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Abstract

We look at the effects of restructuring on three issues: (a) economic surplus and environmental quality, (b) the cost of NO_x control policies and who bears the costs, and (c) the cost-effectiveness of a seasonal and an annual NO_x cap in the SIP Call region. We find that without the NO_x cap, nationwide restructuring leads to higher NO_x and carbon emissions from the electricity sector. Adding either a seasonal or an annual NO_x cap-and-trade regime in the eastern United States mitigates the increase in NO_x emissions but has a much smaller effect on carbon emissions. The out-of-pocket compliance cost associated with achieving a seasonal or an annual NO_x cap is moderately higher with nationwide restructuring than without, but the changes in economic surplus are significantly higher. However, the economic benefits of nationwide restructuring more than offset the higher costs of controlling NO_x emissions in a more competitive environment. The foregone economic surplus is compared with the benefits resulting from NO_x emission reductions using an integrated assessment model of atmospheric transport and valuation of human health effects. We find an annual policy dominates a seasonal policy from a cost effectiveness perspective under limited restructuring, and even more strongly under nationwide restructuring.

Key Words: electricity; restructuring; deregulation; competition; emissions trading; particulates; nitrogen oxides; NO_x; health benefits; cost effectiveness

JEL Classification Numbers: Q2, Q4

Contents

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1. Introduction

The electric power sector is in the midst of two major regulatory changes. One is a change in the scope of economic regulation facing the industry. Historically, all of the functions of the industry—generation, transmission, distribution, and retail sales—typically have been integrated in a single firm that was subject to price regulation, generally based on costs. In recent years, however, generation and retail sales have increasingly been opened up to competition in several states. This process of opening the markets to competition, generally referred to as "electricity restructuring," is ongoing at the state level, and numerous legislative proposals that have been introduced in the U.S. Congress would expand these efforts nationwide.

The second important change facing the industry is the apparently increasing scope and stringency of environmental regulation. Historically, the most stringent environmental standards facing electricity generators have been those imposed on new sources, known as new source performance standards (NSPSs). Beginning with the Clean Air Act Amendments of 1990, existing generators also have faced increasingly stringent regulation of their sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions. Restrictions on summer emissions of NO_x from electricity generators in a majority of eastern states are expected to become even tighter during the next decade with the implementation of the call for amendments to state implementation plans (SIPs) from the U.S. Environmental Protection Agency (EPA), known as the NO_x SIP Call. This new regulation is designed to address the long-range transport of NO_x as a contributing factor to summer air pollution in cities on the East Coast. Recent lawsuits filed by EPA and New York State also have raised the possibility that many existing generating sources were negligent in not bringing their facilities into compliance with NSPSs when they made substantial investments enabling greater electricity generation at these facilities. The EPA also is committed to promulgating a final rule to control mercury from fossil-fired electric power plants by 2004.

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Moreover, concern about global warming and the search for ways to comply with the greenhouse gas reductions called for in the Kyoto Protocol have led to many proposals for capping or reducing carbon emissions from the electricity sector.

In this paper, we analyze how greater competition in the electricity sector is likely to affect environmental quality and the costs of reducing NO_x emissions. The analysis has three dimensions. First, under a given set of NO_x regulations, we ask how allowing greater competition in electricity markets will affect the location and quantity of NO_x emissions and total carbon dioxide (CO_2) emissions from the electricity sector. In the case of NO_x, we further analyze the effects of these changes in emissions on health status and associated economic damages. Second, we seek to determine how allowing competition affects the costs of different NO_x policies as well as who (electricity producers and which customer class of consumers) bears these costs. Third, we look at the cost effectiveness of different approaches to regulating NO_x emissions. We use an integrated assessment model of atmospheric transport and valuation of human health effects to estimate net benefits of the different approaches.

We find that restructuring leads to economic surplus gains for both producers and consumers, and industrial consumers claim the largest share of the additional consumer surplus gains from restructuring. However, without the NO_x SIP Call, nationwide restructuring leads to higher NO_x and carbon emissions from the electricity sector. Adding either a seasonal or an annual NO_x cap-and-trade regime in the eastern United States mitigates the increase in NO_x emissions, but has a negligible effect on carbon emissions, which remain above the level under limited restructuring. The health benefits associated with a seasonal or an annual NO_x policy are greater under nationwide restructuring than under limited restructuring, compared to the each restructuring scenario in the absence of a NO_x policy in the SIP region.

On the cost side, the out-of-pocket compliance costs associated with achieving either a seasonal or an annual NO_x cap are higher with nationwide restructuring than without. Society's economic surplus losses associated with the NO_x caps are less than compliance costs under limited restructuring. This difference is due in large part to the inefficient pricing of electricity, which causes reductions in electricity consumption to be valued less than marginal generation cost under limited restructuring. Under nationwide restructuring electricity is priced efficiently and the economic surplus losses resulting from the NO_x caps are significantly larger. Under limited restructuring the consumers are better off (i.e., consumer surplus increases) and producers are worse off because of the NO_x policies. However, this sharing of burden of the NO_x policies between consumers and producers is mostly reversed under nationwide structuring. The incremental change in consumer surplus is negative when the NO_x policies are added under nationwide restructuring, while producers are almost unaffected.

We evaluate the cost-effectiveness of seasonal versus annual programs by comparing changes in economic surplus in the electricity sector with health benefits. Under limited restructuring, we find significant additional net benefits (benefits minus costs) would be achieved by substituting an annual program for a seasonal program. Under nationwide restructuring an annual program would yield almost $620 million in additional net benefits, compared to a seasonal program. The benefit-cost ratio is less than one in each case (net benefits are negative) but the inclusion of non-health and non-particulate related benefits would be likely to make the benefit-cost ratio greater than one, especially under an annual policy. However, we examine only particulate-related health benefits and the inclusion of non-health particulate-related benefits would boost the relative performance of an annual program.

2. Motivation

The U.S. electric power industry has been in the process of restructuring for nearly 10 years. Electricity restructuring was set into motion with the passage of the Energy Policy Act of 1992. The act called on the Federal Energy Regulatory Commission (FERC) to order all transmission-owning utilities to allow open access to their transmission systems at nondiscriminatory, cost-based transmission rates to facilitate competitive wholesale power transactions.[1] Most of the deregulatory activity directed at retail markets has been at the state level. Between 1992 and the end of 2000, about half of the states in the country passed legislation or made regulatory decisions to allow retail competition.[2] During the 105th and 106th Congress, several bills were introduced to implement retail competition nationwide, but none made it to the floor of the House of Representatives or the Senate.

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[1] FERC implemented this requirement by issuing Order 888 in 1996. Over time, FERC recognized that Order 888 was only a limited success, in part because utilities that owned both generation and transmission facilities had little incentive to really open up their transmission grids for use by their competitors in generation markets. In 1999, FERC issued Order 2000 in an effort to break the link between generation and transmission activities. Order 2000 provides specific guidelines and incentives for the establishment of independent regional transmission organizations to manage use of the transmission grid.

[2] Ando and Palmer (1998), White (1996), and Hunt and Sepetys (1997) analyze the factors that influence state decisions about the direction and pace of restructuring. The status of state deregulatory activities is tracked by the Energy Information Administration (U.S. EIA 2000).

One important unanswered question throughout the debate about electricity restructuring at both wholesale and retail market levels is how the move from regulation to competition will affect the environment.[3] During the debate over FERC orders to open access to transmission systems, environmentalists and others raised concerns that allowing more open access to transmission would lead to the increased use of older, higher-polluting coal-fired facilities in the Midwest and related increases in emissions. As different states debated whether to allow retail competition, environmentalists became concerned about the potential demise of utility programs that promoted demand-side management and the use of renewable energy sources as well as the associated consequences for utility emissions and the environment. In addition, if restructuring delivered the promised lower prices for electricity, then increased levels of electricity demand could also yield higher emissions.

A limited body of earlier research offers a range of perspectives on these questions, but the compendium of evidence is far from conclusive, partly because of the many assumptions that underlie the various scenarios. Several of these studies, including those by Lee and Darani (1996), the Center for Clean Air Policy (1996a, 1996b, 1996c), and Rosen and others (1995), find potentially large effects of increased interregional power trading on utility emissions of NO_x and CO_2. In two analyses of the proposed environmental impacts of its two transmission orders, FERC (1996b, 1999) finds a much more limited effect of increased power trading on air emissions. EIA (1996) also finds that open transmission access increases NO_x emissions by between 1% and 3% above the baseline scenario, with the largest effects happening in the early years.

Palmer and Burtraw (1997) look at the potential impacts of electricity restructuring on NO_x and CO_2 emissions and on subsequent changes in atmospheric NO_x and nitrate concentrations at the regional level and also consider the ultimate effect on human health. Their results concerning emissions effects fall roughly in the middle of the estimates from the prior literature. Burtraw, Palmer, and Paul (1999) find substantially smaller impacts of electricity restructuring on NO_x and CO_2 emissions in the near term, with NO_x emissions increases of 4% or less relative to the baseline and annual carbon emission increases of just under 2% in the absence of any policy to promote renewable energy sources. U.S. DOE (1999) looks at the emissions effects of the Clinton administration's Comprehensive Electricity Competition Act of 1999 and

[3] For a discussion of the many different ways by which electricity restructuring could have an effect on the environment see Palmer (1997), Palmer (2001), and Burtraw, Palmer, and Heintzelman (2000).

demonstrates that the act, with its provisions to promote greater use of renewables and distributed generation, will lead to a reduction in NO_x and carbon emissions compared with an average cost baseline.

Most of the prior analyses of the effect of restructuring on emissions ignored the effect of EPA's 1998 NO_x SIP Call on summer NO_x emissions from electricity generators in the eastern United States.[4] EPA's NO_x SIP Call is designed to address problems of long-range transport of ozone in this region. It includes a regional cap-and-trade program for summertime NO_x emissions in the SIP Call region, which, as recently reconstituted by the courts, includes 19 states and the District of Columbia.[5] The five-month summer emissions cap under this program is based on an average NO_x emission rate of about 0.15 pound per million Btu's of heat input at fossil fuel–fired boilers. The program would lead to annual reductions in NO_x emissions of 22% by 2007 and summertime reductions of 40% in the same year (U.S. EPA 1998a.). In the SIP Call region, the program would reduce NO_x emissions by 40% annually in 2007 and by 62% in the summers (U.S. EPA 1998b, Table 2-1).[6] By imposing summertime caps on NO_x emissions that apply to both new and existing generating facilities, this program eliminates the possibility of increasing aggregate summertime NO_x emissions in the SIP Call region as a result of restructuring.

Nonetheless, NO_x emissions during other seasons and in other regions could rise as a result of increased power trading or increased generation to meet higher levels of demand brought about by anticipated lower prices under competition. These additional NO_x emissions could contribute to higher concentrations of ground-level ozone. Moreover, additional NO_x emissions could contribute to higher concentrations of particulate matter, which has been firmly associated with human health morbidity and mortality effects; particulate matter also is considered by many economists and health scientists to pose a more serious threat to human health than ozone concentrations. In addition, NO_x emissions cause the deposition of nitrates, which contribute to environmental problems such as the acidification of some ecosystems.

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[4] Palmer and others (1998) and Burtraw, Palmer, and Paul (1999) include an annual cap on NO_x emissions in the SIP region. U.S. DOE (1999) includes the five-month summer cap applied to the original 22-state NO_x SIP Call region.

[5] For more information about the recent history of the regulation of NO_x emissions from the electric power sector, see Burtraw and others (2000).

[6] The percent reductions pertain to EPA's original program that targeted 22 states and the District of Columbia. The EPA baseline includes only Phase I controls in the OTR.

If NO_x emissions from electricity generators were subject to an annual cap, then restructuring would have no effect on aggregate NO_x emissions.[7] Environmentalists have proposed expanding the NO_x SIP Call to an annual program (Environmental Defense 2000). Burtraw and others (2000) analyze the cost-effectiveness of different NO_x policies, including a SIP seasonal and a SIP annual policy. They find that an annual NO_x emissions cap in the SIP Call region yields nearly $400 million more in annual net benefits in 2008 than those realized with a seasonal policy. In their analysis, they assume that no states move to implement electricity restructuring beyond those that had made a decision as of 2000. Thus, they do not consider how additional changes in economic regulation facing the industry might affect the cost-effectiveness of different NO_x control polices. Also, they measure net benefits as the difference between particulate related health benefits and compliance costs. They do not consider economic surplus in the electricity market.

In this paper, we consider the effects of restructuring on (a) economic surplus and environmental quality, (b) the cost of NO_x control policies and who bears the costs, and (c) the cost-effectiveness of a seasonal and an annual NO_x cap in the SIP Call region. We anticipate that restructuring might affect the cost and cost-effectiveness of a NO_x emissions cap-and-trade program in several ways.

First, more widespread adoption of marginal cost pricing is expected to lead to accelerated productivity gains in the electricity generation sector nationwide. In our model, these productivity enhancements take several forms including lower heat rates, higher generating unit availability and lower costs of production at existing generators. The cost savings associated with these improvements may offset some of the costs of greater NO_x controls, or introduce additional flexibility in compliance due to greater flexibility in the operation of generators. Alternatively, efficiency improvements at existing coal plants that have relatively high emission rates could raise the opportunity costs of substituting away from using these plants toward lower polluting plants. This change could be perceived to raise the costs of reducing NO_x emissions.

Second, the consumption of electricity during peak periods is consistently above its economically efficient level because electricity is priced below its marginal cost. This is true for all customers in those regions where restructuring has not taken place and electricity is priced at

[7] The location of NO_x emissions could be affected by restructuring, and environmental damages could be associated with those shifts in location.

average cost, and to a lesser degree in competitive regions for residential and commercial customers who face a uniform electricity price that does not vary by time-of-day (although it is tied to marginal rather than average costs). In other words, the opportunity cost to consumers, or equivalently the marginal consumer surplus, is less than marginal cost of production.[8] Consequently, the imposition of an environmental policy that raises cost may have a smaller effect on consumer surplus than is the measure of the compliance cost of the policy.[9] The converse is true in baseload periods, when electricity price is consistently greater than marginal cost. However, where the inefficient pricing problem is eliminated with time-of-day marginal-cost pricing of electricity, the economic costs of the NO_x control policy is guaranteed to be greater in magnitude than the compliance costs due to the loss in consumer surplus associated with reduced consumption.

Third, nationwide adoption of retail competition could generate greater inter-regional trading of electricity, particularly if widespread restructuring leads to expansion of inter-regional transmission capability as assumed in the scenarios modeled here. With greater transmission capacity, electricity generation could migrate out of the SIP Call region helping to reduce NO_x emissions in the region and potentially lower the costs of achieving the NO_x emission caps, but increasing emissions in the West.

Finally, restructuring may have an effect on the distribution of NO_x control costs born by producers and by consumers. Tradable NO_x emission allowances have an opportunity cost equal to the marginal cost of NO_x emission reductions. We assume allowances are allocated to firms at zero cost – so-called “grandfathering” - as currently intended by most states planning to participate in the NO_x trading program and as characterized the SO_2 trading program implemented under the 1990 Clean Air Act Amendments. In average cost regions, emission allowances are reflected in the calculation of total costs according to their original cost when acquired by the firm. Because the original allocation was at zero cost, only the costs of allowances acquired in excess of the original allocation are considered to be part of the total

[8] Brennan (1998) discusses this inefficiency in taxing electricity to fund utility DSM programs. He also points out that the inefficiencies associated with pricing electricity transmission and distribution, the two industry segments with declining average costs, at average cost without congestion pricing work in the other direction. However, since the cost of generation constitutes more than 60% of the total cost of electricity, we conjecture that the inefficiency with respect to generation pricing outweighs the inefficiency with respect to pricing of T&D.

[9] In a similar context, Oates and Strassman (1984) demonstrate that monopoly pricing of a polluting good limits consumption, and thereby reduces the size of the environmental externality associated with its production.

costs to be recovered in the price of electricity. However, in marginal-cost regions, the opportunity cost of NO_x emissions allowances is reflected in the electricity price in a manner analogous to other variable costs of generation, such as fuel costs. In this case, NO_x emissions allowances are reflected in marginal costs to the extent that the marginal generating unit at any particular instant requires NO_x emissions allowances to generate. When the marginal generating unit is coal-fired, the cost of NO_x emissions allowances is fully reflected in the price of electricity paid by consumers. When the marginal generating unit is gas-fired, the cost of NO_x emissions allowances will play a smaller role in the price of electricity because gas-fired units typically have lower emissions per unit of generation, and producers will bear more of the cost of the NO_x policy.

3. Scenarios

The scenarios constructed for this analysis reflect a combination of assumptions about how many regions have implemented marginal-cost pricing of electricity and about the environmental regulatory regime governing NO_x emissions from the electricity sector. In the next two sections, we describe the economic regulatory scenarios and the NO_x policy scenarios in turn. In each of the scenarios, we assume that no policies are implemented to reduce CO_2 emissions and that no changes are made in the regulation of SO_2 emissions beyond those established under the 1990 Clean Air Act Amendments.

3.1 Economic Regulatory Scenarios

Analyzing the effects of nationwide restructuring on environmental quality and emissions control costs requires a baseline scenario with which the more comprehensive restructuring scenario can be compared. Because several regions have already restructured their electricity markets, it would be unrealistic for this baseline to assume average-cost pricing of electricity, as applied under cost-of-service regulation, in all regions. Instead, we construct a *limited restructuring* scenario by assuming that marginal-cost pricing of electricity is implemented in those regions and subregions of the North American Electric Reliability Council (NERC), where most of the population resides in states that have already made a commitment to implement restructuring. The schedule for transition from cost-of-service to marginal-cost or market-based pricing under the baseline scenario is reported in Table 1 by region. In the limited restructuring scenario, no other regions adopt marginal-cost pricing over the course of the forecast period, which extends to 2012. All other regions are assumed to price electricity at average cost.

The alternative economic regulatory scenario labeled *nationwide restructuring* assumes that restructuring is implemented across the country by 2008. As shown in the column of Table 1 labeled nationwide restructuring, three regions are assumed to implement restructuring in 2004 and the remaining five regions do so by 2008. Several features distinguish how prices are set in restructured regions. First, we assume that in all marginal cost regions, utilities recover 90% of their costs of assets that are "stranded" in the transition from cost of service to competitive pricing. Second, we assume that the use of time-varying prices of electricity will become more widespread as a result of restructuring. We represent this assumption by requiring industrial customers to face time-of-day pricing in any region that has implemented marginal cost pricing. In all other regions and for all other customer classes in all regions, the retail price is assumed not to vary between peak and off-peak times, but can vary across seasons.

The third way that prices differ between marginal and average cost regions is the pricing of ancillary reserve services. In all regions, scheduled outages and flexible (non run-of-river) hydro generation are allocated to minimize cost by season and time block (for hydro), then generation within a time block is dispatched according to variable cost. After energy demand is satisfied, remaining generation capability is ordered according to fixed cost (per MW) to construct a supply curve for reserve services. Reserve services are differentiated to the extent that steam generators are limited to provide only fifty percent of total reserves and the total reserve requirement in each region is based on total demand. The determination of price for reserve services differs between marginal and average cost regions. In marginal cost regions, an equilibrium marginal price for reserve services is determined through a simultaneous convergence in all regions and time blocks. We impose an incentive compatibility constraint requiring that, in addition to those units providing reserve services, generating units also receive the marginal reserve price. This constraint guarantees that units have no incentive to switch between generation and reserve services as long as each behaves atomistically (strategic market power has no role). In contrast, in average cost regions we take the fixed cost (per MW) of the marginal reserve unit and apportion it across all time blocks in which that unit provides generation or reserve services, and recover only a portion in the time block in which the unit is marginal. These two approaches yield quite comparable marginal reserve "prices" reflecting the marginal scarcity value of reserve services for a given level of generation capacity and electricity demand.

In addition to the method of pricing electricity there are several parameters in the model that take on different values in the nationwide restructuring scenario than in the limited restructuring scenario (Table 2). They fall into three categories: productivity change, transmission capability and renewables policy. Productivity change is implemented in the model through changes in four parameters: improvements in the maximum capacity factor at existing generators, reductions in the heat rate at existing coal-fired generators, reductions in operating costs and reductions in general and administrative costs at all existing generators. The rate of change in these four parameters is a function of the proportion of the country that has committed to marginal cost pricing. A single value applies to the entire country, reflecting the common availability of technology and the common investment climate shared by firms in different regions, as well as the expectation that marginal cost pricing and competition could spread to all regions in the future. As the number of regions committing to marginal cost pricing grows, the rate of improvement in these four parameters grows.[10] Table 2 is a summary of the ratios of the values in 2008 to the values in 1997 (the year of our data) for each of these variables under the two economic restructuring scenarios.

Two of the key uncertainties surrounding the future of the U.S. electricity system are how much the utilities that own transmission lines will choose to invest in expanding transmission capability and when these investments will take place. Regulators have been struggling to price electricity transmission in a way that provides economic signals of the costs created by congesting the transmission grid and, at the same time, provides incentives for transmission owning utilities to make investments that would reduce that congestion. With more open markets there will be greater pressure to trade electricity and, presumably that pressure will be translated into expanded transmission capability. We anticipate this outcome by making different assumptions regarding transmission capability in the two economic scenarios. In the limited restructuring scenario, we assume that inter-regional transmission capability does not grow over time. In the nationwide restructuring scenario, we assume that by 2008 transmission capability is 10% higher than it was in the limited restructuring scenario.

Many restructuring proposals also include provisions to promote the use of nonhydroelectric renewables-based technologies for electricity generation. The most popular provision of this type is the renewables portfolio standard (RPS). An RPS is a requirement that a certain percentage of the electricity sold to customers must be generated using a renewables-

[10] Specifically, the rate of change in the three productivity change parameters is a weighted sum. The sum is the proportion of megawatt hours sold in marginal cost pricing regions times an optimistic rate of change, plus the proportion of megawatt hours sold in average cost pricing regions times the historical rate of change (under average cost pricing) in each parameter. The weights are constructed using electricity sales data from 2000, prior to the implementation of restructuring in most states.

based technology. RPS proposals are part of the restructuring legislation in several states, including Connecticut, Maine, and Massachusetts. RPS requirements ranging from 3% to 7.5% have been included in different legislative proposals for federal restructuring. Most RPS proposals exclude hydroelectric facilities.[11] We assume that an RPS is implemented in 2008 in the nationwide restructuring case, which mirrors recent proposals by setting a goal for penetration of renewables while setting a cap on the subsidy that can be earned by renewables. The cap is set at $17 per megawatt-hour, slightly inflated from the $15 cap included in the Clinton administration proposal. In every example we describe, the subsidy cap is binding, yielding renewables-based electricity generation of less than 3.5% of total generation. The nonhydroelectric renewables-based technologies that qualify for the RPS in our model are wind, solar, dedicated biomass, municipal solid waste, and geothermal.[12]

3.2 NO_x Policy Scenarios

Each of the two economic regulatory policy scenarios described above is investigated in conjunction with each of three different sets of assumptions about NO_x policy. The *baseline NO_x* policy scenario includes the NO_x trading program (known as “Phase II”) in the northeastern Ozone Transport Region (OTR) but excludes new policies to reduce NO_x in the multi-state SIP Call region. The regions included in the OTR NO_x trading program are identified in Table 1.

The first alternative NO_x policy scenario is labeled *SIP Seasonal,* and it corresponds to EPA’s proposed program described previously as the NO_x SIP call. This scenario includes a five-month summer ozone program implemented in the eastern United States represented by the regions in our model that are approximately equal to the SIP Call region.[13] The included regions

[11] For a discussion of different RPS proposals, see Clemmer, Nogee, and Brower 1998.

[12] We assume that any electricity generated by co-firing a coal-fired generator with a minimal percentage of biomass fuel would not be allowed to be counted against an RPS.

[13] These regions include NE (New England); MAAC (Maryland, District of Columbia, Delaware, and New Jersey; most of Pennsylvania); New York; STV (Tennessee, Alabama, Georgia, South Carolina, and North Carolina; parts of Virginia, Mississippi, Kentucky, and Florida); ECAR (Michigan, Indiana, Ohio, and West Virginia; parts of Kentucky, Virginia, and Pennsylvania); and MAIN (most of Illinois and Wisconsin; part of Missouri). They exclude a small portion of western Missouri that is part of the 19 states and small parts of Illinois and Wisconsin. These regions include the eastern half of Mississippi, Vermont, New Hampshire, and Maine, which are not part of the region identified by EPA. However, the other New England states—Connecticut, Massachusetts, and Rhode Island—are part of the eastern region covered by the OTR. The reconciliation of these two programs may ultimately involve their participation.

are identified in the last column of Table 1. The emissions cap under this policy is 444,300 tons per five-month summer season within the SIP Call region, compared with an emissions level of 1.465 million tons in the baseline NO_x scenario in year 2008 under limited restructuring.[14]

The second alternative NO_x policy scenario is *SIP Annual*. Here, the average emissions rate achieved during the five-month summer season for the SIP Call region is extended to an annual basis. The annual emissions cap under this policy is 1.06 million tons per year within the SIP region, compared with an emissions level of 3.502 million tons in the baseline NO_x scenario in year 2008 under limited restructuring.

In both of the alternative NO_x policy scenarios we assume the policy is announced in 2001 and implemented in 2004. We report results for 2008, hoping thereby to avoid transitional difficulties in implementing the policy that may characterize the first years of the program (NERC 2000).

4. The Models

The Haiku electricity market model calculates equilibria in regional electricity markets with interregional electricity trade.[15] The model includes fully integrated algorithms for investment and retirement of generation capacity, selection of NO_x emissions control technology, and SO_2 compliance. It simulates demand, prices, supply composition, and the emissions of major pollutants (NO_x, SO_2, mercury, and CO_2). Generator dispatch is based on minimizing the short-run variable costs of generation.

Two important components of the Haiku model are the Intraregional Electricity Market Component and the Interregional Power Trading Component. The Intraregional Electricity Market Component solves for a market equilibrium identified by the intersection of price-sensitive electricity demand for three customer classes (residential, industrial, and commercial) and supply curves for four time periods (peak, shoulder, middle, and base load hours) in three

[14] This emission cap was determined by applying the emissions rate of 0.15 lb per MMBtu to fossil-fired generation in the baseline for 1997, which is the same methodology applied by EPA. Forecast electricity generation varies slightly in our model, and the geographic coverage varies slightly, from the EPA model (U.S. EPA 1998a, 1998b, 1999).

[15] The Haiku model was developed to contribute to integrated assessment with support from EPA, the U.S. Department of Energy, and Resources for the Future.

seasons (summer, winter, and spring-fall) within the 13 NERC regions and subregions.[16] Each regional supply curve is parameterized using cost estimates and capacity information for up to 45 aggregate "model plants" defined by technology, fuel, and vintage. The Interregional Power Trading Component solves for the level of interregional power trading necessary to achieve equilibrium in regional electricity prices (gross of transmission costs and power losses). These interregional transactions are constrained by the assumed level of available interregional transmission capability.

The model can be used to simulate changes in electricity markets that stem from public policy associated with increased competition or environmental regulation. In this analysis, we consider changes in both types of policies. We look at how electric market restructuring is likely to affect NO_x and CO_2 emissions and the costs of controlling NO_x policy.

Changes in emissions of relevant pollutants are fed into the Tracking and Analysis Framework (TAF). TAF is a nonproprietary and peer-reviewed model constructed with the *Analytica* modeling software (Bloyd and others 1996).[17] TAF integrates pollutant transport and deposition (including formation of secondary particulates but excluding ozone), visibility effects, effects on recreational lake fishing through changes in soil and aquatic chemistry, human health effects, and valuation of benefits.

In this exercise, only human health effects are evaluated. These values are calculated at the state level and aggregated to the NERC subregion level; changes outside the United States are not evaluated. Health effects are characterized as changes in health status predicted to result from changes in air pollution concentrations. Impacts are expressed as the number of days of acute morbidity effects of various types, the number of chronic disease cases, and the number of statistical lives lost to premature death. The health module is based on concentration–response functions found in the peer-reviewed literature,[18] primarily from articles reviewed in EPA's

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[16] The electricity demand functions include customer class specific elasticities of demand that vary by season. Electricity consumers pay a price based on the average marginal cost across different load blocks, but customers do not see prices that vary by time-of-day.

[17] Each TAF module was constructed and refined by experts in that field, and the integrated model draws primarily on peer-reviewed literature. TAF is the work of a team of over 30 modelers and scientists from institutions around the country. As the framework integrating these literatures, TAF itself was subject to an extensive peer review in December 1995, which concluded that "TAF represent(s) a major advancement in our ability to perform integrated assessments" and that the model was ready for use by NAPAP (ORNL 1995). The entire model is available at www.lumina.com\taflist.

[18] See Bloyd and others 1996 and http://www.lumina.com/taflist.

criteria documents (for example, EPA Section 812 prospective and retrospective studies). It contains concentration–response functions for particulate matter smaller than 10 microns in diameter (PM_{10}), total suspended particulates, SO_2, sulfates, nitrogen dioxide, and nitrates. In this exercise, the potency of nitrates for mortality effects is treated as distinct from the potency of sulfates. Sulfates are considered relatively more potent than other constituents of PM_{10}; and nitrates are treated as comparable to other components of PM_{10}.[19] For morbidity PM_{10} is modeled according to a scheme designed to avoid double counting of measures such as symptom days and restricted activity days, using a variety of studies from the literature.[20] NO_x is included for respiratory symptom days, eye irritation days, and phlegm days.

Inputs to the health effects module consist of changes in ambient concentrations of SO_2 and NO_x, demographic information on the population of interest, and miscellaneous additional information, such as background PM_{10} levels for analysis of thresholds, though no thresholds are presumed to exist in this exercise. The change in the annual number of impacts of each health endpoint is the valued output. The health valuation submodule of TAF assigns monetary values taken from the environmental economics literature to the health effects estimates produced by the health effects module. The benefits are totaled to obtain annual health benefits for each year modeled. The numbers used to value these effects are similar to those used in recent regulatory impact analysis by EPA. In particular, the value of a statistical life (VSL) is adjusted somewhat downward, compared with EPA numbers, because EPA numbers are drawn primarily from studies of prime-age working males facing small risks of workplace mortality. In contrast, particulate pollution primarily affects seniors and people with impaired health status, and it is also thought to affect young children than the general population.[21] Various authors suggest that the value of health effects should be responsive to the nature of the injury and issues like age and health status (Krupnick and others 2000). This controversy is discussed in EPA's recent studies.

[19] The PM_{10} mortality concentration-response function used in this analysis is drawn from Schwartz and Dockery (1992).

[20] For nitrates, which are modeled as PM_{10}, morbidity endpoints include asthma attacks, chronic bronchitis in adults and children, chronic cough, emergency room visits, restricted activity days, hospital admissions, and respiratory symptom days.

[21] The value of a statistical life used is $3.815 million (1997 dollars), about 25% less than that used in recent EPA studies.

5. Results

The results of this analysis are presented in four parts. We begin with a discussion of the effects of the different policies on NO_x and carbon emissions and the health benefits associated with reduced NO_x emissions. Next we present the changes in electricity markets associated with both restructuring and NO_x policies that underlie these environmental effects. Then we discuss the approaches used by generators to comply with the NO_x policies and how they are likely to change as a result of nationwide restructuring. The final section deals with the cost of the two SIP policies and the economic surplus changes associated with restructuring.

5.1 Changes in Emissions and Health Benefits

Our analysis indicates that comprehensive NO_x regulation significantly reduces annual NO_x emissions. Table 3 is a summary of annual NO_x emission levels in 2008 under a baseline scenario that combines limited restructuring assumptions with the OTR seasonal NO_x policy and differences from this baseline for all other scenarios. The table is divided into two sections, one for emissions in the SIP Call region and one for national NO_x emissions. In each section of the table emission levels for the combined baseline (with limited restructuring and the OTR seasonal NO_x policy) are reported in the shaded upper left-hand cell. The remaining cells in each section of the table report changes in emission levels for alternative combinations of restructuring scenarios and NO_x policies relative to the combined baseline scenario.

Comparing the rows within each column in the top half of Table 3 illustrates our findings are consistent with the reductions expected by EPA. Under the limited restructuring scenario, a seasonal SIP policy reduces annual emissions within the SIP region by 30% and an annual SIP policy reduces emissions by 70%. The two SIP policies achieve slightly greater reductions within the SIP Call region under a nationwide restructuring scenario with a reduction of 1194 thousand tons from a seasonal SIP policy and of 2818 tons under an annual SIP policy.

The table also illustrates the role of the SIP policies in muting emissions increases that otherwise would result from nationwide restructuring. In the absence of the SIP policies, NO_x emissions within the SIP region in 2008 increase by 417 thousand tons, more than 12%, relative to the combined baseline. This is commensurate with an important increase in the net export of electricity leaving the SIP region under nationwide restructuring. However, through sensitivity analysis we find this increase in exports is not due to growth in transmission capability as conjectured in Section 2, but instead it is due to changes in the economics of power production that accompany the institution of marginal cost pricing. In particular, we find increased utilization of coal facilities in the STV and ECAR subregions when these regions transition to marginal cost pricing. In the absence of a SIP policy most of the effects of restructuring on NO_x emissions occur within the SIP Call region, where most of the older coal-fired generating capacity is located. Furthermore, the SIP policies fully mitigate the increase in emissions from restructuring under the baseline NO_x policy, although absolute levels of emissions in the SIP region remain roughly 400 thousand tons greater with nationwide restructuring under each of the seasonal NO_x policy scenarios.

A comparison of the top and bottom halves of Table 3 shows that the changes in national NO_x emissions associated with the different NO_x policy scenarios are somewhat smaller than the changes identified within the SIP Call region. This finding suggests that increasing the stringency of the NO_x policy within the SIP Call region leads to some shifting of generation to other regions and, therefore, to small NO_x emissions leakages outside the SIP Call region. Again we find the change in electricity transmission is not due to expansion of transmission capability under nationwide restructuring. Instead, the leakage is due to the relative economics of power production.

The emission results for NO_x were entered into the TAF model to estimate changes in pollutant concentrations as a consequence of atmospheric transport and, in turn, changes in health status. Table 4 is a summary of the monetized values of those health impacts for the country as a whole in which changes from the combined baseline scenario are reported. Roughly 80% of the reported health effects result from reductions in premature mortality, and the remaining 20% are attributable to morbidity changes. The health benefits results mirror the NO_x emission results reported in Table 3. In the absence of tighter restrictions on NO_x emissions in the SIP Call region, higher NO_x emissions associated with nationwide restructuring have a negative effect on human health. However, the introduction of the SIP NO_x policies yields large health benefits and the largest benefits occur under the annual SIP policy relative to the OTR Seasonal policy under nationwide restructuring.

Table 5 is a summary of the effects of restructuring and more comprehensive NO_x policies on carbon emissions from the electricity sector both within the SIP Call region and across the nation. Although the SIP Seasonal policy leads to a slight decrease in the carbon emissions in the SIP Call region, nationwide it leads to a slight increase. The SIP Annual NO_x policy leads to slightly higher carbon emissions both in the SIP Call region and nationwide under limited restructuring. With nationwide restructuring, carbon emissions in the SIP Call region and the nation are lower under the SIP policies than under the OTR baseline, though they remain higher than under limited restructuring under any of the NO_X policies.

The effect of restructuring on carbon emissions is comparable to the effect on emissions of NO_x. Within the SIP Call region, restructuring increases carbon emission increases more than 7% in the absence of a NO_x policy for the region and nearly 6% when restructuring is combined with the NO_x emissions caps. Nationwide, restructuring with the OTR seasonal NO_x policy baseline produces increases carbon emissions by 34.2 million metric ton, or almost 5%. Other studies have suggested that restructuring could lead to similarly large increases in carbon emissions. In particular, when restructuring is predicted to result in more inter-regional power trading, the accelerated retirement of nuclear facilities or both, near-term increases in coal-fired generation and the associated increases in carbon emissions can be substantial. (Palmer and Burtraw 1997, Rothwell 1998) The last two rows in the right-hand column of Table 5 show that adding a NO_x policy in the SIP Call region on top of nationwide restructuring helps to reduce restructuring-related increases in nationwide carbon emissions, but carbon emissions are still about 4.4% higher than in the combined baseline.

5.2 Changes in Technology, Output, and Price

The results for emissions and health benefits follow in part from the effects of nationwide restructuring and more comprehensive NO_x policies on the mix of technologies and fuels used to generate electricity. The results also follow from the change in the total amount of electricity generation. The policy changes have an effect on the price of electricity, although not always the one generally anticipated.

Table 6 is a summary of the effects of the NO_x policies and nationwide restructuring on generation by fuel, total generation, and the retail price of electricity in the SIP Call region. This table reports levels for each variable in the combined baseline scenario in the first row and changes from baseline in subsequent rows. Neither of the NO_x SIP policies has much effect on total generation in the SIP Call region. Under limited restructuring, total generation falls by about 1% with the addition of a seasonal or an annual NO_x emissions cap in the region. The SIP Seasonal policy increases the regional price by 1.1%, whereas the SIP Annual policy increases price by 0.7%.

With the transition from limited to nationwide restructuring, price falls and consumption increases dramatically, and the contribution of coal-fired generation grows substantially. Under the OTR baseline, nationwide restructuring results in a 14% increase in coal-fired generation and a 25% decline in gas generation. Adding the two SIP policies to the nationwide restructuring scenario reduces the attractiveness of existing coal facilities and results in a smaller increase in coal-fired generation relative to the combined baseline.

To some extent, existing coal-fired generation is used more intensively under nationwide restructuring because of the optimistic assumptions about improvements in productivity at existing facilities under this scenario. However, sensitivity analysis indicates that the assumption of time-of-day pricing for industrial customers has a relatively larger effect on the choice of generation technology. Time-of-day pricing provides an incentive for industrial customers to reduce consumption in the peak period and reduces the utilization of gas-fired units; and, time-of-day pricing also provides an incentive for industrial customers to increase consumption during the baseload period, which is dominated by coal. In the absence of time-of-day pricing for industrial customers, we find more gas generation and significantly less coal generation, in addition to higher electricity prices and reduced consumption.

The average electricity price in the SIP Call region falls by 2.8 $/MWh, or more than 4%, with nationwide restructuring under the OTR baseline NO_x policy. Adding a seasonal NO_x policy in the SIP region reduces the restructuring-induced decline in electricity price by roughly one-third. Extending the NO_x policy in the SIP region to an annual basis with nationwide restructuring reduces slightly further the restructuring-induced decline in electricity price. Nonetheless, average electricity price in the SIP Call region is 2.5% less than in the limited restructuring baseline with the OTR baseline NO_x policy. In sum, the ordering of the effect on electricity price is reversed under limited and nationwide restructuring. Under limited restructuring, the seasonal SIP policy leads to a higher electricity price than the annual policy. This difference is mainly because of a switch from coal to gas under the seasonal policy as compared to an increased usage of coal under the annual policy. However, under nationwide restructuring the seasonal SIP policy leads to a lower electricity price than the annual policy, and there is almost no evidence of fuel switching due to the NO_x policies even though coal is used less.

Table 7, the national analog of Table 6, shows that in general the effect of the two SIP policies on electricity price under the limited restructuring baseline tends to be less pronounced nationally than in the SIP Call region, as one would expect. Under limited restructuring, the SIP seasonal policy produces a decline in coal-fired generation, but coal-fired generation increases with the SIP annual policy. The seasonal SIP policy induces fuel switching from coal to natural gas, although under the annual policy both coal and gas generation increase at the national level.

Though renewable technologies constitute a small share of generation in the baseline, they are affected by the NO_x policies in an unexpected way. Under limited restructuring, both the seasonal and annual SIP policies result in a decline in renewables generation for the nation of roughly 20 million MWh. Renewable generation falls under the SIP policies as an indirect consequence of the fact that the cost of natural gas generation falls relative to the cost of coal generation as coal installs post-combustion controls to reduce NO_x emissions. As a result gas units have higher utilization both within and outside the SIP region, and the fixed cost of gas units are spread over more generation. Consequently the cost of a new gas-fired plant per kWh of generation is lower and the going-forward profits of these plants are higher, making them more likely to be built. The utilization rate of wind generation is unaffected by these changes because it has low variable costs and is always operated when wind resources are available. However, the new gas-fired capacity crowds out the construction of new renewables, primarily new wind turbines. In particular, we see more new gas combined cycle plants being constructed and fewer wind turbines being constructed in ECAR under the SIP policies. In SPP, which is outside of the SIP region, new combined cycle and combustion turbine plants displace new wind plants, and exports from SPP into the SIP region increase.

In comparison to the combined baseline, the RPS included in the nationwide restructuring scenario results in a 28 billion kilowatt hour (kWh), or 50%, increase in renewables generation nationwide. The introduction of the SIP policies has hardly any further effect on the renewables generation under nationwide restructuring when the RPS policy also is in effect.

A comparison of the bottom sections of Tables 6 and 7 shows that the effect of restructuring on national average electricity price is greater within the SIP Call region than it is nationwide. Nonetheless, nationwide restructuring produces a 3.4% decline in national average electricity price under the OTR Baseline NO_x policy and price declines of at least 2.6% when combined with a seasonal NO_x policy. Table 7 also shows that nationwide restructuring results in substantial increases in coal generation and commensurate declines in gas-fired generation. Table 8 is a summary of the effects of the different policies on new capacity additions and it reveals that the increased coal generation comes from increased use of existing plants, whereas the decline in gas-fired generation comes largely from reduced investment in new plants.

The negative effect of nationwide electricity restructuring on electricity price identified in these simulations depends importantly on the assumption that some subset of electricity consumers—in this case industrial customers—will face time-of-day pricing in restructured regions. When we perform a sensitivity analysis in which we exclude the possibility of time-of-day pricing of electricity, we find that electricity price on average actually rises as a result of nationwide restructuring. Switching from average cost pricing to marginal cost pricing produces efficiency gains that tend to lower prices, but this result is offset by two factors that tend to increase prices. One is the fact that marginal cost of generation and reserve is increasing and significantly higher than average cost during peak periods. Under marginal cost pricing, producers have the opportunity to earn economic profits in excess of costs that is not possible under average cost pricing. The second factor is the incentive compatible institution used to price reserves in restructured regions. This mechanism compensates all participants in energy and reserve markets for supplying reserve services and thereby increases total payments for reserves during peak time periods, which tends to increase prices. When the prices faced by at least some consumers vary by time-of-day these consumers can respond to increases in peak prices by reducing demand, thereby keeping price increases in check. However, when prices do not vary by time-of-day, the effect of providing reserve services on average price is more diluted and so is the demand response.

5.3 Emissions Control Investments

The main way emissions are reduced to comply with the NO_x emissions cap is by the installation of post-combustion controls. We model two types of post-combustion controls: selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR). A distinguishing feature of these technologies is that SCR is likely to have higher capital costs and somewhat lower variable costs per ton of NO_x reduced than SNCR. Therefore, the decision about which type of post-combustion control to install would be influenced by the expected utilization of a facility. Other things equal, a base load unit that is utilized many hours of the year would be more likely to install SCR, and a unit that is utilized fewer hours of the year would be more likely to install SNCR.

The amounts of capacity retrofitted with post-combustion controls are reported in Table 9. This table includes only retrofit controls; it does not include controls installed to comply with NSPS. It shows that the total amount of post-combustion retrofits changes very little with a shift from a seasonal to an annual NO_x policy. However, there is a shift toward more use of SCR relative to SNCR under the SIP annual policy, under both limited and nationwide restructuring. Table 10 is a summary of the annual operation and maintenance (O&M) expenses, capital expenses, and total expenses for all types of post-combustion controls combined in the baseline, and the added expense under each NO_x policy and with nationwide restructuring. The total additional annual cost of a SIP seasonal policy with limited restructuring is 2.15 billion dollars. Additional compliance costs are roughly 27% higher for an annual SIP policy than a seasonal

SIP policy. Under nationwide restructuring, an annual SIP policy yields total additional compliance costs of 2.87 billion dollars, which are about 17% higher than for a seasonal SIP policy.

Table 11 is a summary of the cost of post-combustion control per ton of emission reductions achieved under the policy scenarios at all generating units in the SIP Call region. In the baseline, a marginal cost of about $1,356 per ton is reported, which is the marginal cost of reductions in the eastern OTR states. In the SIP Seasonal scenario with limited restructuring, the average cost in 2008 is $2,112 per ton, and the marginal cost (equivalent to the predicted price for an emissions allowance) is about $3,401 per ton.[22] When the cap is extended year-round in the SIP Annual scenario, the average cost under limited restructuring falls to $1,133 per ton, and the marginal cost falls to below $1,985.

Under nationwide restructuring the average cost of a seasonal NO_x cap is about $300 more than in the limited restructuring scenario, but the marginal cost is about $30 lower. For an annual policy under nationwide restructuring the average cost of NO_x control is roughly $60 greater and the marginal cost of control is about $180 lower than in the limited restructuring case.

Figure 1 shows how the marginal control cost curve under a seasonal SIP policy changes with nationwide restructuring. Because of greater coal use in the absence of the policy, the amount of total NO_x emission reductions required in the summer season to achieve the cap is higher with nationwide restructuring than under limited restructuring. The quantities to be reduced are illustrated by the vertical lines. However, because the technology (model plant) that determined the marginal cost of control is run more under nationwide restructuring, its marginal control costs with SCR is less than under limited restructuring because the capital costs are spread over a greater number of kWh. Consequently, it shifts back in the schedule of marginal cost of control. As a result a different technology becomes marginal and the marginal cost of control, and equivalently the permit price falls.

[22] Average cost is calculated as the ratio of the total cost of post-combustion controls divided by the total change in emissions during the relevant season at all units in the SIP Call region.

5.4 Economic Costs and Benefits

The cost of post-combustion controls plus any change in electricity price do not constitute the total economic cost of a policy. A complete measure of compliance cost for the NO_x control policies would include the cost of switching fuels as well as the out-of-pocket abatement expenditures represented by post-combustion controls. And to electricity price increases, which affect consumers' pocketbooks, one must add the loss in well being from a reduction in electricity consumption and the portion of the compliance costs borne by producers. Similarly the benefits of nationwide restructuring include the changes in producer profits that result from the policy as well as the change in consumer well-being associated with increased electricity consumption in response to the fall in electricity prices that results from restructuring.

To achieve a more complete measure of economic cost, we estimate changes in consumer and producer surplus under various policies. Consumer surplus represents the difference between willingness to pay for electricity services and the price actually paid by consumers. Producer surplus represents the difference between revenues received by producers and the costs incurred in providing electricity service. By construction, in average cost regions the price is such that producer surplus is approximately zero.

Table 12 is a summary of the changes in consumer and producer surplus in the electricity sector relative to the combined baseline (OTR Seasonal case with Limited Restructuring) for the year 2008.[23] Numbers in parentheses indicate the changes relative to values under the OTR Seasonal case with Nationwide Restructuring.

Under the limited restructuring scenario, both the seasonal and annual SIP policies result in a loss in total social surplus. The SIP policies lead to higher costs, but since prices decrease because of the SIP policies, producers lose while consumers are better off. However, the total change in economic surplus is less than the estimated compliance cost for both the seasonal and annual NO_x policies reported in Table 10. This finding follows from the observation noted in Section 2 that the opportunity cost to consumers, or equivalently the marginal consumer surplus, is less than the marginal cost of production when average cost is less than marginal cost. This

[23] Changes outside the electricity sector could be important due to pre-existing policies, such as the labor income tax, or market structure that distorts markets away from economic efficiency. The interaction of new environmental policies with pre-existing distortions can amplify the effect of pre-existing distortions (Goulder et al., 1999). Table 12 does not report consumer surplus measures for the combined basecase because the constant elasticity demand curves are hyperbolic and only changes in surplus are meaningful.

occurs in most time blocks. Consequently, under limited restructuring the foregone economic surplus that results from raising prices or reducing consumption is less than the out-of-pocket cost of reducing pollution (Oates and Strassman, 1984). However, if the inefficient pricing problem was eliminated with time-of-day marginal-cost pricing of electricity, the economic cost of the NO_x control policy would be guaranteed to be greater than changes in production cost.

Implementing nationwide restructuring leads to gains in social surplus composed of substantial gain for consumers and producers. The increase in surplus is due to increased production efficiency and to allocational efficiency improvements resulting from pricing of electricity closer to marginal cost. The distribution of the surplus increase depends on the change in electricity price. In time blocks when marginal costs are greater than average costs, then average electricity revenue under marginal cost pricing may exceed average cost, resulting in producer surplus. The converse holds when marginal costs are less than average costs. In the aggregate consumers could benefit or not from the transition to marginal cost pricing. However, in our model producers are sure to benefit because of the provision for recovery of 90% of any costs that are stranded by the transition to greater competition.

One can look down the columns of Table 12 to compare the total economic cost of each NO_x policy under a given restructuring policy. Under limited restructuring, the incremental cost of a SIP Seasonal policy is $1.8 billion. Consumers are better off because of lower electricity prices and producers bear all the costs. One significant reason this occurs is that under limited restructuring about three-quarters of coal-fired generation occurs in regions with average cost pricing. In these regions the price of allowances received at zero cost by a firm is not reflected in electricity price. Consequently, consumers benefit due to lower effect on price under limited restructuring, although this comes at the expense of allocational efficiency. The incremental total economic cost of extending the seasonal policy to the SIP Annual policy is $830 million. Consumers and producers share the incremental cost of extending the policy from a seasonal to an annual basis.

Under nationwide restructuring the cost of a SIP Seasonal policy is $2.24 billion, or 27% higher than under limited restructuring, and in the case of nationwide restructuring consumers bear most of the cost of a seasonal policy while the increase in consumer surplus due to restructuring is reduced. The incremental economic cost of extending the seasonal policy to the SIP Annual policy is $570 million, and consumers bear all of the incremental cost of extending the policy to an annual basis. Producers lose only a modest amount under the seasonal NO_x policies but they actually benefit slightly by extending the seasonal policy to an annual NO_x policy. Despite the costs of the NO_x policies, when compared to the combined limited restructuring baseline with the OTR Seasonal NO_x policy, the social surplus gains from restructuring dramatically outweigh the losses associated with adding either SIP policy.

The change in consumer surplus associated with different policies can be decomposed into the portions associated with each of the three different classes of customers. Table 13 provides that breakdown. Under limited restructuring, the consumer surplus gains associated with a SIP seasonal policy are shared almost equally between residential and commercial customers, with industrial customers experience a slight loss in surplus. Under a SIP annual policy with limited restructuring, total consumer surplus gains are smaller than with a seasonal policy. Residential and commercial customers have slightly smaller surplus gains under an annual policy and industrial customers lose under this policy. Industrial consumers also bear the largest portion of the consumer surplus losses from both types of SIP policies under nationwide restructuring.

Among the three customer classes, industrial consumers are also the main beneficiaries of nationwide restructuring. They receive close to half of the surplus gains from nationwide restructuring under the OTR seasonal NO_x baseline. Commercial customers receive the next largest share of surplus gains, and surplus gains attributable to residential customers are typically less than half the size of those attributable to industrial customers. The large share attributable to industrial customers follows from the combination of a relatively flat load shape and access to time-varying prices. As a result of restructuring, prices during the base period fall by more than the average prices paid by other customer classes. Because compared to commercial or residential customers, industrial customers have more constant demand over the course of the year, they benefit even more from these larger price declines. Industrial demand falls some during peak periods in response to higher prices there, but these reductions in demand are more than offset by increases in consumer surplus in the base periods.

This analysis provides only an incomplete accounting of costs and benefits of restructuring and NO_x control policies. Costs are underreported because we exclude costs outside the electricity sector associated with interactions with existing policies such as labor income taxes (Goulder, et al. 1999). Benefit estimates are incomplete because we report only benefits stemming from particulate-related improvements in health status and ignore benefits from reduced acidification, materials damage and concentrations of ozone (U.S. EPA. 1998c). Nonetheless, we can compare net benefits of each NO_x policy option under each restructuring scenario to examine the relative cost-effectiveness of the policies, given this information. Table 14 summarizes results from previous tables and allows us to calculate net benefits, as the sum of benefits and costs, for each scenario.

The first observation to make is that under limited restructuring the difference between benefits and economic costs is improved, compared to a measure that compared benefits to compliance costs. This improvement occurs because economic cost is less than compliance cost under limited restructuring. Second, we observe that the economic surplus loss in the electricity sector under limited restructuring is $830 million greater under the annual policy than under the seasonal policy. However, health benefits improve by $1.03 billion under the annual policy. Consequently, we find an annual policy under limited restructuring would capture about $200 million in additional net benefits. This finding reaffirms earlier findings that examined only compliance cost rather than economic cost and found that an annual SIP program is more cost effective than a seasonal one under limited restructuring (Burtraw et al, 2000).

The finding applies even more strongly to the nationwide restructuring scenario. Table 14 reports that the SIP Annual policy yields almost $620 million in additional net benefits compared to the SIP Seasonal policy. The inclusion of benefits resulting from reduced ozone concentrations would not alter this conclusion because ozone-related benefits accrue mostly in the summer season and therefore would increase the measured net benefits of both NO_x policies about equally. However, non-health related benefits from particulate reductions accrue on an annual basis. The EPA (U.S. EPA. 1998c) suggests benefits from reduced nitrogen deposition would be on the order of magnitude of $300 million per year, and most of these would accrue outside the summer season. The inclusion of these benefits would strengthen the relative cost-effectiveness of an annual policy.

6. Conclusion

The debate surrounding restructuring of the electricity industry often has been acrimonious. A key point of contention has been the concern that gains that may be realized through lower electricity prices would be offset to an important degree by a deleterious increase in pollutant emissions.

This study looks at various effects of retail restructuring of electricity markets and likely concurrent changes in environmental regulations. The results of this study are consistent with those of earlier studies that show that both producers and consumers benefit as a result of electricity market restructuring. Producers benefit as a result of increased productive efficiency, and consumers benefit from lower prices. Consumer surplus gains to industrial customers are more than twice as large as those accruing to residential customers and the gains to commercial customers are in between. Our findings with respect to surplus changes stem importantly from several key assumptions in our model about the extent of recovery of stranded costs, the extent of productivity enhancements associated with greater competition, the operation of reserve markets, the institutions used to compensate all electricity suppliers for reserve services and access to time-of-day pricing of electricity.

Our results also are consistent with those of earlier studies that suggest electricity restructuring could increase air pollution. Widespread adoption of electricity restructuring leads to a greater reliance on coal relative to natural gas and thus leads to higher NO_x and carbon emissions. Implementing a NO_x control policy that caps either seasonal or annual emissions of NO_x in the eastern United States could offset the increase in NO_x emissions. However, the NO_x policies would do little to combat the increase in carbon emissions from restructuring because most of the NO_x reductions are attributable to the installation of post-combustion controls and not to fuel switching away from coal.

The cost of environmental compliance in the nationwide restructuring case is moderately higher than in the limited restructuring scenario for both seasonal and annual SIP policies. Compliance cost of post-combustion controls range from 5% to 14% higher in the nationwide restructuring case, and the average cost per ton ranges from 5% to 15% higher in the nationwide restructuring case. At the same time, electricity price under nationwide restructuring combined with each of the environmental scenarios is lower than electricity price in the limited restructuring baseline with an OTR Seasonal NO_x policy.

But, out of pocket compliance costs do not represent the full economic costs of these policies. An examination of the changes in economic surplus resulting from the incremental environmental policies compared to the OTR Seasonal NO_x baseline, under a given restructuring scenario, reveals that the economic costs in the electricity sector of both SIP policies are higher in the nationwide restructuring case. These costs range from 8%-27% higher than in the limited restructuring case, when measured against the OTR Seasonal NO_x baseline under each restructuring regime. The additional costs stem in part from changes in electricity price, which yield commensurate increases in revenue for producers and reductions in electricity consumption by consumers. More fundamentally, the relative opportunity costs of emission reductions are greater under nationwide restructuring because of the greater utilization of coal.

Under limited restructuring, we find consumers are insulated from the cost of the SIP Seasonal NO_x policy and actually gain consumer surplus due to the decline in electricity price while producer surplus loss is greater than the compliance cost. Under nationwide restructuring, however, consumers bear most of the cost of a SIP seasonal NO_x policy and producers are insulated from the cost. In moving from a seasonal to an annual policy consumers pay about 70% of the cost under limited restructuring, while under nationwide restructuring consumers pay the full cost and more, leaving producers indifferent between an annual NO_x policy and the OTR Seasonal NO_x baseline.

Among customer classes, we find that while residential and commercial customers split the gains from the two SIP NOx policies under limited restructuring, industrial customers always lose under these more stringent NOx policies. Under nationwide restructuring, industrial customers also lose more than do commercial or residential customers as a result of the two SIP policies.

Finally and most importantly for current policymakers, our results confirm the findings of prior work with respect to the greater cost-effectiveness of an annual SIP policy relative to a seasonal SIP policy under both restructuring scenarios. The additional health benefits from reduced concentrations of particulates associated with an annual NO_x cap in the SIP region more than outweigh the additional costs of an annual policy relative to a seasonal one. In the limited restructuring case, we find an annual policy would provide over $200 million in additional net benefits compared to a seasonal policy.

The relative cost effectiveness of an annual NO_x policy is even greater under nationwide restructuring. We find that the annual policy under nationwide restructuring yields $620 million in additional net benefits compared to a seasonal NO_x policy.

The benefit side of this calculation includes only particulate related health benefits from NO_x reductions. Incorporating estimates from the literature of the non-health related benefits from reduced nitrogen deposition would make the annual policy appear even more cost-effective than a seasonal policy. The net benefits of the NO_x policies are negative in all cases, based on just the partial measure of particulate related health benefits. Other analysis suggests the inclusion of non-health and non-particulate health benefits including especially ozone benefits would be likely to make net benefits positive (U.S. EPA. 1998c). This analysis demonstrates that the net benefits would be greatest in any case under an annual approach in place of a seasonal approach to controlling NO_x emissions in the SIP region.

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Table 1. NERC subregions, the year marginal cost pricing begins, and subregions covered by cap and trade NO_X policies under modeled scenarios.

NERC Subregion	Geographic Area	Year Marginal Cost Pricing Regime Begins		OTR NO_X Trading Region	SIP NO_X Trading Region
		Limited Restructuring	Nationwide Restructuring		
ECAR	MI, IN, OH, WV; part of KY, VA, PA	-	2004		ECAR
ERCOT	Most of TX	2002	2002		
MAAC	MD, DC, DE, NJ; most of PA	2000	2000	MAAC	MAAC
MAIN	Most of IL, WI; part of MO	-	2004		MAIN
MAPP	MN, IA, NE, SD, ND; part of WI, IL	-	2008		
NE	VT, NH, ME, MA, CT, RI	2000	2000	NE	NE
NY	NY	1999	1999	NY	NY
FRCC	Most of FL	-	2008		
STV	TN, AL, GA, SC, NC; part of VA, MS, KY, FL	-	2008		STV
SPP	KS, MO, OK, AR, LA; part of MS, TX	-	2008		
NWP	WA, OR, ID, UT, MT, part of WY, NV	-	2008		
RA	AZ, NM, CO, part of WY	-	2004		
CNV	CA, part of NV	1998	1998		

Table 2. Distinguishing features of restructuring scenarios in 2008.

	Restructuring Scenario	
	Limited	**Nationwide**
Ratio of Technical Parameter Values 2008 to 1997		
Maximum Availability Factor	1.0205	1.0411
Heat Rate	0.9864	0.9730
General and Administrative Cost	0.7500	0.6741
Non-Fuel O&M Cost	0.7642	0.7001
Transmission Capacity	-	10 % increase from 2008
Renewables Portfolio Standard	None	RPS with $17 per MWh price cap on tradable renewable credits

Table 3. Annual NO_x emissions in the SIP Call region and nation in the OTR Seasonal Limited Restructuring Case, and changes under alternative scenarios for 2008 (thousand tons).

NO_x Policy	Restructuring Scenario	
	Limited	**Nationwide**
	SIP Region	
OTR Seasonal	3,449	+417
SIP Seasonal	-1,031	-777
SIP Annual	-2,408	-2,401
	Nation	
OTR Seasonal	5,533	+567
SIP Seasonal	-992	-623
SIP Annual	-2,378	-2,266

Table 4. Annual particulate-related health benefits due to changes in NO_x emissions from the OTR Seasonal Limited Restructuring Case under alternative scenarios for 2008 (Billion 1997 dollars).

NO_x Policy	Restructuring Scenario	
	Limited	**Nationwide**
OTR Seasonal		-0.29
SIP Seasonal	+0.75	+0.59
SIP Annual	+1.78	+1.78

Table 5: Annual carbon emissions in the SIP Call region and nation for the OTR Seasonal Limited Restructuring Case, and changes under alternative scenarios for 2008 (million metric tons).

NO_x Policy	*Restructuring Scenario*	
	Limited	**Nationwide**
	SIP Region	
OTR Seasonal	371.5	+28.1
SIP Seasonal	-4.7	+21.1
SIP Annual	+3.9	+21.8
	Nation	
OTR Seasonal	660.8	+34.2
SIP Seasonal	+3.4	+29.0
SIP Annual	+10.2	+28.3

Table 6: Annual generation by fuel and electricity price in the SIP Call region in the OTR Seasonal Limited Restructuring Case, and changes under alternative scenarios, for 2008.

Policy Scenario	Regional Generation (million MWh)			Regional Price (1997$/MWh)
	Coal	Gas	Total	
Limited Restructuring				
OTR Seasonal NOx	1,095	460	2,139	64.4
SIP Seasonal NOx	-19	+4	-20	+0.7
SIP Annual NOx	+11	-19	-7	+0.5
Nationwide Restructuring				
OTR Seasonal NOx	+157	-116	+45	-2.8
SIP Seasonal NOx	+130	-112	+23	-1.9
SIP Annual NOx	+134	-115	+23	-1.6

Table 7: Annual generation by fuel and electricity price in the nation in the OTR Seasonal Limited Restructuring Case, and change under alternative scenarios, for 2008.

Policy Scenario	National Generation (million MWh)			National Price (1997$/MWh)
	Coal	Gas	Total	
Limited Restructuring				
OTR Seasonal NOx	1,767	1,182	3,996	62.2
SIP Seasonal NOx	-8	+39	+1	-0.3
SIP Annual NOx	+17	+21	+14	-0.1
Nationwide Restructuring				
OTR Seasonal NOx	+230	-241	+36	-2.1
SIP Seasonal NOx	+205	-221	+24	-1.6
SIP Annual NOx	+204	-220	+23	-1.4

Table 8: National cumulative new generation capacity by fuel in the OTR Seasonal Limited Restructuring Case, and changes under alternative scenarios, for 2008 (MW).

Policy Scenario	Coal	Gas	Total
Limited Restructuring			
OTR Seasonal NOx	2,611	222,210	239,800
SIP Seasonal NOx	-35	+5,000	-5,600
SIP Annual NOx	+55	-700	-9,800
Nationwide Restructuring			
OTR Seasonal NOx	-997	-58,980	-53,500
SIP Seasonal NOx	-188	-59,200	-55,000
SIP Annual NOx	-215	-55,930	-51,200

Table 9: Nationwide retrofit post-combustion capacity in the OTR Seasonal Limited Restructuring Case, and changes under alternative scenarios for 2008 (thousand MW).

NO_x Policy	Restructuring Scenario					
	Limited			Nationwide		
	SCR	SNCR	Total	SCR	SNCR	Total
OTR Seasonal	0.00	11.44	11.44	0.00	+0.98	+0.98
SIP Seasonal	+144.20	+57.36	+201.56	+168.10	+29.18	+197.28
SIP Annual	+169.60	+30.35	+199.95	+185.60	+7.56	+193.16

Table 10: National annual cost of post-combustion control in the OTR Seasonal Limited Restructuring Case, and changes under alternative scenarios in 2008 (billion 1997 dollars).

NO_x Policy	Restructuring Scenario					
	Limited			Nationwide		
	O&M	Capital	Total	O&M	Capital	Total
OTR Seasonal	0.016	0.014	0.030	+0.002	0.001	+0.003
SIP Seasonal	+0.995	+1.151	+2.146	+1.152	+1.304	+2.456
SIP Annual	+1.408	+1.320	+2.728	+1.479	+1.389	+2.869

Table 11: Cost per ton of adopting post-combustion control for 2008 (1997 dollars per ton of NO_X reduction).

NO_x Policy	Restructuring Scenario			
	Limited		Nationwide	
	Average	Marginal	Average	Marginal
OTR Seasonal	-	1,356	-	1,334
SIP Seasonal	2,112	3,401	2,438	3,370
SIP Annual	1,133	1,985	1,195	1,801

Table 12: Changes in consumer and producer surplus under alternative scenarios, for 2008. Parentheses indicate change from OTR Seasonal case under Nationwide Restructuring Scenario (billion 1997 dollars).

NO_x Policy	Restructuring Scenario					
	Limited			Nationwide		
	Consumer Surplus	Producer Surplus	Total	Consumer Surplus	Producer Surplus	Total
OTR Seasonal	-	-	-	+7.60	+6.04	+13.64
SIP Seasonal	+1.08	-2.84	-1.76	+5.65	+5.75	+11.40
				(-1.95)	*(-0.29)*	*(-2.24)*
SIP Annual	+0.50	-3.09	-2.59	+4.82	+6.01	+10.83
				(-2.78)	*(-0.03)*	*(-2.81)*

Table 13: Changes in consumer surplus by customer class under alternative scenarios, for 2008 (billion 1997 dollars).

NO_x Policy	Restructuring Scenario					
	Limited			Nationwide		
	Customer Class			Customer Class		
	Residential	Commercial	Industrial	Residential	Commercial	Industrial
OTR Seasonal	-	-	-	+1.40	+2.82	+3.32
SIP Seasonal	+0.60	+0.57	-0.06	+1.00	+2.33	+2.34
SIP Annual	+0.50	+0.42	-0.39	+0.60	+1.90	+2.28

Table 14: Changes in economic surplus in the electricity sector, changes in particulate-related health benefits, and calculation of net benefits for 2008 (billion 1997 dollars).

NO_x Policy	Restructuring					
	Limited			Nationwide		
	Electricity Sector (Surplus Change)	Particulate-Related Health Benefits	Net Benefits	Electricity Sector (Surplus Change)	Particulate-Related Health Benefits	Net Benefits
OTR Seasonal	-	-	-	+13.64	-0.29	+13.35
SIP Seasonal	-1.76	0.75	-1.01	+11.40	0.59	+11.99
SIP Annual	-2.59	1.78	-0.81	+10.83	1.78	+12.61

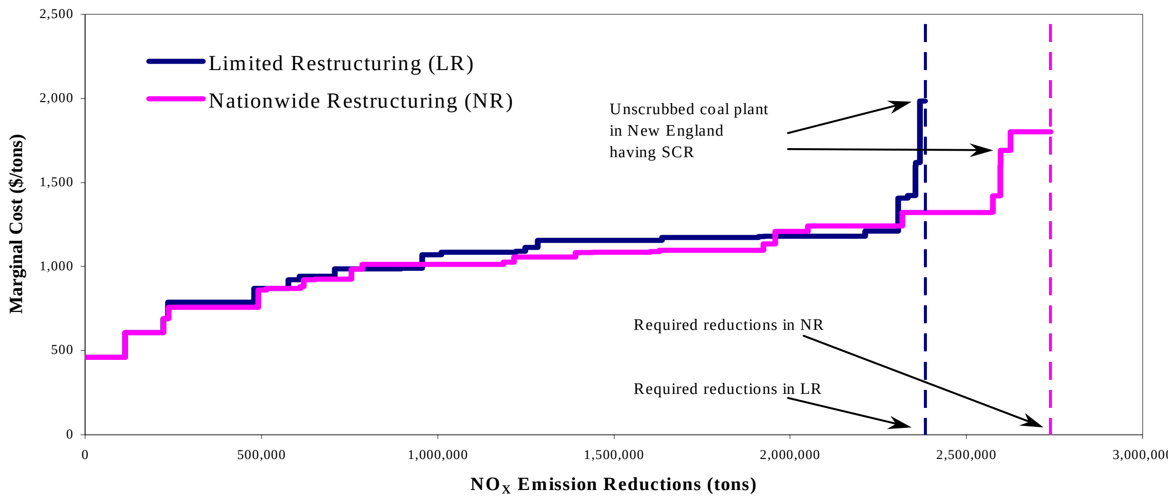

Figure 1: Required emission reductions and schedule of marginal costs of control for SIP Seasonal policy under limited restructuring and nationwide restructuring for 2008.