'Second-Best' Adjustments to Externality Estimates in Electricity Planning with Competition

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Abstract

A number of state public utility commissions are using "social costing" methods to consider externalities in electricity resource planning. The most comprehensive and formal method is the use of monetary place-holders in the financial evaluation of new investments and potentially in system dispatch to reflect quantitative estimates of externality values. This approach necessarily must take existing environmental and social regulation as given. Furthermore, regulated utilities face increasing competition from electricity generators outside their service territory who may not be affected by social costing. The lack of universal and uniform social costing places PUC actions soundly in the realm of "second-best policy" and they may have unintended consequences that should be anticipated by regulators. This paper addresses two prominent possibilities: the potential substitution of unregulated supplies of energy services in place of electricity generated by the regulated utility, and the effect social costing may have on the relationship between the regulated price and marginal cost. These issues are considered within a normative model of social welfare maximization, which is applied to three representative hypothetical utility case studies to calibrate a second-best optimal adder to correct for externalities in electricity planning.

Key Words: second-best, environmental regulation, electricity regulation, environmental adders

JEL Classification Numbers: Q25, Q48, L51

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1. INTRODUCTION

"Social costing" describes methods for estimating and accounting for externalities of economic activities. Such methods have been most developed in the electric utility industry, where PUCs in twenty-nine states have adopted or are considering some form of social costing to influence utility planning decisions.[2]

A PUC is awkwardly situated in this endeavor for several reasons. First, it must take as given federal, and usually state, regulations designed to address such externalities, such as the federal Clean Air Act and state hazardous waste regulations. Second, PUCs must necessarily take a piecemeal approach to the problem of internalizing externalities because these bodies have limited authority—each PUC regulating only electric utilities (and sometimes natural gas, communications, and water utilities) in one state—while the scope of the problem is much larger, involving externalities from many sectors, including nonutility generators in the

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[1] Dallas Burtraw and Karen Palmer are both Fellows in the Quality of the Environment Division, Resources for the Future. Alan Krupnick is a Senior Fellow in the Quality of the Environment Division at RFF. We gratefully acknowledge guidance and comments from Winston Harrington, Tracy Lewis, and Peter Wilcoxen, and able research assistance from David Edelstein and Steve Puller. This research was supported in part by the U.S. Department of Energy, the U.S. Environmental Protection Agency, the Stanford Center for Economic Policy Research and the Stanford Institute for International Studies. Address correspondence to: Resources for the Future, 1616 P Street NW, Washington DC, 20036.

[2] See US GAO (1995), Nagelhout (1993), Consumer Energy Council of America Research Foundation (1993), Mitchell (1991) and Cohen, *et al.* (1990).

electric sector, and sources in multiple states. Third, the interposition of the PUC in utility ratemaking has, itself, helped to create a gap between marginal private cost and price, a gap that may be altered by social costing approaches. Together, these reasons place PUC efforts firmly in the "realm of the second-best," meaning that it is uncertain whether social costing efforts improve social welfare.[3]

With industry restructuring on the horizon, concerns about PUC behavior regarding social costing may seem misplaced, as the PUC's influence may be undermined. However, many state legislatures, environmental groups, and others are intent on requiring that environmental concerns be maintained if restructuring is to go forward. Indeed, increased competition does consumers no favor if it promotes inexpensive electricity while also sanctioning nonprice taxes in the form of environmental externalities. Consequently the search for regulatory tools that are robust to changes in industry structure is of interest to many regulators. Quantitative tools may have new-found relevance in this context if they can be shown to be applicable in a consistent fashion with less direct involvement by regulators.

The policy tool that has gained the widest interest and is most consistent with the development of quantitative estimates of externalities is the use of "adders" to account for externalities in financial analysis. Adders are similar to taxes, but they are not actually charged and no revenue is exchanged. Instead they serve as place-holders intended to influence the

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[3] A healthy literature on these second-best issues has arisen. See for example Dodds and Lesser (1994), Burtraw and Krupnick (1992) and articles by Freeman, *et al.*, (1992), Hobbs, (1992), Joskow (1992) and others in recent issues of *The Electricity Journal;* Project 88-Round II (1991), Agathen (1992), Ottinger *et al.* (1990), Palmer, *et al.* (1995), Palmer and Dowlatabadi (1993), Bernow, *et al.*, (1991), Heslin and Hobbs, (1989), Walthers and Jurewitz (1992).

choice of technology in investment decisions on the basis of *least social cost* rather than least *private* cost. Nonetheless, if adders have any effect on the outcome of the resource planning process, they will have an indirect effect on price and utility costs due to the reordering of investment options.

Despite their promise as a form of incentive-based environmental regulation, the use of adders has significant potential flaws. This paper focuses on two prominent potential unintended consequences that stem from the indirect effect that adder policies have on the price of electricity. The first is the environmental consequences of "bypassing" the regulated energy source.[4] For instance, higher electricity prices may induce a residential customer to heat with wood instead of electricity, which would have adverse environmental effects of its own that are not reflected in the estimates of externality associated with a new source of electricity. Alternatively, a large industrial firm may decide to reallocate production away from the service territory of a utility subject to social costing and toward an area with lower electricity prices; or, under future regulatory structures now under consideration, it may opt to contract directly for supply from nonutility generators or utilities located out of state.

A second unintended consequence stems from the fact that, for the present, electricity prices typically do not reflect marginal costs, and this can have important implications for economic efficiency. For example, Gilbert and Henly (1991) estimate that deviations from

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[4] This is a bit of a misnomer because in the natural gas industry the term "bypass" has a particular connotation regarding the purchase by large industrial customers from interstate pipeline companies, effectively bypassing the local distribution system and state level regulation. We use the term more broadly, to describe reductions in demand that might result from fuel switching or possibly the shift of industrial production to facilities outside the utility's service territory.

marginal cost pricing in Northern California have a negative impact on consumer welfare that is equivalent to about 7% of the cost of providing electricity. The application of adders may exacerbate this inefficiency, or alternatively be corrective, depending on the circumstances in an individual service territory.[5]

Taking these issues into account, the question we address is whether the second-best optimal adder for the purpose of promoting economic efficiency is equivalent to the measure of externality as it is estimated in a social cost analysis.[6] In this paper we extend and apply a normative model of social welfare maximization developed in Burtraw, *et al.* (1995). The model assumes the goal of the PUC is to maximize social welfare—defined as economic efficiency—taking environmental and other social policy as given. The model relates the optimal adder to exogenous estimates of externalities, through a formula that depends solely on information that, in principle, is observable and available to regulators. This paper extends the model by incorporating multiple customer classes, multiple options for customer bypass, and multiple types of environmental cost. We apply the model to three representative utilities in different regions of the country that face different environmental challenges and technological options and obtain results that calibrate a second-best optimal adder for each utility to correct for externalities.

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[5] See Tschirhart (1994) for a graphical exposition.

[6] Several major studies to estimate marginal damages in specific contexts and to develop methodologies that may be transferable to other settings have been finished recently. One is sponsored by the U.S. Department of Energy and is being conducted by Oak Ridge National Laboratories and Resources for the Future (ORNL/RFF 1994). A parallel and collaborative effort has been completed in the European Community (EC, 1994). Another comprehensive effort has been completed in New York State by RCG/Hagler, Bailly, Inc. (RCG 1994). Several other states and utilities have launched more circumscribed efforts (see for example, Desvousges, *et al.*, 1994).

We find that the optimal adder may differ substantially from externality estimates. In some cases the adder is greater, and in some cases it is less. The marginal cost pricing issue imposes a greater influence on this outcome than does bypass. This finding is promising because planners are likely to have more confidence about price and marginal cost data relative to other parameters in the model. Own price elasticity of demand for electricity also is a critical determinant of the optimal adder. When elasticity estimates are large, as in some of our case studies, the optimal adder can deviate significantly from the externality estimate. Hence, the efficacy of a rule of thumb suggested in Freeman, *et al.* (1992) that adders be set equal to externalities appears to depend importantly on this feature. In contrast, information about cross-price elasticities and externalities stemming from bypass options exert relatively little influence on the optimal adder, except when especially large externalities are associated with bypass options.

These results illustrate that under current regulatory structures, given the resources that would be required to generate meaningful externality estimates, further efforts to make second-best adjustments to these estimates to account for the marginal cost pricing and bypass issues are likely to yield significant benefits at relatively low cost. However, if the evolving industry structure causes prices to more closely reflect marginal costs in the future, then second-best issues may become less important in calibrating an optimal adder.

The next section presents a sketch of the theoretical model and several extensions necessary for its application. Section 3 describes the data and assumptions we employed to apply the model. Section 4 presents the results of three empirical applications. Section 5 presents a sensitivity analysis of these results, and Section 6 concludes.

2. THE ECONOMIC MODEL

Let us assume the goal of the utility regulator (PUC) is to maximize social welfare, subject to environmental policy established by statute and environmental agencies. We assume the utility complies with all relevant regulations and attempts to minimize its costs in fulfilling its obligation to serve demand at a regulated price. The PUC sets prices which may vary by customer class but which are sufficient to recover cost to ensure both the solvency of the firm and that no excess profits are earned. The regulated utility has various technology options, and utility customers have options to bypass the grid and substitute alternative sources of energy, which may have their own forms of pollution not subject to social costing.

We follow Burtraw, *et al.* (1995) in the organization of the problem. They model a problem involving two generation technologies, one bypass technology, and one customer class. We extend their model to allow for multiple bypass options and customer classes. For simplicity, we limit the exposition to the investment planning problem; however, this paper also has direct relevance to the dispatch (operation) of existing resources taking full social costs into account.[7]

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[7] Dodds and Lesser (1994) outline difficulties in the application of social costing to system dispatch. The critical assumption of our model if applied toward that purpose is that firm operates capacity in accord with plans developed in the resource planning process. This assumption is restrictive in two contexts. In a resource planning scenario, the possibility exists that the regulated firm could misrepresent its intended dispatch of a new facility. Typically, it seems the incentive is for the firm to over-represent the need for a new facility. However, new facilities are more efficient with lower operating costs than existing facilities inviting them to be run more once they are in place. The fact that they are also typically cleaner further reduces concern about strategic behavior with respect to social costing. However, in a dispatch planning scenario where "cleaner" facilities do not have lower operating costs, an incentive may exist for the firm to disregard "dispatch adders" when no one is looking in order to run facilities that entail less private cost. Hence, oversight would be important, which may be achievable by *ex post* comparison with resource plans.

The model is formulated as a two-stage problem and is solved backwards. First, the firm's cost minimization problem is solved for an arbitrary set of regulatory parameters. Second, the first order conditions for the firm are substituted into the PUC's problem in setting adders to influence the utility's resource plan. Although the adders are not actually paid by the utility, the PUC forces the utility to make decisions on the basis of these adders, that is, as if they were being paid. Hence the adders appear as "costs" in the utility's objective function. The problem for the firm is to allocate production quantities (*x* and *y*) between two generation technologies (x and y) with different emissions and cost characteristics in order to minimize costs, subject to the regulatory variables (*w* and **a)**:

$$\min_{x,\, e^x, e^y} \Psi(w,\mathbf{a}) = C(x, e^x) + K(w - x, e^y) + \mathbf{a}'\mathbf{e}^x + \mathbf{a}'\mathbf{e}^y + \lambda^x(s^x x - e^x) + \lambda^y(s^y(w - x) - e^y) \qquad (1)$$

where:

Ψ = costs.

$w \equiv w^s + w^t$ = quantity of regulated electricity (watts) demanded by all customer classes.

C = cost of producing x; $C_x > 0$, $C_{xx} > 0$, $C_e < 0$, $C_{ee} > 0$.

K = cost of producing y; $K_y > 0$, $K_{yy} > 0$, $K_e < 0$, $K_{ee} > 0$.

x = quantity produced with technology x.

$y \equiv w - x$ = quantity produced with technology y.

$\mathbf{a}$ = is a vector of adders for pollutants $j = 1, \ldots, J$.

$\mathbf{e}^i$ = a vector of emissions of pollutants $j = 1, \ldots, J$ indexed by technology i.

λ^i = a vector of Lagrange multipliers regarding emission constraints for technology i.

$\mathbf{s}^i$ = a vector of exogenous constraints on emissions j indexed by technology i.

Adders on emissions appear as the third and fourth terms in equation (1). Emissions of each pollutant *j* are multiplied by an adder to yield a shadow cost for those emissions $(a^j e^{ij})$. The last two terms describe exogenous constraints for each technology that specify emissions must be less than or equal to the product of an emissions standard times output $(e^{jx} \leq s^{jx} x)$. For each technology there are J such constraints. The Kuhn-Tucker conditions describing the cost minimum allow for the possibility that such constraints are binding or not. The solution identifies a level of output and associated emissions that minimize costs inclusive of the adders on emissions.

In setting policy, the PUC anticipates the firm's behavior, conditional on regulatory variables. We assume the PUC has perfect information so there are no detection or enforcement problems regarding the firm's cost minimization problem. The PUC sets the value of the regulatory parameters to maximize social welfare—the sum of consumer and producer surplus—subject to the revenue requirement:

$$\max_{w^s,\, w^t,\, a^x} W = P^s(z^s) + P^t(z^t) - C(x, \mathbf{e}^x) - K(w - x, \mathbf{e}^y) - S(u^s) - T(u^t) - \mathbf{F}(\mathbf{e}) + \theta\left(p^s w^s + p^t w^t - C* - K*\right) \tag{2}$$

where:

P^k = willingness to pay function for customer class $k = s, t$.
u^k = unregulated supply of energy services demanded by customer class $k = s, t$.
$z^k \equiv w^k + u^k$ = all energy services consumed by customer class k.
$S,\ T =$ cost of unregulated supply for customer class s, t.
$\mathbf{F}$ = damage function mapping emissions (or more generally, effects)
into monetized damages, $\mathbf{F} : \mathbf{e} \to \Re$.
θ = a Lagrange multiplier regarding the firm's revenue requirement.
p^s, p^t = Endogenous price from residual demand curves for electricity.
Note that in equilibrium : $S' = P^{s\prime} = p^s$, and $T' = P^{t\prime} = p^t$.
$C^*,\ K^*$ = Conditional costs incorporating the solution to equation (1).

The first two terms in equation (2) reflect consumer benefits for customer classes *s* and *t*. The third and fourth terms represent costs of the regulated utility, and the fifth and sixth terms represent costs of the unregulated supplier.

The seventh term $\mathbf{F}(\mathbf{e})$ represents environmental damage.[8] Temporal variation in the effects of a pollutant can be captured by introducing a time index to the array **e**. We avoid geographic complications by assuming that production alternatives are located at a common site. The emissions vector should be thought of as simplified notation that incorporates a pollution transport function to reveal the *effects* of pollution. The model can be extended to consider different generation sites in a straightforward way by indexing the source of emissions by location.

Derivation of a solution for this problem parallels closely that provided in Burtraw, *et al.* (1995) subject to extensions of the model and slight changes in notation. Algebraic manipulation of the first order conditions leads to the following solution for each customer class $k \in \{s,t\}$:

[8] We reserve the terms *externality* to describe monetized impacts per unit of output ($/kWh) and *damage* to describe impacts per unit of emission ($/lb.). Dodds and Lesser (1994) properly emphasize that the marginal unit in resource planning is not a kWh, in part because resource planning involves discrete decisions about kilowatts of capacity. We assume that the emissions rate is constant over changes in output for each technology (the marginal and average are identical). This assumption is not technically correct, for instance, because start-up of a generator has higher than average emissions. Also, as Dodds and Lesser point out, in capacity planning there are many externalities that are one-time impacts, say, during the construction phase of a facility, and these costs should be levelized over the life of the facility. The term "incremental" can be used in place of "marginal damage" to accommodate these points, but in any case the planner has the task of identifying appropriate margins for analysis. Our assumption is not only mathematically convenient but also is a judicious reflection of regulatory practice. Dodds and Lesser also emphasize that marginal damage of emissions is not equal to average damage in general. Fortunately, empirical evidence suggests that damage functions are approximately linear over relevant ranges so this concern causes few complications. See Dewees (1992) and citations in note 5 above. By implication the externalities associated with individual effects are additive. In cases of complementarities this will represent an overestimate of true willingness to pay to avoid these effects; in cases of substitutes this will represent an underestimate.

$$\left(\alpha^{x,k} - \alpha^{y,k}\right) = \left(\frac{\varepsilon^{w,k}\left(1 - \frac{K_y + K_e \sigma^y}{p^k}\right) + 1}{\frac{\varepsilon^{w,k}}{p^k} E^y + \frac{u^k}{w^k} \frac{\varepsilon^{uk,pk}}{p^k} E^{uk} + 1} \right) \left(E^x - E^y\right) \qquad (3)$$

where:

$\alpha^{i,k}$ = **adder on *output* ($ / kWh) for technology** *i*.

$\varepsilon^{w,k}$ = **price elasticity of demand for electricity.**

σ^y = **marginal** *and* **average emission rate for technology y**.

p^k = **endogenous price of electricity.**

E^i = **externality ($ / kWh) for technology** *i*.

$\varepsilon^{uk,pk}$ = **cross price elasticity of demand for** *u*.

Equation (3) gives the necessary condition for optimality when two adders are being set by the regulator. For convenience this formula expresses the solution in terms of the difference between adders per unit of *output*, since the α^{ik} and E^i are denominated in $/kWh.[9] The equation specifies the magnitude of the difference between adders as a function of the difference between externalities for the two technologies. This one equation fully specifies a solution for customer class *k* when two technologies are considered. Since an adder is not actually paid, its magnitude does not have an independent effect on the utility's investment. Rather, it is its magnitude relative to other adders that matters. In general, setting *n* adders requires *n*-1 conditions expressing the relative magnitude of the adders to identify a solution. For example, if only one technology was to be considered the adder would be irrelevant. Hence, the regulator has only three choice variables in this formulation $(w^s, w^t \text{ and } \alpha^x)$.

[9] The notation here differs slightly from Burtraw, *et al.*, (1995) where α denotes the adder on emissions rather than output.

Without loss of generality, let us consider the adder on output from technology y to be pegged at a specific value $(\alpha^{y} = 0)$, so that equation (3) represents the optimal adder on output from x. The adder differs from the externality term due to the first term on the right-hand side, which we refer to as the *adjustment factor*. All the information contained in the adjustment factor, including price, marginal cost, elasticities and externality estimates for the unregulated technology in principle are readily observable.

The numerator of the adjustment factor reflects the benefits of moving toward marginal cost pricing. The numerator is positive unless demand is very elastic and the marginal cost of *y* is less than the price of electricity. The first term in the denominator includes the elasticity of demand and the marginal damage of output from the reference technology. The second term in the denominator includes the cross-price elasticity of demand between regulated and unregulated supplies of energy services, and the externalities associated with the unregulated supply. If the cross-price elasticity is large and the externalities from unregulated supplies are large, then this term will be large. This will tend to reduce the adjustment factor and the specified adder. The reason is that the likelihood of driving customers away from regulated supplies of electricity would be large and the social costs would be large, so this unintended consequence of social costing mitigates against its application. Under usual conditions, the denominator is always positive. Hence, typically the optimal adder for *x* moves positively with externality estimates for *x*, as intuition would suggest.

For illustration, if price equals marginal cost, the numerator in the expression is one. The greater the externality from the unregulated source, which appears as the second term in the denominator, the smaller is the adder. If externalities from the unregulated source and from the reference technology y are zero, the denominator is also one, and the adder on *x* is precisely equal to the externality from *x*. If technology y also causes external costs, the difference in the adders on *x* and *y* will be a function of the difference in their externality values. However, the difference would not be one-for-one, due to the first term in the denominator.

We designate y as the arbitrary reference technology, which we calibrate to be the lowest private cost technology currently available to the utility. To calibrate the basic model for additional regulated technologies is straight forward because the adder does not depend on any technology other than the reference technology y. Hence the adjustment factor would be unchanged, and all that would be needed is information about the externalities associated with the additional regulated technologies (the second term on the right-hand side of equation 3).

A different adjustment factor will apply for each customer class, where the class is uniquely identified by information about retail price, cross-price elasticities and unregulated options for bypass. To calibrate the model for our case studies requires one additional extension. Customers in class *k* may have multiple options for unregulated supplies of energy services $\left(u^k = 1,\ldots,U^k\right)$. Information about relevant cross-price elasticities and externalities for each unregulated supply is needed. The additional options cause the denominator of the adjustment factor to be amended to reflect a sum of terms pertaining to externalities from each unregulated supply. The new formulation which we estimate is presented in equation (4).

$$\left(\alpha^{x,k} - \alpha^{y,k}\right) = \left(\frac{\varepsilon^{w,k}\left(1 - \dfrac{K_y + K_e\sigma^y}{p^k}\right) + 1}{\dfrac{\varepsilon^{w,k}}{p^k} E^y + \dfrac{1}{w^k p^k} \sum\limits_{u=1,\ldots,U} u^k \varepsilon^{uk,pk} E^{us} + 1} \right) \left(E^x - E^y\right) \tag{4}$$

3. DATA AND ASSUMPTIONS FOR EMPIRICAL EXERCISE

In this section we describe the data requirements for application of equation 4. Some of these data such as prices, demand elasticities, marginal costs and consumption levels are utility-specific. Other data such as emission rates are generic. For this exercise we treat marginal damages as generic.

We characterize three hypothetical east coast utilities: a Southern utility, a Mid-Atlantic utility and a Northern New England utility. **Table 1** describes these hypothetical utilities and footnotes describe how we developed the data for these utilities. The adjustment factors are expected to vary across utilities depending on (1) the relationship between price and marginal cost of electricity, (2) the size of the own and cross-price elasticities of demand and (3) the bypass options available to utility customers.

For this exercise we focus on a limited set of damages stemming from emissions of three air pollutants (NOx, TSP and SO_2). We adopt the values for damages from emissions of these air pollutants developed by Ottinger, *et al.* (1990) listed in **Table 2**, and apply them uniformly to all three regions. Given differences in the population densities, atmospheric conditions and a host of other features across the three regions, the true marginal damages are likely to differ significantly across regions and across locations within a particular region. However, differentiation of the damage values across regions is beyond the scope of this research.[10]

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[10] Externality values also should be differentiated across energy forms. Emissions from a household furnace or small commercial burner will have different dispersion characteristics and therefore different exposure patterns than emissions from a utility boiler with a high stack. This detail is also beyond the scope of the current paper. See ORNL/RFF (1994). Also, we do not take into account the effect that SO_2 allowance trading beginning in 1995 will have on the proper measure of externality. (Burtraw, *et al.*, (1995); Dodds and Lesser (1994); Freeman, *et al.*, (1992); Hobbs, (1992).)

Table 1. Characteristics of Service Territories

	Southern	**Mid-Atlantic**	**No. New England**
Key Region	Tennessee	Mid Atlantic Area Council (MAAC)	ME, NH, VT
Key Utilities in Region	TVA	MAAC	ME Public Service, Bangor Hydro, Central ME Power
Average Price (cents/kWh in 1991)			
residential	5.61[a]	6.9	10.46
comm/industrial	5.35[a]	6.5	7.54
Reference Technology[b,c]	Coal with flue gas desulfurization	Natural Gas Combined Cycle	Natural Gas Combined Cycle.
Marginal Cost[d] (cents/kWh in 1991)	4.93	5.15	11.37
Residential Elasticities			
Own (Est.)		(winter) (summer)	
Own (Alt.)[g]	-2.24[e]	-0.48 -0.40[f]	-0.47
Cross (Est.)	0.4		
gas[h]			
oil	-0.66	<0.6[i]	
wood	1.89		0.13[j]
			0.13[j]
Comm/Industrial Elasticities		(winter) (summer)	
Own (Est.)[k]	-1.37	-0.19 -0.25[f]	-1.54
Own (Alt.)[g]	0.6		
Cross (Est.)			
gas[h]	0.12	<0.6[i]	2.03[j]
oil	0.06		2.03[j]
coal	0.15		
wood			2.03[j]

Notes for Table 1:

a. Based on 1991 data from Tables 40 and 46 of Energy Information Agency (1993b).

b. *Technical Assessment Guide* (EPRI 1989) for cost and operating characteristics.

c. Fuel cost from U.S. EIA (1993a).

d. Marginal cost estimates include line losses. Marginal cost for new NGCC based on Central Maine Power's most recent estimate.

e. Calculated from Jorgenson, Slesnick and Stoker (1988), combined with information on energy expenditure shares for households in Tennessee in 1989. Fuel consumption based on EIA (1992), *The State Price and Expenditure Report* (1990), and the U.S. Household Consumer Expenditures Survey from the Bureau of Labor Statistics (Branch, 1993). We combine these data with appropriate price coefficients from the Jorgenson, *et al.* model to calculate Allen net own and cross-price elasticities of demand for each type of energy. [These estimated expenditure shares are based on actual data and are not the expenditure shares that the model might predict for the typical Tennessee household.] Elasticity estimates are long-run, reflecting an assumption that capital stocks optimally adjust to prevailing energy prices.

f. Palmer, *et al.* (1995).

g. Alternative estimates are from Bohi and Zimmerman (1984).

h. We treat natural gas like an unregulated energy source even though retail supply of natural gas by local distribution companies (LDCs) is regulated by state PUCs, because LDC planning decisions are not generally subject to social costing.

i. Based on simulations of a gas demand model developed by an LDC in this region.

j. The cross-price elasticity is calculated using own price elasticities holding total energy demand constant. this is applied to each category of substitute fuels. Natural gas has limited residential penetration in Maine so it is excluded.

k. We obtain commercial and industrial own and cross-price elasticities from a tiered model of industrial input demands for 35 sectors (Jorgenson and Wilcoxen, 1990). This structure assumes demand for energy inputs is weakly separable from demand for nonenergy inputs. The first tier of inputs include capital, labor, materials and energy. Within the energy tier, the model breaks out demand for coal, crude petroleum, refined petroleum, electricity and natural gas.

We use net Allen elasticities which means total output of each energy-consuming sector is held fixed, but consumption of total energy is allowed to adjust in response to a change in the price of electricity. Due to a lack of disaggregate rate data, industrial and commercial customers are lumped together. However, own and cross-price elasticities of demand are defined separately for each of the 35 sectors. Energy consumption data is based on sources including the Manufacturing Energy Consumption Survey (US EIA, 1991), the 1987 Census of Mineral Industries (US Dept. of Commerce, Bureau of Census, 1990) and the 1987 and 1982 input-output tables from the Bureau of Economic Analysis. For those sources which provided only national data, we combined this data with national gross product data by industry to calculate energy input shares by energy types for each industry. We then applied these national shares to state level gross product data to estimate state level energy consumption and expenditures by energy type for each of the 35 industry sectors.

Table 2. Damage Values Used in Empirical Exercise

Pollutant	Damage Value ($/lb.)
NO_X	0.82
TSP	1.19
SO_2	2.03

Table 3. Emission Factors by Fuel Type and Customer Class (Pounds per million BTUs combusted)

	TSP	NOx	SO_2
Industrial*			
Natural Gas Combustion	0.0091	0.13579	0.0006
Bituminous Coal Combustion	0.06155	0.60961	0.93494
Fuel Oil Combustion	0.02622	0.14421	0.02048
Wood Combustion	0.0545	0.2500	0.0750
Residential			
Natural Gas Combustion	0.0091	0.095	0.0006
Fuel Oil Combustion	0.03277	0.12979	0.02048
Wood Combustion	3.4275	0.1924	0.0385

*The emission rates for commercial customers are identical to industrial rates except for those associated with natural gas combustion which are identical to residential emission rates.

Sources are as follows: The industrial and residential values for emissions from natural gas combustion are identical with the exception of oxides of nitrogen . These emission factors come primarily from the prepared testimony of Emily J. Caverhill with the industrial NOx values supported by AP-42. The emission factors for coal combustion assume that industrial users are using coal to generate electricity and emission factors are based on EPRI TAG information for a new pulverized coal plant with wet flue gas desulfurization to achieve 90% sulfur removal and a coal with 2% sulfur by weight. For fuel oil, all industrial emissions factors assume industrial boilers (gross heat rate = 10×10^6 to 10×10^7 Btu's/hour) and a medium sulfur fuel (2% sulfur by weight). Residential emissions factors for oil assume residential boilers (gross heat rate = $<.5 \times 10^6$ Btu's/hour) and distillate oil. Emission factors for industrial wood use are based on a fluidized bed boiler technology as reported in AP-42. Residential wood emission factors assume a non-catalytic wood stove with some emission reduction features.

Emissions factors are listed in **Table 3**. Most of these emission factors were taken from the *Compilation of Air Pollutant Emission Factors* (US EPA, Office of Air and Radiation, 1985), commonly referred to as the AP-42.

4. EMPIRICAL APPLICATIONS

Using equation 4 we estimated adjustment factors for the three service territories listed above. Our best estimates for the adjustment factor are presented in **Table 4**. For each we consider two classes of customers. A "neutral" estimate of the adjustment factor would have a value of one, implying the optimal adder is equivalent to the estimate of externality. Table 4 indicates the estimates vary considerably around this value.

Table 4. Best Estimates of Adjustment Factors for Three Service Territories by Customer Class

	Residential	**Comm./Industrial**
Southern Utility	1.152	1.129
Mid-Atlantic Utility	0.886	0.965
Northern New England Utility	1.024	1.791

In the Southern reference environment adjustment factors are greater than one indicating that the optimal adder would exceed the value of its externality estimate. In this example the price of electricity exceeds the marginal cost of delivered electricity generated with the reference technology, making the numerator of the adjustment factor less than one. The denominator is affected by the externalities associated with alternative generation sources, and the use of substitute energy technologies has fewer externalities than those associated with generating electricity using the reference technology. Hence, the denominator is also less than one, causing the adjustment factor to be greater than one. This amplifies the consideration of externalities in the planning process, making "dirtier" generating technologies even less appealing, and relatively "cleaner" and higher cost technologies more appealing. Adoption of cleaner technologies would ultimately lead to a higher price of electricity, exasperating the difference between price and marginal cost which has a negative effect on social welfare. However, in this example the direct impact on welfare of increasing the difference between price and marginal cost is offset by the environmentally beneficial switch to nonutility sources of energy services.

In the Mid-Atlantic service territory we calculate an adjustment factor that is less than one. The externalities associated with the utility's own resource option and the consumer's substitute possibilities are approximately equal. Hence, the adjustment factor primarily reflects the fact that the price of electricity exceeds the marginal cost of generation with the reference technology. Social welfare is increased by minimizing the effect of technology choice on the price-marginal cost difference.

Two factors distinguish the hypothetical Northern New England Utility from the other two case studies. One is that it has a much higher price of electricity and an even higher long-run marginal cost of future generation, due primarily to higher costs of access to natural gas. Second is that the substitute fuel options tend to have greater emissions than those generally preferred by or available to customers of the previous two utilities. In particular, customers of the Northern New England utility would be more apt to substitute wood for electricity than would customers of the other utilities.

The adjustment factors for the Northern New England Utility are greater than one despite the fact that the alternatives to electricity are relatively dirty. The choice of a cleaner technology by the utility will have a relatively greater effect on the price than would a relatively dirty technology. This will promote substitution to alternatives which are also dirty. However, in this example the price of electricity is less than the marginal cost, particularly for commercial and industrial customers, indicating that electricity is under-priced from the viewpoint of economic efficiency. Technology choices that are cleaner and presumably more expensive have the indirect benefit of increasing price and reducing the welfare loss stemming from inefficient pricing. In this example the net result is an adjustment factor that promotes the choice of cleaner technology.

These examples are not necessarily representative of what one would expect to find in other parts of the country nor do they reflect better information that may be available to utilities and regulators in the regions we studied. However, they do represent a variety of alternatives reflecting the types of adjustments to externality estimates that would be necessary to maximize social welfare from a second-best perspective.

5. SENSITIVITY ANALYSIS

In this section we explore the sensitivity of our estimates. We seek to identify the variables that have the greatest impact in calibrating the adjustment factors, the stability of adjustments overall, and places where more information would make the greatest contribution to improving estimates.

Table 5. Elasticity Estimates of the Adjustment Factors

	South Resid.	South Com/Ind	MidAtl. Resid.	MidAtl. Comm.	NNEng. Resid.	NNEng. Com/Ind
Adjustment Factor	1.152	1.129	0.886	0.965	1.024	1.791
Price (ε^{p})	-3.281	-1.678	-0.416	-0.161	-0.475	-1.312
Marginal cost (ε^{mc})	0.630	1.415	0.408	0.157	0.491	1.303
Own externality (ε^{E})	0.579	0.297	0.010	0.004	0.007	0.031
Elas of demand ($\varepsilon^{\varepsilon}$)	0.207	-0.089	-0.128	0.034	0.046	0.469
Unreg externality (ε^{UE})	-0.001	-0.034	0.000	-0.000	-0.022	-0.021

First, given the estimates reported in Table 4 and associated input data, we calculated *elasticities of the adjustment factors* with respect to each input parameter. The elasticities represent the percentage change in the adjustment factor with respect to a percentage change in the input parameter. These estimates are reported in **Table 5**, where we also repeat the best estimates of the adjustment factors for convenience.

The elasticities in Table 5 indicate that the most important determinants of the magnitude of the adjustment factor are price (ε^{p}) and marginal cost (ε^{mc}) of the utility supplied electricity, and by implication the relationship between price and marginal cost. In contrast, the elasticity of the adjustment factor with respect to changes in the pollution externality (measured in $/kWh) from the utility's technology (ε^{E}) appears to be of lesser importance. Also relatively unimportant is the elasticity of the adjustment factor with respect to the own-price elasticity of demand for electricity ($\varepsilon^{\varepsilon}$) and the weighted sum of the percentage change in the externality from substitute sources (ε^{UE}).[11]

The elasticity estimates in Table 5 are encouraging because one can expect the PUC to have the most reliable information about the input parameters that appear to be most important in the model. One would expect information about price and marginal cost to be relatively reliable; in contrast, information about externalities or the quantity of consumption from substitute sources (captured in the ε^{UE} term) may be less reliable.

Although the elasticities capture relative sensitivity in the proximate neighborhood of our specific point estimates, they may be misleading if input parameters vary a great deal from those used in the model. To explore this issue, we calculated adjustment factors for a number of wide ranging sets of values.

Table 6 reports results when we vary marginal cost and own price elasticity estimates for the Southern utility. Our best estimate of the adjustment factors are in the shaded cells. Since the own price elasticity estimates we calculate are high we recalculated the adjustment factors using alternative values found in the literature (Bohi and Zimmerman, 1984). In this example, the adjustment factors tend to increase with the marginal cost of electricity and with the absolute value of the own price elasticity of demand for electricity. Furthermore, we observe that when own price elasticity for electricity demand is high, changes in the marginal cost of electricity have a greater impact on the adjustment factor. When own price elasticity is

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[11] The elasticity with respect to changes in the pollution externality from substitute sources is difficult to capture in a relevant comparison to the other input parameters because there exist multiple sources which are part of a weighted sum within the denominator of the adjustment factor in equation 4. The weighted sum represents the percentage change in the externality from substitute sources when there is a change in the price of electricity. Hence we focus on the elasticity with respect to changes in the weighted sum, which is reported as (ε^{UE}) in Table 5.

low, differences in marginal cost have less of an impact. This pattern also emerges from similar experiments in the other two reference environments.

Table 6. Sensitivity Analysis of Adjustment Factors for the Southern Utility

	MC = 4.93 cents	MC = 5.53 cents
Residential		
own price elasticity (ε^p) = -2.24	1.152	1.531
own price elasticity (ε^p)= -0.4	1.018	1.064
Commercial/Industrial		
own price elasticity (ε^p)= -1.37	1.129	1.323
own price elasticity (ε^p)= -0.6	1.032	1.105

The example for the Northern New England utility is characterized by particularly dirty opportunities for substitute energy sources for the residential sector (wood) as well as relatively clean potential sources for the commercial/industrial sector (gas). To investigate the impact of the externalities associated with substitute energy on the magnitude of the adjustment factor, we calculated adjustment factors without the possibility of substitution. The results of such an experiment are reported in **Table 7** for the Northern New England utility in the row labeled $(\varepsilon^{uk,pk} = 0)$. By comparing these estimates with our best estimate, we see that consideration of emissions from substitute technologies reduces the size of the adjustment factor, and the reduction is greater for residential customers who have relatively dirtier substitute options than commercial customers. However, in both cases the extent of the decrease is small in absolute terms, never exceeding .10 in value.

Table 7. Sensitivity of Adjustment Factors for the Northern New England Utility with no substitutes and with five times damage estimates

	Residential	**Commercial/Ind.**
Best estimate	1.025	1.791
Assuming no substitutes $\left(\varepsilon^{uk,pk} = 0\right)$	1.074	1.838
Five times damage estimates **(5x)**	0.963	1.827

The size of the impact of including marginal damages from fuel switching in the calculation of the adjustment factor will depend on the number of external impacts included and the size of the externalities associated with these impacts. To reflect the possibility of significantly larger damage estimates than we have characterized, as might result from carbon dioxide emissions, we calculated the adjustment factors using damage estimates that were five times the level of the Ottinger, *et al.,* estimates reported in Table 2. The new results appear in the third row of Table 7. When externalities are five times the levels assumed originally, the impact of including substitutes in the calculation is much greater. The value of the adjustment factor falls below one for the residential sector, mitigating the externality penalty imposed on utility generation to avoid substitution to even more polluting sources. Hence, in this case the potential increase in externalities associated with substitutes outweighs the inefficient pricing effect.

In summary, distinctions between price and marginal cost (of the utility's reference technology) seem to be the most important in calibrating the adjustment factor. Their importance is amplified when consumers are more sensitive to changes in the price of electricity, i.e., when own price elasticity is high. If price is *less* than marginal cost, the adjustment factor generally will be greater than one, which amplifies the penalty on dirty generation. The higher price of electricity that would result closes the gap with marginal cost yielding a positive effect on social welfare. This tends to be true even when the damage from substitute sources is less than from utility's own generation. If price is *greater* than marginal cost, the adjustment factor tends to be less than one which diminishes the penalty on dirty generation, in order to avoid the price affect which indirectly harms social welfare. This is true unless the damage from substitute sources is significantly smaller than from utility generation.

6. CONCLUSION

Practitioners of social costing should be cognizant of two potential unintended consequences that affect the attainment of economic efficiency—the possibility for customers to substitute away from regulated supplies of electricity and the effect that social costing has on the relationship between electricity price and marginal cost. We find that the relationship between the optimal value of adders for generation technologies and estimates of externalities depends on characteristics of the particular service territory in which social costing is conducted. In general, setting adders equal to externality estimates will fail to achieve economic efficiency from the perspective of second-best policy making. The relative difference between optimal adders and the externality estimates may easily differ by 10-20% or more in the case studies we examined.

Hence, the rule of thumb suggested by Freeman, *et al.*, (1992), setting adders equal to externality estimates, fails to optimize social welfare in general. It performs best, and equivalently, the adjustment factor that we estimate is close to one, when own-price and cross-price elasticity estimates are small in absolute value, when price is proximate to marginal cost, and when the reference technology and substitute technologies have similar externality estimates. However, when price is greater than marginal cost, *ceteris paribus,* the adjustment factor is less than one reflecting the cost of choosing relatively expensive new technologies that exacerbate the price-marginal cost difference. When price is less than marginal cost, the adjustment factor will be greater than one reflecting the implicit benefit of raising prices to reflect social opportunity costs.

The adjustment factor also depends on the relationship between externality estimates for the reference and substitute technologies. For instance, if price equals marginal cost and if the substitute technology is relatively dirty with large associated externalities, the adjustment factor will tend to be less than one reflecting the social cost of promoting cleaner, but typically more expensive, technology in electricity generation. If price equals marginal cost and the technologies have similar externalities, the elasticities have little influence and the adjustment factor will equal one. However, in general, if either of these conditions does not hold, large elasticities will amplify the implied deviation of the adjustment factor from one.

In the case studies we examined we find that the difference between price and marginal cost appears to be the driving influence in determining the magnitude of the adjustment factor, and hence the relationship between the optimal adders and externality estimates.[12] This issue stems from the seminal work by Buchanan (1969) which suggested that in the imposition of a Pigouvian *tax* on a monopolist, as opposed to an adder, could reduce social welfare. It is noteworthy that the results we obtain in the context of social costing in a regulated industry differ somewhat from those obtained by Oates and Strassmann (1984) who use numerical

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[12] However, if externalities are very large then the relative magnitude of externalities associated with substitute sources of energy services could become a driving factor in the calculation of the adjustment factor.

methods to suggest that it may be reasonable to ignore market structure issues, and in particular the distinction between price and marginal cost, when setting effluent fees.

The ongoing potential restructuring in the electricity industry toward greater competition is likely to lead to a convergence of price and marginal cost of electricity. This would seem to lessen the need for an adjustment to externality values. However, restructuring is also likely to enhance the menu of options available to consumers, and to result in greater own and cross-price elasticities. In this case sensitivity of the optimal adjustment factor to environmental externality would be heightened. Coupled with the possibility of global warming which could impart large estimates of externality, the adjustment factor could remain significantly different from one even in a restructured electricity industry.

In conclusion, if regulatory agencies decide to invest in substantial research efforts to estimate the externalities associated with electricity generation, a concomitant investment to address the questions outlined in this paper would appear to have large benefits at a relatively low cost.

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