, we distinguish between public provision, the decision by a government to provide a particular good or service, and public production, the decision by the government to produce a service itself rather than contract for it or require (through regulations) private agents to produce it. This paper focuses on the production decision, taking public provision as given.[3]

A number of economic and political factors may influence the choice between public and private production of publicly provided goods. Direct cost differences between public and private production may exist if state and federal laws create factor cost differences between the public and private sectors; federal tax policy, for example, may create significant differences in capital costs. Indirect cost differences may arise from the differing institutional structures of public and private production. Relatively stronger incentive structures, for example, may cause private firms to be more efficient than their public competitors. On the other hand, the transaction costs of market exchange (Coase 1937; Klein, Crawford, and Alchian 1978; Williamson 1979, 1985)) may, in certain cases, cause private production to be relatively less efficient.[4]

The degree to which these economic factors influence privatization decisions

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[3] Throughout the paper, we focus on goods and services that are produced for government consumption; we do not consider the case of government enterprises selling goods and services to the private sector (although some of the factors discussed here may influence these types of institutional issues as well).

[4] This idea has been previously discussed by Borcherding (1983, 1988).

will obviously be determined as part of a larger political process. Thus a complete model of privatization must also consider a third set of factors related to the political environment. In essence, we require an economic theory of public enterprise (analogous to economic theories of regulation (Stigler 1971, Peltzman 1976)) that explains the choice between public and private production as the result of a political process in which decision-makers pursue their own interests in light of constituent interests, economic conditions, fiscal constraints, etc. Direct and indirect cost differences between public and private ownership will then influence the privatization decision through their influence on these variables (most notably constituent interests).

In contrast to the large literature on the performance of public and private enterprises, the empirical literature on institutional choice is relatively sparse. Using data collected by the International City Managers Association in 1982, a number of analysts (Ferris 1986; Ferris and Graddy 1986, 1988, 1991; Morgan, Hirlinger, and England 1988; and, most comprehensively, Stein 1990) have related municipal contracting decisions to a variety of demographic (population size, metropolitan status, etc.), political (power of public employees, power of unions, etc.), and fiscal (property tax limitations and other measures of fiscal stress) variables. While results vary across services, a general finding is that these variables are only weakly related to contracting decisions. For example, Stein (1990, p. 107) finds that none of his "hypothesized relationships are confirmed for more than one-third of the sixty-four functional areas studied". Moreover, the partial confirmation of at least two main hypotheses can be explained not by the success of the underlying theory but by the endogeneity of the supposedly independent variables used to test them.[5]

On the whole, such general analyses of contracting provide only limited insight into the forces that influence governments' institutional choices. As in other areas of economics, it is therefore fruitful to explore specific industries in greater detail. However, only a few studies consider public/private decisions within specific industries. Pashigian (1976) considered the switch from private (but regulated) to public provision/production of transit in the 1960's and early 1970's; he found, *inter alia*, that capture of regulators by consumers, rather than producers, accelerated the switch to public production. McGuire, Ohsfeldt, and Van Cott (1987) consider the case of school bus ownership and find that some non-monetary concerns, in particular the risk of labor unrest, appear to influence the privatization decision more than direct economic costs. They interpret this finding as a sign that education bureaucrats may prefer to contract out services if they can thereby avoid annoying labor troubles. Dubin and Navarro (1988) examine institutional structures for refuse collection. They

[5] To test the proposition that property tax limits induce greater contracting out, Stein (1990) includes a dummy variable for whether a property tax limitation was passed in 1978 or later. He concludes that the positive relation between such tax limits and contracting out implies that such limits caused contracting out. Because his data focus on contracting for services in 1982, an equally plausible explanation is that the same political factors that led certain states to pass property tax limitations during the late 1970's and early 1980's also led municipalities to pursue contracting strategies. Stein also tests whether municipalities with higher levels of local government employees have lower levels of contracting. In this case, the underlying theory is that larger numbers of local government employees will imply that such employees have greater political power to block contracting. As Stein (1990) notes, an equally plausible prediction is that reduced contracting of itself causes increased government employment (someone has to pick up the garbage, fight fires, etc.). He finds some evidence that the latter prediction is, in fact, correct.

find that political factors (e.g., the fraction of votes for a Democratic presidential candidate) and economic factors (e.g., economies of density) both influence the institutional choice. They also illustrate how recognizing the endogeneity of ownership can alter the results of analyses that compare performance under different institutional structures.

With the exception of Pashigian (1976), all previous studies of contracting relate contracting decisions in a single year to potential explanatory variables measured in that year. The studies thus do not directly examine the contracting decision of local governments; they merely examine the cross-sectional pattern of contracting in a particular year. This distinction is important if contracting decisions, once made, tend to be maintained for significant periods of time while potential explanatory variables vary. In such cases, the cross-sectional relationship between explanatory variables and contracting in a particular year need not reflect their true causal relationship; indeed, as the example of the previous footnote illustrates, some explanatory variables may be influenced by the contracting choice, thereby causing an endogeneity problem.

We may expect that privatization/contracting decisions will be particularly persistent in services, like waste disposal, that are capital intensive. For such services, a study of privatization decisions should focus on the decisions themselves, rather than on the pattern of privatization in any one year. This is the approach taken in this study.

3. WTE AND LGR IN THE UNITED STATES

a. Waste-to-energy

Waste-to-energy (WTE) facilities process solid waste; they reduce the volume of the waste (by about 90%) while recovering useful energy (steam, electricity, hot water, etc.). WTE facilities do not include facilities that produce energy by processing other types of waste (e.g., hazardous waste, sludge, waste biomass) nor do they include facilities that process solid waste without recovering energy (e.g., solid waste incinerators).[6] In some circles WTE facilities are also known as resource recovery facilities.[7]

There are five basic types of WTE facilities. Massburn facilities burn mixed waste with little pre-processing (various contaminants - appliances, lead batteries, etc. - are removed if possible). Modular massburn facilities operate similarly, but are constructed from pre-fabricated components rather being field-erected like traditional massburn facilities. Refuse derived fuel (RDF) facilities separate waste, in varying degrees, into combustible, non-combustible, and recyclable portions; the combustibles are shredded and, in some cases, made into fuel pellets. The shredded waste or fuel pellets are then either burned on-site (i.e., with a dedicated boiler) or off-site (e.g., as

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[6] The definition of 'incinerator' has varied over time and across political beliefs. Industry reserves the term 'incinerator' for projects that do not recover energy, while WTE opponents refer to all waste-burning facilities as incinerators. Because it captures a legitimate technical difference (energy recovery), the term WTE is used herein.

[7] In the early 1980's, the term 'resource recovery' included WTE, recycling, and composting since all recover resources (energy and materials) from waste. More recently, it has become standard to differentiate between energy recovery and materials recovery.

extra fuel in a utility coal-fired power plant); the non-combustibles are sent to a landfill. Pyrolysis facilities heat waste to produce a liquid or solid fuel. Tires-to-energy facilities, finally, are specialized for the processing of vehicle tires; they may use either a massburn or an RDF-type process. In some cases, each of these facilities may be designed to process other types of waste, including wastewater sludge, medical waste, wood chips, etc. Such facilities are included in this study only if they are primarily designed to process solid waste.

WTE facilities have usually been developed jointly by municipalities and private firms. In a typical case, a municipality (a city, county, or public authority) would begin by recognizing a need for long-term waste disposal capacity. The municipality would then develop and issue a request for proposals from WTE vendors; through a process of bidding and negotiation, the municipality would then select a vendor to develop the facility.

The actual facility development could follow a number of different procurement strategies. At one extreme, the municipality could completely privatize the project by selecting a full-service waste disposal contract with a privately-owned facility. Under this approach, the municipality would simply pay a negotiated service fee (a tipping fee) for waste disposal. Alternatively, the municipality could select full-service procurement with public ownership. Under this structure, the municipality commits to an operating contract for waste disposal services while financing and owning the project itself. Other procurement strategies include the turn-key and architect/engineer approaches, in which the municipality contracts with one or a group of firms to build a facility that the municipality will then own and, typically, operate.

While municipal sponsorship, by either a single municipality, as just described, or a small number of neighboring communities, has been the predominant method of facility development, recent years have seen a dramatic increase in the number of facilities developed without specific sponsors. Such facilities, known as merchant facilities, are developed by private firms with the intent of selling disposal capacity under contracts and on the spot market to local communities and private haulers.

Both public and private WTE facilities are primarily financed with tax-exempt revenue bonds (often called industrial development bonds or private activity bonds). These bonds are usually structured to be non-recourse, so that repayment depends on the revenues generated by the project. Due to federal limitations on tax-exempt debt issuance, these bonds can be used only for those portions of a WTE facility that are involved in waste disposal. Any portions of the facility that process the resulting energy (e.g., to produce electricity) must be financed from other sources of capital. For publicly-owned facilities, these sources include general obligation debt, grants and loans from state and federal governments, and taxable debt; for private facilities, they include taxable debt and equity.[8]

In some cases, facility ownership is split between two separate parties in order

[8] For more detail on WTE financing, see Monet (1986) and Chen, France, and Sharpe (1990).

to reallocate tax benefits. Firms with large cash flows, e.g., Ford Credit Corporation and Philip Morris, can purchase the plants to access the tax benefits of depreciation and investment tax credits and then lease the facilities back to the original owner. For purposes of governance, it is the party to whom these firms lease that is the true owner. In principle, leasing provides a means for public entities to access the tax benefits of private ownership while maintaining greater control over a facility. In reality, leasing by a public entity is uncommon; only three publicly owned (in the governance sense) WTE projects have been structured so that private parties receive the tax benefits of ownership. For purposes of this paper, I therefore assume that the ownership choice is strictly binary - public with no tax benefits (or costs) or private with tax benefits (or costs).

b. Landfill gas recovery

Landfill gas recovery (LGR) facilities, also known as methane recovery facilities, collect and process methane that is produced by the anaerobic decomposition of waste in landfills. Methane collection is important for safety reasons since accumulated gas can cause explosions. It has become standard practice for landfill owners to monitor methane generation and, often, to collect the gas for controlled flaring. Rather than flaring gas without energy recovery, some landfills install LGR systems to process the gas. These facilities may burn the methane to generate electricity, may provide it directly to an industrial customer, may refine it to sell to a natural gas pipeline, or may process it to produce a synthetic fuel. A typical

LGR system thus has two components, a collection system and a processing system; these usually have the same owner.

Unlike WTE facilities, LGR facilities are not usually financed with tax-exempt revenue bonds.[9] Publicly owned facilities are usually financed by general obligation bonds or local government revenues, while privately owned facilities are financed by a combination of equity and bank loans (letters of credit).

c. Ownership patterns for WTE and LGR facilities

At this point it is useful to note the general patterns of ownership in the WTE and LGR industries. Before doing so, however, a brief word about data sources is appropriate.

The main source of data for this study are two surveys conducted by Governmental Advisory Associates (GAA). These surveys have collected institutional, financial, and technological information on essentially all WTE facilities that process municipal solid waste (Gould 1993) and all landfill gas management systems that recover energy (Gould 1991). They include not only those facilities that were operating at the time of the survey, but also facilities that were in construction, advanced planning, conceptual planning, or had already been built and subsequently shut down. The surveys also include information on some facilities that were planned but never built (scratched facilities), but these are not included in the current study.

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[9] LGR facilities are not used for waste disposal *per se*, so to use tax-exempt revenue bonds, they must qualify under other portions of the tax code (e.g., as a "small-issue").

Where appropriate the GAA data have been supplemented by a variety of other data sources (see Appendix A).

Turning to the pattern of institutional structures in the WTE industry, Table 1 categorizes owners of the 248 facilities in our primary sample (facilities that have been built or are currently planned). Local governments, which are taken to include individual cities and counties, groups of cities and counties, and public authorities, own more than 45% of the facilities; private firms own a similar share, split between municipally-sponsored and merchant facilities. The remaining facilities are owned by the federal government, state governments, or have not yet determined an owner ('Pending'). Of the 183 facilities sponsored by municipalities (115 owned by local governments plus 68 by private firms), 63% are publicly owned. About 46% of the local facilities and 36% of the federal are operated by private firms. The rest are operated by their owners or, in a few cases, by organizations in the same sector (e.g., a private firm may contract for operations with another private firm).

Table 1: Ownership of Waste-to-Energy Facilities

Local Government	115
Private Firms - Sponsored	68
Private Firms - Merchant	49
State Government	11
Federal Government	3
Pending	2
Total:	248

Table 2 provides ownership information for LGR collection and processing facilities. Only 164 observations are available for processing (as compared to 170 for collection) because some facilities have not yet determined processing ownership. Facilities are differentiated by whether they are located on a public or private landfill.[10] Not surprisingly, essentially all facilities at private landfills are privately owned. In addition, about two-thirds of collection facilities and three-quarters of processing facilities at public landfills are privately owned. In most cases the facility owner is also the facility operator.

Table 2: Ownership of Landfill Gas Recovery Facilities

Facilities on Public Landfills	Collection	Processing
Local Government	30	21
Private Firm	65	69
Federal Government	1	1
Sub-total:	96	91
Facilities on Private Landfills		
Local Government	0	1
Private Firm	74	72
Sub-total:	74	73
Total:	170	164

[10] For purposes of this study, we define a public landfill to be one with a public owner or a public operator. Of the 96 landfills defined to be public, 85 have both a public owner and operator, 8 have a public owner and a private operator, and 3 have a private owner and a public operator.

4. PRIVATIZATION AND FEDERAL TAX POLICY

We now examine how federal tax policy influences the costs and benefits of privatization. We begin by reviewing the relevant features of corporate tax policy. After discussing previous analyses that relate tax policy to public/private decisions, we then develop a simple accounting model to estimate the taxation-induced capital cost difference between public and private ownership. This model suggests some simple cross-tabulations to test whether tax policy has influenced privatization decisions; these analyses indicate that it has.

a. General background

Federal tax policy influences the relative cost of private and public ownership by delimiting the extent to which tax-exempt financing is available, by determining the difference in required rates of return between taxable and tax-exempt sources of capital, and by determining the amount of tax benefits (from tax credits and depreciation deductions) that can be realized if a project is privately owned. The relevant tax policies have changed repeatedly, most notably in 1981 and 1986.

Federal tax policies limit the extent to which tax-exempt revenue bonds can be used to finance private activities.[11] Because waste disposal is considered a public good, the federal government has exempted solid waste disposal facilities from many of these limitations. As a result, both publicly and privately owned WTE facilities are usually financed with tax-exempt revenue bonds. Portions of a WTE facility that

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[11] See Zimmerman (1991) for a comprehensive review of federal policies in this area.

are used to process steam (e.g., to generate electricity) after waste disposal must be funded with other sources of capital (e.g., general obligation debt, state and federal grants, taxable debt, or private equity), unless the processed steam/electricity is sold to another tax-exempt entity (e.g., a municipal electric company). As noted earlier, LGR facilities are typically not financed with tax-exempt revenue bonds; private facilities are financed with equity and taxable borrowing, while public facilities are financed out of municipal revenues or tax-exempt general obligation bonds.

Since 1984, the federal government has limited the total annual amount of tax-exempt debt that each state can issue for certain private activities. From 1984 to 1985, this cap included both privately and publicly owned WTE facilities. The tightened cap enacted in 1986 only includes privately owned facilities, however. Under this cap private projects have to compete for tax-exempt financing with other projects (e.g., housing and student loans) within a state.

Federal tax policy influences the relative capital costs of public and private ownership in two ways. First, the personal income tax determines the difference in required returns for taxable and tax-exempt bonds. Second, the corporate tax rate places a wedge between the before and after tax cost of equity; it creates no such wedge for public or private debt. The corporate tax rate has generally changed gradually over time, with the exception of the major drop from 46% to 34% in the Tax Reform Act of 1986 (TRA86).

The costs and benefits of private ownership are heavily influenced by federal policies defining tax credits and establishing the rules for capital depreciation. A 7-

10% investment tax credit (ITC) on capital equipment existed, with a few exceptions, from 1962 to 1985. In addition, WTE facilities could receive an energy investment tax credit on a portion of facilities built between 1978 and 1987. Since 1978, LGR facilities have received an alternative energy production credit for each unit of gas produced; this credit, whose value depends on the price of oil, will continue for a least another decade.

Depreciation rules specify how quickly a firm can write-off its investment against taxes; these rules have changed a number of times over the last thirty years. The Economic Recovery Tax Act (ERTA) of 1981 created a very favorable accelerated cost recovery system (ACRS) that allowed the rapid depreciation of capital through short tax lifetimes and front-loading of depreciation. For privately-owned facilities financed by tax-exempt revenue bonds, the Deficit Reduction Act of 1984 eliminated the ACRS front-loading, but maintained the ACRS service lives. TRA86 then substantially lengthened depreciation schedules (but increased front loading) for all facilities. TRA86 also established different service lives for facilities funded by tax-exempt debt and facilities funded by taxable debt.

To estimate the capital cost differences between public and private ownership that are induced by the federal tax code, we will develop a simple accounting model that calculates the present value of waste disposal capital costs under public and private ownership. To perform these calculations (and, thereby, to focus on the aspects of tax policy that are most relevant for the current analysis), we make a number of simplifying assumptions. First, because WTE facilities have continued to be successful in accessing tax-exempt financing, we will assume that the recent bond caps have not affected WTE financing decisions (see Kenyon 1991 and Zimmerman 1991 for general analyses of the effects of bond caps). Second, because our focus is corporate tax policy, we will not consider directly the effects of the personal income tax; these effects will be implicitly included in the difference between taxable and tax-exempt interest rates. Third, we will not model the alternative production credit associated with LGR operations; this credit provides additional incentives for private ownership beyond those considered here. Finally, throughout the paper we will assume that private facility owners are able to take full advantage of the tax benefits of ownership. This assumption is reasonable because many major WTE owners are large corporations with other profitable lines of business and because other private owners, in contrast to public owners, often structure sale-leaseback arrangements to allocate tax benefits to firms with large cashflows.[12]

b. Previous analyses of taxation and privatization

Only a handful of studies have analyzed the effect of tax policies on the public/private ownership choice. Seelaus (1987) considers the effect of TRA86 on privatization of wastewater treatment plants. He concludes that before TRA86 private ownership was less expensive than public whereas after the reform private ownership

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[12] As noted previously, government facility owners rarely structure tax ownership so that tax benefits flow to private parties. Private owners, in contrast, have executed at least nine such transactions. The disparity in leasing activity (and other tax structuring activity) between the private and public sectors is something of a mystery since the tax benefits of leasing should be much higher for public entities than for private firms.

was more expensive. Holcombe (1990) goes further, arguing that private ownership has always been disadvantaged by the tax system, and that TRA86 merely increased this disadvantage. As we will see, both authors are correct that TRA86 dramatically reduced the benefits of private ownership relative to public. However, their quantitative estimates of the capital cost differences are incorrect due to certain errors. Whereas the errors in Seelaus (1987) are relatively minor,[13] the errors in Holcombe (1990) dramatically bias his results against private ownership.[14]

A related literature examines the lease versus purchase decision from the perspective of the public sector (Callahan 1981; Masse, Hanrahan, and Kushner 1987). In certain circumstances, leasing may allow a private party (the lessor) to access the tax benefits of owning a piece of capital, while the public sector lessee

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[13] One problem is his method of discounting. He uses a typical approximation (discounting total project after-tax cashflows at the weighted after-tax cost of capital), instead of an exact approach (discounting after-tax equity cashflows at the after-tax equity rate of return). While the two approaches yield the same results under certain circumstances (Brealey and Myers 1988, p. 453-454), the specific time pattern of cashflows for these projects (tax benefits early, operating losses later) cause them to yield noticeably different results. As we discuss later, Seelaus (1990) also assumes a capital structure inconsistent with project financing.

[14] He assumes that private investors demand a fixed real, after tax rate of return *not including* any tax benefits of ownership. In reality, investors demand a rate of return inclusive of tax benefits. He assumes that this rate is 20%; with inflation of 5% and a corporate tax rate of 46%, this implies a before tax rate of return of 48% before tax benefits. Including tax benefits drives the required rate of return substantially higher, far above the rates usually used in project evaluations. In addition, he compares public projects that pay interest on debt covering 100% of a typical project to private projects that pay interest on debt equal to 100% of project costs plus equity returns on another 20%. Since he focuses only on tax costs and benefits, this assumption makes private ownership look better if tax-exempt finance is available and makes it look comparatively worse when tax-exempt finance is not available.

actually uses it. Like those papers, and unlike the analyses of Holcombe (1990) and Seelaus (1987), this paper will develop an explicit formula for the cost difference between public and private ownership.

Another series of papers examines the resource allocation distortions that occur when private and public capital are taxed at different rates (Fortune 1983). While this literature primarily focuses on the effect of tax policy on marginal investment incentives in the public and private sectors, this paper will focus on the ownership decision for inframarginal investments. In other words, it takes the investment decision as given and examines the difference in capital costs between public and private ownership. It thus focuses on the institutional margin, not the investment margin.

c. A model of capital cost differences

To quantify the difference in capital costs between public and private ownership, we now develop a simple accounting model that tracks the costs of financing a WTE facility; with slight changes in interpretation, the model applies equally to LGR facilities. As noted, we take the investment decision as given; the project will be developed and the question is how project costs differ between public and private ownership. To focus on capital cost differences, we ignore any operating revenues (e.g., from selling recovered energy or materials) or operating costs associated with the facility. We also assume that the cost of building a facility is the same under public and private ownership; this cost is normalized to $1.

Our analytic approach will be to compare the net present value cost to a municipality of owning a WTE facility to the NPV cost of contracting with a private firm for the same WTE services.[15] Under public ownership, the municipality issues debt to fund 100% of the project; this debt is paid off over L years. For simplicity, we assume that the bonds are issued as serial bonds that yield a constant time pattern of debt service payments. In other words, the municipality pays debt service ds_m in each of L years. At the end of L years, it owns a facility with salvage value s. Thus, the cost of the facility to the municipality equals the present value of its debt service less the salvage value:

$$Cost_{muni} = \sum_{t=1}^{L} \frac{ds_m}{(1+r_m)^t} - \frac{s}{(1+r_m)^{L+1}}, \tag{1}$$

where r_m is the municipal discount rate.

Because the debt service is constant over time, we can simpify this expression to

$$Cost_{muni} = \alpha_m ds_m - \frac{s}{(1+r_m)^{L+1}}, \tag{2}$$

where α_m is the discounting factor defined by

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[15] An alternative to this discounted cash flow approach would be to compare effective tax rates for WTE facilities under private and public ownership. The discounted cash flow approach is adopted here because it more closely approximates the type of project analyses that financial consultants prepare when comparing costs under different ownership structures; this approach is also used in much of the related literature, including Holcombe (1990), Masse, Hanrahan, and Kushner (1987), and Seelaus (1987).

$$\alpha_m \equiv \sum_{t=1}^{L} \frac{1}{(1+r_m)^t}. \tag{3}$$

Under private ownership, the municipality pays an annual service fee sf_t to the private developer. For simplicity, we assume that this fee is constant in nominal terms over the L year contract: $sf_t = sf$.[16] Thus, the cost to the municipalilty of contracting with a private firm is

$$Cost_{priv} = \sum_{t=1}^{L} \frac{sf}{(1+r_m)^t} = \alpha_m sf \tag{4}$$

We now determine how the service fee depends on corporate tax policy. A private developer's return equals the net present value of the service fees, calculated using a private discount rate, plus the tax benefits of depreciation and tax credits, plus the salvage value of the facility, less income taxes, interest payments, and principal payments.

Let r_p be the private developer's required after-tax rate of return on a WTE project. If f_e is the fraction of the facility that is financed with equity, then to achieve the developer's required rate of return, the annual service fee must satisfy

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[16] This is not an unreasonable assumption. Real service fees are often structured as a fixed rate plus a rate that escalates with some measure of inflation. The variable rate typically covers O&M costs (which we are ignoring), while the fixed rate covers capital costs.

$$f_e \le \sum_{t=1}^{L} \left(\frac{sf(1-\tau) + k_t + \tau d_t - pi_t(1-\tau) - pp_t}{(1+r_p)^t}\right) + s\frac{1 - \tau_{cg}AD}{(1+r_p)^{L+1}}, \qquad (5)$$

where τ is the corporate tax rate, the k_t are tax credits, d_t are depreciation deductions, pi_t and pp_t are private interest and principal payments, τ_{cg} is the capital gains tax rate, and AD is the accumulated depreciation on the project at the end of L years. Inequality 5 thus requires that the NPV of net operating cashflows plus the net salvage value of the facility must equal or exceed he original equity investment (which, for simplicity, we assume is made in year 0).

A competitive market for this service, *ex ante*, implies that competing suppliers will bid their service fees down so that inequalilty 5 holds with equality. This equality then implicitly defines the annual service fee that a municipal customer must pay the private developer as a function of the required equity return, the salvage value, and the structure of corporate tax policy. The service fee is given by

$$sf = ds_p + \frac{1}{\alpha_p}\left(\frac{f_e}{1-\tau} - \frac{k}{1-\tau} - \frac{\tau z}{1-\tau} + \frac{\tau P}{1-\tau} - \frac{s}{1-\tau}\frac{1 - \tau_{cg}AD}{(1+r_p)^{L+1}}\right) \qquad (6)$$

where we have assumed that the annual debt service payment ds_p is constant over time ($ds_p = pi_t + pp_t$), where α_p is a discounting factor defined using the private discount rate r_p, and where we have defined

$$k \equiv \sum_{t=1}^{L} \frac{k_t}{(1+r_p)^t},$$
$$z \equiv \sum_{t=1}^{L} \frac{d_t}{(1+r_p)^t},$$
$$P \equiv \sum_{t=1}^{L} \frac{pp_t}{(1+r_p)^t}. \tag{7}$$

Equation 6 has a straightforward interpretation. The annual service fee must cover the project's debt service (the first term on the right-hand side) and provide the required rate of return to the private investor (the second term). Note that when the tax benefits of private ownership are large and the project is highly leveraged (i.e., f_e is small), the second term can be negative, implying that a private developer would be willing to accept an operating loss on the project in order to get the tax benefits. In such cases, the annual service fee will be less than the annual debt service payments. Of course, service fees below the annual debt service requirements are not compatible with the project financings usually used for these projects; we return to this issue below.

Using equations 2 and 6, we calculate the municipal-private cost differential as

$$\begin{aligned}\Delta &\equiv Cost_{muni} - Cost_{priv} \\ &= \alpha_m(ds_m - ds_p) - \frac{\alpha_m}{\alpha_p}\frac{f_e}{1-\tau} + \frac{\alpha_m}{\alpha_p}\left(\frac{\tau z}{1-\tau} - \frac{\tau P}{1-\tau}\right) + \frac{\alpha_m}{\alpha_p}\frac{k}{1-\tau} \\ &\quad + s\left(\frac{\alpha_m}{\alpha_p(1-\tau)}\frac{1-\tau_{cg}AD}{(1+r_p)^{L+1}} - \frac{1}{(1+r_m)^{L+1}}\right)\end{aligned} \tag{8}$$

The α ratio, which converts NPVs calculated using the private discount rate into NPVs using the municipal rate, appears because we have allowed the municipal and private discount rates to differ. If these rates are the same, the α ratio will equal 1; if, as is often assumed, the municipal discount rate is lower than the private one ($r_m < r_p$), the ratio will be somewhat greater than 1.

The first term of equation 8 reflects the difference in debt service payments between municipal and private ownership. Contrary to the claims of some analysts, the deductibility of interest payments does not give the private sector a capital cost advantage. Rather, the deductibility implies that debt service under private ownership can be treated as a flow-through to the sponsoring municipal entity.

The second term in equation 8 reflects the cost of equity returns; these returns are scaled by $1/(1-\tau)$ because the public sector must pay them on a before-tax basis. The third term, reflecting the impact of depreciation, illustrates that the depreciation benefits of private ownership arise not from the existence of depreciation alone but from the acceleration of that depreciation relative to principal payments. The depreciation benefits, like the tax credit benefits included in the fourth term, are scaled by $1/(1-\tau)$ because these after-tax benefits reduce the before-tax payments that the municipality must pay to the private investor. The final term reflects the net difference in the salvage value of the facility.

d. Capital cost differences for WTE facilities

We now apply equation 8 to model the capital cost difference between municipal and private ownership of WTE facilities. To do so, we require some basic assumptions about facility capital structure, tax treatment, and financing costs. We first assume that 75% of the facility costs qualify for tax-exempt revenue bonds and that this amount of bonds will be issued under either public or private ownership. We assume that a private owner finances the remaining 25% of the facility with equity. A public owner might access a number of different capital sources, including general obligation debt or, as has become more common recently, taxable debt. For purposes of the current calculation, we assume that the public sector uses taxable debt.[17]

For depreciation purposes, we assume that 90% of facility costs are considered personal property (equipment), with 10% real property (structures), and that 80% of the facility is for solid waste disposal and 20% for energy processing; together, these assumptions imply how facility depreciation is calculated (see Appendix B). We also assume that the salvage value of the facility will equal 30% of its original cost and that projects are financed over 20 years. These figures are consistent with actual values (see, e.g., Monet 1986 and Chen, France, and Sharpe 1990).

For the tax-exempt borrowing rate, we use the S&P index of high quality municipal yields; for the taxable rate we use Moody's Aaa corporate yields. Both of these series are reported in the *Economic Report of the President* (1993). To estimate required equity returns, we assume that equity investors demand a risk premium over

[17] A municipality using general obligation debt would usually face a lower interest rate than that on taxable debt and thus this assumption might seem to overstate municipal financing costs. Because of the need to get public approval for general obligation bonds issues and the exhaustion of local debt capacity, however, use of general obligation debt for a WTE facility may impose significant non-interest costs that also ought to be included in a cost comparison. Use of the taxable bond rate is a rough way of including these costs here.

the 30 year Treasury rate. The 30 year rate is available from Salomon Brothers (1993). Ibbotson Associates (1993) reports an average equity risk premium of 7.3% over the 1926-1992 period. Assuming a beta of 1.0, we add this value to the 30 year Treasury rate to estimate required equity returns.[18]

To isolate the effects of tax policy changes over time, we first calculate equation 8 using average interest rates and equity rates over the 1972-1992 period. These are

Tax-exempt	7.55%
Taxable	9.83%
Before Tax Equity	16.48%.

Based on these assumptions, Figure 1 reports the difference between municipal and private capital costs for WTE facilities over the period 1962 to 1992 (see Appendix B for a summary of the underlying tax assumptions). Note that the value is

[18] The cost differences we report will therefore include two components: one related purely to the different financing assumptions and one related to the tax effects. The financing assumptions imply, in essence, that the WTE project faces different risk-adjusted costs of capital under public and private ownership. While this assumption is standard in many project finance analyses (see, e.g., Seelaus 1987 and Holcombe 1991) and in the type of consultant reports that are prepared for municipalities making these decisions, it does conflict with the standard finance intuition that project risk is, to first order, invariant to ownership structure and that, except for taxes, the overall capital cost of a project should be the same under public or private ownership. The reader should keep in mind, therefore, that these financing assumptions may cause private ownership to look more expensive, relative to public ownership, than it would in an analysis that assumed the same capital cost (up to taxes) under each ownership structure. While this assumption thus influences the level of the numbers reported in Figures 1-4, it has much less impact on later empirical work that relates the capital cost differential to privatization decisions. Those analyses focus on changes in the capital cost differential over time; such changes are relatively unaffected by the capital cost modeling used here (put another way, the difference between the two approaches is a mostly a matter of the overall level of the capital cost difference; there is much less difference in changes over time).

always positive, indicating that, over this period, private capital costs have been lower than public ones. As other analysts have suggested, ERTA increased the benefits of private ownership while TRA86 dramatically reduced those benefits.

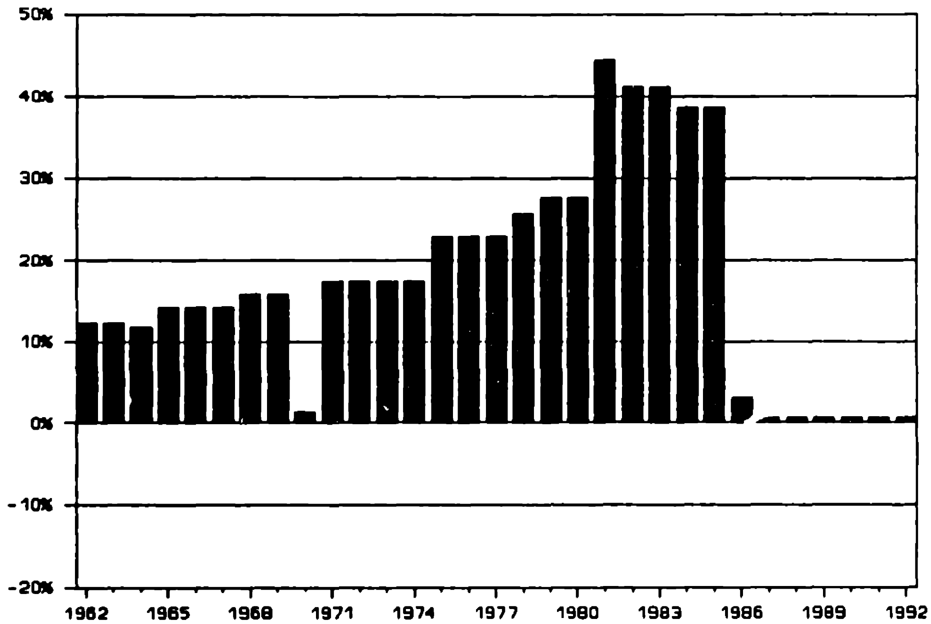

Figure 1: The difference between public and private capital costs, as a fraction of total investment, for WTE facilities, assuming average returns, fixed capital structure, and actual tax policy over 1962-1992.

While the analysis of Figure 1 uses average interest rates and equity returns to illustrate the effect of tax law changes, an estimate of public-private cost differences over 1962-1992 requires actual rates during this period. Figure 2 thus reports the capital cost differential using the actual time series of interest rates and estimated equity returns. Compared to Figure 1, Figure 2 demonstrates a greater increase in the benefits of private ownership during the early 1980's and a greater decrease in those benefits during the late 1980's.

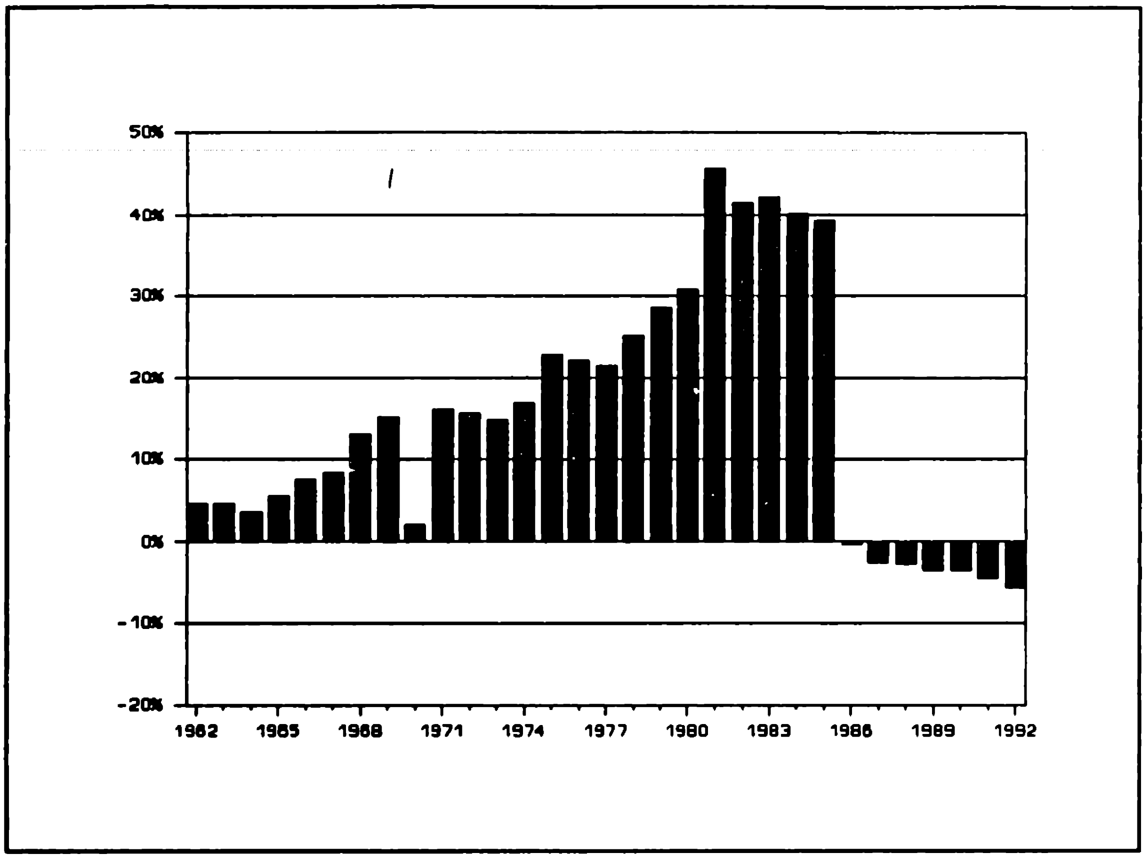

Figure 2: The difference between public and private capital costs, as a fraction of total investment, for WTE facilities, assuming actual returns, fixed capital structure, and actual tax policy over 1962-1992.

The simple analysis embodied in Figures 1 and 2 overlooks an important aspect of project finance (also overlooked by Seelaus (1987) and Holcombe (1990)). In order to execute a project finance arrangement, bond holders need to be assured that debt payments will be made. However, when projects are highly leveraged and tax benefits are large, the service fee required to achieve necessary equity returns will be less than the annual debt service. For 1981, for example, the previous analysis generates a coverage ratio (the ratio of the service fee to the annual debt service) of only 0.77. Debt holders require coverage ratios in excess of 1.00.

To illustrate the importance of the financing terms, Figure 3 reports results when we require that a project achieve a coverage ratio of 1.10. The equity investor still earns its required return; what changes is that the equity investment adjusts to ensure that the coverage requirement is met.[19] If non-qualifying costs (the costs that cannot be financed with tax-exempt debt) exceed the equity investment, we assume the firm issues some taxable debt as well. Comparing Figure 3 with Figure 2, we see that endogenizing the capital structure in this way reduces the apparent impact of tax law changes.[20] Analyses that ignore changes in capital structure will therefore overstate the impact of tax law changes on public-private cost differentials. The differentials reported in Figure 3 will be used in later empirical work that considers whether tax law changes actually influenced privatization decisions.

e. Capital cost differences for LGR facilities

A similar analysis was performed for LGR facilities, assuming a seven year

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[19] The resulting equity fraction range from about 38% during the early 1980's to about 15% after TRA86 (in 1986). These are roughly consistent with reported capital structures in the industry. For example, Scully Capital Services (1987) projects that TRA86 would cause equity fractions to drop from 30% to 15%, while Monet (1986) reports private facility bids with as little as 10% equity.

[20] Of course, the 1.10 coverage ratio is just a rough rule of thumb to endogenize the capital structure. A more advanced analysis would determine beta's for the equity and debt returns under various capital structures and use these to scale the equity and debt returns. Note also that the 1.10 figure is very rough; actual projects may have ratios significantly higher.

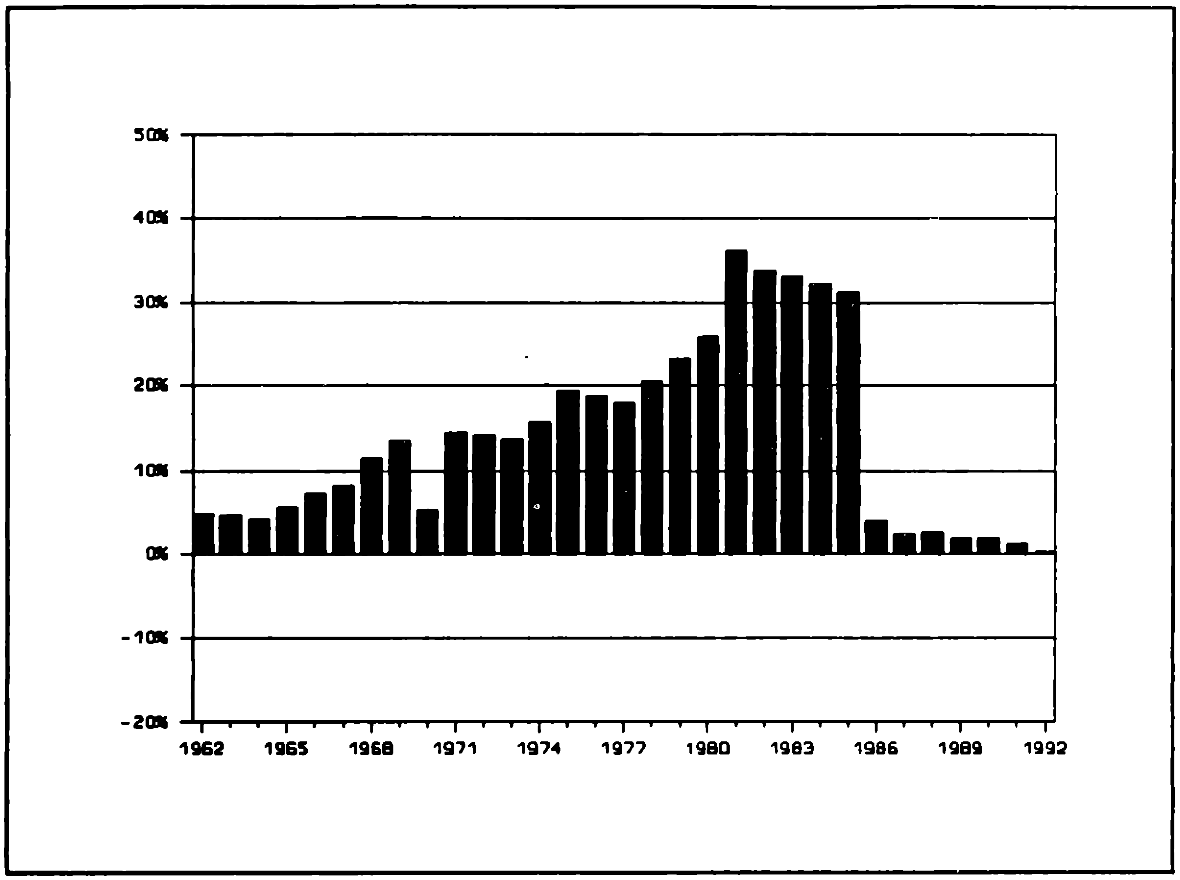

Figure 3: The difference between public and private capital costs, as a fraction of total investment, for WTE facilities, assuming actual returns, endogenous capital structure, and actual tax policy over 1962-1992.

financing period.[21] We assume that these facilities are entirely personal property. Under public ownership, they are financed with 100% tax-exempt debt, while under private ownership they are financed with a mix of equity and taxable debt (the latter is a proxy for the letters of credit that are often used). Tax-exempt, taxable, and

[21] In practice, public landfills usually receive annual royalty payments from private developers, rather than paying an annual service fee. Equation 7 still captures the capital cost difference between public and private ownership, however. To see this, note that each royalty payment can be represented as the difference between the annual revenues of the project and the portion of those revenues kept by the private developer. The transaction can thus be modelled as though the public owner receives all project revenues and then pays an annual service fee to the private developer. Equation 7 then applies directly.

equity returns are calculated as in the WTE case.

Figure 4 reports the results for 1975 to 1992. The time pattern of cost differentials displays the same basic pattern as in the WTE industry, although it is somewhat smoother due to the shorter financing period. During the early 1980's, private ownership was clearly favored over public. Because this capital cost analysis does not include the tax benefits associated with operating a LGR facility, Figure 4 does not reflect the total tax-induced difference in costs. Since 1978, the alternative energy production credit has been available for each unit of recovered landfill gas. Including this credit in the analysis would make private ownership more attractive over the post-1978 period.

f. The time pattern of WTE privatization

The basic prediction of the tax analysis is that private ownership of LGR and WTE facilities should be more common under the favorable ERTA tax rules than it was under the rules that held prior to 1981 or after TRA86. As a simple test of this theory, we can examine the pattern of ownership decisions made during three regimes - pre-ERTA (up through 1980), ERTA (1981 through 1985), and TRA86 (1986 and after).

In making these analyses, it is important to select an appropriate sample of facilities. For WTE, the appropriate group is all facilities sponsored by a public entity. Because there is no variation is ownership of state and federal facilities (all are owned by the government they serve), we focus in particular on ownership at the

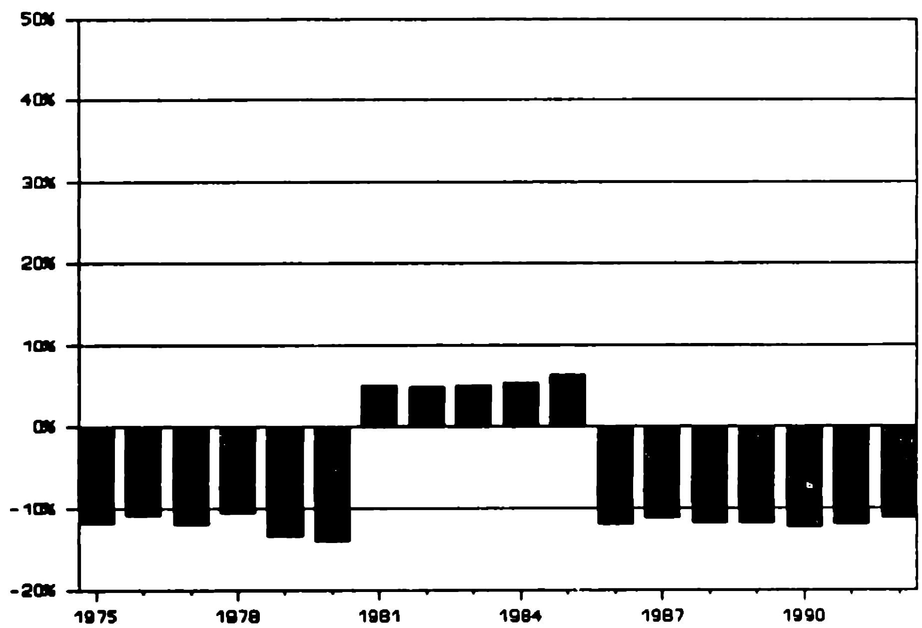

Figure 4: The difference between public and private capital costs, as a fraction of total investment, for LGR facilities, assuming actual returns, fixed capital structure, and actual tax policy over 1975-1992.

183 municipally-sponsored facilities. Table 3 reports the breakdown between municipal and private ownership for municipally-sponsored projects during the three tax regimes.[22]

As table 3 illustrates, private ownership became more common after ERTA and less common after TRA86. These changes are significant both statistically (as illustrated by the χ^2 values testing independence across the two tax changes) and

[22] Tax regimes were determined by estimating the time during which ownership decisions were made and the tax policy that then would have been expected to apply to the facility. On average, facilities were planned from 2 to 5 years before their on-line dates, although in some cases, the period is longer. For a detailed discussion of the method by which decision periods were determined, see Appendix A.

Table 3: Tax regimes and ownership of municipally sponsored WTE facilities

Owner: / Period:	Municipal	Private	Total
Pre-ERTA	45	9	54
ERTA	36	39	75
TRA86	34	20	54
Total:	115	68	183

Comparison	$\chi^2(1)$	p-value
Pre-ERTA versus ERTA	16.78	0.000
ERTA versus TRA86	2.83	0.092

economically. While private firms owned more than 50% of facilities developed under ERTA, they owned only 17% of facilities developed under earlier tax laws and only 37% of facilities developed after TRA86. These changes suggest that changes in tax law do influence privatization decisions. The relative increase in private ownership between the pre-ERTA and TRA86 periods suggests, however, that other factors matter as well.

g. The time pattern of LGR privatization

To analyze LGR privatization, we consider ownership decisions for facilities at public landfills.[23] As illustrated in Table 4, the relative level of private ownership of both collection and processing facilities increases significantly (both statistically

[23] For this analysis, we assume that LGR facilities were developed under the tax policy in force two and a half years before their reported on-line dates (see Appendix A).

Table 4: Tax regimes and ownership of LGR facilities

a. Ownership of collection systems at public landfills

Tax Regime	Private	Public	Total
Pre-ERTA	8	6	14
ERTA	31	6	37
TRA86	26	18	44
Total	65	30	95

Comparison	$\chi^2(1)$	p-value
Pre-ERTA versus ERTA	4.01	0.045
ERTA versus TRA86	5.88	0.015

b. Ownership of processing systems at public landfills

Tax Regime	Private	Public	Total
Pre-ERTA	8	6	14
ERTA	31	4	35
TRA86	30	11	41
Total	69	21	90

Comparison	$\chi^2(1)$	p-value
Pre-ERTA versus ERTA	6.08	0.014
ERTA versus TRA86	2.83	0.093

and economically) under ERTA and then decreases significantly under TRA86. These results also support the tax policy hypothesis.

Of course it is possible that other factors are driving the changes in ownership of these facilities. In the case of LGR facilities, we can partially control for such factors by using facilities at private landfills as a control group. Specifically, we can control for any factors that may have made integration between landfill owners and facility owners more attractive in the early 1980's and less attractive later. Such potentially confounding variables include changes in technology and changes in landfill regulation.

Tables 5 and 6 present a breakdown of facility integration by tax period. Part a of each table reports integration at public landfills, while part b reports integration at private landfills. The first comparison in each part includes all of the relevant landfills, while the second part excludes certain landfills; this exclusion will be explained momentarily.

As we would expect from the previous discussion of public ownership, integration at all public landfills increases significantly after ERTA and then decreases after TRA86 (the numbers differ slightly from the previous analysis because some facilities are owned by public entities that differ from the public landfill owner). Integration at all private landfills shows no particular change from ERTA; however, the degree of integration increases dramatically following TRA86.

This change in integration at private landfills might seem to imply that some change in the mid-1980's made integration itself more attractive. If true, this finding

Table 5: Tax regimes and integration at LGR collection facilities

a. Public landfills

	Are the landfill and the collection system integrated?					
	All Facilities			Excluding Developers		
	Yes	No	Total	Yes	No	Total
Pre-ERTA	6	8	14	4	8	12
ERTA	6	31	37	4	30	34
TRA86	17	27	44	16	27	43
Total	29	66	95	24	65	89
Comparison		$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Pre-ERTA vs. ERTA		4.01	0.045		2.87	0.090
ERTA vs. TRA86		4.97	0.026		6.39	0.011

b. Private landfills

	Are the landfill and the collection system integrated?					
	All Facilities			Excluding Developers		
	Yes	No	Total	Yes	No	Total
Pre-ERTA	5	6	11	1	4	5
ERTA	12	17	29	2	13	15
TRA86	23	11	34	1	9	10
Total	40	34	74	4	26	30
Comparison		$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Pre-ERTA vs. ERTA		0.05	0.816		0.13	0.718
ERTA vs. TRA86		4.37	0.037		0.06	0.802

Table 6: Tax regimes and integration at LGR processing facilities

a. Public landfills

	Are the landfill and the processing system integrated?					
	All Facilities			Excluding Developers		
	Yes	No	Total	Yes	No	Total
Pre-ERTA	6	8	14	4	8	12
ERTA	4	31	35	2	30	32
TRA86	9	32	41	8	32	40
Total	19	71	90	14	70	84

Comparison	$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Pre-ERTA vs. ERTA	6.08	0.014		5.44	0.020
ERTA vs. TRA86	1.47	0.225		2.81	0.094

b. Private landfills

	Are the landfill and the collection system integrated?					
	All Facilities			Excluding Developers		
	Yes	No	Total	Yes	No	Total
Pre-ERTA	5	6	11	1	4	5
ERTA	11	18	29	1	14	15
TRA86	23	10	33	1	9	10
Total	39	34	73	3	27	30

Comparison	$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Pre-ERTA vs. ERTA	0.19	0.665		0.74	0.389
ERTA vs. TRA86	6.29	0.012		0.09	0.763

would imply that increased integration at public landfills might be due not to tax law changes (which do not affect the integration decision at private landfills), but to whatever factor promoted integration at private landfills.

This reasoning fails because it ignores an important confounding factor that led to the increase in integration at private landfills in the late 1980's. During this period, major LGR facility developers, most notably Waste Management and Browning Ferris, the two largest waste management firms, installed many LGR facilities on their own landfills. It is not surprising that LGR developers that own landfills tend also to own the facilities at these landfills. Because they can provide the facilities themselves, there is usually no external supplier that might otherwise own the facility.

Landfills owned by LGR developers should therefore not be included in a control group intended to mirror the type of integration decisions made at public landfills.[24] Instead, an appropriate control group should include those private landfills that, like most public landfills, do not have the option of providing the facility themselves.

Thus, the second set of comparisons in Tables 5 and 6 exclude any landfills owned by LGR developers. For the private landfills, this means excluding landfills owned by Waste Management, Browning Ferris, and a few smaller developers. For the public landfills, it happens that a public entity, the Los Angeles County Sanitation

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[24] This is true for purposes of these simple cross-tabulations; in more detailed econometric work, we control for developer status with dummy variables rather than excluding these observations.

Districts (LACSD), is also a major LGR developer (it even owns at least one facility that is not located on one of its landfills). Landfills owned by the LACSD are therefore excluded as well.[25] One landfill that is operated by Waste Management, but owned by a public entity is also excluded.

The sample of public landfills excluding developers shows the familiar pattern of integration increasing and decreasing with the two tax changes. The private landfills excluding developers, however, show no indication of integration changing over time. This comparison (essentially a difference-in-differences comparison) suggests that factors peculiar to the public sector are driving the public integration decision; these results thus support the tax policy explanation.

5. TRANSACTION COSTS, ASSET SPECIFICITIES, AND INTEGRATION

We now discuss how transaction costs associated with asset specificities may influence the governance structures of waste disposal facilities, in general, and privatization of such facilities, in particular. We begin by reviewing the basic ideas of transaction cost economics and its insights regarding private decisions about contracting and vertical integration. We then argue that public production of publicly-

[25] A complete analysis of public enterprise would, of course, try to explain why LACSD has become a major player in the waste disposal business. For current purposes, however, it is sufficient to focus on typical public sector landfill owners and treat LACSD as a special case. The results of the analyses considered in this paper are largely invariant to the inclusion or exclusion of LACSD landfills. For example, the results of Table 4 remain the same if we exclude the LACSD landfills (the significance of the ERTA to TRA86 change for processing facilities increases to the 5% level, however).

provided goods and services is institutionally similar to vertical integration between private firms and that transaction cost concerns may therefore influence privatization decisions. Some simple cross-tabulutions of institutional patterns against various measures of transaction costs suggest that transaction cost issues do influence governance structures, including privatization decisions, in the waste disposal industry.

a. Transaction cost economics

In deciding whether to provide a public service by owning production facilities or by contracting with a private firm, a government faces a choice similar to that of a firm deciding whether to make or buy its inputs. In particular, the government's privatization decision involves the same type of institutional/governance issues as arise in decisions about vertical integration. To understand privatization decisions it is therefore useful to consider some institutional reasons why firms may vertically integrate.[26]

The transaction cost paradigm (Coase 1937; Williamson 1979, 1985; Klein, Crawford, and Alchian 1978) suggests one set of institutional factors that influence vertical relationships. Transaction cost reasoning begins with the simple observation that economic transactions can be organized under a variety of institutional structures ranging from anonymous spot markets à la Walras to complete vertical integration.

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[26] Of course firm decisions about vertical integration may also be driven by other factors (e.g., market foreclosure, avoiding double marginalization problems, etc.) that may be less applicable to the public enterprise decision; see Perry (1989).

Exchange under these institutions is not costless; in particular, contrary to standard neoclassical assumptions, exchange through markets is not costless. Furthermore, the costs of exchange vary across institutional structures depending both on the type of transaction that is being made and on the relevant production technology. As a result, it is possible that in some situations non-market forms of exchange will exhibit lower transaction costs than market exchange. Of course, production costs may also vary across governance structures. The transaction cost paradigm predicts that firms will select governance structures in order to minimize total costs, including both direct production costs and transaction costs.

While the notion of transaction costs has often proved difficult to operationalize, Klein, Crawford, and Alchian (1978) and Williamson (1983, 1985) have noted that asset specificities often give rise to such costs. An asset is considered specific to a transaction if its value in that transaction is larger than its value in alternatives. Following Williamson (1983), Joskow (1988, pp. 106-107)) described four common types of specificity:

> Site specificity: The buyer and the seller are in a "cheek-by-jowl" relationship with one another, reflecting ex-ante decisions to minimize inventory and transportation costs. Once sited, the assets in place are highly immobile.
>
> Physical asset specificity: When one or both parties to the transaction make investments in equipment and machinery that involves design characteristics specific to the transaction and which have lower values in alternative uses.
>
> Human asset specificity: Investments in relationship-specific human capital that often arise through a learning-by-doing process.
>
> Dedicated assets: General investments by a supplier that would not

otherwise be made but for the prospect of selling a significant amount of product to a particular customer. If the contract were terminated prematurely, it would leave the supplier with significant excess capacity.

Once a specific asset is in place (i.e., sunk), the difference in value between the current use and the next best alternative generates a rent over which the transacting parties could, in principle, bargain. Both the costs of this bargaining and the costs of any efforts to mitigate it (including, possibly, foregoing the specific investment in the first place) may be significant. As a result, firms may prefer to replace spot market transactions with long-term exchange relationships, such as long-term contracts or vertical integration, that avoid such bargaining.

When significant uncertainties exist, long-term contracts will have to be carefully structured to protect specific assets. As a result, such contracts will be complex, will cover long time periods (up to fifty years for the coal plants Joskow (1988) studies), and will include specialized provisions (e.g., requirements contracting, take-or-pay provisions, etc.) that guarantee demand to the facility. As uncertainty increases, it becomes more difficult, and more costly, to design, negotiate, and execute long-term contracts that attempt to protect specific assets under all possible contingencies. As a result, vertical integration may become a more attractive method of governance.

The transaction cost analysis of governance thus implies that long-term relationships are required when assets are specific, exchange continues over time, and parties are willing, *ex post*, to expropriate from one another (in Williamson's (1985) terms, they are opportunistic). When uncertainties are large, these long-term relationships are likely to take the form of complex long-term contracts or vertical integration.

The main predictions of transaction cost economics have received empirical support in a number of industries. Monteverde and Teece (1982), for example, find that automobile manufacturers tend to produce parts that are specific to their models, while they tend to out-source generic parts. Joskow (1985) finds that coal mines are more likely to be owned by electric utilities when coal-fired power plants are located near them. In the absence of integration, relationships between mines and the minemouth coal plants are governed by very long, complex contracts. As noted in Joskow (1988), similar results supporting transaction cost predictions hold in a number of other industries, including aerospace production, marketing, and aluminum production.

While both the theoretical and empirical literatures focus on vertical integration between private firms (Borcherding 1983, 1988 are exceptions), it should be clear that nothing in the argument is specific to private enterprise. In particular, we can view government purchasing and selling structures as ranging along the same continuum of governance structures (with public production a special case of vertical integration) and being subject to similar variations in transaction costs.

b. Asset specificities and integration in the WTE industry

We now consider the extent to which transaction costs related to asset specificities influence integration in the WTE industry. We focus on integration, in general, as well as privatization *per se*, because both public and private institutional relations should be influenced by similar types of transaction costs. Factors that promote integration should, all else equal, discourage privatization.

WTE facilities typically involve substantial fixed capital investment. Because solid waste is expensive to transport, these facilities tend to be located near the waste sources they serve and tend to be sized so as to provide a substantial amount of waste disposal capacity to that source. Thus WTE facilities are characterized by both site and dedicated asset specificities.

WTE facilities are typically expected to have service lives of twenty or more years; thus, the relationship between waste supplier and the facility is of a very long-term duration. Future conditions in the waste disposal market are subject to significant uncertainties, due to potential changes in environmental regulations and waste generation rates (due both to economic factors and potential recycling policies); revenues from energy sales may be similarly uncertain due to price fluctuations. Given this combination of specific assets, long-term relationships, and significant uncertainty, we should expect relationships between waste suppliers and WTE facility owners to be governed under complex long-term contracts or vertical integration. Because significant uncertainties tend to make even complex contracts incomplete, we expect that integration will be particularly attractive.[27]

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[27] The trade press includes a number of accounts that indicate that contracts in this industry are incomplete. For example, an article entitled "So you think you have a ironclad contract?" (Siemer 1984) discusses how the courts substantially revised a contract between a county and a private WTE developer. In this case, the contract revisions went against the county, whose primary sunk decision was signing a contract

The pattern of governance structures in the industry supports this hypothesis. At least 138 of the 246 facilities[28] in our primary sample (about 56%) are integrated with their primary waste sources.[29] This figure includes 11 federal facilities, 2 state facilities, 9 completely private facilities, and 115 municipal facilities. In addition, at least 54 facilities operate under long-term (10 or more year) contracts.[30] These include 2 completely private facilities, 1 state facility, and 51 privately owned/municipally-sponsored projects. In total then, at least 74% (182 out of 246) of the facilities are governed by long-term relationships. The fraction is substantially higher for municipally-sponsored projects; at least 91% of these (166 out of 183) are governed by vertical integration or long-term contracts.

Long-term contracts for waste disposal tend to be quite long. Of the 51 privately owned/municipally-sponsored projects mentioned above, only 3 have contracts as short as 10 years; 37 of the contracts are for 18 to 22 years, while 11 are for 25 years or more.

WTE facilities are typically protected by policies that guarantee waste

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that continued to bind it after the revisions. It is easy to imagine a similar case with a ruling going against the developer.

[28] Recall that two of the 248 facilities had ownership decisions pending; these facilities are dropped from the sample.

[29] The figure may actually be somewhat higher because some merchant facilities receive waste from affiliated waste haulers. For example, American Ref-Fuel, a joint venture of Browning Ferris Incorporated (BFI) and Air Products, tends to locate its facilities in areas where BFI is a major hauler. Relationships between waste haulers and waste disposal facilities are beyond the scope of the current study but may be a fruitful topic for further research.

[30] Contract lengths are missing in some cases.

deliveries. These guarantees can be implemented via contractual provisions such as put-or-pay provisions, which require that the waste generator pay for a minimum amount of waste disposal in each year, even if it does not generate that much waste, or requirements contracts, which commit a waste generator to deliver a large fraction of its waste to a particular facility. Guarantees can also be implemented by flow control ordinances, laws that require local waste to be delivered to a specific facility, or *de facto* flow control, in which waste is guaranteed by the absence of any alternative disposal sites.

Almost three-quarters of municipally-sponsored facilities report that waste is guaranteed to the facility (124 out of 167 reporting this item). Of these facilities, 73 report contractual guarantees, 5 report flow control legislation, and 46 report de facto flow control.

Table 7: Guarantees at municipally sponsored WTE facilities

	Private	Municipal	Total
Waste Guaranteed	53	71	124
Waste not Guaranteed	10	33	43
Total	63	104	167

	$\chi^2(1)$	p-value
Test of Independence	5.16	0.023

Transaction cost concerns suggest that privately owned/municipally-sponsored facilities require more protection than publicly owned projects. Specifically, the contractual relationship requires greater safeguards than the integrated relationship of public ownership. Some safeguards may be required under either governance structure to provide assurances to debt-holders; under private ownership, however, safeguards may also be required for the equity investors. Table 7 tests this prediction. It illustrates that while waste guarantees are common for both types of facilities, they are significantly more common for privately owned/municipally-sponsored facilities; 84% of these facilities are protected by guarantees, while only 68% of municipally-owned facilities are so protected.

The aggregate pattern of WTE governance is thus consistent with transaction cost predictions. Long-term contracts covering twenty or more years and vertical integration with waste suppliers are standard, as are contractual and legislative provisions that guarantee waste supplies. Because vertical integration often means public ownership, these results suggest that transaction cost rationales may explain some of the extent of public ownership.

While the aggregate pattern of governance in the WTE industry is consistent with transaction cost predictions, a more detailed test of the theory requires that we test whether differences in specificity among WTE facilities are associated with the hypothesized differences in governance; there are a number of sources of such variation in specificity.

Asset specificities are exacerbated, for example, when the entity that provides waste to a WTE facility is also the fuel customer for that facility. In such cases, the waste supplier/fuel customer is dependent on the facility both for waste disposal and energy; the potential risks of hold-up by the WTE facility are thereby amplified. We therefore predict that WTE facilities are more likely to be owned by their waste supplier when that supplier is also the facility's fuel customer.

Table 8: Patterns of integration at WTE facilities

	Are the waste supplier and the WTE facility integrated?					
	All WTE			Municipally Sponsored WTE		
	Yes	No	Total	Yes	No	Total
Fuel customer is the waste source	39	3	42	22	3	25
Fuel customer is not the waste source	92	98	190	89	60	149
Total	131	101	232	111	63	174
		$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Test of Independence		27.63	0.000		7.41	0.006

As Table 8 illustrates, the patterns of integration in this industry strongly support this hypothesis. In more than 90% of the cases in which waste suppliers are also the fuel customer, the facility is integrated with the waste supplier; such integration occurs in slightly less than 50% of the other cases. A similar pattern holds for municipally-sponsored facilities.

Facilities provide both waste disposal and energy services in a number of different settings. All 11 federal facilities and 2 of the 3 state facilities fall in this category. The federal facilities are all military bases in which the waste produced by residents is burned to provide steam or electricity for the base. The two state facilities are both prisons in Texas, in which the waste produced by inmates is burned to produce steam for the prison. Four additional facilities in this category are located at colleges or private factories.[31]

Table 9: Patterns of integration at WTE facilities

	Are the waste supplier and the WTE facility integrated?					
	All WTE			Municipally Sponsored WTE		
	Yes	No	Total	Yes	No	Total
Facility uses an RDF technology	24	36	60	23	20	43
Facility does not use an RDF technology	110	76	186	91	49	140
Total	134	112	246	114	69	183
		$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Test of Independence		6.70	0.010		1.86	0.173

The degree of specificity of a facility also depends on the technology it employs. For example, facilities using an RDF process are likely to be less specific than other facilities because some RDF equipment (shredders etc.) can be put to other uses (e.g., as part of a recycling or landfilling process) or, in some cases, moved to

[31] The Fisher Guide division of General Motors owns one of these facilities. According to the GAA survey (Gould 1993), GM purchased this facility from a local government to provide waste disposal and energy services. This example calls to mind the famous GM-Fisher Body integration discussed by Klein, Crawford, and Alchian (1978) and Klein (1988).

other sites. As a result, transaction cost theory predicts that RDF facilities will integrate with their waste sources less often than other types of facilities. Table 9 tests this prediction. It illustrates that RDF facilities are substantially less likely to integrate with their primary waste sources; this pattern holds both for municipally-sponsored facilities and for all facilities.

Facilities that co-process sludge with solid waste are likely to be more site specific (since they should be located near the source of sludge), as well as physically specific (they include specialized equipment to process the sludge) and, perhaps, specific in the sense of a dedicated asset, than other WTE facilities. We should therefore expect sludge processing facilities to be more often integrated with their municipal sponsors. Unfortunately, this prediction is difficult to test because of the small number of co-disposal facilities (5 out of 183 municipally-sponsored facilities). Of these facilities, 4 are municipally owned and 1 is privately owned. While this 80% level of integration is higher than the 62% rate (111 of 178) for other municipally sponsored facilities, it is not statistically significant (p-value of 0.325). Moreover, it may also be due to the availability of federal funding for wastewater treatment. Of the 4 publicly owned projects, three received federal funding, a significantly greater fraction than for WTE in general (we return to funding issues below).

A discussion of governance structures in the industry would not be complete without an explanation for the dramatic increase in merchant facilities in recent years (merchant facilities have increased from 4 before TRA86 to more than 20 since then).

While a complete examination of the rise of merchant facilities is beyond the scope of the current paper, it appears to be related to the much-heralded "disposal crisis" and the associated increases in fees at disposal facilities. When tipping fees rise in a region, the effective service territory around a facility increases as well since that area is determined by a tradeoff between transportation costs and tipping fees. An increase in tipping fees, all else equal, thus implies that facilities are less specific. An increase in tipping fees also makes it more likely that private investors will be willing to finance assets with high sunk costs that are not protected by long-term service agreements (this is an option value argument). I expect that a combination of these asset specificity and option value arguments will account for the rise of merchant facilities starting in the mid to late 1980's. Testing this hypothesis is a subject for future research.

c. Asset specificities and integration in the LGR industry

Although LGR systems require that capital equipment be located at a very specific site (the host landfill), they are not typically site-specific assets. LGR systems are constructed from industrial equipment (pipes, compressors, electric generators, etc.) that are, by and large, both entirely generic and easily portable. Indeed, equipment is often housed inside semi-trailers parked on landfills rather than inside specialized structures. As a result, much of the equipment can be easily transported to other uses; the GAA database (Gould 1991) reports a number of instances of such movement, including both shut facilities whose equipment was removed and operating facilities whose equipment came from other LGR sites.

As a result, it is unlikely that, in the aggregate, relationships between landfill owners and LGR developers are significantly influenced by site-specificity concerns; this expectation is consistent with the relatively low level of integration in the industry (see Table 6). However, there are particular cases in which specificities may influence the relationship between landfills and LGR systems or that between the systems and their fuel customers. For example, as in the case of WTE facilities, we may expect that integration between the landfill and the LGR system will be more common when the fuel customer and the landfill owner are the same entity. In such cases, the landfill owner is significantly more dependent on the LGR facility. We may also expect that direct gas customers will be more likely to integrate than are other customers. This follows because direct gas customers are likely to receive a greater portion of their fuel inputs from an LGR system than are gas pipelines or electric utilities. The direct gas relationship thus has more of the flavor of a dedicated asset specificity.

Table 10 tests these hypotheses for collection systems using the entire population of landfills as well as the sample that excludes developers who, as we are argued earlier, are much more likely to integrate landfill and collection ownership; results for processing facilities (not reported) are similar. Some observations are missing because relevant variables (e.g., technology type or fuel customer identity)

Table 10: Patterns of integration at LGR collection facilities

a. LGR/landfill integration versus fuel customer/landfill integration

	Are the landfill and the collection system integrated?					
	All Landfills			Excluding Developers		
	Yes	No	Total	Yes	No	Total
Fuel customer is landfill owner	9	3	12	8	3	11
Fuel customer is not landfill owner	44	89	133	9	80	89
Total	53	92	145	17	83	100
		$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Test of Independence		8.34	0.004		27.67	0.000

b. LGR/fuel customer integration versus direct gas customer

	Are the fuel customer and the collection system integrated?					
	All Landfills			Excluding Developers		
	Yes	No	Total	Yes	No	Total
Fuel customer uses gas directly	4	24	28	4	13	17
Fuel customer does not use gas directly	5	111	116	4	78	82
Total	9	135	144	8	91	99
		$\chi^2(1)$	p-value		$\chi^2(1)$	p-value
Test of Independence		3.83	0.050		6.59	0.010

were not reported.[32]

The pattern of integration strongly supports both hypotheses. When the fuel customer and the landfill owner are the same, 75% of LGR systems integrate with the landfill owner; in contrast, when the fuel customer is separate, only 33% of systems integrate. While direct gas customers exist on less than 20% of the sampled landfills, they make up almost half of the facilities that are integrated with the fuel customer. These results are strengthened if we exclude landfills owned by developers (who typically do integrate into LGR ownership and do not need fuel from a facility). These findings support the idea that transaction costs associated with energy sales influence the institutional structure of LGR systems.

d. Implications for environmental policy

The institutional structure of the waste disposal industry is currently a subject of concern to recycling advocates. As noted above, WTE tipping fees are typically set in long-term contracts, rather than spot markets, and waste quantities are often guaranteed by contractual provisions or flow control. Recycling advocates have argued that the contractual guarantees discourage communities from developing

[32] Some additional analyses were conducted to test whether any biases are introduced by the exclusion of observations with missing values. For example, we might expect that observations that do not report a fuel customer are likely to have a fuel customer different from the landfill owner. The results of the fuel customer/landfill owner analysis remain substantially the same if we assume that all missing values represent a fuel customer different from the landfill owner.

recycling programs and that the contractual prices exceed not only spot tipping fees[33] but also the cost of recycling. Following the same line of reasoning that once led antitrust scholars to view restrictive vertical contracts as "mysterious, suspect, and indicative of market power" (Joskow 1991, p. 60), recycling advocates have argued that these contracts represent monopolization of the waste disposal market and should, therefore, be invalidated.

The institutional perspective described above illustrates that this monopolization argument relies upon an excessively *ex post* view of the world. In a world of long-lived specific assets, monopolization arguments must be based on an examination of the entire contracting process, not on how specific contractual terms appear with years of hindsight. Without evidence of collusion or market power during the competitive contracting stage, there is little reason to believe that WTE contract terms represent market power so much as they reflect the need to protect these sunk capital investments.

6. AN ECONOMETRIC ANALYSIS OF WTE AND LGR PRIVATIZATION

Proceeding sections have considered separately the effects of federal tax policy and transaction costs on institutional choice in the WTE and LGR industries. To further refine our understanding of institutional choice in these industries, we now

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[33] This is true in many regions because the long-heralded "disposal crisis" evaporated in many regions of the country during the late 1980's and early 1990's.

estimate econometric models that include tax policy and transaction cost variables together with political and other explanatory variables.

The basic econometric set-up will be the familiar logit model of a binary qualitative choice; privatization is treated as a simple yes/no decision. We model the probability that public ownership is chosen as a function of various explanatory variables X and a vector of coefficients ß:

$$\text{Prob(Public Ownership)} = F(X\beta), \tag{8}$$

where F is the logistic function. The coefficient vector ß is estimated in the usual manner via maximum likelihood.

Under suitable assumptions, the logit model can be derived from utility maximizing behavior (McFadden 1973); as a result, equation 8 could be interpreted as a structural representation of a utility maximizing government official deciding whether or not to privatize.[34] Alternatively, the model can be viewed as a simple reduced form that relates explanatory variables and the privatization decision without a specific structural interpretation. Given the complexities of political decision-making processes, this reduced-form interpretation seems more realistic and will be adopted here.

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[34] Structural models of this sort are developed in many related analyses, including Masten, Meehan, and Snyder (1991), who test transaction cost theories of integration in private firms, and Dubin and Navarro (1988), who test theories of public contracting.

a. WTE privatization

To analyze the factors underlying WTE privatization, we consider a number of representations of tax policy, asset specificity, and related variables. The relevant variables are summarized in Table 11.

Table 11: Variables in the WTE logit analyses.

Variable	Description
PREERTA	1 if the facility was planned before ERTA; 0 otherwise.
TRA	1 if the facility was planned after TRA86; 0 otherwise.
DELTACC	The estimated capital cost difference between public and private ownership in the year the facility was planned; these are displayed in Figure 3.
DELTACC* COST	Interaction between DELTACC and COST, where COST is defined as the cost of the facility in millions of dollars per TPD of capacity.
FUELCUST	1 if waste supplier is also the fuel customer; 0 otherwise.
SLUDGE	1 if the facility also burns sludge; 0 otherwise.
RDF	1 if the facility uses an RDF technology; 0 otherwise.
MODULAR	1 if the facility uses a modular massburn technology; 0 otherwise.
ELECTRIC	1 if the facility produces electricity; 0 otherwise.
DEMO	1 if the facility is described as experimental or demonstration; 0 otherwise.
FEDFUND	1 if the facility was financed, at least in part, by federal grants, revenues, etc.
STFUND	1 if the facility was financed, at least in part, by state grants, revenues, etc.

Federal tax policy can be modeled in a number of ways. First, consistent with the simple cross-tabulations presented in our earlier discussion, we can use dummy variables to represent the main tax policy regimes. Thus, one analysis will use dummy variables for the PREERTA and TRA periods; coefficients on these variables will represent the difference in the propensity to privatize between these periods and the ERTA period, holding other factors constant. Second, we can use the estimated capital cost differentials in Figure 3 to capture year-by-year changes in the relative attractiveness of private ownership. The DELTACC variable is defined as the expected capital cost difference (public less private) in the year a project was originally planned. Third, we can recognize that the relative value of the tax benefits of private ownership of a given facility depends not only on the tax law at the time of construction but also on the construction cost of the facility. All else equal, tax policy should have less influence on inexpensive facilities. In order to distinguish this effect from effects due to the size of a facility, we therefore define COST to be the cost per unit of facility capacity; capacity is measured in tons per day (TPD). The interaction term DELTACC*COST then captures capital cost differences.

A number of measures of asset specificities can also be included. First, the FUELCUST variable identifies waste sources that are also the fuel customer for a project. As argued earlier, we expect such projects to integrate (i.e., be municipally owned) more than others. The SLUDGE variable identifies facilities that co-dispose solid waste and sludge. In addition, technology dummies (RDF and MODULAR) will capture any systematic differences in municipal ownership of these facilities, including those due to differential specificities. As discussed above, RDF facilities are less specific than other facilities, due to greater flexibility of equipment use, and thus we expect less public ownership of them. The MODULAR variable is included merely to test for any systematic patterns of ownership for these facilities due to unrecognized specificities or other factors; a priori, we have no specific expectation for its effect. We similarly include the ELECTRIC variable to test whether electricity-producing facilities are more or less likely to be municipally owned than other facilities. The trade literature suggests that private firms may prefer to be involved in projects that produce electricity (which can often be sold at favorable rates to local utilities); if this is true, we expect a positive coefficient on this variable.[35]

An additional angle on asset specificities would be to use information on facility costs. For a given facility size, a larger amount of sunk costs should, all else equal, imply increased specificity and, therefore, increased public ownership. This institutional argument thus reverses the more familiar causal argument that, due to public sector inefficiencies, certain facilities are more expensive *because* they are publicly owned. Disentangling these contrary effects is beyond the scope of the current study. Explorations with the COST variable (not reported here) indicate that it does not enter regressions significantly and often has the 'wrong' sign; thus, we do not include it in the reported results.

Some other influences on privatization will also be considered. We should note, for example, that some WTE facilities were built as experimental or demonstration facilities rather than as full-fledged municipal facilities. While these

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[35] As far as this reasoning goes, it is not clear why any profit opportunities from selling electricity are not bid away during the contract competition stage.

facilities may have been partially sponsored by a municipality that would provide waste, they still have more of the flavor of private projects; because they have shorter expected lives, such facilities are also less specific assets. We predict, therefore, that such facilities will tend to be privately owned. The dummy variable DEMO tests this prediction.

Finally, we should also consider whether the availability of funding from higher levels of government may have influenced ownership decisions. Although the degree of federal funding in the WTE industry has been substantially lower than that in other types of infrastructure (most notably highways and wastewater treatment), the federal government has played a role, as have some states. Restrictions on grant proceeds from higher-level governments may favor public ownership over private. Thus, the availability of funding may influence the ownership decision. Unfortunately, we do not observe the terms under which financing was offered nor do we observe whether financing was offered but rejected. Thus, we cannot directly test whether state and federal government funding systematically favors public ownership. The pattern of ownership does suggest that this is true, however, since 20 of 22 municipally-sponsored projects receiving federal funding are publicly owned as are 33 of 38 receiving state funding.

Although we cannot model the availability of funding directly, we can use simple dummy variables (FEDFUND and STFUND) that identify facilities that used federal and state funding to proxy for the availability of higher-level funding (such financing was obviously available to any facility that accepted it). Because these variables may introduce some bias into the analysis (they represent financing decisions, not financing availability), we report all regressions with and without them.

Table 12 reports six logit analyses of WTE ownership using these variables; each pairs of columns uses one of the three methods of representing the capital cost variables. Within each pair, the first column includes the financing dummy variables while the second excludes them. Consistent with our previous analyses, all three equations indicate that tax policy has a significant effect on municipal ownership. The transaction cost variable FUELCUST enters with a significant coefficient in the expected direction; facilities that serve both waste and energy needs of a client are much more likely to be owned by that client. The SLUDGE coefficients are all indistinguishable from zero and have the wrong sign. The small number of sludge facilities prevents any statistically significant test of this particular asset specificity.

Coefficients on the MODULAR variable are also indistinguishable from zero. The coefficients on ELECTRIC indicate that electricity-producing facilities are more likely to be privately-owned than other facilities, consistent with the belief that the private sector prefers such projects. The coefficients on DEMO, while not significant, do have the expected sign, indicating (weakly) that demonstration facilities are more likely to be privately owned.

Finally, facilities that receive federal or state funding are significantly more likely to be publicly owned. Assuming that this result reflects an underlying bias by state and federal governments to fund only public projects, we can conclude that such funding discourages privatization.

Table 12: Logit analyses of ownership at municipally sponsored facilities; municipal ownership = 1, private ownership = 0 (standard errors in parentheses).

Variable	1a	1b	2a	2b	3a	3b
PREERTA	1.45 (0.55)	1.44 (0.51)	-	-	-	-
TRA	1.09 (0.45)	0.76 (0.42)	-	-	-	-
DELTACC	-	-	-3.77 (1.47)	-2.83 (1.40)	-	-
DELTACC*COST	-	-	-	-	-43.1 (13.2)	-28.5 (11.58)
FUELCUST	1.34 (0.74)	1.71 (0.70)	1.45 (0.73)	1.86 (0.70)	1.61 (0.76)	2.00 (0.72)
SLUDGE	-0.81 (1.50)	-0.40 (1.28)	-1.13 (1.43)	-0.50 (1.24)	-1.20 (1.39)	-0.13 (1.32)
RDF	-1.14 (0.52)	-1.23 (0.50)	-1.02 (0.50)	-1.03 (0.47)	-1.53 (0.54)	-1.37 (0.51)
MODULAR	-0.11 (0.52)	-0.25 (0.57)	-0.01 (0.59)	-0.10 (0.55)	-0.34 (0.58)	-0.36 (0.56)
ELECTRIC	-1.05 (0.54)	-1.37 (0.52,	-1.44 (0.52)	-1.71 (0.49)	-1.26 (0.55)	-1.60 (0.51)
DEMO	-2.70 (1.82)	-1.41 (1.32)	-2.15 (1.83)	-0.62 (1.25)	-1.90 (1.68)	-0.56 (1.24)
FEDFUND	2.33 (1.18)	-	2.35 (1.14)	-	2.81 (1.23)	-
STFUND	1.43 (0.56)	-	1.47 (0.56)	-	1.69 (0.59)	-
CONSTANT	0.40 (0.64)	1.10 (0.58)	2.03 (0.62)	2.38 (0.60)	1.99 (0.62)	2.32 (0.57)
n	173	173	173	173	168	168

Probabilities of public ownership for an average facility

ERTA	52.7%	51.3%	59.7%	58.7%	60.0%	58.9%
TRA86	76.8%	69.3%	81.6%	76.4%	81.7%	74.7%

Based on these models, we can estimate how changes in tax law alter the mix of public and private projects. Estimates of the probability of public ownership under ERTA and TRA86 are reported at the bottom of Table 12; these assume a project that takes average values for all variables except the tax variables. These results indicate that TRA86 increased the probability of public ownership by 22 to 24 percentage points. Put another way, the tax reform reduced the probability of private ownership by over 50% (from 47.3% to 23.2% in the first column, for example).

b. LGR privatization

The logit analysis of LGR privatization proceeds in a similar manner, using the variables described in Table 13. The effects of tax policy are modelled both by using the tax period dummies and by using the estimated capital cost differential illustrated in Figure 4. The DELTACC*COST approach of the WTE analysis is not used because of limited information on LGR facility capital costs.

To test the impact of one type of specificity identified earlier, the FUELCUST variable identifies landfill owners who are also the fuel customers for an LGR facility. The GASPIPE, DIRGAS, and OFFELEC variables capture any differences between these technologies and the most common technology, on-site electric generation. We have no particular expectations about specificy differences etc. between these technologies, so we have no expectation for the sign of coefficients on them (the direct gas analysis discussed previously examined integration between a fuel customer and the facility, not between the landfill and a facility).

Table 13: Variables used in the LGR logit analyses.

Variable	Description
PREERTA	1 if the facility was planned before ERTA; 0 otherwise.
TRA	1 if the facility was planned after TRA86; 0 otherwise.
DELTACC	The estimated capital cost difference between public and private ownership in the year the facility was planned; these are displayed in Figure 5.
FUELCUST	1 if waste supplier is also the fuel customer; 0 otherwise.
GASPIPE	1 if the facility sells gas to a pipeline; 0 otherwise.
DIRGAS	1 if the facility sells to a direct gas user; 0 otherwise.
OFFELEC	1 if the facility sells to an off-site electricity generator; 0 otherwise.
VOTEDIFF	For the presidential election immediately before a facility was planned, the difference between the fraction of votes for the Democratic candidate in the county where the facility is sited and the fraction of votes for the Democrat in the United States as a whole.
FTE	Local public employees per million population in the community that owns the landfill; measured in the year before the facility was planned.
INC85	Per capita income in the community in 1985 (in thousands of dollars).
POP	Population in the sponsoring community in the year before the facility was planned (in millions).
LA	1 if the landfill is owned by the Los Angeles County Sanitation Districts; 0 otherwise.
PUBLF	1 if the landfill is publicly owned or operated; 0 otherwise.
WMI	1 if the landfill is owned or operated by WMI; 0 otherwise.
BFI	1 if the landfill is owned or operated by BFI; 0 otherwise.
OTHER	1 if the landfill is owned or operated by a small LGR developer; 0 otherwise.

To test some simple political explanations of privatization decisions, the LGR analysis also includes two political variables. Following Dubin and Navarro (1988) we may expect that privatization will be more common in regions with a conservative or Republican orientation and will be less common in more Democratic areas. As an approximation of the political leanings of a community, we look at voting in the presidential election before the privatization decision was made. The variable VOTEDIFF is defined as the difference between the percentage of votes for the Democratic candidate in that election in the county containing the facility and the percentage for the Democrat in the U.S. as a whole. This normalization is required since the relevant elections take place in multiple years.

To test the idea that public employees will tend to favor public ownership, we also include a variable that proxies the relative political strength of these employees. FTE is defined as the ratio of full-time equivalent local government employees to the local population. The hypothesis is that higher values of FTE will be associated with higher amounts of public ownership. Note that, unlike previous analyses, we measure this variable in the year prior to the privatization decision. Thus, it accurately reflects the abundance of public employees at the time of the decision.

In addition, we also include two demographic variables, POP and INC85, to test whether community population and income levels are related to privatization patterns.[36] The variable LA then controls for facilities owned by the Los Angeles

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[36] In future revision, INC85 will be replaced by a variable equal to income in the year of decision for each project.

County Sanitation District which, as argued earlier, is a very special case.

The logit results are presented in Table 14. The first two columns contain results for collection facilities, while the second two report results for processing facilities. The results are consistent with the argument that tax policy influences privatization. The coefficients on the ERTA and PREERTA variables have the correct signs and are economically significant; the coefficients on PREERTA do not reach standard levels of statistical significance, however. The coefficients on DELTACC are both economically and statistically significant.

As illustrated at the bottom of the table, these results imply that, holding all else equal, TRA86 had a substantial impact on the probability of public ownership. For an average facility, TRA86 increased the probability of public ownership from about 4% to slightly less than 20% for processing facilities and roughly 30% for collection facilities. In other words, TRA86 reduced privatization by 15% to 30% of ERTA levels.

As expected, both the FUELCUST and LA variables are strongly correlated with public ownership. The technology variables are somewhat related to ownership. All the facilities serving gas pipelines in this sample are privately owned (note that some excluded observations are not, however). The DIRGAS variable gets idiosyncratic results, appearing to be positively related to public ownership of collection systems and negatively related to public ownership of processing systems. Facilities that send gas off-site to produce electricity tend somewhat to be publicly owned.

Table 14: Logit analysis of ownership at public landfills

	Collection System		Processing System	
Variable	1	2	3	4
PREERTA	1.69 (1.65)	-	1.93 (1.42)	-
TRA	2.59 (1.14)	-	1.73 (1.01)	-
DELTACC	-	-13.8 (6.3)	-	-9.87 (5.52)
FUELCUST	3.86 (1.16)	3.78 (1.17)	3.05 (0.97)	3.06 (0.97)
GASPIPE	(a)	(a)	(a)	(a)
DIRGAS	1.52 (0.96)	1.58 (0.97)	-0.62 (1.08)	-0.62 (1.06)
OFFELEC	2.15 (1.70)	2.24 (1.68)	2.97 (1.77)	3.00 (1.78)
VOTEDIFF	1.75 (4.21)	1.95 (4.14)	5.10 (4.22)	5.18 (4.13)
FTE	4.12 (3.88)	4.46 (3.67)	-0.37 (4.26)	-0.36 (4.26)
INC85	0.15 (0.15)	0.15 (0.14)	-0.14 (0.22)	-0.14 (0.22)
POP	0.70 (0.44)	0.76 (0.45)	0.28 (0.25)	0.28 (0.25)
LA	(b)	(b)	(b)	(b)
CONSTANT	-7.05 (2.43)	-6.35 (2.26)	-1.93 (2.70)	-1.40 (2.61)
n	72	72	70	70

a. GasPipe = 1 predicts private ownership; 4 observations dropped.
b. LA = 1 predicts public ownership; 5 observations dropped.

Probabilities of Public Ownership for an Average Facility

ERTA	4%	4%	4%	4%
TRA	34%	29%	19%	18%

The other variables, however, are much less successful in explaining public ownership. The results for VOTEDIFF, for example, provide only weak support for the idea that communities that vote Democratic tend to prefer public ownership; while all four coefficients are positive, none are significant. The FTE variable performs less well, as it switches sign between the collection and processing facilities; this is consistent with some results of Stein (1990) who, as noted earlier, finds little relation between FTE and contracting decisions. The POP results indicate that larger communities may be more likely to integrate. INC85 is not significant and changes sign between collection and processing.

In sum the results are consistent with the tax theory and our asset specificity prediction. While political and demographic factors may influence privatization, the standard proxies used here provide little if any explanatory power.

As noted in a previous discussion, we can test whether the tax results are capturing some unobserved changes in the benefits of integration *per se* by using facilities at private landfills as a control group. Table 15 reports two logit analyses of integration at all landfills. Each includes the DELTACC variable, a dummy for public landfills, and an interaction between the two. If the tax theory is correct, we expect the interaction term to have a significant negative coefficient while the DELTACC variable will have a coefficient near 0. The PUBLICLF dummy then captures the average difference in integration between public and private landfills. Because we expect LGR developers to own facilities at their own landfills, we also include the developer dummy variables WMI, BFI, OTHER, and LA.

Table 15: Logit analyses of integration at landfills

	Collection	Processing
Variable	Coeff.	Coeff.
DELTACC	2.76 (4.48)	0.31 (4.80)
DELTACC* PUBLICLF	-16.5 (7.12)	-11.8 (7.49)
PUBLICLF	-0.75 (0.85)	-0.76 (0.94)
FUELCUST	3.01 (0.90)	2.97 (0.83)
GASPIPE	-1.15 (1.02)	-0.85 (1.08)
DIRGAS	1.01 (0.59)	0.57 (0.66)
OFFELEC	2.77 (1.79)	3.13 (1.72)
WMI	4.12 (0.84)	4.53 (0.90)
BFI	2.27 (1.11)	2.34 (1.24)
Other	3.85 (1.29)	4.14 (1.31)
LA	(a)	(a)
CONSTANT	-2.40 (0.68)	-2.68 (0.78)
n	147	144

(a) LA County = 1 implies integration; 5 observations dropped.

The results of Table 15 illustrate that the changes in integration are restricted to public landfills. The DELTACC variable enters insignificantly, while the DELTACC*PUBLICLF variable enters significantly and with the expected sign. These results suggest that the change in integration patterns between the ERTA period and other timeperiods is due to tax law changes and not other unobserved factors.

7. CONCLUSION

In recent years, many nations, including the United States, have begun to reevaluate the role of government in the economy. In particular, much attention has been given to determining an appropriate frontier between the activities of the state and the activities of private firms. This paper has explored some of the factors that determine where that frontier lies.

Both the theoretical and empirical evidence discussed above indicate that federal tax policy can significantly affect the incentives of private firms to provide capital intensive services to local governments. Perhaps unbeknownst to policy-makers, changes in federal tax policy thus move the frontier between public and private enterprise. To the extent that this frontier is a continuing matter of public concern, it is important that the influences upon it of federal tax policies be more widely understood. Although not explored in depth in this paper, limited evidence suggests that similar concerns apply to the distribution of federal and state grants as well; in the waste disposal industry, at least, such policies appear to favor public enterprise over private.

While increased privatization appears to be a general policy goal for many governments, a transaction cost perspective suggests that there may be limits to the benefits of privatization. In particular, because vertical integration can safeguard specific assets, public ownership (which is, after all, vertical integration when the public sector is a major buyer or seller) may be a preferred institutional structure in some cases. The empirical evidence presented above suggests that, in the WTE industry at least, institutional structures have been designed in a way that protects specific assets.

This line of reasoning implies that typical analyses of public versus private production costs and performance can provide only a partial perspective on the relative costs of public enterprise. When such enterprises require investment is specific assets, it may be optimal to accept some degree of production inefficiency in order to gain the institutional efficiencies of vertical integration. While this paper does not demonstrate that policy-makers have made such a tradeoff, the results suggest that such tradeoffs are plausible and should be a subject of further research.

This institutional line of reasoning also challenges current environmental arguments that long-term WTE contracts and related governance structures represent inefficient monopolization of disposal markets. While this argument is consistent with old-fashioned economic analyses that focus solely on institutional structures and not the context in which they were developed, the transaction cost view demonstrates that a dynamic perspective is required, in which the *ex ante* character of competition, rather than *ex post* structure of institutions, is the basis for analyses of monopolization.

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APPENDIX A: DATA SOURCES

As noted in the text, the primary data sources for this study are two surveys performed by Governmental Advisory Associates (Gould 1991, 1993). The LGR survey was executed in 1991, while the WTE survey was executed in 1992. These surveys provide a wealth of information on project technologies, finance, and institutional arrangements.

The information in these surveys was augmented by sources in the trade literature. These sources include the annual WTE-Incineration-Resource Recovery reviews published from 1984 to 1992 in the November issue of *Waste Age*, the 1993 "Energy-from-Waste Activity Report" published by *Solid Waste & Power*, various issues of *Alternative Sources of Energy, Biocycle, Independent Energy, Solid Waste & Power, Waste Age*, and the 1970 through 1992 *Proceedings of the Biennial Waste Processing Conference*.

These sources supplemented the GAA data in a number of ways. In a handful of cases, they identified facilities that were excluded from the GAA surveys. More importantly, they provided historical information about the facilities such as when a facility was originally planned and whether the ownership structure had changed over time.

The GAA data do not identify a specific year in which the ownership structure of a facility was originally determined; instead, the data identify the year the facility entered commercial operation (or is expected to begin operation) and, in some cases, the year in which bonds were issued. In order to estimate the year in which institutional decisions were made, I reviewed the trade literature for announcements about, or histories of, each project. Where such announcements were not available, I estimated the decision year based on the development period (operation year less decision year) for similar projects. Development periods of two to five years are typical; in some cases, however, the period is substantially longer.

For LGR facilities, I have assumed that project ownership was determined based on the tax law that held two and a half years prior to the on-line date of the facility. This two and a half year figure is based on a limited review of the trade literature as well as the fact that many of the conceptually planned facilities noted in the GAA survey were expected to have on-line dates two to two and a half years in the future. Note that the two and a half years covers not only the period of facility construction (which, according to GAA, is on the order of six months to a year) but also the period during which financing is arranged, permits are acquired, and energy sales contracts are negotiated.

In a few instances, the review of the trade literature indicated that the original owner of a facility differed from the one reported in the GAA database. For these instances of changed ownership, I have used the original owner, not the one reported by GAA; these changes account for the minor differences between the ownership data reported here and the figures reported by GAA.

APPENDIX B: TAX POLICY ASSUMPTIONS, 1962-1992

The capital cost calculations summarized in Figures 1-4 involve a substantial number of assumptions regarding underlying corporate tax policy. The main tax assumptions used in these analyses are as listed in the following table (these are based on a review of the relevant tax codes):

Year	ITC	% ITC Deducted from Tax Basis	Energy ITC	Corporate Tax Rate	Corporate Capital Gains Rate	Depreciation Rules
1962	7%	100%		52%	52%	Pre-1971
1963	7%	100%		52%	52%	Pre-1971
1964	7%	100%		50%	50%	Pre-1971
1965	7%			48%	48%	Pre-1971
1966	7%			48%	48%	Pre-1971
1967	7%			48%	48%	Pre-1971
1968	7%			52.8%	52.8%	Pre-1971
1969	7%			52.8%	52.8%	Pre-1971
1970				48%	48%	Pre-1971
1971	7%			48%	30%	ADR-71
1972	7%			48%	30%	ADR-71
1973	7%			48%	30%	ADR-71
1974	7%			48%	30%	ADR-71
1975	10%			48%	30%	ADR-71
1976	10%			48%	30%	ADR-71
1977	10%			48%	30%	ADR-71
1978	10%		10%	46%	30%	ADR-71
1979	10%		10%	46%	28%	ADR-79
1980	10%		10%	46%	28%	ADR-79
1981	10%		10%	46%	28%	ACRS
1982	10%	50%	10%	46%	28%	ACRS
1983	10%	50%	10%	46%	28%	ACRS
1984	10%	50%	10%	46%	28%	ACRS-84
1985	10%	50%	10%	46%	28%	ACRS-84
1986			7.5%	34%	34%	MACRS
1987				34%	34%	MACRS
1988				34%	34%	MACRS
1989				34%	34%	MACRS
1990				34%	34%	MACRS
1991				34%	34%	MACRS
1992				34%	34%	MACRS

The energy ITC applies only to WTE facilities, not LGR facilities; the 7.5% figure for 1986 is based on the assumption that a facility planned in that year would receive this credit on half its capital costs (the credit went up to 15% but covered only expenditures through the end of 1987).

The depreciation rules are as follows:

Pre-1971 From 1962 until the introduction of the ADR system in 1971, the IRS allowed double declining-balance depreciation over specific lifetimes. For waste reduction plants, this lifetime was 12 years, for electric or steam plant (the energy generating portion of a facility) it was 28 years, and for structures it was 40 years. The projected salvage value of a facility was deducted from the depreciable tax basis.

ADR-71 In 1971, the Asset Depreciation Range system specified a range of lifetimes for each type of personal property of roughly 20% above and below the class lifetime; in practice, the lower bound was now used. Thus, waste reduction plant now had a lifetime of 9.5 years, electric and steam of 22.5 years, and structures of 40 years.

ADR-79 In 1979, the IRS introduced new guideline lifetimes for solid waste disposal facilities. The new class lifetime was 10 years, with an actual lifetime of 8 years.

ACRS The Economic Recovery Tax Act of 1981 (ERTA) introduced the Accelerated Cost Recovery System (ACRS) that replaced the class lifetimes with four general classes of property. Personal property was depreciated at 150% declining balance with a switch to straight-line, while structures were depreciated at 175% over 15 years. Both waste processing equipment and electric and steam generation equipment were 5 year property (the latter is true because the equipment is not owned by a public utility). ACRS eliminated the deduction of salvage from the depreciable tax base.

ACRS-84 The Deficit Reduction Act of 1984 required that facilities financed with tax-exempt industrial development bonds (IDBs) be depreciated straight-line over their ACRS lives. Structures were now depreciated at 175% declining balance (or straight-line if financed with IDBs) over 18 years.

MACRS The Tax Reform Act of 1986 replaced the ACRS with the Modified Accelerated Cost Recovery System. Under MACRS, waste disposal equipment are 7 year/200% property, electric/steam generation are 20 year/150% property, and structures are 31.5 year/straight-line property. Property financed with IDBs is depreciated straight-line over 10, 27.5, and 40 years.

ESSAY 3

COMBINATORIAL AUCTIONS FOR TRADEABLE PERMITS

1. INTRODUCTION

The creation of tradeable permit markets has received increasing attention from environmental policy-makers in recent years. Permit markets have already been created in a number of programs to control air and water emissions and are under consideration for many other such programs.[1]

This growing acceptance of tradeable permit systems can be traced, at least in part, to a long series of theoretical and empirical studies that have examined the costs of different regulatory systems. These studies have argued that tradeable permits, and other market-based regulatory systems, can substantially reduce the costs of environmental regulation, compared to traditional command and control, because they allow firms to adopt least-cost compliance strategies (Tietenberg (1985) reviews these studies).

In actual applications, however, it may be difficult for these systems to achieve the full economic benefits associated with permit trading; transaction costs and market

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1. Programs already authorized in the United States include the Emissions Trading Program for criteria air pollutants, permits for water effluents in Wisconsin and North Carolina, for the phase-out of lead in gasoline, for the phase-out of chlorofluorocarbons, for sulfur dioxide emissions from electric utilities, for NO_x and SO_x emissions in the Los Angeles air basin, and for smog-causing emissions in Massachusetts. Additional market systems have been proposed for air emissions in other air basins, for national and global emissions of greenhouse gases, and for imposing minimum standards for recycled content in products, among other applications.

thinness, among other factors, can limit their efficiency.[2] Since the magnitude of these inefficiencies varies with the institutional setting within which permits are distributed and traded, it is important that permit market institutions be chosen carefully.

This paper will describe a particular type of market institution -- the uniform price combinatorial auction -- that may offer significant efficiency benefits, relative to other market institutions, in distributing and trading tradeable permits. A combinatorial auction is a call auction in which participants submit sealed orders (bids to buy, offers to sell, etc.) for combinations of multiple goods. An optimization algorithm then determines which orders to accept and reject in order to maximize the gains from trade in the market. As in other uniform price auctions, these orders are then executed at non-discriminatory prices, i.e., each participant faces the same price for each type of permit.

Combinatorial auctions are appropriate for tradeable permits because, as will be discussed below, most permit systems involve a significant number of different types of permits. The sulfur dioxide trading system that has recently begun in the United States, for example, involves up to thirty different types of permits (where each type is defined by its first year of validity), while the trading system in the Los Angeles air basin involves at least eighty types of permits (two types of pollutants in two geographic zones on two annual compliance schedules for at least ten years).

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2. Stavins (1993) discusses some of the implications of transaction costs in tradeable permit markets.

In developing combinatorial auctions for tradeable permits, the paper will build on a number of previous studies that have developed auctions for the simultaneous allocation of multiple goods. Such auctions have been developed for allocating airport landing and takeoff slots (Rassenti, Smith, and Bulfin 1982), for coordinating natural gas purchases and delivery in pipeline networks (McCabe, Rassenti, and Smith 1989, 1990, 1991c; Hogan 1992), for coordinating power sales in electric systems (McCabe, Rassenti, and Smith 1991c), for allocating electric transmission capacity (Hogan 1991), and for scheduling projects aboard spacecraft (Banks, Ledyard, and Porter 1989). McCabe, Rassenti, and Smith (1991a) review many of these applications.

The paper proceeds in the following manner: Section 2 briefly discusses the relationship between market institutions and efficiency in tradeable permit systems. Section 3 designs a combinatorial auction by which a government may distribute permits. Section 4 then generalizes this auction to the problem of trading permits after initial distribution. To provide a concrete example, section 5 develops a trading auction for sulfur dioxide emission allowances. Section 6 considers alternative mechanisms that might be used for distributing and trading permits, and section 7 concludes.

2. MARKET INSTITUTIONS AND THE EFFICIENCY OF PERMIT SYSTEMS

Theoretical analyses of tradeable permit systems typically abstract from the institutional settings within which the systems are implemented. Such analyses are useful because they clearly demonstrate the potential benefits of permit systems, e.g., their ability to achieve a specified environmental target at least cost. Such analyses are not useful, however, in selecting among different institutions for implementing permit systems or in evaluating the factors that prevent permit systems from achieving their theoretical potential.

Experience with existing permit systems indicates that permit market performance can be sensitive to institutional factors such as the magnitude of transaction costs and the thinness of markets. Atkinson and Tietenberg (1991) provide an excellent example of this sensitivity in their examination of bubble transactions made under the Emissions Trading Program in the United States. Noting that previous researchers (e.g., Hahn and Hester 1989) had concluded that the level of bubble trading was far below that required for a cost-effective allocation of emissions, Atkinson and Tietenberg reviewed actual bubble transactions to see whether the process by which they were made could explain the apparent inefficiency of the market.

They found that trading was executed via sequential, bilateral trades. They then demonstrated that such a trading process could not achieve an efficient allocation of permits if, as required by the Environmental Protection Agency (EPA), each individual trade had to satisfy air quality standards. The equilibrium of this constrained trading process differed substantially from the cost-effective allocation of permits.

While Atkinson and Tietenberg discuss this "trading process hypothesis" primarily as it applies to non-uniformly mixing pollutants (for which the location of emissions matters and, as a result, some regulation of trades may be appropriate), they rightly note that when transaction costs exist or market information is limited, the problem is also relevant to uniformly mixing pollutants (actually to pollutants that, regardless of physical properties, are regulated as though they are uniformly mixing). Under these circumstances, information about correct permit prices is likely to spread slowly. When firms attempt to make trades, search costs will limit the number of counter-parties they can contact and the quality of price information they can access. As a result, firms will make compliance decisions based on imperfect information about the permit market; some inefficient compliance decisions will therefore result.

These problems are likely to be exacerbated in permit systems that involve multiple permit types. Although standard textbook analyses of tradeable permits tend to focus on systems that use only a single permit type, actual permit systems are likely to use multiple permits. Permits may be differentiated across time to reflect regulatory limits in separate years, seasons, etc., across distinct pollutants, across priority of use (e.g., if they are weather dependent), or across different regions (e.g., if the permits represent effects on air quality at various receptors). In all these cases, firms will need to hold portfolios of permits. Creating an appropriate portfolio can involve significant transaction costs as traders will, in general, need to participate in multiple markets and thus identify and negotiate with multiple counter-parties.

Transaction costs may also arise from regulatory oversight of trading. Some systems require, for example, that trades be reviewed by the government to ensure that regional air quality standards are not violated.[3] The costs of such review (e.g., the cost of modeling air quality) can be substantial.

Decentralized permit market institutions, such as sequential, bilateral trading, thus suffer from potential inefficiencies associated with search and negotiation costs, the thinness of markets, and the cost of satisfying regulatory constraints. Centralized permit markets, in particular centralized call auctions, can remedy many of these potential inefficiencies both during the initial distribution of permits and during trading in the permit after-market.

In distributing permits, the government can select between direct distribution based on political criteria or distribution via an auction.[4] A well-designed auction can lead to a relatively efficient initial allocation of permits and, thereby, reduce the importance of inefficiencies in the after-market.[5] Free distribution followed by trading, however, will generally lead to a less efficient allocation as transaction costs, market uncertainty, and, perhaps, market power reduce the ability of participants to identify and achieve an optimal allocation of permits.

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3. The bubble program has worked this way, as would the pollution offset system suggested by Krupnick, Oates, and Van de Verg (1983).

4. Note that the use of an auction does not mean that the government has to raise revenue. Following Hahn and Noll (1982), the government can implement a revenue neutral auction in which all revenues are returned to firms. Political considerations can determine how the revenues are distributed while the auction implements an efficient permit allocation. For an experimental examination of a revenue neutral auction (in a system involving a single permit type), see Franciosi, Isaac, Pingry, and Reynolds (1993).

5. Allocation by auction may also reduce the magnitude of inefficiencies in the after-market (Oehmke 1987).

Similar concerns apply to the institutional structure within which permits trade after initial distribution. By centralizing potential market participants in time and space, call auctions for trading reduce transaction costs associated with search and negotiation. They also serve to thicken the market, providing greater trading opportunities and improved price information. Centralized call auctions also facilitate multi-lateral trades that might otherwise be unachievable through decentralized trading institutions. Such multilateral trading is desirable whenever firms need to acquire permit portfolios or when regulatory restrictions imply that multilateral trades can achieve more efficient allocations than can a sequence of bilateral trades (as in bubble trading). Centralized trading may also provide economies in meeting regulatory standards if, for example, the costs of regulatory review can be spread over multiple trades. Centralized trading can also increase the extent of anonymity in permit markets. A number of utilities that have executed bilateral trades in the sulfur dioxide market have already been criticized for their choice of trading partners; anonymous central markets can reduce such criticism.

As discussed in a later section, a range of auction mechanisms can be used for simultaneously trading multiple permit types. Combinatorial auctions are particularly well-suited to this task, however, because they explicitly account for the interrelationships between the markets for each type of permit. A number of experimental studies have illustrated the benefits of combinatorial mechanisms. Motivated by the example of airport landing and takeoff slots, Rassenti, Smith, and Bulfin (1982) compared the experimental performance of a combinatorial auction to that of separate auctions for each type of slot; in both cases, they allowed post-auction trading of slots in a secondary market. They found that the allocation of slots was significantly more efficient after the combinatorial auction than after the separate auctions; this efficiency advantage existed even after trading in the secondary market (which was used much more often after the separate auctions than after the combinatorial auction). They also found that the relative efficiency advantage of the combinatorial auction increased with the complexity of the allocation problem.

In a related analysis, Banks, Ledyard, and Porter (1989) developed an auction mechanism to schedule payloads aboard spacecraft; each payload uses a variety of spacecraft resources (data management, manpower, pressurized volume, etc.). In simple experimental settings, they found that combinatorial auctions, in which payload sponsors bid for access to resource combinations, performed significantly better that either separate markets for each resource or administrative allocation of the resources.[6]

While these two studies considered one-sided auctions (i.e., a single seller and many buyers) for multiple goods, other studies have considered multi-sided auctions for multiple goods. McCabe, Rassenti, and Smith (1990), for example, consider a market of natural gas producers, transporters (pipelines), and final demanders. The authors compare the efficiency of a centralized auction, in which final demanders submit bids for delivered gas, pipelines submit offers for transport, and producers

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6. It should be noted that the mechanism developed by Banks, Ledyard, and Porter (1989) was not a sealed-bid auction. Instead, bidders could submit bids, observe the implied resource allocation, and then update their bids over some timeperiod.

submit offers of gas at the wellhead, to that of a decentralized bargaining process. They find that the centralized auction mechanism achieves significantly higher allocational efficiencies than the bargaining process. A related analysis (McCabe, Rassenti, and Smith 1989) finds that the centralized auction continues to yield high allocational efficiencies in more complex environments that reflect the network structure of natural gas systems.

These studies have illustrated how centralized auctions may successfully coordinate the allocation of multiple goods. The results of Rassenti, Smith, and Bulfin (1982), moreover, suggest that the benefits of centralized auctions may increase as the complexity of the allocation problem increases (and thus more closely approximates real-world allocation problems). The experimental evidence thus supports the idea that combinatorial auctions can improve the efficiency of resource allocation. The following sections discuss how such combinatorial auctions may be designed and implemented for tradeable permits.

3. COMBINATORIAL AUCTIONS FOR DISTRIBUTING PERMITS

While a range of auction mechanisms for distributing permits are possible,[7] we focus on sealed-bid, uniform price auctions in which permits go to the highest bidders. As noted above, such auctions have performed well in experimental settings (see, e.g., McCabe, Rassenti, and Smith (1989)). We focus on sealed-bid auctions because permit markets will often involve a relatively large number of participants;

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7. See Lyon (1986) and section 6 below.

coordinating an auction is much simpler when participants submit only a single round of sealed bids. We focus on uniform price auctions[8] because they have good incentive properties, they are relatively simple for participants to understand, they create clear price signals, and they exhibit a desirable type of *ex post* fairness in that all auction participants face the same prices. Uniform prices are also desirable when payoffs to market participants, such as the electric utilities participating in the sulfur dioxide allowance market, depend not only on their absolute performance but also on their relative performance. Uniform prices reduce the risk of unfavorable relative performance evaluations.

To provide some intuition for this analysis, Figure 1 illustrates the familiar case of a sealed-bid, uniform price auction for a single type of permit. The government announces that it will distribute Q^* permits and solicits bids for them; these bids can then be aggregated into a demand curve. Permits are sold to the highest bidders (in this case bids 1 to 3). Although any price between the lowest accepted bid and the highest rejected bid can clear the market, the standard protocol is to set the price equal to the latter to make the auction as much like a second-price auction as possible.

a. Allocation

Our goal is to generalize the single-good, uniform price auction to the more complex market environments within which permits will be distributed. Let T be the

8. Also known as non-discriminatory or competitive auctions.

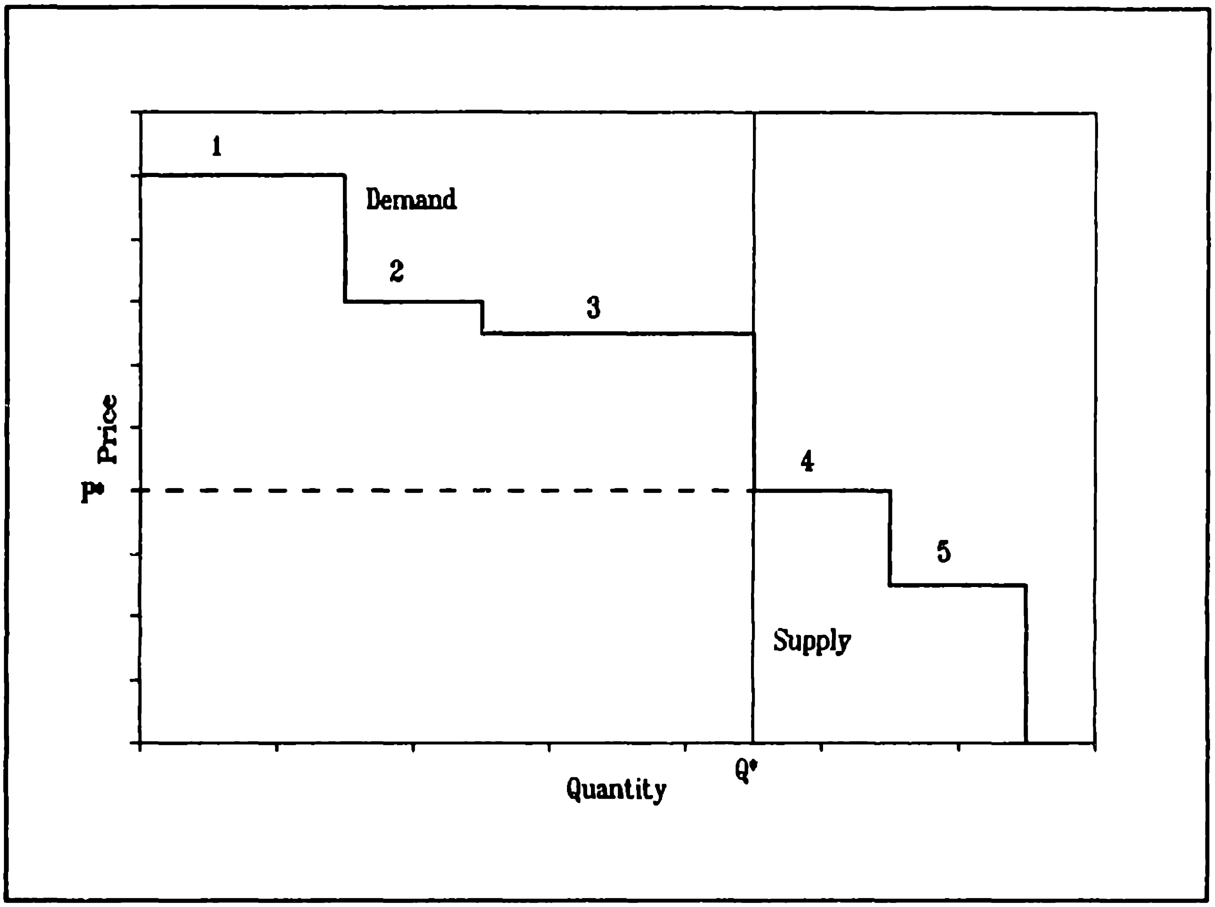

Figure 1: A multiple unit, single good auction with price set by the first rejected bid.

number of permit types. T can represent any dimension or set of dimensions (timeperiods, number of pollutants, receptor sites, priority, etc.) along which permits differ. If $T > 1$, firms will not, in general, have well-defined demand curves for each of the individual permit types. Instead, the individual demands will depend on the price and quantity outcomes in other permit markets.

While potential permit buyers cannot, in general, identify their willingness to pay (WTP) for one type of permit in isolation from the markets for the others, they can identify their WTP for specific combinations of permits. We therefore design an auction that solicits bids on permit combinations. In the most general form of such a combinatorial auction, bidders enter bids for each possible combination of permits. The auction then maximizes the value of accepted bids, subject to the constraint that the number of distributed permits does not exceed the limits set by the government.

To express this formally, define:

N	Number of bidders
I	Number of bids
E_t	Number of type t permits; t = 1 to T
B_i	Willingness to Pay (WTP) for bid i
a_{it}	Number of type t permits in bid i
e_{in}	1 if bid i submitted by bidder n, 0 otherwise
x_i	1 if bid i accepted, 0 otherwise

The optimal allocation of permits, given the submitted bids, is then determined by an integer programming problem:[9]

$$\underset{\{x_i\}}{Maximize}\ SURPLUS \equiv \sum_{i=1}^{I} x_i * B_i$$

subject to

$$\sum_{i=1}^{I} x_i * a_{it} \le E_t,\ \forall\ t = 1..T \qquad (1)$$

$$\sum_{i=1}^{I} x_i * e_{in} \le 1,\ \forall\ n = 1..N$$

$$x_i \in \{0,1\}$$

The first set of constraints requires that the number of permits of each type sold be less than or equal to the number available. The next set of constraints then requires that each bidder has at most one bid executed; these constraints force the

9. A similar problem is set out by Rassenti, Smith, and Bulfin (1982) in designing a combinatorial auction for airport landing and takeoff slots.

program to place correct values on each permit combination.[10]

This problem represents the most general version of a one-sided combinatorial auction. Unfortunately, it is very computationally and operationally demanding for real-world implementation: a bidder with positive valuations for all possible permit combinations would have to submit $(E_1+1) * \ldots * (E_T+1)$ bids to cover all eventualities. We therefore desire a sufficiently equivalent, but much less demanding, combinatorial auction mechanism.

Such a mechanism can be created by providing flexibility in bid definitions so that a single bid can cover a range of permit combinations. These flexible bids represent, in essence, step-wise linear approximations to each firm's permit demand curves. Bids still specify a maximum number of each permit type to trade and a maximum value for the bid. However, each bid is now interpreted not only as a bid for the entire combination but also as a series of bids for pro-rata fractions of the total. For example, a bid of $100 for 10 type 1 permits and 40 type 2 permits represents a bid of $10 for the combination {1,4}, a bid of $20 for {2,8}, etc. The rationale for structuring bids in this manner is that while firms will differ in the ratios in which they demand permits, individual firms will have relatively constant ratios, at least over significant portions of their production technologies. The bid structure

10. To illustrate the use of these constraints, consider a bidder who places the following bids: $100 for a type 1 permit, $200 for a type 2 permit, and $250 for one of each. If the program could execute the first two bids, they would incorrectly imply a valuation of $300 for the pair of permits, rather than the $250 specified in the third bid.

allows firms to represent these fixed ratio regions by a single bid.[11]

This approach assumes that bidders are willing to have their bids fractionally filled by any amount between 0 and 1 (represented, for bid i, by $x_i \in [0,1]$). In essence, this is an assumption of convexity in their production technologies. To allow non-convexities, e.g., to represent fixed costs, we can allow firms to specify whether a bid is flexible, as above, or is all-or-nothing (AON), in which case it must either be filled in full or rejected ($x_i \in \{0,1\}$).

To allow firms flexibility in bid definition, they can submit multiple bids. Following Rassenti, Smith, and Bulfin (1982), we allow bidders to link their bids using a number of logical constraints. A *not if* constraint specifies that one bid should not be executed if another is; an *only if* constraint specifies that a bid should be executed only if another one is as well; and a *less than* constraint specifies that a bid should be filled by a fraction that is less than or equal to that of another bid.

To illustrate how these constraints are represented, consider two bids A and B and the corresponding x_i, i = A,B. Without loss of generality, we assume that A Not If B is entered only when A and B are both AON and A Only If B only when B is AON;[12] A Less Than B can apply to any pair of bids. Formally, these are

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11. This linear approximation approach relies on the fact that polluters will want to trade large numbers of each type of credit. This approach would not work in markets, like that being developed by the Federal Communications Commission for allocating portions of the electromagnetic spectrum, in which each permit is unique.

12. Without loss of generality because any flexible bid can be split into a small AON piece, which is used in the logical constraints, and a larger flexible piece whose execution is contingent on the execution of the small piece.

expressed as:

A Not If B	$x_A + x_B \leq 1$
A Only If B	$x_A - x_B \leq 0$
A Less Than B	$x_A - x_B \leq 0.$

Firms can use linked combinations of AON orders and flexible orders to implement any desired bidding strategy. For example, a bidder wanting to buy a minimum of 10 permits and a maximum of 20 would enter an AON bid for 10, a flexible bid for 10, and the logical constraint that the latter should be executed only if the former is as well.

We can now formalize the allocation portion of this combinatorial distribution auction (henceforth "CDA"). Let N, I, and T be as before; in addition, define

M	Number of constraints
E_t	Number of type t permits
B_i	Willingness to pay (WTP) for bid i
a_{it}	Maximum number of type t permits in bid i
x_i	Fraction of bid i that is accepted.

Then the optimization problem is the following integer programming problem[13,14]:

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13. This program assumes that permits are perfectly divisible. If they are not, indivisibility constraints could be added: For each bid i, define g_i to be the greatest common divisor of the elements of the set $\{a_{it} | a_{it} > 0\}$. Define $v_i = x_i * g_i$ and require the v_i to be integers. The optimal allocation then contains only complete permits. This paper will assume that permit indivisibilities are not a problem.

14. Hogan (1991) describes a similar auction of electricity transmission rights. He allows minimum-maximum bids but does not express the auction as an integer program. Instead, he solves the problem as a linear program that ignores the minimum order constraints. If some of these constraints are violated, he then eliminates some of the binding minimum orders and re-solves the program. Through an iterative process, he ultimately identifies the best allocation in which no minimum orders are binding. The auction described here may reach a different solution since it allows binding minimum orders (AONs) to be executed. For a given set of bids, the CDA may therefore achieve a greater surplus than the Hogan algorithm.

CDA ALLOCATION PROGRAM:

$$\underset{\{x_i\}}{\textit{Maximize}}\ \textit{SURPLUS} \equiv \sum_{i=1}^{I} x_i * B_i$$

subject to

$$\sum_{i=1}^{I} x_i * a_{it} \le E_t,\ \forall\ t = 1..T$$
$$0 \le x_i \le 1,\ \forall i \qquad (2)$$
$$x_i \in \{0,1\}\ \textit{if bid } i \textit{ is AON}$$
Logical Constraints

For simplicity, the logical constraints are not expressed formally. If the solution to the program is not unique (which should be a rare occurrence unless participants concentrate their orders on a few focal prices), it is sufficient to choose randomly among the set of solutions or choose between them based on other criteria (e.g., favoring participants who submit orders early).

b. Pricing

The solution to the allocation problem represents the optimal combination of bids to accept and reject. We now consider the problem of determining the prices at which accepted bids should be executed. Unfortunately, pricing is, in general, quite difficult in integer programming problems. While linear programs produce dual prices (shadow values) that can be used as market-clearing prices, integer programs typically do not.

The main problem is that market-clearing prices need not exist; i.e., there may be no prices at which all accepted bids are willing to be executed and all rejected bids are not; this is a standard problem in markets with indivisible goods and/or other non-convexities. The auction thus requires some protocol for selecting prices that implement the accepted bids, even if some rejected bids would be willing to be executed as well.

Following Rassenti, Smith, and Bulfin (1982), we can express this price setting problem as an additional optimization problem in which we minimize the importance of rejected-but-willing bids. In this "pseudo-dual" problem (so-called because it is a modified version of the dual to the allocation problem), the importance of these bids is measured by the surplus they would receive if they were able to be executed. Given a set of prices $\{p_t\}$, we define a measure of this lost surplus, denoted w_i, for each bid. The w_i are equal to zero for accepted bids, for rejected bids that are unwilling to be executed at the prices $\{p_t\}$, and for rejected bids that are excluded because of logical constraints. For rejected-but-willing bids, the lost surplus is defined to be the amount by which the WTP for bid i exceeds the cost of filling the bid at the given set of prices. Thus,

$$w_i = B_i - \sum_{t=1}^{T} a_{it} * p_t. \tag{3}$$

Given these definitions, we search for prices that minimize the magnitude of the lost surplus, subject to the constraint that all accepted orders are willing to be executed. Let A denote the set of accepted bids and let R denote rejected bids *except* those rejected because of logical constraints (partially-filled bids are treated as both accepted and rejected). We solve the linear program:

CDA PRICING PROGRAM:

$$\textit{Minimize}: \underset{\{p_t\}}{} \; LOSTSURP \equiv \sum_{i=1}^{I} w_i$$

subject to:

$$\sum_{t=1}^{T} p_t * a_{it} \leq B_i, \; \forall i \in A \tag{4}$$

$$w_i \geq B_i - \sum_{t=1}^{T} p_t * a_{it}, \; \forall i \in R$$

$$w_i \geq 0, \; \forall i$$

$$p_t \geq 0, \; \forall t$$

The first set of constraints requires that accepted bids are willing to be executed at the chosen prices. The next two constraints then define the lost surplus measures.

This linear program will always be feasible. If the integrality constraints in the allocation problem are not binding (so the integer program could be treated as a linear program), then the lost surplus will be zero and market clearing prices will exist.

It is likely that multiple price vectors will achieve the minimal lost surplus. To see this, note that in Figure 1 (in which the lost surplus equals zero) any price between bid 4 and bid 3 clears the market. As we discuss in a moment, a price equal to bid 4 is desired so that the auction resembles a second-price auction. To do this here, a third optimization problem is required; the objective is to maximize the buyers' net surplus subject to the constraints that accepted bids are willing to be executed and the minimum lost surplus ($LOSTSURP^*$) is achieved:

CDA PRICING TIE-BREAKER:

$$\underset{\{p_t\}}{\textit{Maximize}}: \; BUYERSURP \equiv \sum_{i \in A} \left(B_i - \sum_{t=1}^{T} p_t * a_{it}\right) * x_i$$

subject to:

$$\begin{aligned} &\sum_{t=1}^{T} p_t * a_{it} \leq B_i, \; \forall i \in A \\ &w_i \geq B_i - \sum_{t=1}^{T} p_t * a_{it}, \; \forall i \in R \\ &\sum_{i=1}^{I} w_i = LOSTSURP^* \\ &w_i \geq 0, \; \forall i \\ &p_t \geq 0, \; \forall t \end{aligned} \tag{5}$$

If the vector of optimal prices is still non-unique, it is sufficient to select at random from the equivalent prices.[15]

Figures 2 and 3 illustrate the basic pricing protocol in an auction for a single type of permit. In Figure 2, bids have been ordered and aggregated into a demand curve. Bid 3, the bid at which supply crosses the demand curve, is an AON bid; the optimal allocation will therefore require that some lower value bid replace a higher value one. In this case, it is optimal for bid 3 to "bump" bid 2, yielding the "demand curve" in Figure 3. For bids 1 and 3 to be willing to be executed, price must be set below bid 3. To minimize the lost surplus for bid 2 (the shaded area), it follows that

15. Throughout this paper, we give special attention to the problem of non-unique prices. While non-uniqueness is typically uncommon in the primal (i.e., allocation) program, it is almost certain to occur in the dual program. As illustrated in Figure 1, for example, there will typically be an interval of market-clearing prices in the pure linear program; prices will be unique only when the last accepted bid and the first rejected bid have the same valuations. Note that the attention to choosing prices distinguishes this paper from most previous efforts (e.g., those by Rassenti, Smith, Bulfin, McCabe, and Hogan) who simply accept the dual prices provided by their linear programs.

the price is equal to bid 3.

c. Computational Issues

As just described, the CDA involves three separate optimization problems: an integer program for allocation and two linear programs for pricing. Modern computers and software allow even large linear programs to be solved very rapidly; as a result, the pricing problems do not pose any significant computational challenges. The allocation problem, in contrast, can pose some challenges because integer programs can be much more computationally demanding than linear programs. It is difficult to generalize about such programs because the computational burden is very sensitive to the details of a problem.[16] Based on example auctions developed in work related to this paper, however, it appears that CDA's can be solved in a relatively short period of time (seconds to a few minutes) for even substantial auctions (hundreds of orders). Because these auctions will typically be executed only occasionally, rather than continuously, solving times much greater than these would likely be acceptable and thus the computational burdens of a CDA appear quite manageable.

16. A common solution technique for integer programs is the branch and bound algorithm, in which a series of linearized versions of the integer program are solved. If the integer constraints turn out not to be binding, this algorithm will solve the problem in the same time as required for a single linear program. If the integer constraints turn out to be important, however, the same algorithm might have to solve a multitude of linear programs before finding the integral optimum. Thus programs of the same size (number of rows and columns) may require substantially different amounts of time to solve.

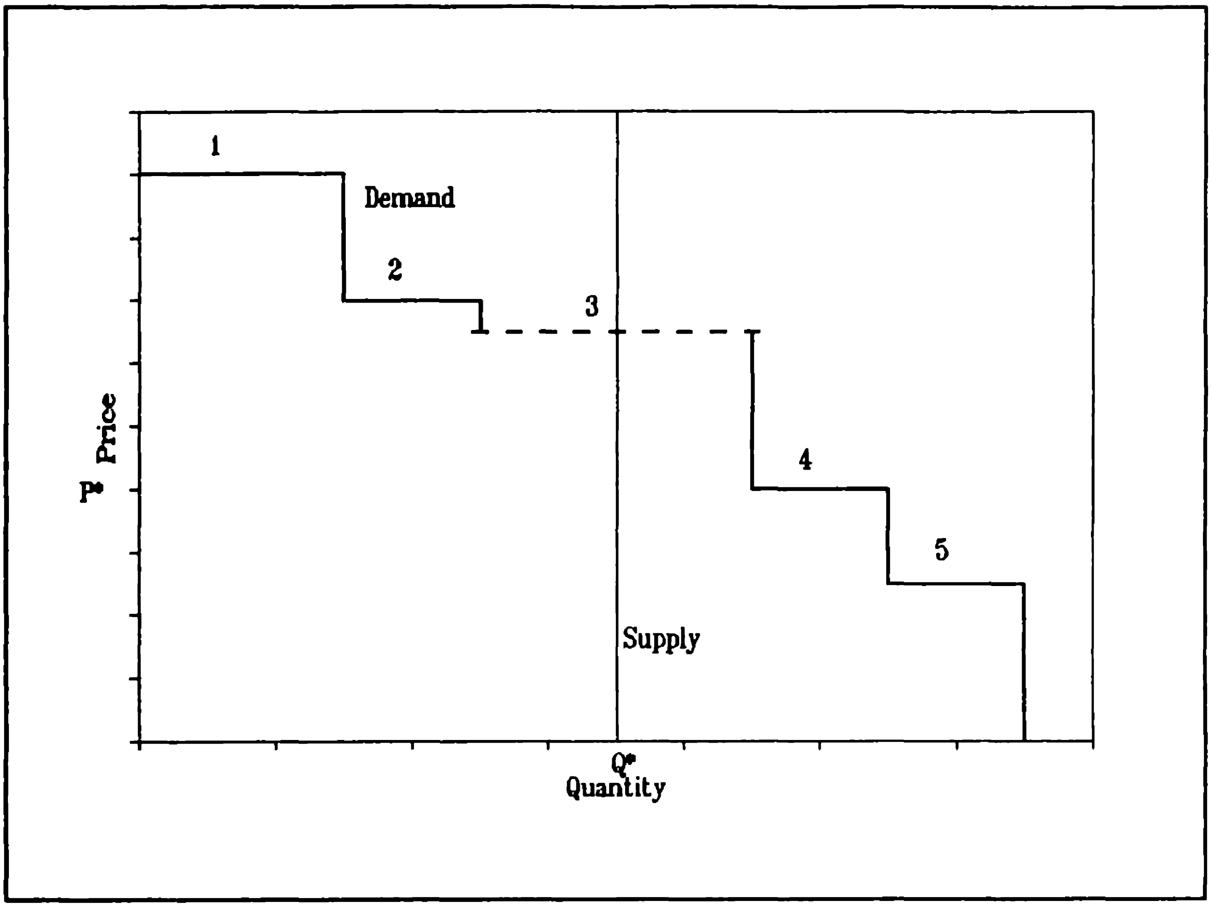

Figure 2: A multiple unit, single good auction in which bid 3 is all-or-nothing.

d. Incentive Issues

Like any uniform price multi-unit auction, the CDA is not fully incentive compatible. Because participants' accepted and rejected bids are used to set prices at the margin, participants will have some incentive to under-reveal their true valuations (both in order to lower the price of the accepted bid at the margin and to lower the price paid by successful inframarginal bids). However, the incentives for this under-revelation should decline quickly with the number of participants; once the number is large, an individual firm should expect to have a low probability of influencing prices and should submit bids that are close to its true valuations. Rustichini, Satterthwaite,

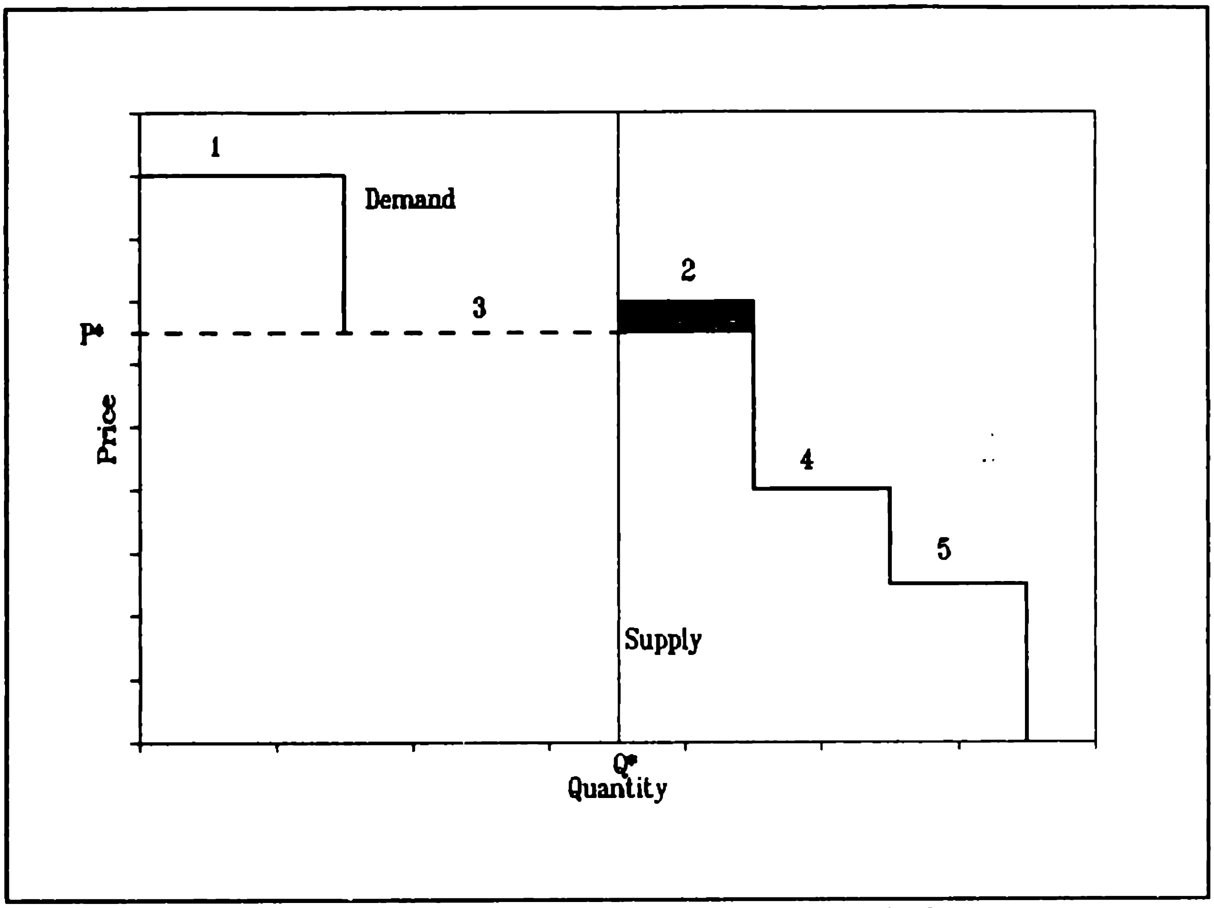

Figure 3: A multiple unit, single good auction; bid 3 bumps bid 2.

and Williams (1992) demonstrate this convergence to price taking in a theoretical analysis of a related class of uniform price auctions where buyers and sellers each want to trade a single unit of a good. Our intuition here is that these results extend, probably with slower rates of convergence, to multi-unit demands.

We ignore the additional incentive problems associated with revenue neutral auctions; for a theoretical discussion see Lyon (1986) and for experimental evidence indicating that efficiency is not hurt in these auctions (and, in fact, may be improved), see Franciosi, Isaac, Pingry, and Reynolds (1993). We also ignore the issues associated with the potential resale of allowances. The potential for resale will change the individual valuations that are the basis for bidding strategies.

As a final issue, note that if we drop the requirement of uniform pricing, it would be possible to implement a fully incentive compatible auction. As argued by Lyon (1986), for example, we could implement a Vickrey-Groves mechanism in which each accepted bidder pays the difference between the system surplus achieved when its bids are included and the system surplus when they are excluded. The cost of incentive compatibility is high, however; not only are uniform pricing and its associated benefits lost, but the allocation problem must be solved $N_A + 1$ times, where N_A is the number of bidders with accepted bids.

e. Implementation

Thus far, we have assumed that the CDA is implemented as a sealed-bid auction. Experimental evidence indicates, however, that sealed-bid auctions may be less efficient than comparable mechanisms that allow bidders to update their bids (see, e.g., Smith, Williams, Bratton, and Vannoni (1982) and McCabe, Rassenti, and Smith (1991b)). In essence, the one-shot nature of sealed-bid auctions prevents market information from feeding back to participants and their bidding strategies. As a result, strategic bids that get rejected in the auction do not have the opportunity to be updated.

For that reason, it may sometimes be preferable to implement a version of the auction in which bidders are allowed to update their bids. One approach is to use an iterative version of the CDA. The auction works in the same way, but bidders are allowed to see temporary auction results, and update their bids until some stopping rule is achieved (e.g., no improvements forthcoming; all vote to accept, etc.). In essence, this is an attempt to create a Walrasian auctioneer for the permits (see, e.g., Smith, Williams, Bratton, and Vannoni 1982). Such an iterative approach will be most useful for auctions involving a small number of bidders. For a large number of bidders, the incentive problems associated with sealed-bidding should decrease while the practical burdens of iterative bidding increase.

4. COMBINATORIAL AUCTIONS FOR TRADING PERMITS

The auction described in the previous section is a one-sided auction in which the government, as the sole owner of the tradeable permits, seeks bids from firms that wish to purchase the permits. After initial distribution, by whatever means chosen, additional mechanisms are needed to allow trading of permits among firms in the marketplace. Such trading will involve buyers of permit combinations, sellers of combinations, and participants who want to trade combinations that simultaneously buy and sell different permit types. In this section we show how the CDA can be generalized to the problem of trading permits.

As a foundation for this analysis, note that just as the CDA generalized the single good, uniform price auction, the combinatorial trading auction (CTA) will generalize the single good, uniform price double auction. Figure 4 illustrates such an auction, where demand and supply curves have been created from submitted bids and offers, respectively.

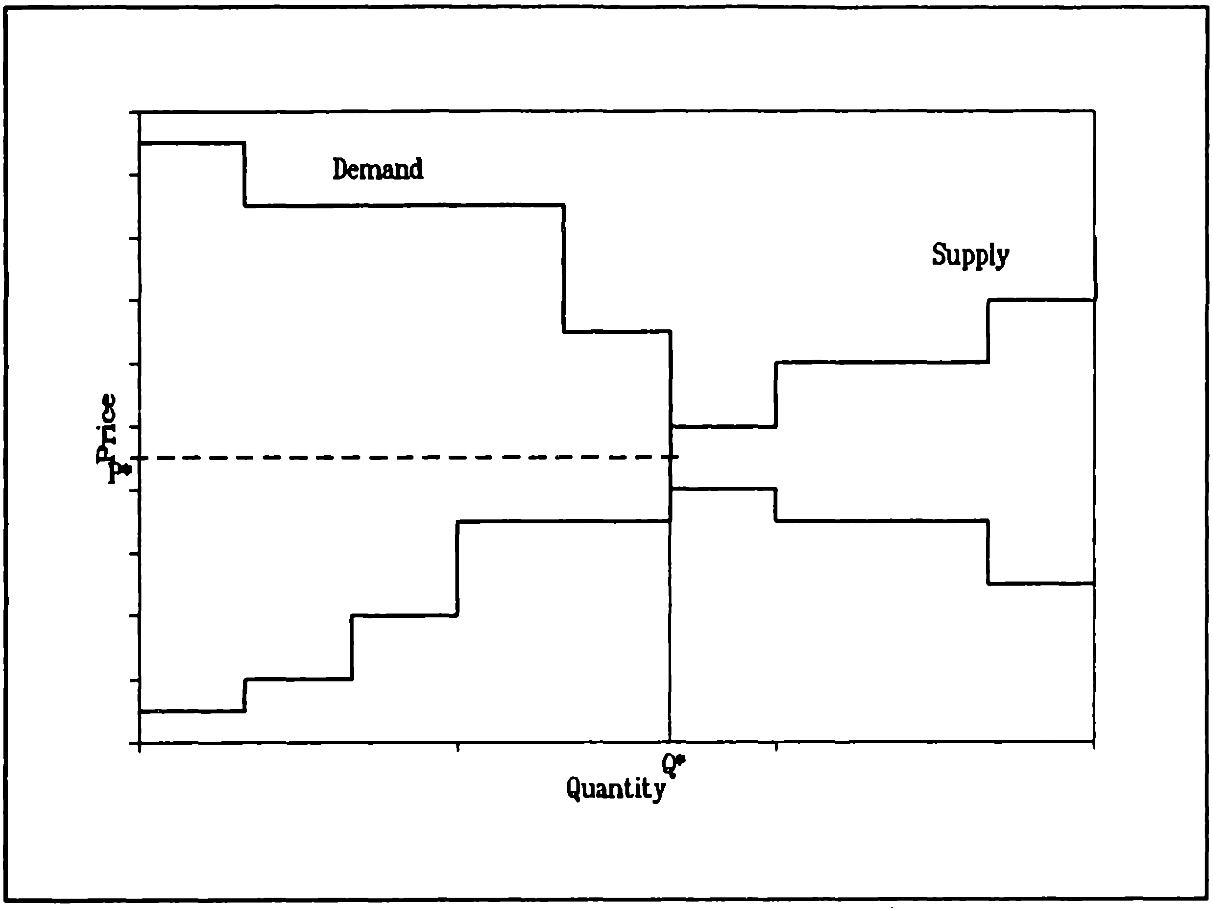

Figure 4: A multiple unit, single good k-double auction (k = 0.5).

In this auction, Q^* permits will trade, with the price set as follows: Let p_1 be the lowest price for an accepted bid, p_2 be the highest price for an accepted offer, p_3 be the highest price for a rejected bid, and p_4 be the lowest price for a rejected offer. Define $p_H = \min(p_1,p_4)$ and $p_L = \max(p_2,p_3)$. Any price in the range $[p_L, p_H]$ clears the market.

Following Rustichini, Satterthwaite, and Williams (1992), we characterize the choice of a price in this interval by a number k in the interval [0,1]. In a k-double auction, the clearing price is set as:

$$p = kp_H + (1-k)p_L,\ k \in [0,1].$$

There are three standard choices for k. A k of 1/2 is often used based on notions of fairness, since it shares the marginal gains from trade equally among buyers and sellers; this k can also be justified as the outcome of a bargaining process. The other two choices correspond to the two extremes of the interval (k = 0 or 1).

a. Allocation

We will develop the CTA as a generalization of the CDA. A complete generalization of the CDA requires a somewhat detailed foray into certain aspects of mathematical program definition; this generalization is discussed in Appendix A. For our current purposes, it is sufficient to work with a simpler situation in which we assume that the auction can be formalized as a pure linear program. Thus we exclude situations in which bidders submit AON bids or sellers submit an appropriate analogue.

Unlike the double auction described above, bids and offers are not the only orders that may be submitted to the CTA. Participants may also want to submit swaps, in which different types of permits are simultaneously bought and sold (the idea is that some permits are being swapped for others). While bids are submitted with a positive total cost, representing WTP, and offers are submitted with a negative total cost, representing a willingness-to-accept, a swap may be submitted with either a positive or negative total cost.

As in the CDA, the objective function of the auction will be to maximize the gains from trade from accepting submitted orders subject to a variety of constraints.

In this case, the surplus is defined as the sum of the total costs of accepted orders. If the only orders are bids and offers, this surplus measure simplifies to be the difference between the total WTP of accepted bids and the total willingness-to-accept (WTA) of accepted offers.

Market clearing constraints require that the number of each permit type bought must be less than or equal to the number sold. These constraints are inequalities because excess permits may be included in the optimal allocation (e.g., if the optimal allocation requires only type A permits from an offer to sell combinations of type A and type B). In the completely linear setup we have assumed, such excess permits will 'trade' at a zero price.[17]

If trading is subject to regulatory review, we add any regulatory constraints that the government may impose on trading; these may take the form of geographic restrictions, as in the bubble system, for example. We also include logical constraints that link the orders submitted by individual auction participants. For simplicity, neither of these sets of constraints will be represented formally.

To define the CTA, we define:

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17. Experience with the only extant permit auction suggests that such surpluses are unlikely. In the March 1993 EPA auction of SO_2 allowances, many bidders submitted exceptionally low bids for the allowances (about a quarter of the quantity bid were priced at $11.00 or less while allowances actually traded for $131 or more). If such bids are entered in a CTA, they would pick up any otherwise surplus permits.

N	Number of participants
I	Number of orders
B_i	Total cost for order i (positive for bids, negative for offers)
a_{it}	Number of type t permits in order i (positive for bids, negative for offers)
x_i	Fraction of order i that is accepted

The allocation problem may then be written as:

LINEAR CTA ALLOCATION PROGRAM:

$$\underset{\{x_i\}}{\textit{Maximize}}\ \textit{SURPLUS} \equiv \sum_{i=1}^{I} x_i * B_i$$

subject to

$$\sum_{i=1}^{I} x_i * a_{it} \le 0,\ \forall\, t = 1..T \qquad (6)$$

$$0 \le x_i \le 1,\ \forall i$$

Logical Constraints

Regulatory Constraints

b. Pricing

Because of its linear structure, the linear CTA will always have market clearing prices. As usual, these prices need not be unique. As a result, we require some algorithm for selecting among them. One reasonable approach is to share the marginal gains from trade equally among buyers and sellers (swappers are taken to be buyers if their total cost is positive and to be sellers otherwise). To determine these prices, we solve two optimization problems that maximize and minimize, respectively, the payments made by buyers, subject to the optimal allocation being implemented. The average of these two price vectors then shares the marginal gains from trade equally between buyers and sellers. This pricing protocol generalizes the 0.5-double auction; other weightings of the two price vectors similarly generalize the full range of k-double auctions.

The CTA design is similar to a computer-assisted auction developed by McCabe, Rassenti, and Smith (1989, 1990) for natural gas markets. However, these authors overlook the non-uniqueness of shadow prices in their auction. As a result, their proposed auction mechanisms are incomplete; clearing prices are determined at the whim of whatever linear programming package is used (when multiple solutions exist these packages typically return one of them without noting the non-uniqueness) rather than by a specific algorithm. As computer-assisted auctions are adapted to commercial use, it will be important for the mechanisms to be completely defined.[18]

c. Computational Issues

The same basic computational issues arise here as arose for the CDA. In the completely linear case described here, the auction is simply an easy-to-solve linear program.

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18. That McCabe, Rassenti, and Smith (1989) overlooked the non-uniqueness of clearing prices led them to understate the performance of their auction in certain experiments. These experiments compared auction results generated by players given specific cost and demand values to the competitive equilibrium that was implied by those values. While the quantities in the competitive equilibrium were unique, equilibrium prices were not. In evaluating their experiments, the authors compared prices in the experiments to one particular set of competitive equilibrium prices that, it turns out, maximizes the buyer surplus. Their finding that prices to buyers tended to be higher, and buyer surpluses lower, than predicted by this particular competitive equilibrium is therefore not surprising. Because of this unintentional bias in their choice of a single competitive price level, the computer-assisted auction actually performed better, relative to the goal of achieving a competitive equilibrium, than McCabe, Rassenti, and Smith (1989) originally concluded.

d. Incentive Issues

The same basic incentive issues apply here as in the CDA: the auction is not incentive compatible[19], but in large systems agents should have little incentive to misrepresent their bids.

A second set of incentive issues arise from the fact that participation in the CTA is voluntary. In typical analyses of auction design, a maintained assumption is that the auction is the only mechanism for allocating the goods in question. In applications of the CTA, however, there may be alternative mechanisms for trading. An area for theoretical and experimental work would be to explore how market fragmentation and informational externalities between separate trading institutions may affect agents' incentives to participate in a different mechanism, their choice of strategies, and the relative efficiency of resultant auction outcomes.

5. A TRADING AUCTION FOR SULFUR DIOXIDE ALLOWANCES

To inject some concreteness into our otherwise abstract discussion of combinatorial auction design, it is useful to consider a specific application of a combinatorial auction. We focus on the market for the sulfur dioxide (SO_2) emission allowances that were created under the Clean Air Act Amendments of 1990 (CAAA)

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19. Incentive compatibility is more difficult for the CTA because of budget balancing constraints (the auctioneer will typically not take or give money; any commissions are netted out of the submitted total costs). It is well known that budget balancing undermines incentive compatibility; see, e.g., Fudenberg and Tirole (1991, Chapter 7) and references therein.

(see also Bartels, Marron, and Lipsky (1993)).

The CAAA placed a series of caps on SO_2 emissions from electric utilities in the continental United States; emissions will ultimately be limited to 8.95 million tons per year, about half of emissions in 1985. Tradeable allowances are used to implement these caps. Each SO_2 allowance will be defined as the right to emit one ton of SO_2 any time after a specified date; a 1995 allowance can thus be used in 1995 or it can be banked for use in later years. In the initial distribution, firms received allowance portfolios with issue dates ranging from 1995 to 2024 (as each year passes the EPA will issue an additional year of allowances so that there are always thirty years outstanding). A small fraction of the allowances (2.8%) were withheld, however, for distribution by revenue neutral auctions and direct sales by the EPA.

At the time of this writing, on the order of twenty trades have been announced. These have been executed as bilateral, negotiated trades, often brokered by consultants. In addition, 150,010 allowances have been sold through an EPA auction (described below). Formal allowance markets are being developed, including a futures market operated by the Chicago Board of Trade (CBOT), spot and forward cash markets operated by Cantor Fitzgerald Environmental Brokerage Services, and, possibly, other cash and option markets operated by the CBOT and the New York Mercantile Exchange. Cantor Fitzgerald will also offer a CTA, a simplified version of which we discuss here (for a description of this auction directed to electric utilities, see Bartels, Marron, and Lipsky (1993)).

The combinatorial nature of the allowance trading problem derives from the temporal demand for allowances. Because control strategies -- including the installation of scrubbers or conversion to low sulfur fuels -- require significant planning horizons, utilities (and other market participants) will want to trade streams of allowances that cover multiple years (most bilateral trading has involved allowance streams).

As described above, a CTA is designed for trading such allowance combinations. In fact, the basic structure of a trading auction for SO_2 allowances is identical to that of the CTA described in section 4, except that there are, as yet, no regulatory constraints on trading (and, as before, we assume that the auction can be represented as a linear program although in actual implementation it will involve complications such as those described in Appendix A). The different permit types correspond to the different years in which permits are valid ($T = 30$).

Because permits can be banked, participants may submit swap orders in which they buy allowances in one year and sell allowances in a later year; such swaps essentially bank allowances from one year to the next. Participants who hold excess allowances in the early years of the program may also submit a related type of swap, in which they sell early allowances and buy later ones; these swaps allow firms to profit from their early allowance holdings rather than simply banking the allowances to the future.

In considering the actual implementation of this auction, some important issues arise regarding the settlement of trades. Although the foregoing description of the auction has, like the rest of this paper and most of auction theory, assumed that trades would be settled immediately, many traders may prefer to structure their trades as forward settling (this is true of many trades executed to date). In particular, buyers will want to structure their purchases so that allowances needed in a future year are delivered and paid for in that year.

Within the context of a CTA, forward settlement can be achieved in at least two ways. First, the auction can simply require immediate settlement and leave the problem of forward settlement to firms to resolve via external financial arrangements. For example, buyers could get loans from financial firms that are willing to structure payment schedules aligned with allowance usage; the financial firms would hold the allowances as collateral.

A second option is to build forward settlement into the auction mechanism itself. In this case, the auction would determine uniform forward prices at which all trades would be executed. While a number of details arise in developing a forward settling auction (in particular the problem of handling participants who have different discount rates), the basic structure of the CTA applies.

6. COMPARISON WITH OTHER MARKET FORMS

Having explored in detail the design and implementation of combinatorial auctions, it is important to consider how they compare to other possible market institutions.

a. Distribution

A range of other auction mechanisms could be used for distributing permits. One obvious alternative would be separate auctions for each permit type; these could be held simultaneously or sequentially. In either case, firms would have a difficult time bidding since, as argued previously, their valuations for each permit type will depend on the unknown outcomes in other auctions. Because of the difficulty of the resulting strategic bidding problem, it is unlikely that an efficient allocation of permits will result. Experimental evidence supports this conclusion. In experiments using a simple combinatorial mechanism and simultaneous auctions, Rassenti, Smith, and Bulfin (1982) found that the combinatorial auction achieved much higher levels of efficiency.

Another alternative is a Swiss auction (von Ungern-Sternberg 1991), in which multiple goods are offered in simultaneous auctions, but winning bidders can withdraw their bids *ex post*. Such withdrawal can eliminate some problems of simultaneous auctions, e.g., ending up with too many permits. Such an auction could be quite complex to implement, however, and does not offer any advantages over a combinatorial mechanism.

A more promising alternative is to auction pre-specified permit combinations. If buyers demand certain common combinations, this approach can facilitate efficient distribution without requiring a fully combinatorial mechanism.[20] The utility of such

20. Such a design was considered, but rejected for political reasons, for the revenue neutral auction defined in the Clean Air Act Amendments of 1990 (Hausker 1992).

pre-packaging is limited, however, because it requires the government to identify appropriate combinations. If, as is likely, firms differ in their desired combinations, a combinatorial mechanism is better because it allows bidders to choose their own combinations.

A final alternative is the somewhat peculiar auction that the EPA uses for its annual distribution of SO_2 allowances (Federal Register 1991). Each year two types of permits are auctioned (and offered for direct sale): permits good in the current year (or 1995 for the auctions in 1993 and 1994) and permits good seven years later. Permits go to the highest bidders, who then pays their bid price. Bidders have the right to withdraw their bids if they can only be partially filled.

This auction does not allow firms to purchase real allowance portfolios. Firms that buy 1995 allowances will very likely need them in 1996 to 1999, as well. By limiting the allowances offered to two particular years, the auction unnecessarily encourages buying and banking (i.e., buying 1995 allowances to use in later years); it is not a mechanism designed for efficient allocation.

b. Trading

An obvious alternative for trading permits is the use of spot and forward markets for each type of permit. When information is well-dispersed and the individual markets are thick, such independent markets provide an excellent mechanism for trading. Firms would be able to act as price takers and therefore would adopt and implement optimal compliance plans with little difficulty.

Of course, as argued in previous sections, these assumptions may not hold; if not, completely decentralized markets will be unlikely to achieve an efficient distribution of permits. Even so, individual spot and forward markets will likely operate in parallel with a CTA. Such markets will provide a useful means for adjusting permit holdings in between periodic auctions.

In the absence of centralized spot markets or call auctions, the structure that would likely dominate permit trading is bilateral negotiation. While such negotiations have been the basis for most previous trades of tradeable permits, they are an imperfect mechanism, subject to high transaction costs, loss of anonymity, and limited distribution of information in the market (on the latter, see Wolinsky 1990). Negotiated trades can fill a niche, e.g., when trading partners need to structure deals in specialized ways (e.g., non-standard settlement), but, in general, firms should do at least as well in centralized auctions such as the CTA. This is particularly true if centralized auction mechanisms, like the CTA, can be structured for forward settlement.

As an alternative trading mechanism for SO_2 allowances, the Environmental Defense Fund (EDF) suggested a catalog approach to trading (Dudek and LeBlanc 1991 and LeBlanc, Dudek, and Tripp 1991). In this approach, a market maker would provide a catalog describing various lots offered for sale at some minimum price. Buyers would then bid on the bundles of interest (as described by EDF, these bids appear not to be binding but instead serve as the basis for further negotiations).

While this mechanism provides some market flexibility and does employ the mechanism of a centralized auction house, it still suffers from the coordination problems inherent in having multiple, interrelated auctions. In addition, the requirement of negotiations after the bidding both reduces the information content of the bids and unnecessarily eliminates anonymity between the traders. The CTA provides a much more powerful mechanism for achieving the goals of the catalog auction.

The EPA auction provides a final trading alternative because it allows sellers to enter offers. These offers will be matched with bids after the withheld allowances have been distributed. As noted by Cason (1992), this auction creates some interesting incentive problems because the lowest accepted offers are matched with the highest remaining bids. Because this is a bid price auction, sellers thus have an incentive to distort their offers downward in hopes of being assigned a higher price bidder. As noted previously, this mechanism is not one designed for efficient permit trading.[21] In the first auction, moreover, selling by allowance owners was virtually absent. Only 10 of the 150,010 allowances sold came from private parties.

7. CONCLUSION

Tradeable permit systems can often provide substantial cost-efficiencies relative to traditional regulatory approaches. However, imperfections in permit markets can limit these gains. The combinatorial auctions described in this paper

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21. The EPA, among others, has rightly noted that it ought not to be the primary marketplace in which allowances are traded. For that reason, it may be beneficial that the EPA auction is so peculiar.

offer one way to reduce these imperfections and thereby increase the efficiency of permit markets. Like other computer-assisted auction mechanisms (Banks, Ledyard, and Porter 1989; McCabe, Rassenti, and Smith 1991a), they do this by combining the benefits of decentralized, free markets -- in particular, decentralized decision-making -- with the benefits of centralized exchange -- coordination and multilateral trading.

In essence, these auctions bring to permit markets the same optimizing structure that economists have long used in estimating the benefits of least-cost environmental regulation. While many studies have analyzed the potential of permit systems using mathematical programming techniques, the auctions described here actually use those techniques in distributing and trading permits. In so doing, they can both facilitate trading in existing permit systems and help to make feasible more complex systems that otherwise might be impractical due to high transaction costs or thin markets (Hahn 1986).

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APPENDIX A: THE GENERALIZED COMBINATORIAL TRADING AUCTION

This appendix generalizes the linear CTA to include orders that specify minimum numbers of allowances to sell or minimum required revenues. As in the CDA, we allow bidders to specify bids as AON; when linked to flexible orders using logical constraints, these AON orders can be used to represent minimum allowance requirements. To provide an analogous opportunity for sellers, we allow them to specify a minimum required revenue for each offer. Offers will be executed, in whole or in part, only if the minimum revenue is achieved. This minimum might reflect the fixed costs of a control technology that can be used to produce a range of permit quantities.

To model such minimum revenue offers requires that the auction handle price times quantity terms, rather than just quantity terms, in determining the optimal allocation. Because both price and quantity are choice variables, the resulting program is no longer linear. It can be solved in three ways: (1) non-linear integer programming, (2) an iterative process in which integer programs are solved, shadow prices calculated, the minimum revenue constraints checked, and a new integer program developed until the best solution is found in which the constraints are satisfied, or (3) linearizing the problem so that it may be expressed as an integer program[22].

To describe the minimum revenue constraints, we define

22. This can be done by using additional integer variables to express multiplications of choice variables in terms of addition; the non-linearities are thereby linearized. While this approach was included in a previous version of this paper, it is tangential to the main thrust of the auction discussion; details are available from the author.

MR_i Minimum required revenue for order i; defined only if $B_i < 0$.
xi_i Indicator variable for order i; $xi_i = 1$ if $x_i > 0$; $xi_i = 0$ otherwise

For offers without a minimum required revenue, we have $MR_i = 0$; for offers with a minimum, $MR_i < 0$. With these definitions, we have the non-linear constraint

$$\sum_{t=1}^{T} x_i * a_{it} * p_t \leq MR_i * xi_i, \; if \; B_i < 0. \tag{7}$$

The left-hand side equals the (negative of the) total revenue received on the order, while the right-hand side equals the (negative of the) minimum required revenue, if the order is executed ($xi_i = 1$), or 0. The indicator variable xi_i forces the constraint to apply only if the order is executed; when the order is not executed, the constraint is satisfied trivially.

A second source of difficulty in the general CTA involves the pricing stage of the auction. In the CDA it is always possible to lower prices enough to implement any surplus-maximizing allocation of permits; in the CTA, however, the surplus-maximizing allocation may not admit uniform prices at which all accepted orders are willing to be executed.[23] Given this situation, we can either allow some variation in the prices paid by different participants or impose the constraint that the optimal allocation be amenable to uniform pricing. We adopt the latter course, because it allows the auction to be non-discriminatory.

23. Consider an AON bid for two permits at a value of $100 and two offers, one for a permit at $30, the other at $60. The optimal allocation would execute all three orders. Uniform pricing requires that the price of each allowance be at least $60, implying a cost to the bidder of at least $120. Thus, the optimal allocation cannot be implemented by uniform prices.

To implement this approach we add an additional set of constraints to the allocation stage to ensure that uniform prices exist at which all accepted orders are willing to be executed:

$$\sum_{t=1}^{T} x_i * a_{it} * p_t \leq x_i * B_i. \tag{8}$$

The general CTA allocation program is then defined by adding the new constraint sets (7) and (8) to the linear CTA (6). Because market clearing prices need not exist, the auction market prices are then determined by a pseudo-dual like that of the CDA. If these prices are unique then they will be the same as the prices determined in the allocation stage.