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Spillovers from Climate Policy to Other Pollutants

Stephen P. Holland

5.1 Introduction

Spillovers from climate policy (also known as ancillary benefits or ancillary costs) have important implications for policy design, modeling, and benefit-cost analysis. Spillovers arise since climate policy could lead, for example, to a reduction in particulate matter (PM) emissions as well as CO_2 emissions. In this case, the ancillary benefits of reduced PM emissions from the policy should be included in a benefit-cost analysis and may well lead the benefit-cost analysis to recommend more stringent climate policies. Unfortunately, spillovers can be either positive or negative since firms change production processes in response to climate policies, and these changes may lead either to an increase or decrease in emissions of other pollutants. After presenting a theoretical description of spillovers from climate policy, this chapter empirically tests for and decomposes climate policy spillovers in electric power generation.

Climate policy spillovers have received attention in the estimation of health benefits from reduced air pollution. This extensive literature, which is recently surveyed in Bell et al. (2008), varies considerably in its sophistication with regard to air quality modeling and the responses of polluters to climate

policy.[1] For example, Cifuentes et al. (2001) simply assumes climate policy uniformly reduces pollution across all spatial areas. Other studies use much more sophisticated air quality modeling to estimate the effects of emissions reductions. Bell and colleagues conclude that although the various studies are difficult to compare, the results provide "strong evidence" that the short-term ancillary benefits to public health of climate policy are "substantial."

Burtraw et al. (2003) focus on the responses to climate policy of electric power generators.[2] Using a sophisticated simulation model of electricity supply, the authors show that a carbon tax would have ancillary health benefits from reduced NO_x emissions of about eight dollars per metric ton of carbon. Since emissions of SO_2 are capped, they note that there are no ancillary health benefits from SO_2 emissions, but they estimate additional benefits from avoided future investment in emissions control equipment. Groosman, Muller, and O'Neill (2009) estimate similar effects with a sophisticated model of pollutant transport.[3]

Ancillary benefits from climate policy have also been studied in agriculture and forestry where climate policy could benefit soil quality, wildlife habitat, water quality, and landscape aesthetics.[4] Finally, ancillary benefits have been estimated to be substantial in developing countries where regulation of pollutants may be less stringent.[5]

5.2   The Theory of Spillovers from Climate Policy

Emissions are generally modeled using one of three equivalent approaches: as an input in the production process, as a joint product that is a "bad," or as abatement from some hypothetical level, for example, business as usual. The first approach has a number of advantages for modeling spillovers from climate policy since it is readily adaptable to modeling multiple pollutants and allows for a broad range of substitution possibilities. Moreover, it allows a simple way to model climate policies, for example, a carbon tax or cap and trade, as an increase in the price of CO_2 emissions (from a zero price).

In this framework, climate policy spillovers are shifts in input demands in response to an increase in the price of CO_2. Theory shows that input

1. See also European Environment Agency (2004).

2. Ancillary benefits have also been studied in transportation; see Walsh (2008) and Mazzi and Dowlatabadi (2007).

3. The more conservative estimates in Groosman and colleagues recognize that emissions of SO_2 are capped.

4. See Feng, Kling, and Gassman (2004), Plantinga and Wu (2003), and Pattanayak et al. (2002). Elbakidze and McCarl (2004) point out that ancillary benefits must be skeptically considered with agricultural offsets since offset emissions reductions from other sectors might also have ancillary benefits.

5. See Dudek, Golub, and Strukova (2003) for analysis of ancillary benefits in Russia; Dessus and O'Connor (2003) for analysis of Chile; and Joh et al. (2003) for analysis of Korea. Greenstone (2003) studies pollutant spillovers across media and finds little evidence that the CAAAs increase releases into waterways and the ground.

demand may either increase or decrease, depending on whether the input is a substitute or a complement to CO_2. Additionally, the effects of climate policy can be decomposed into two effects: an output effect, which generally decreases the demand for all inputs, and a substitution effect, which depends on whether the inputs are net substitutes or net complements for CO_2.[6] Importantly, demand for pollution inputs that are net substitutes can still fall with climate policy if the output effect outweighs the substitution effect.[7]

To illustrate these principles, consider electricity generation that leads to emissions of SO_2 and NO_x, as well as CO_2. Suppose climate policy caused dual fuel generating units to switch from fuel oil to natural gas. Since natural gas generally has lower sulphur content than fuel oil, SO_2 and CO_2 would be net complements: for a given amount of electricity emissions of SO_2 would be lower in response to climate policy. Since the output effect also serves to reduce SO_2 emissions, climate policy would have ancillary benefits from SO_2. Now suppose that climate policy caused natural gas-fired generating units to increase their combustion temperature, which reduces CO_2 emissions but increases NO_x emissions. In this case CO_2 and NO_x would be net substitutes. Note however, that since the output effect leads to a reduction in NO_x emissions, the overall effect may still be a reduction in NO_x emissions from climate policy if the output effect is stronger than the substitution effect. Thus, climate policy could have ancillary benefits or ancillary costs.

Spillovers are illustrated in figure 5.1 for the case of electricity production with emissions of CO_2 and NO_x. The first panel of figure 5.1 shows the input demand for CO_2. If marginal productivity is decreasing (the usual case) then the input demand (equivalently the value of the marginal product) is downward sloping. The firm would increase use of an input if the value of the marginal product were greater than the input cost. Thus at the optimum, the value of the marginal product equals the input cost. In the unregulated equilibrium, this marginal product would be zero and CO_2 emissions would be $e^0_{CO_2}$. If climate policy increases the price of CO_2 emissions to t_{CO_2}, for example through a carbon cap or tax, then CO_2 emissions would fall to $e^1_{CO_2}$.

Panel B of figure 5.1 illustrates the spillovers to NO_x emissions from climate policy. In the absence of climate policy, the NO_x input demand is illustrated by the downward sloping solid line and NO_x emissions are $e^0_{NO_x}$. The response of NO_x emissions to climate policy depends on two factors: (a) whether NO_x and CO_2 are substitutes or complements, and (b) regulations on NO_x emissions. In general NO_x and CO_2 can be substitutes or

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6. These effects are equivalent to income and substitution effects from demand theory. Deschênes (chapter 2, this volume) develops an equivalent framework for labor demand with scale and substitution effects.

7. Decomposing responses into output and substitution effects is also useful since output effects may not be effective for reducing emissions if regulations are incomplete or firms have market power. See Holland (2012) for further discussion of output effects with incomplete regulation.

Panel A.   Demand for CO_2 emissions.

Panel B.   Demand for NO_x emissions.

Panel C.   Supply and demand for electricity.
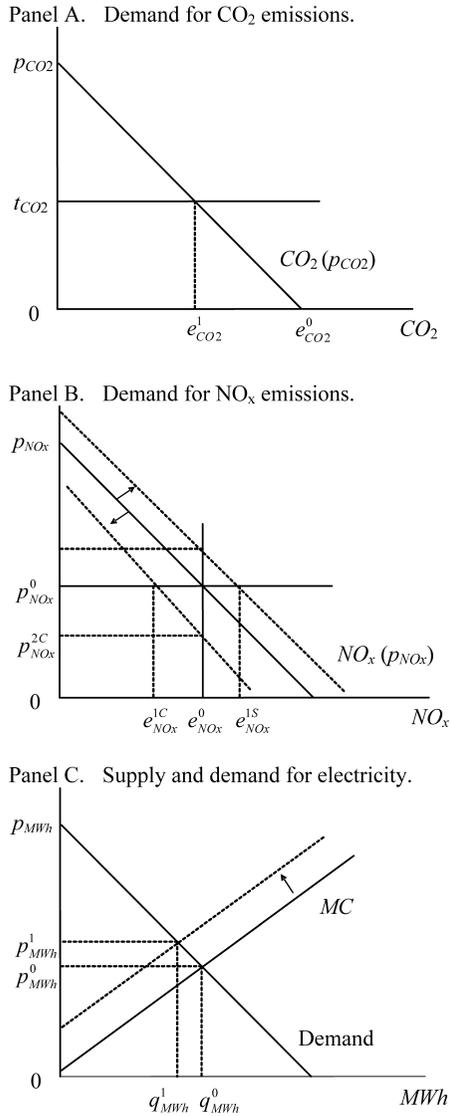
Fig. 5.1   **Graphical model of spillovers from climate policy**

complements. If NO_x and CO_2 are complements, then climate policy leads to an inward shift in the input demand for NO_x, that is, decreases the demand for NO_x emissions. On the other hand, if NO_x and CO_2 are substitutes, then climate policy increases the demand for NO_x emissions.

Whether or not climate policy changes, NO_x emissions depends crucially on the environmental regulation of the NO_x emissions. Two polar

cases illustrate the effects: cap and trade in NO_x versus a NO_x tax. If NO_x is subject to an emissions cap (as in RECLAIM or in the NO_x Budget Program), then climate policy does not change NO_x emissions but changes the price of permits in the NO_x market. For example, if NO_x and CO_2 are complements, then climate policy decreases demand for NO_x emissions. Since emissions are capped, NO_x emissions remain at $e_{NO_x}^0$ and there are no spillover benefits, but the NO_x price falls from $p_{NO_x}^0$ to $p_{NO_x}^{2C}$.[8]

On the other hand, if NO_x emissions are subject to price regulation, then NO_x emissions change in response to climate policy. For example, if NO_x and CO_2 are complements, then climate policy would decrease demand for NO_x emissions and emissions would decrease from $e_{NO_x}^0$ to $e_{NO_x}^{1C}$. Alternatively, if NO_x and CO_2 are substitutes, then climate policy would *increase* NO_x emissions from $e_{NO_x}^0$ to $e_{NO_x}^{1S}$.

Panel C of figure 5.1 shows the effect of climate policy in the electricity market. Since climate policy increases the marginal cost of electricity production, the equilibrium price of electricity will rise from p_{MWh}^0 to p_{MWh}^1 and the equilibrium production will fall from q_{MWh}^0 to q_{MWh}^1. This output effect will serve to reduce emissions of both CO_2 and NO_x. Note that the output effect makes it unlikely that NO_x and CO_2 would be gross substitutes since the substitution effect (which increases NO_x emissions) would need to outweigh the output effect (which decreases NO_x emissions).

Holland (2010) illustrates the proper valuation of climate policy spillovers for benefit-cost analysis. Two results are noteworthy. First, spillovers can affect the optimal carbon price. In particular, if there are ancillary benefits, then the optimal carbon price would be set *higher* than the marginal damages. Second, spillovers should be included in benefit-cost analysis just as other benefits or costs are included. In fact, from a theoretical standpoint, spillovers are indistinguishable from changes in any other input, such as labor. However, care must be taken to evaluate environmental spillovers according to their damages since market prices are not available.

Holland (2010) also extends the theoretical analysis in this section by deriving theoretical predictions. In particular, both the input demand and conditional input demand must be decreasing in the own price and output effects must be negative. These predictions will aid in the identification of empirical models.

5.3   Estimation Strategy

Spillovers resulting from responses to climate policy cannot be directly estimated in industries that are not yet subject to climate policy. Moreover, in industries currently subject to climate policy, it would be difficult to dis-

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8. Burtraw et al. (2003) note that the falling NO_x price may have benefits from avoided future control equipment.

entangle the effects of climate policy from the effects of other environmental regulations.

To overcome these difficulties, I exploit the symmetry of input substitution and estimate the response of CO_2 emissions to the change in the price of NO_x emissions.[9] This has two advantages. First, NO_x emissions have been regulated extensively so it is possible to design an estimation strategy with variation in NO_x regulations. Second, CO_2 was not regulated, so there is no need to disentangle the effects of the NO_x regulation from CO_2 regulation. To proxy for changes in NO_x prices, I use changes in attainment status under the Clean Air Act Amendments (CAAAs). Regions that fail to achieve an ambient air quality standard are deemed to be in nonattainment. Designation as nonattainment under the CAAAs triggers additional regulations, which vary according to each state's implementation plan (SIP).[10] In this study, attainment status for one-hour ozone proxies for the price of NO_x, which is a primary ozone precursor. Since California had multiple changes into and out of attainment, the analysis focuses on California power plants.

The estimation strategy uses a fixed effects estimator. The basic estimating equation is:

(1) $$\ln(Emiss_{it}) = \beta Nonattain_{it} + f_i + g_i t + v_{jt} + \varepsilon_{it},$$

where $Emiss_{it}$ is emissions (of NO_x, CO_2, or SO_2) from generating unit i at time t; $Nonattain_{it}$ is a dummy variable indicating that unit i is in nonattainment for one-hour ozone at time t; f_i is a unit-specific fixed effect; $g_i t$ is a unit-specific linear trend; v_{jt} is a market-year-month fixed effect for market j; and ε_{it} is the error term. To correct for possible serial correlation, the error term, ε_{it}, is clustered at the generating unit.

The parameter of interest, β, indicates the response of emissions to a change in attainment status. Since the nonattainment dummy is a proxy for an increase in the price of NO_x emissions, the estimated coefficient captures the own price effect when NO_x emissions is the dependent variable. With CO_2 emissions as the dependent variable, the estimated coefficient captures the spillover. A positive (negative) coefficient indicates that NO_x and CO_2 are gross substitutes (complements). The own and spillover conditional (net) effects can be estimated by controlling for output in equation (1), and the output effect can be estimated directly when output is the dependent variable.[11]

9. Exploiting symmetry requires care since it only holds for marginal changes. See Holland (2010) appendix 2 for details on the symmetry of input substitution.

10. For detailed descriptions of the regulatory effects of nonattainment designation under the CAAAs, see Greenstone (2002).

11. By estimating $\ln(Emiss_{it}) = \beta^c Nonattain_{it} + \beta^{MWh} \ln(MWh_{it}) + f_i + g_i t + v_{jt} + \varepsilon_{it}$ and $\ln(MWh_{it}) = \beta' Nonattain_{it} + f_i + g_i t + v_{jt} + \varepsilon_{it}$ in addition to equation (1), all four derivatives in the Slutsky equation in Holland (2010) appendix 2 are estimated separately. However, the identity $\beta = \beta^{MWh} \beta' + \beta^c$ holds since the sample and all conditioning variables are identical.

Most of the potentially confounding variation is controlled for by the fixed effects. The unit-specific fixed effects capture any differences in emissions across units due to fuel-mix, generation technology, generator capacity, installed emissions control equipment, or any other time-invariant characteristics of the generating units. The unit-specific linear trends capture any trends at the unit level, for example, phasing out of old units. The market-year-month fixed effects are a vector of indicators for each month of each year for each market; for example, one indicator is for January 1999 for the northern California market (NP15) and another indicator is for January 1999 for the southern market. The market-year-month fixed effects capture all variation over time such as seasonal effects and changes in relative fuel prices, in labor costs, in capital costs, and in regulations affecting all generators as well as differences across the markets. This flexible set of fixed effects captures most of the potentially confounding effects.

Given this extensive set of nonparametric controls, model identification is based on variation in the attainment status of generating units over time in the sample. Intuitively, the generating units with unchanged attainment status would serve as controls for the generators with changed attainment status (the treated group).[12] The estimated effect would be biased if there were unobserved differential trends in emissions that were correlated with the change in attainment status. This threat to identification is addressed in two ways. First, the multiple changes into and out of attainment in California diminish the potential for bias from unobserved trends. Second, the model incorporates unit-specific linear trends to control for any unit-specific trends, which would not be captured by the market-year-month fixed effects.

The estimated spillover effect could also be incorrectly identified if regulatory authorities used the additional statutory authority to attempt to reduce emissions of other pollutants. In this case, changes in attainment status would indicate variations in the prices of both NO_x emissions and other pollutants, and the estimated effect would combine the direct and spillover effects. This potential confounding is limited by analyzing spillovers on CO_2 emissions. During the sample period, there was still substantive disagreement over whether CO_2 was a harmful pollutant and CO_2 was neither listed nor regulated by the Environmental Protection Agency (EPA) as a criteria pollutant. This lack of regulatory attention to CO_2 emissions suggests that the nonattainment indicator is not a proxy for an increase in the price of CO_2 emissions and that the spillover effect is properly identified.[13]

Identification is supported further by the testable predictions from theory. In particular, Holland (2010) shows that own price effects are nonpositive

12. With change at one time in attainment status, the estimator would be similar to the well-known difference-in-differences estimator.
13. This argument does not hold for SO_2 emissions.

for both factor demands and conditional factor demands and that output effects are nonpositive. A nonpositive estimate of β in equation (1) with NO_x emissions as the dependent variable is consistent with the theoretical predictions. With CO_2 emissions as the dependent variable, there are no additional testable implications since cross price effects can be either negative or positive.

5.4   Data

This analysis requires data on emissions, generation, attainment status, and other regulations. Availability of the emissions data limit the sample to the years 1997 to 2004. Emissions data come from the hourly US EPA continuous emissions monitoring systems (CEMS) for power plants. The data are very accurate, include all fossil fuel-fired generators meeting certain requirements, and have been used in a number of studies.[14] The hourly generating unit-level data are aggregated to the month for three reasons. First, a number of units report emissions in hours for which they report no output. Aggregation accurately captures emissions and output while incorporating any start-up emissions from generating units. Second, if regulations caused a unit to be run fewer hours, disaggregated data would not capture this reduction with the proportional (log) estimating equations. Aggregation captures the zero production hours. Finally, the data are highly serially correlated. Aggregation reduces the problem of serial correlation.

Since California had the most variation in attainment status, the primary analysis focuses on California. Of the twelve counties in California with changes in attainment status, only three counties have relevant power plants: Contra Costa, San Francisco, and San Diego. After dropping nonreports and data inconsistencies, the model identification is based on changes in attainment status at 29 of 178 generating units. The data are discussed further in Holland (2010).

5.5   Estimation Results

The results from estimating equation (1) are presented in table 5.1. Each column reports the results from one of seven regressions. Column (1) reports estimates where $\ln(NO_x)$ is the dependent variable, that is, the NO_x factor demand, and columns (3) and (5) capture the factor demands for CO_2 and SO_2. Columns (2), (4), and (6) estimate the conditional factor demands since they control for output, that is, $\ln(MWh)$. Column (7) reports estimates from regressing output on the same set of controls. Throughout, the unit fixed

14. For example, see Puller (2007), and Holland and Mansur (2008).

Table 5.1   **Main results: California results for NO_x, CO_2, and SO_2 emissions and megawatt hours**

	ln(NO_x)		ln(CO_2)		ln(SO_2)		ln(MWh)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Nonattain	–0.516**	–0.221*	–0.326*	0.003	–0.371**	–0.037	–0.365*
	(0.203)	(0.131)	(0.190)	(0.030)	(0.170)	(0.132)	(0.200)
ln(MWh)		0.809**		0.900**		0.897**	
		(0.016)		(0.010)		(0.013)	

Notes: There are 8,239 monthly observations for 178 generating units. (8,188 observations for the SO_2 regressions.) Dependent variable is log of emissions or log of MWh of generation. Regressions additionally control for market-year-month fixed effects, generating unit fixed effects, and generating unit linear trends. Standard errors clustered at the generating unit. Controls for other regulations (CO, NO_2, and eight-hour ozone nonattainment and ARP NO_x Early Election) are not jointly significant in six of the seven regressions.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

effects, unit-specific linear trends, and market-year-month fixed effects are highly significant but are not reported.

The estimates of the three testable implications, in columns (1), (2), and (7), are all negative. Thus, the regression results are consistent with the theoretical predictions. Moreover these results show that approximately half of the estimated 40 percent reduction in NO_x emissions can be attributed to substitution effects with the remainder being attributable to output effects.

The pollutant spillover effects are reported in columns (3) through (6). For CO_2, the point estimate indicates that nonattainment designation reduced CO_2 emissions by 30 percent, suggesting gross complementarity. Controlling for output, the point estimate is very near zero. This suggests that almost all of the reduction in CO_2 emissions can be attributed to output effects. Similarly, the results for SO_2, columns (5) and (6), also indicate gross complementarity almost entirely due to output effects. The coefficient for the output effect in column (7) estimates a 30 percent reduction in output with nonattainment designation.

The coefficients on output in (2), (4), and (6) imply emissions elasticities for the three pollutants of 0.8 to 0.9. These estimates are statistically less than one implying that the emissions rates (emissions per MWh) are declining in output. However, the limited net effects suggest that the emissions rates do not vary substantially with changes in prices of other environmental inputs, that is, pollutant spillovers do not change emissions rates.[15]

Table 5.2 splits the sample into old and new plants based on the average age of the plants' units. These results show that the reductions in table 5.1

15. Holland (2010) presents additional specifications and robustness tests.

Table 5.2   **Old and new plants: California results for NO_x, CO_2, and SO_2 emissions and megawatt hours**

	$\ln(NO_X)$		$\ln(CO_2)$		$\ln(SO_2)$		$\ln(MWh)$
Panel A: Old plants (average start year before 1980). 5,566 observations with 89 units.							
Nonattain	–0.715**	–0.297*	–0.462**	–0.011	–0.325*	0.124	–0.511**
	(0.230)	(0.159)	(0.198)	(0.020)	(0.174)	(0.140)	(0.222)
$\ln(MWh)$		0.817**		0.883**		0.887**	
		(0.018)		(0.012)		(0.013)	
Panel B: New plants (average start year after 1995). 2,673 observations with 89 units.							
Nonattain	0.154	0.090	0.044	–0.037	–0.536	–0.615*	0.085
	(0.445)	(0.279)	(0.507)	(0.053)	(0.517)	(0.364)	(0.495)
$\ln(MWh)$		0.754**		0.957**		0.926**	
		(0.037)		(0.022)		(0.030)	

Note: Regressions additionally control for other regulations, for market-year-month fixed effects, for generating unit fixed effects, and for unit-specific linear trends.

come primarily from the reductions in output and emissions at older plants. Since newer plants are less polluting, they use the NO_x input more efficiently and thus did not reduce output in response to the change in attainment status.

The results are subject to three additional caveats. First, the power of the test is reduced since electric power generators were likely not the marginal polluter targeted by the change in attainment status. In particular, the state implementation plans (SIPs) for reducing NO_x emissions do not focus on electric power generation. Second, the estimates cannot control for local economic conditions that may have been correlated with changes in attainment status. Finally, the symmetry assumption requires care in interpreting the coefficients as spillovers from climate policy. Although the estimates are valid estimates of spillovers from ozone policy, they are only locally valid estimates of spillovers from climate policy.

5.6   Conclusion

Spillovers from climate policy are important for policy design, modeling, and benefit-cost analysis. This chapter shows that spillovers arise from output effects (which have ancillary benefits) and substitution effects (which may have ancillary benefits or ancillary costs). The ambiguous net effect highlights the importance of polluters' responses to climate policy.

The chapter then tests for ancillary benefits from climate policy in electricity power generation. The estimates are consistent with ancillary benefits from climate policy arising primarily from reductions in output (primarily at older plants) rather than from changes in emissions rates.

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Comment   Charles D. Kolstad

This chapter addresses an important question in the economics of environmental regulation—a question often given cursory lip service but rarely the subject of rigorous analysis. When an industry is subject to emission regulations for pollutant x, there may be changes in emissions of pollutant y, due either to changes in the technology of production or changes in the quantity of the underlying good produced. For instance, regulating carbon dioxide emissions can result in changes in emissions of particulate matter.

This is an important issue on many counts. A cost-benefit analysis of a proposed regulation should appropriately take into account the benefits/costs of such spillovers. Furthermore, environmental justice issues are often important in regulatory debates and environmental justice frequently involves changes in pollutants that are not the ones being directly regulated. That is the case with carbon emissions in California. Environmental justice proponents are concerned that regulating carbon emissions will result in increases in criteria air pollutants (e.g., particulates) in low income areas of cities.

Although Professor Holland's main contribution is his empirical analysis, he does discuss the theory behind the issue of spillovers. If NO_x emissions are efficiently regulated then marginal costs and benefits from NO_x are always balanced, both before instituting a CO_2 regulation and after. Thus nonzero spillovers from CO_2 regulation in part are due to inefficient NO_x regulations.

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