NBER WORKING PAPER SERIES

THE COMPETITIVENESS IMPACTS OF CLIMATE CHANGE MITIGATION POLICIES

Joseph E. Aldy
William A. Pizer

Working Paper 17705
http://www.nber.org/papers/w17705

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 2011

We benefited from the excellent research assistance provided by Evan Herrnstadt. This research was supported by the Pew Center on Global Climate Change and Resources for the Future. Elliot Diringer, Garth Heutel, Trevor Houser, Arik Levinson, Joanna Lewis, Steve Lin, Carol McAusland, and David Popp, and seminar participants at the 2007 Mannheim Climate Policy Network meeting, the 2008 Pew Center on Global Climate Change Business Environmental Leadership Council meeting, Resources for the Future, Duke, UNC, and Harvard provided helpful comments on an earlier version of the paper. All errors and omissions remain the responsibility of the authors. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

The Competitiveness Impacts of Climate Change Mitigation Policies
Joseph E. Aldy and William A. Pizer
NBER Working Paper No. 17705
December 2011
JEL No. F18,Q52,Q54

ABSTRACT

In order to clarify ongoing debates over the competitiveness impacts of climate change regulation, we develop a precise definition that can be estimated with available domestic production, trade, and energy price data. We use this definition and a 20+ year panel of 400+ U.S. manufacturing industries to estimate and predict the effects a U.S.-only $15 per ton CO2 price. We find competitiveness effects on the order of a 1.0 to 1.3 percent decline in production among energy-intensive manufacturing industries, representing about one-third of the policy's impacts on these firms' output.

Joseph E. Aldy
Harvard Kennedy School
Taubman 382, Mailbox 58
79 JFK Street
Cambridge, MA 02138
and NBER
joseph_aldy@hks.harvard.edu

William A. Pizer
Sanford School of Public Policy
Duke University
Box 90312
Durham, NC 27708
and NBER
billy.pizer@duke.edu

I. Introduction

The debate over climate change policy has largely focused on the design of instruments that will impose a price on the emissions of carbon dioxide (CO_2) and other greenhouse gases. In the context of this debate, attention has turned to the prospect that policy instruments such as cap-and-trade and emission taxes could cause adverse competitiveness effects for energy-intensive firms in developed countries, such as in Western Europe and the United States, if they move forward with mitigation efforts while major developing countries postpone action.[1] The concerns about competitiveness are consistent with the pollution haven hypothesis that suggests that firms relocate economic activity from high regulatory cost to low regulatory cost countries.

While sometimes framed as a "jobs versus the environment" question with regard to conventional pollution (Morgenstern et al. 2002), this effect is especially troubling in the context of climate change policy. The relocation of economic activity would increase CO_2 emissions in developing countries, thereby undermining the global environmental benefits of the developed country's emission mitigation policy. That is, it is a "jobs *and* the environment" problem.

In this paper, we present evidence that the competitiveness impacts of carbon pricing would reduce production by about 1 percent, representing a small share – perhaps one-third – of the overall impact of recent climate proposals on energy-intensive industries. To draw these conclusions, we begin with a formal definition of adverse competitiveness effects, a definition that is frequently unclear in existing studies. We then derive an estimable expression for this definition and use data to calculate the effect for a unilateral U.S. emission mitigation policy on the U.S. manufacturing sector. Here, we employ a somewhat

[1] A variety of energy and climate policies could cause adverse competitiveness impacts by raising the cost of using fossil fuels, including state cap-and-trade programs (such as in California and the northeastern states), state renewable and alternative energy mandates in the power sector, and greenhouse gas regulatory mandates under the Clean Air Act.

novel empirical strategy that examines the historical relationship between energy prices and production and consumption in the U.S. manufacturing sector. Taking advantage of the fact that market-based CO_2 policy instruments such as cap-and-trade and emission taxes operate primarily by raising energy prices, we use this estimation to infer the competitiveness effect of U.S.-only CO_2 regulation.

Our approach uses idiosyncratic, within-industry energy price variation to identify the competitiveness effect defined in our theoretical section below.[2] This is akin to estimating the various elasticities used to run computable general equilibrium models that have yielded previous economy-wide competitiveness and emission leakage estimates, except that we generate results in a reduced-form regression framework of equilibrium outcomes at a much more disaggregated level (4-digit industry). In particular, through interaction terms, we allow the estimated effects to vary with the energy intensity of production, allowing us to differentiate impacts among more or less energy-intensive industries.

Our estimated model in hand, we simulate the impacts of a U.S.-only $15 per ton CO_2 price, translated into the likely changes in energy prices. We focus on $15 per ton CO_2 because the energy price changes are consistent with the observed variation in our historic energy price data; $15 per ton is also in line with prices expected under various cap-and-trade and carbon tax legislative proposals in recent years.

We find that the higher energy prices associated with this carbon price would lead to a production decline of between 3 and 4 percent among key energy-intensive sectors (e.g., iron and steel, aluminum, cement, etc.). We also find, however, that this energy price increase would cause a 2 to 3 percent decline in consumption (defined as production plus net imports). The decline in consumption reflects efforts to economize on the use of energy-intensive

[2] As discussed below, we focus on consumption and production, rather than net imports directly for econometric reasons.

manufactured commodities in end-use products and substitution to less-energy-intensive input (more below).[3] This suggests that an emission mitigation policy would induce a roughly 1 percent shift in production overseas -- our estimated adverse competitiveness effect. Put another way, as a share of the total 3 to 4 percent effect on production, the "competitiveness" component is only about one-third.

More broadly across the manufacturing sector, there is an interesting pattern. Supply declines less for less energy-intensive goods -- but always declines. Demand, however, rises for the least energy-intensive goods, reflecting the substitution noted above. For these less energy-intensive industries, the competiveness effect can actually be larger than the supply effect (net imports rise by more than supply declines). Put another way, the energy-intensive firms that have remained in the United States may be more resilient to energy price shocks than some of the less energy-intensive firms who actually see demand for their products rise. Quantitatively, the overall results suggest the competitiveness effects associated with a $15 per ton CO_2 price is consistently around 1 percent, a shift suggesting that relatively small effect (compared to annual fluctuations) to industry at the price levels we can study.[4]

Our work builds on a substantial literature that has examined the more general question of whether environmental regulations adversely affect the competitive position of American industry. Numerous theoretical analyses have suggested that environmental policy could create so-called "pollution havens" in developing countries:

[3] These estimated impacts may also reflect the limits to the capacity of foreign firms to supply more of these goods at a given price in the short run.

[4] To put the 1 percent competitiveness impact in context, the absolute value of the annual real percentage change in the value of shipments in the manufacturing sector averaged 8.8 percent during our sample. Some energy-intensive industries, such as iron and steel and aluminum, experienced annual percentage changes on average in excess of the manufacturing sector average. Other energy-intensive industries, including chemicals, paper, cement, and bulk glass, experienced annual percentage changes in value of shipments in the 5.6 to 8.0 percent range, on average.

> "The conventional wisdom is that environmental regulations impose significant costs, slow productivity growth, and thereby hinder the ability of U.S. firms to compete in international markets. This loss of competitiveness is believed to be reflected in declining exports, increasing imports, and a long-term movement of manufacturing capacity from the United States to other countries, particularly in 'pollution-intensive' industries" (Jaffe et al. 1995, p. 133).

Empirically evaluating this conventional wisdom has proven challenging (Jaffe et al. 1995; Levinson and Taylor 2008). A variety of factors may mitigate or dominate the effect of environmental regulatory costs in determining manufacturing location decisions. First, the availability of relevant factors of production, such as appropriately skilled labor, natural resources, and capital, can play a more significant role than pollution control costs (Antweiler et al. 2001). Second, transportation costs may discourage relocation to countries far from the major markets for manufactured goods (Ederington et al. 2005). Third, firms with a significant share of their investments in large, fixed physical structures also appear to move activity less in response to environmental regulations (Ederington et al. 2005). Fourth, proximity to firms that produce inputs or purchase outputs – e.g., agglomeration economies – also discourages relocation (Jeppesen et al. 2002).

Since the most pollution-intensive industries tend to be relatively immobile by these measures of "footlooseness," the empirical literature typically finds quite limited impacts of environmental regulations on international competitiveness. Recent research by Levinson and Taylor (2008) shows that U.S. pollution abatement costs in the 1970s and 1980s increased net imports in the manufacturing sector from Mexico and Canada. The estimated increase in net

imports roughly equaled about 10 percent of the total increase in bi-lateral trade for both Mexico and Canada, suggesting that other factors played much more substantial roles in the evolution of trade among the North American trading partners. An extensive literature on the competitiveness effects of variation in environmental policies across the U.S. states has shown more significant impacts on domestic firm relocation resulting from variation in the stringency of environmental regulations (Henderson 1996; Greenstone 2002). Recent work by Kahn and Mansur (2010) finds even larger effects looking at adjacent counties. The larger *domestic* competitiveness impacts may reflect the fact that labor costs and availability of capital do not vary much across the U.S. states and counties, and transportation costs are less important, relative to the international context.

This empirical literature has focused on retrospective analyses of U.S. environmental regulations. The absence of a domestic CO_2 regulatory or taxation regime precludes us from taking exactly the same approach. The popular alternative has been to use applied computable general equilibrium models to simulate potential competitiveness impacts of pricing carbon (IPCC 2001). While informative, this approach suffers from assumed rather than estimated parameters and insufficient detail to break out differences in behavior or results among industries with different energy intensities. Indeed, it is typical to make a common set of assumptions that yield a common response across the entire manufacturing industry to a carbon pricing policy. As our analysis shows below, this approach can underestimate the impacts on the more energy-intensive manufacturing industries. Furthermore, these CGE models focus on aggregate estimates of emission leakage, not effects on individual industries.

To motivate our empirical analysis, the next section presents an analytical model of the competitiveness impacts of environmental regulations – particularly the case of climate change, where we distinguish between the absence of foreign regulation (where global coordination on a regulatory regime is the benchmark)

versus the presence of domestic regulation (where zero regulation is the benchmark). Section three presents our empirical methods and data. Then we present the results of our empirical analyses of the relationships between energy prices and production and consumption. Section five illustrates the results of our simulation of a near-term unilateral U.S. CO_2 mitigation policy on the U.S. manufacturing sector. The final section concludes with comments on future research and implications for policy design.

II. Definition of the Competitiveness Effect

In order to define the competitiveness effect, we have to consider the benchmark or counterfactual where we presume there is no such effect. Studies of the competitiveness impacts of conventional local pollution regulation usually examine the effect of domestic regulation against a static, largely unregulated, environment. That is, the counterfactual is no regulation anywhere. However, an effective international climate change effort will require significant regulation by all countries. Recent studies show that even reducing developed countries' greenhouse emissions to *zero* by 2050, will not be sufficient for global attainment of moderate mitigation goals if developing countries take no action (Blanford et al 2009). For this reason, we employ an assumption of comparable regulation in all countries as our climate policy benchmark. That is, we ask what happens when a particular country acts when *everyone should be acting*, versus conventional studies that ask what happens when a particular country acts against a backdrop of *no one acting*.

From a U.S. perspective, this benchmark means we need to distinguish between the effects on U.S. manufacturing associated with U.S.-only regulation versus a global CO_2 pricing regime. Global regulation would still cause a shift in production towards less carbon-intensive products and processes, with a corresponding decline in those products and processes with high emissions. If

U.S. and foreign firms face comparable CO_2 pricing policies -- effectively ensuring a so-called level playing field with respect to climate policy -- then any decline in production in carbon-intensive U.S. firms would not be considered a competitiveness effect. The true notion of a competitiveness effect is therefore the difference between this outcome and what happens to U.S. firms with U.S.-only regulation.

To further elaborate this definition, consider a simple model of market equilibrium:

$$(1)\quad D(p) = S(p, r_{US}) + NI(p, r_{FOR})$$

where $D(p)$ is domestic demand as a function of domestic market price p, $S(p, r_{US})$ is domestic supply as a function of domestic market price p and domestic regulation r_{US}, and $NI(p,r_{FOR})$ is foreign supply (net imports) as a function of domestic price p and foreign regulation r_{FOR}. We make the standard assumptions that $D_p < 0$, $S_p > 0$, $NI_p > 0$, $S_r < 0$, $NI_r < 0$ (that is demand is downward sloping, supply and net imports are upward sloping, and regulation increases costs).

Now imagine a global climate regime that increases r_{US} to $r'_{US} = r_{US} + \Delta r_{US}$ for domestic producers and r_{FOR} to $r'_{FOR} = r_{FOR} + \Delta r_{FOR}$ for foreign producers. Taking the total derivative of (1), we can solve for the change in price under global regulation, Δp_0:

$$(2)\quad \Delta p_0 = \frac{S_r(p, r_{US})\Delta r_{US} + NI_r(p, r_{FOR})\Delta r_{FOR}}{D_p(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})}$$

This implies a corresponding change in domestic supply associated with global regulation ΔS_0:

(3)

$$\Delta S_0 = S_r(p, r_{US})\Delta r_{US} + S_p(p, r_{US})\Delta p_0$$
$$= \frac{D_P(p)}{D_P(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})} S_r(p, r_{US})\Delta r_{US} + \frac{S_P(p, r_{US})}{D_P(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})} NI_r(p, r_{FOR})\Delta r_{FOR}$$

Note that the sign of expression (3) is ambiguous: the first term is negative and the second positive. Unless foreign regulation has a larger effect than domestic regulation on the domestic market, the net effect will be negative. This is shown graphically in Figure 1, where the left panel shows domestic supply and demand and the right panel shows net imports. Δp_0 is the vertical change in price, and ΔS_0 the horizontal change in supply, associated with global regulation. The horizontal lines across the two panels reflect the equilibrium prices, with and without regulation, where net imports equal the difference between domestic demand and supply. While the general case is ambiguous, Figure 1 shows the (conventional) negative effect on domestic supply from global regulation.

Assuming $r\square_{FOR}$ and $r\square_{US}$ are considered appropriate responses under a global climate agreement, we would not look at the decline ΔS_0 as a competitiveness effect. That is, it does not represent an adverse effect on U.S. firms arising from the absence of regulations abroad. So where is the competitiveness effect? Now consider what happens if there is *no* foreign regulation. From (2), we have a price change from U.S.-only regulation of Δp_1:

$$(4)\ \Delta p_1 = \frac{S_r(p, r_{US})\Delta r_{US}}{D_p(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})}$$

and a domestic supply change from U.S.-only regulation of ΔS_1:

$$\Delta S_1 = S_r(p, r_{US})\Delta r_{US} + S_p(p, r_{US})\Delta p_1$$

$$(5) \quad = \frac{D_P(p)}{D_P(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})} S_r(p, r_{US})\Delta r_{US}$$

This is shown graphically in Figure 2, where the right panel again shows net imports and the left panel shows domestic supply. Δp_1 is the vertical change in price, and ΔS_1 the horizontal change in supply, now associated with U.S.-only regulation.

Given the second term in Equation (3) is positive, we know that $\Delta S_1 < \Delta S_0$ and the difference is negative:

$$(6) \quad \Delta S_1 - \Delta S_0 = -\frac{S_P(p, r_{US})}{D_P(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})} NI_r(p, r_{FOR})\Delta r_{FOR}$$

This is what we define as the competitiveness effect (CE) – the equilibrium difference in domestic supply owing to the *absence* of foreign regulation. In Figure 2, where a small circle on the *x*-axis indicates supply with global regulation from Figure 1, this difference is labeled *CE*.

Given this relates to the absence of foreign regulation, not surprisingly, we can understand this expression as the negative of the effect of *foreign-only* regulation on domestic supply (e.g., compare to Equation (3)). This is the "missing" element when the U.S. acts alone to regulate a global pollutant associated with goods that compete in a global market, absent comparable actions by other nations. While this measure depends on events abroad – notably the vertical shift in net imports, $NI_r(p,r_{FOR})\Delta r_{FOR}$ – it is fundamentally about the effect on U.S. firms.

In the context of empirical analysis, if our data allowed us to construct a proxy measure of foreign regulation, we could quantify this reduced-form effect directly. We could estimate the coefficient on foreign regulation in a regression with domestic production as the regressand and both domestic and foreign regulation as the regressors (e.g., Equation (3)). The product of this foreign regulation coefficient estimate and a value of the absent foreign regulation would yield our measure of a competitiveness effect from comparable U.S.-only regulation. Unfortunately, such data are not available and, instead, we are confronted with the question of how we might estimate this effect in (6) with primarily domestic data.

One possibility is to focus on the effect of U.S.-only regulation on net imports. This has intuitive appeal – it appears to be the shift overseas of production, emissions, and jobs, arising from U.S. regulation that fuels the rhetoric over competitiveness in the first place – even if we know it is not exactly correct. From above, this measure equals:

$$(7)\ \Delta NI_1 = \frac{NI_p(p, r_{FOR})}{D_p(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})} S_r(p, r_{US}) \Delta r_{US}$$

How does this relate to the true competitiveness effect in (6)? We can rewrite the two expressions (6) and (7) as:

$$(8)\ \Delta S_1 - \Delta S_0 = -\left(\frac{S_P(p, r_{US}) NI_p(p, r_{FOR})}{D_P(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})} \right) \left(\frac{NI_r(p, r_{FOR}) \Delta r_{FOR}}{NI_p(p, r_{FOR})} \right)$$

and

$$(9)\ \Delta NI_1 = \left(\frac{S_p(p, r_{US}) NI_p(p, r_{FOR})}{D_p(p) - S_p(p, r_{US}) - NI_p(p, r_{FOR})} \right) \left(\frac{S_r(p, r_{US}) \Delta r_{US}}{S_p(p, r_{US})} \right)$$

where the first term is opposite in sign but otherwise the same in both expressions and the second term equals the (negative of the) vertical supply shift associated with regulation in foreign (8) and domestic (9) markets (the change in supply divided by the *dq/dp* slope). Therefore, the effect of domestic regulation on net imports will reflect the true competitiveness effect to the extent the marginal cost increase is the same for domestic and foreign producers. A larger cost increase for foreign producers means we underestimate the competitiveness effect; a smaller increase for foreign producers means we overestimate the competitiveness effect. Figures 1 and 2 show the case where these vertical shifts are the same and the change in net imports with U.S.-only regulation equals the true competitiveness effect.

We believe it is reasonable approximation to assume that domestic and foreign climate change regulation should have comparable impacts on the marginal costs of production for domestic and foreign manufacturers. First, it is likely that governments will implement policies that deliver comparable carbon prices. This may reflect a harmonized carbon tax, as some economists have advocated (Cooper 2007, Nordhaus 2007). It could reflect the linkage of domestic emission mitigation policies that result in a common clearing price in tradable allowance markets (Jaffe and Stavins 2010). It could also reflect implicit price coordination among nations as they develop and implement their domestic emission mitigation policies (Pizer 2007). The threat of imposing a carbon tax on imports from unregulated foreign producers may also induce regulatory convergence across nations.

Second, comparable carbon prices would likely yield comparable increases in the marginal cost of production in the manufacturing sector. The energy-intensity of manufacturing is fairly similar by industrial activity across developed countries. Given the extensive investment in new manufacturing capacity in China over the past decade, the characteristics of the production technology in China are approaching those of the developed world – particularly those destined for competitive export markets. For example, the energy intensity of advanced cement manufacturing in China exceeds the average international advanced cement manufacturing intensity by less than 6 percent (Tsinghua University of China 2008). The energy intensity of blast-oven furnace steel manufacturing in China is a few percentage points better than that of the United States, although U.S. electric arc furnace technology still requires less energy than Chinese plants (Hasanbeigi et al. 2011).

In the event that cost increases from a notion of equitable global regulation *do* differ significantly across nations, then our measures would yield a biased estimate. If foreign producers have lower marginal compliance costs, then the price increase from foreign regulation would be lower and the expression (7) would provide an overestimate. If foreign producers have higher marginal compliance costs (e.g., suppose an identical carbon price across nations raises production costs more in Chinese manufacturing because of higher energy intensities), then the larger foreign cost increase suggests (7) is an *under*-estimate of the competitiveness effect in (5). In the end, we believe that, to a first order, cost increases are likely to be similar, and our use of net import effects from U.S.-only regulation should provide a reasonable estimate of the true competitiveness effect.

III. Methods and Data for Empirical Analysis

We are ultimately interested in a reduced-form estimate of the impact of U.S. regulation on net imports in Equation (9), e.g. the coefficient on regulation in a regression with net imports on the left-hand side. We do not directly estimate a net imports regression, however, because of the large variation in industry size and the variation in the sign of net imports in our data (which prevents a direct log transformation). We considered two possible alternatives: (1) estimating separate regressions in logarithms for domestic supply and demand, then looking at differences in relevant coefficients, and (2) estimating one regression using net imports as a share of domestic supply (which has been the traditional approach in the literature). Given $NI = D - S$, the relationship among these various approaches and the implied derivative of net imports (with respect to regulation R) can be expressed as:

$$(10)\quad \left(\frac{1}{S}\right)\frac{\partial NI}{\partial R} = \frac{\partial \ln D}{\partial R} - \frac{\partial \ln S}{\partial R} + \left(\frac{NI}{S}\right)\frac{\partial \ln D}{\partial R} = \frac{\partial (NI/S)}{\partial R} + \left(\frac{NI}{S}\right)\frac{\partial \ln S}{\partial R}$$

where $\partial NI/\partial R$ is the derivative of net imports – what we really care about, ($\partial \ln D/\partial R - \partial \ln S/\partial R$) is the difference between the derivatives of logged demand and logged supply – the estimate using approach 1, and $\partial(NI/S)/\partial R$ is the derivative of net imports as a share of domestic production – the estimate using approach 2.

Both approaches, examining $\partial NI/\partial R$ via consideration of ($\partial \ln D/\partial R - \partial \ln S/\partial R$) or $\partial(NI/S)/\partial R$, slightly misrepresent what we really care about, $\partial NI/\partial R$. This error is small when net imports as share of domestic production (NI/S) is small, something true for 75 percent of the industries in the sample (where we define small as ±15 percent). While the results for these industries are similar using either approach, the first approach using ($\partial \ln D/\partial R - \partial \ln S/\partial R$) can be corrected easily as we have an estimate of $\partial \ln D/\partial R$. In addition, the second approach breaks down when there are observations with S very small compared to NI, leading to unusually large swings in NI/S for small changes in domestic

production, something that arises for 5 industries (where NI>2S) in our sample and requires those industries to be dropped with the second approach. For that reason, we focus on the first approach using ($\partial \ln D/\partial R - \partial \ln S/\partial R$) and consider the corrected estimates in Table 2 that presents the results of our carbon pricing simulation below.

Having chosen the basic approach, we estimate a two-equation system of regressions using a sample of more than 400 U.S. industries at the 4-digit industry (SIC 1972) level of disaggregation over the 1974-1994 period. The basic regression specification takes this form of reduced-form estimates of a system of domestic supply and demand:

$$(11)\quad Y_{itk} = \alpha_{ik} + \alpha_{tk} + f(r_{US,it}; \beta_k) + \delta_k' X_{it} + \varepsilon_{itk}$$

where Y_{itk} represents the measure for outcome k – the natural logarithm of supply and demand measures (S and D in equations (1-10)) for industry i and year t; the α's are fixed effects for industries (i), and years (t); $r_{US,it}$ represents the level of U.S. "regulation" – the natural logarithm of the average electricity cost in 1987 dollars as discussed below; X_{it} is a vector of additional determinants of the industry outcome measures, including average industry tariffs and factor intensity variables (to estimate the returns to human capital and physical capital).

The two-equation system of regressions permits correlation in the residuals, a factor that must be included when we calculate our net import effect with parameters from both equations using a seemingly unrelated regression framework. In addition, we correct the standard error estimates to control for industry-specific heteroskedasticity.

Energy prices serve as a proxy for the impact of a carbon pricing regime because cap-and-trade programs and carbon taxes both would raise energy prices.

In turn, we use electricity prices as our primary measure of energy prices because electricity expenditures represented a majority of energy expenditures for 88 percent of all manufacturing industries in our sample. It is also an informative index of fossil fuel prices, since all three types of fossil fuels are used to generate electricity in our sample. In any case, we were unable to construct industry-specific price measures for other fuels.[5]

It is also worth noting that our use of energy prices as a proxy for regulatory stringency circumvents a number of problems noted in the empirical pollution haven literature, which typically use the ratio of regulatory compliance costs to value added as a proxy for the stringency of environmental regulations. Levinson and Taylor (2008) note that changes in production levels can affect this ratio of pollution abatement cost expenditures (PACE) to output and create an endogeneity problem. Production levels change this regulatory cost burden measure directly, as production or a related variable is the denominator of the PACE share. Production levels can also change the numerator of the PACE share indirectly, as changes in production affect plant turnover, scale economies, and the difficulty in meeting regulatory standards – all of which affect regulatory compliance costs. In contrast, energy prices are unlikely to be endogenous to individual industry production decisions.

Finally in our specification, industry fixed effects capture time-invariant characteristics of industries that may affect these measures of competitiveness and year fixed effects account for common shocks, such as those from monetary policy, world oil prices, etc. that affect all industries in a given period of time. Thus, identification is premised on idiosyncratic, within-industry electricity price

[5] The NBER-CES manufacturing industry database provides data on electricity expenditures and quantity of electricity consumed that allows us to construct an annual average electricity price by industry. The Annual Survey of Manufactures collected only energy expenditures data, not quantities or prices of energy, for all other fuels.

shocks, typically driven by utility- and region- specific changes over time related to where industries are located.

We consider various forms for the relationship $f(r_{US,it};\beta)$ between U.S. regulation (e.g., electricity prices) and our left-hand side variables, ranging from a simple linear function of energy prices to flexible functions that allow the energy price elasticities across industries to vary based on each industry's average energy intensity over the relevant sample period. We ultimately settle on a flexible cubic-spline approach, although we introduce the results in the next section with simpler approaches to provide context and motivation for the cubic spline. Intuitively, higher energy intensities imply larger cost impacts from rising energy prices. Viewed through the lens of carbon dioxide regulation, the very high positive correlation between energy consumption and carbon dioxide emissions implies that energy intensity is effectively a carbon pollution intensity measure. Thus, a carbon pricing regime that imposes a common marginal cost on emissions will result in heterogeneity in the compliance costs per unit of output across the manufacturing sector. Flexible estimation of the supply and demand elasticities as a function of this "pollution intensity" allows us to capture this effective compliance cost impact.

We use the value of shipments by industry from the NBER-CES manufacturing dataset developed by Bartlesman et al. (2000) as our measure of domestic supply.[6] We define demand (consumption) as domestic supply (production) plus net imports, which we construct from the NBER trade database developed by Feenstra (1996). As noted above, we undertake our analysis with these supply and demand measures in logarithms because of the significant variation in size of U.S. manufacturing industries. We define energy intensity as the ratio of all energy expenditures to value of shipments (constructed from the

[6] All measures of output, net imports, and prices have been deflated to constant 1987 dollars.

Annual Survey of Manufactures, multiple years and Bartlesman et al. 2000). For each industry, we calculate the average intensity over 1974 to 1994, as well as sub-samples for 1974-1985 and 1986-1994 as discussed in the next section. Figure 3 presents the cumulative distribution function for industry average energy intensity over 1986-1994.

We constructed electricity prices from NBER-CES data on electricity expenditures and quantity of electricity purchased.[7] We also control for average industry tariff rates, the physical capital share of value added, and the human capital share of value added, consistent with Ederington et al.'s (2005) analysis of the impacts of domestic environmental regulation on net imports. The average tariff is expressed in percentage points, and represents the average industry-level tariff based on the total duties collected multiplied by 100 scaled by total customs value (constructed from data provided by Magee and Feenstra et al. 2002). The physical capital share is represented by one minus the ratio of total payroll to value added (constructed from data provided by Bartlesman et al. 2000). The human capital share is calculated as total payroll minus payments to unskilled labor, scaled by industry value added. Payments of unskilled labor are estimated from the *Current Population Survey* as the number of workers, multiplied by average annual income of workers with less than a high school diploma (constructed from U.S. Bureau of the Census, and Bartlesman et al. 2000). For constructing a consistent dataset, we employed several concordances made available by Jon Haveman.

Let us explain why we abridge our sample at 1994. Our import data comes from Feenstra (1996), which provides us with U.S. bilateral trade by 4-digit SIC through 1994. These data require transformation due to differences between the import-based SIC codes (MSIC) and domestic-based SIC codes.

[7] We thank Wayne Gray for providing data for 1978.

Essentially, a number of SIC codes are defined by processing methods, and this information is unknown for imports. Feenstra overcomes the differences in SIC and MSIC using a weighting matrix derived from data in the U.S. Census Bureau's "U.S. Commodity Imports and Exports as Related to Output." The Census Bureau notes that this publication was "discontinued because of a significant decrease in the Census Bureau's budget in 1996 and the conversion of the SIC to the new North American Industry Classification System (NAICS) starting with the 1997 production data." Since our average tariff rate and consumption data are derived in part from these import data, we cannot reasonably extend our sample beyond 1994.

IV. Empirical Estimates of the Effects of Electricity Prices on Domestic Supply and Demand

To provide context and motivation for our preferred flexible regression specification, we first present simplified results for the domestic supply and demand models with and without linear interactions between energy price and the historic energy intensity of the industry. Without the interaction, this is akin to previous papers that regress domestic supply and/or net imports on the level of environmental compliance costs or on the ratio of environmental compliance costs to the value of shipments. In both cases, we allow for the effect of the electricity price to vary between the 1974-1985 and the 1986-1994 time periods. We establish this distinction to account for the impacts of the period of higher energy prices (1974-1985) on fuel switching (as the utility sector switched from petroleum to coal in power generation in the late 1970s and early 1980s) and on investments in more energy efficient capital in the manufacturing sector. The more recent period may also better characterize the potential impacts of a carbon pricing regime on the manufacturing sector.

The left half of Table 1 shows results without including energy intensity and is comparable to previous work, for example Levinson and Taylor (2008), Ederington et al. (2005), and Grossman and Krueger (1991). In each of these three papers, the ratio of net imports to value of shipments is regressed on the ratio of pollution abatement costs to value of shipments (or value added), as well as other controls that enter the regression equation linearly. The estimated supply and demand elasticities with respect to electricity prices are quite small, with the supply elasticities about -0.1. We cannot statistically distinguish the 1974-1985 supply elasticity from the 1986-1994 supply elasticity. The demand elasticities, interestingly, are statistically significant but the latter period has a positive sign. Our more flexible regression specifications (both the right half of Table 1 and Figure 5 below) reveal a pattern where, in response to higher energy prices, demand rises for less energy-intensive products while demand for more energy-intensive products declines. A model that restricts the response to be the same across all industries, however, ends up being weighted toward the (more numerous) less energy-intensive sectors; hence the positive sign.

Following the supply and demand estimates, we present the difference, representing the effect on net imports and, in turn, the potential competitiveness effect. Note that the standard error of the difference is considerably smaller than the standard errors of the separate estimates; this reflects significant positive error correlation across the supply and demand equations. During the 1974-1985 period, this specification suggests the reverse of a competitiveness effect; higher domestic energy prices lead to a modest decline in net imports. In the 1986-1994 period, we see a more conventional estimate suggesting net imports rise with higher domestic energy prices.

As noted, we expect the response to vary across industries based on energy intensities. The right half of Table 2 shows a simple attempt to capture this with the average energy intensity of each industry (calculated separately for

the two sub-periods) interacted with the electricity price. The result is as we would expect: industries with higher energy intensity see more negative supply and demand responses. Both interactions are highly significant. When we take their difference to compute the competitiveness effect, however, the significance vanishes. A simple linear relationship between the price elasticity and energy intensity is inadequate.

This motivates our use of a cubic spline specification for the relationship between price elasticity and energy intensity. We specify that the dependency of the energy-price coefficient on energy intensity follow a restricted cubic spline with 5 knots at the 5^{th}, 27.5^{th}, 50^{th}, 72.5^{th}, and 95^{th} quantiles of energy intensity, as suggested by Harrell (2001). A restricted cubic spline has linear segments on either end, is connected by cubic segments in the middle, and is twice differentiable everywhere. Given the high skewness of the data, we fit the spline in terms of the log of energy intensity.

We present the results of the flexible regression specifications graphically in lieu of a table of regression coefficients because of the difficulty of interpreting the spline coefficients.[8] We focus our presentation in the paper on the 1986-1994 results.[9] Figures 4 and 5 present the energy price elasticities from our domestic supply (production) and demand (consumption) regression models. The horizontal axis shows the energy intensity as measured by the ratio of energy costs to the value of shipments (as in Figure 3), with the 50^{th} and 95^{th} percentiles of the energy intensity distribution identified by vertical lines. The domestic supply-energy price elasticities presented in Figure 4 reveal a clear trend in increasing sensitivity to electricity price changes for the most energy-intensive

[8] A table of regression coefficients is available from the authors upon request.

[9] Figures for the 1974-1985 period and for specifications that do not distinguish between two periods within the 1974-1994 period are available from the authors upon request. These results look similar to the 1986-1994 period for supply and demand, with slight vertical shifts, but unlike the 1986-1994 period show no statistically significant effects of electricity prices on net imports at higher energy intensities.

industries. The median industry, in terms of energy intensity, has an estimated elasticity of about -0.16, more than twice the estimate of -0.071 in the simple linear regression model (left half of Table 1), and a 95 percent confidence interval that does not include the estimate from the simple linear regression model. The estimated elasticity at the 90th percentile of the energy intensity distribution is about -0.35, roughly five times the value estimates in the simple linear regression model.

Interestingly, a similar, but vertically shifted pattern is evident in the demand (consumption) results presented in Figure 5. Ten of the least energy-intensive industries, representing about 2 percent of the manufacturing sector, experience a statistically significant and positive impact from an increase in energy prices based on these estimates, but 98 percent of industries experience a statistically insignificant or a negative change. This is consistent with a substitution effect into less energy-intensive goods. The median industry does not experience a change in demand that is statistically different from zero. The magnitude of the demand elasticity increases substantially again for the more energy-intensive industries. The estimated elasticity at the 90th percentile of the energy intensity distribution is about -0.25, with the upper end of the distribution approaching -0.4. These two figures show that demand and domestic supply both decline with higher energy prices for the most energy-intensive firms, but that the demand response is less than the domestic supply response, suggesting some increase in net imports when energy prices increase.

Figure 6 shows this more precisely, that is, the net import impact (demand minus supply elasticity) of an energy price increase (the difference between Figures 4 and 5). Here, a 10 percent energy price increase would result in a 1 to 1.5 percent increase in net imports for most manufacturing industries, with some ranging below 1 percent and some, particularly those with energy intensity above 10 percent, exceeding 1.5 percent. As noted previously, the 95th percentile

confidence interval presented in the figure reflects the correlation in the residuals of the supply and demand regression equations that are accounted for in our seemingly unrelated regression modeling framework.

In the previous section, we discussed the fact that measuring the net import effect as the difference between the demand and supply elasticities can misrepresent the true effect when net imports are a substantial fraction of domestic supply. Correcting this is straightforward, but requires us to look at individual industries and their particular ratio of net imports to domestic supply. We now turn to that calculation in the context of a proposed CO_2 mitigation policy.

V. Simulation of Near-term Effects of a CO_2 Mitigation Policy

We can use these statistically-estimated relationships to simulate the effects of a $15 per ton CO_2 price from a unilateral U.S. climate change policy. Based on the Energy Information Administration (2008) modeling of an economy-wide cap-and-trade program, such an allowance price would increase industrial sector electricity prices by about 8 percent, which is approximately equal to a one standard deviation increase in energy prices in our sample.[10] This carbon price is similar to allowance prices expected at the start of cap-and-trade programs proposed in recent legislation, including EPA's (2009) estimate of a $13 per ton CO2 price under the Waxman-Markey Bill (H.R. 2454, 111th Congress), EPA's (2010) estimate of a $17 per ton CO2 price under the American Power Act (draft legislation from Senators Kerry and Lieberman) as well as the first year carbon tax of $15 per ton CO2 in a 2009 Republican-sponsored carbon tax bill

[10] Extrapolating impacts for higher CO_2 prices is beyond the scope of this analysis since it would reflect an out-of-sample prediction.

(H.R. 2380, 111th Congress).[11] Based on these estimated model parameters, this energy price increase then drives the domestic supply, demand, and competitiveness impacts in our simulation.

Approximating $S^{-1}\left(\frac{\partial NI}{\partial R}\right) \approx \frac{\partial \ln D}{\partial R} - \frac{\partial \ln S}{\partial R}$, Figure 7 presents the estimated competitiveness effects of a carbon pricing policy that raised energy prices reflecting $15 per ton CO2 as it varies with energy intensity; it is exactly a rescaled version of Figure 6. The competitiveness effect is on the order of about 1 percent but rises to more than 1.5 percent for the most energy intensive industries. This effect, however, is approximate because it ignores the term $\left(\frac{NI}{S}\right)\frac{(\partial \ln D)}{\partial R}$ in Equation (10).

Table 2 shows the corrected results in the context for all manufacturing and for specific sectors of the most energy-intensive industries, with the results weighted by industry-specific value of shipments (Column 5).[12] This table also provides the approximated competitiveness impacts from Figure 7 for comparison (Column 4), which we can see are quite close. The energy-intensive industries of iron and steel, aluminum, pulp and paper, cement, glass, and industrial chemicals would bear total percentage declines in domestic supply, on the order of -3.2 to -4.4 percent, in considerable excess of the manufacturing sector average of -1.4 percent (Column 2). Most of the lower domestic supply reflects lower demand, however, not an influx of net imports; the demand declines range from about -1.9 to -2.8 percent. Correcting for the relative size of supply and demand, the competitiveness effect is only 1.0 to 1.3 percent. That is, in these industries about

[11] The simulation focuses only on carbon dioxide emissions from fossil fuels. Since this represents 98 percent of all carbon dioxide emissions, and more than 80 percent of all greenhouse gas emissions in the United States, this should serve as a sufficient simulation of the impact of climate policy on U.S. manufacturing industries competitiveness. The key exception may be the cement industry, which has substantial process emissions of carbon dioxide.

[12] In constructing the group aggregates, we estimate each of the component-industry percentage change based on that industry's energy intensity, and then add up these changes based on the component-industry's share of domestic supply within the industry group.

one-third of the decline in domestic supply results from an increase in net imports. Even more narrowly defined industries could experience competitiveness impacts outside this range. The largest impact among energy-intensive industries in our simulation is alkalies and chlorine, a subset of chemicals, with an estimated competitiveness effect of 2.2 percent.

Some non-energy intensive industries experienced larger impacts where domestic consumption is much greater than domestic supply, and where domestic demand rises from a substitution effect. For example, both dolls and leather-lined clothing have effects above 3 percent. This suggests an interesting phenomenon: among the energy-intensive industries that remain in the United States, they may be somewhat more resilient to higher energy prices than less energy-intensive industries that compete with large volumes of net imports.

Given the empirical model's structure that yields common supply and demand elasticities with respect to energy prices for all industries with a comparable energy intensity, the simulation produces similar outcomes for industries with a similar energy intensity. Therefore, we cannot rule out that some individual industries with a particular energy intensity may face a larger or smaller impact than the average that we calculate.

VI. Policy Implications and Further Research

These results suggest that consumers of energy-intensive goods do not respond to higher energy prices by consuming a lot more imports. To a large part, they economize on their use of these higher-priced manufactured goods, perhaps by using less of the good in the manufacture of their finished products or by substituting with other, less energy-intensive materials. Consumers appear to pursue only a limited substitution with imports, suggesting that the imported versions of domestically-produced goods may be imperfect substitutes. Other determinants of trade flows – such as transport costs, tariffs, etc. – may limit the

substitution possibilities. Quantitatively, competitiveness effects are small in the sense that they amount for around 1 percent of supply even among energy-intensive industries. A 1 percent change in supply due to carbon pricing induced competitiveness impacts is small relative to annual fluctuations in supply that average 6 to 10 percent for energy-intensive industries. Compared to the overall effect on supply from proposed policies, this still counts for roughly one-third of the supply effect among energy-intensive domestic suppliers; in fact, it accounts for a larger portion among some *non*-energy-intensive industries. This appears to reflect a substitution across goods, from energy-intensive to non-energy-intensive, and then to non-energy-intensive imports, rather than from energy-intensive domestic production to energy-intensive imports.

Based on our findings, attempting to "protect" energy-intensive U.S. manufacturing firms from international competitive pressures through various policies may have only a limited impact on these firms. The estimated competitiveness impacts, while fairly modest at $15 per ton CO_2, suggest that policymakers may wish to explore policies that target those most likely to face adverse impacts, such as some narrowly defined industries that may face competitive pressures from abroad as their energy costs rise with a greenhouse gas mitigation policy. Indeed, given the modest magnitude of the competitiveness impacts on climate policy in our simulation, the potential economic and diplomatic costs of such policies may outweigh the benefits and commend no action.

Regardless, energy-intensive firms operating under the EU Emission Trading Scheme, a CO_2 cap-and-trade program, have lobbied extensively to receive free allowances in the post-2012 ETS. Similar firms in the U.S. have echoed this request as they have lobbied Congress during its deliberations of a U.S. cap-and-trade program in 2009 and 2010 (see Interagency Competitiveness Analysis Team 2009). The estimated competitiveness impacts in this analysis

could provide a basis for the amount of the gratis allowance allocation necessary to offset output losses associated with a reduced competitive position under climate policy. For example, if primary aluminum production declines 1.2 percent through competitiveness impacts (see Table 2), then the government could grant free allowances equal in value to 1.2 percent of their output in order to secure broader political support for the cap-and-trade program.[13]

There are limitations to these estimates. First, given the historical experience represented in the data used to estimate our model, we cannot simulate the impacts of significantly higher CO_2 prices.[14] Second, our estimates represent near-term impacts over one (or perhaps a few years). Arguably with more time to adjust, U.S. industry could fare better (if they can reduce energy usage) or worse (if they have more time to move operations). Third, even with our disaggregated data and flexible model, we still cannot flexibly capture all of the features relevant for every industry in every international trading situation. The effects for some firms and sectors could be different than what we have estimated. Fourth, in using historical data, we are necessarily assuming the past is a useful guide to future behavior. To the extent there have been or will be substantial institutional changes, this assumption is flawed.

Additional research can further inform our understanding of the competitiveness effects of climate policy. First, the EU implemented in 2005 a CO_2 cap-and-trade program covering the most energy-intensive manufacturing firms and the utility sector. A similar analysis could be undertaken (at the 2-digit

[13] This is analogous to Goulder's (2001) work showing the magnitude of free allowances necessary to fully compensate firms for the costs of climate policy. Our estimates would represent a fraction of Goulder's since these would only offset losses associated with increased net imports and not the direct costs of modifying capital to mitigate emissions. And, while such an allocation might address distributional impact, it will not avoid the underlying problem of some emissions reductions in the United States being thwarted by shifts in production overseas.

[14] It is important to note that our analysis identifies the effect of energy prices on impact and competitiveness measures after controlling for economy-wide factors. It is the residual variation after accounting for economy-wide energy price shocks that drives our results.

ISIC level) of the manufacturing sector in Europe and the simulated results could be compared with realized outcomes under the EU ETS. Second, as emission-intensive firms shed some capital and labor under climate policy, emission-lean firms may benefit by absorbing some of these factors. While some proponents of climate policy have made anecdotal claims about economic winners under CO2 regulation, a rigorous econometric analysis of industries in and beyond manufacturing could explore whether the general equilibrium capital and labor effects dominate the modest burdens emission-lean firms bear under climate policy. It may be especially interesting to also consider how a sectoral (as opposed to economy-wide) emission mitigation policy affects the allocation of capital and labor in the U.S. economy among regulated and non-regulated sectors. This could complement one of the main findings of this work that the majority of the decline in domestic manufacturing production results from declines in domestic consumption.

References

Antweiler, Werner, Brian R. Copeland, and M. Scott Taylor. 2001. "Is Free Trade Good for the Environment?" *American Economic Review* 91(4): 877-908.

Bartlesman, Eric J., Randy A. Becker, and Wayne B. Gray. 2000. "NBER-CES Manufacturing Industry Database." http://www.nber.org/nberces/nbprod96.htm.

Blanford, G., R. Richels, and T. Rutherford2009. Feasible Climate Targets: the Roles of Economic Growth, Coalition Development and Expectations. *Energy Economics* 31: S82-S93.

Cooper, Richard N. 2007. "Alternatives to Kyoto: The Case for a Carbon Tax." in: J.E. Aldy and R.N. Stavins, eds. *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World.* Cambridge, UK: Cambridge University Press, 105-115.

Ederington, J., A. Levinson, J. Minier. 2005. "Footloose and Pollution-Free." *Review of Economics and Statistics* 87(1): 92-99.

Environmental Protection Agency. 2009. EPA Analysis of the American Clean Energy and Security Act of 2009, H.R. 2454, 111th Congress. Washington, DC: EPA, June 23. http://www.epa.gov/climatechange/economics/pdfs/HR2454_Analysis.pdf

Environmental Protection Agency. 2010. EPA Analysis of the American Power Act in the 111th Congress. Washington, DC: EPA, June 14. http://www.epa.gov/climatechange/economics/pdfs/EPA_APA_Analysis_6-14-10.pdf

Feenstra, Robert C. 1996. "NBER Trade Database, Disk1: U.S. Imports, 1972-1994: Data and Concordances." NBER Working Paper no. 5515.

Goulder, Lawrence 2001.

Gray, Wayne. 2007. Personal Communication. August 22, 2007.

Greenstone, Michael. 2002. "The Impacts Of Environmental Regulations On Industrial Activity: Evidence From The 1970 And 1977 Clean Air Act Amendments And The Census Of Manufactures." *Journal of Political Economy* 110(6): 1175-1219.

Grossman, Gene M. and Alan B. Krueger. 1991. Environmental Impacts of a North American Free Trade Agreement. NBER Working Paper 3914. November.

Harrell, F. E., Jr. 2001. *Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression, and Survival Analysis*. New York: Springer.

Hasanbeigi, Ali, Lynn Price, Nathaniel Aden, Zhang Chunxia, Li Xiuping, Shangguan Fangqin. 2011. A Comparison of Iron and Steel Production Energy Use and Energy Intensity in China and the U.S. Lawrence Berkeley National Laboratory Report LBNL-4836E. June.

Haveman, John. "Industry Concordances." http://www.macalester.edu/research/economics/page/haveman/Trade.Resources/tradeconcordances.html.

Henderson, J. Vernon. 1996. "Effects of Air Quality Regulation." *American Economic Review* 86: 789-813.

Interagency Competitiveness Analysis Team. 2009. The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive, Trade-Exposed Industries. An interagency report responding to a request from Senators Bayh, Spector, Stabenow, McCaskill, and Brown. Washington, DC: U.S. Government. http://www.epa.gov/climatechange/economics/pdfs/InteragencyReport_Competitiveness-EmissionLeakage.pdf

Jaffe, Adam B., Steven R. Peterson, Paul R. Portney, and Robert N. Stavins. 1995. "Environmental Regulation and the Competitiveness of U.S.

Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature* 33(1): 132-163.

Jaffe, Judson and Robert N. Stavins. 2010. "Linkage of Tradable Permit Systems in International Climate Policy Architecture." In: J.E. Aldy and R.N. Stavins, eds., *Post-Kyoto International Climate Policy: Implementing Architectures for Agreement.* Cambridge, UK: Cambridge University Press, 119-150.

Jeppesen, Tim, John A. List, and Henk Folmer. 2002. "Environmental Regulations and New Plant Location Decisions: Evidence from a Meta-Analysis." *Journal of Regional Science* 42(1): 19-49.

Kahn, Matthew E. and Erin T. Mansur. 2010. "How do energy prices, and labor, and environmental regulations affect local manufacturing employment dynamics? A regression discontinuity approach. NBER working paper 16538.

Levinson, Arik and M. Scott Taylor. 2008. "Unmasking the Pollution Haven Effect." *International Economic Review* 49(1): 223-254.

Morgenstern, R., W. Pizer, and J.-S. Shih. 2002. Jobs versus the Environment: Is There a Trade-Off? *Journal of Environmental Economics and Management* 43(3), p. 412-436.

Nordhaus, William D. 2007. To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming. *Review of Environmental Economics and Policy* 1(1): 26-44.

Pizer, William A. 2007. "Practical Global Climate Policy." in: J.E. Aldy and R.N. Stavins, eds. *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World.* Cambridge, UK: Cambridge University Press, 280-314.

Tsinghua University of China. 2008. Assisting Developing Country Climate Negotiators through Analysis and Dialogue: Report of Energy Saving and

CO2 Emission Reduction Analysis in China Cement Industry. November 13, 2008. Center for Clean Air Policy. www.ccap.org/docs/resources/694/China%20Cement%20Sector%20Case%20Study.pdf.

U.S. Census Bureau. *Annual Survey of Manufactures*. Various editions.

U.S. Census Bureau, *Current Population Survey.* Various editions.

U.S. Energy Information Administration. 2008. "Energy Market and Economic Impacts of S.2191, the Lieberman-Warner Climate Security Act of 2007." SR-OIAF/2008-01. Washington, DC.

Tables

Table 1. Supply and Demand Regressions, Simple Models

Variable	Supply	Demand	Demand – Supply	Supply	Demand	Demand – Supply
$\ln(P_{elect})_{1974\text{-}1985}$	–0.112**	–0.163**	-0.051**	-0.045	-0.097**	-0.051**
	(0.029)	(0.029)	(0.015)	(0.030)	(0.030)	(0.016)
$\ln(P_{elect})_{1974\text{-}1985}$ × (avg energy inten) $_{1974\text{-}1985}$				-1.513**	-1.566**	-0.052
				(0.18)	(0.19)	(0.090)
$\ln(P_{elect})_{1986\text{-}1994}$	-0.071*	0.068*	0.140**	-0.111**	0.033	0.145**
	(0.034)	(0.034)	(0.017)	(0.036)	(0.035)	(0.019)
$\ln(P_{elect})_{1986\text{-}1994}$ × (avg energy inten) $_{1986\text{-}1994}$				-2.434**	-2.421**	0.013
				(0.21)	(0.22)	(0.115)
tariff (average rate)	–0.0071**	–0.0106**		-0.0066**	-0.0101**	
	(0.0013)	(0.0013)		(0.0013)	(0.0013)	
physical capital	0.22*	0.20		0.23*	0.21*	
	(0.10)	(0.10)		(0.10)	(0.10)	
human capital	0.23	0.12		0.31**	0.20	
	(0.12)	(0.11)		(0.12)	(0.11)	
R^2	0.967	0.963		0.968	0.963	
number of industries	430	430		430	430	
total observations	8,597	8,597		8,597	8,597	

Notes: Panel-corrected standard errors presented in parentheses. **, * denote statistical significance at the 1 and 5 percent levels, respectively. Regressions also include year and industry fixed effects. Standard errors associated with (supply – demand) account for correlation across equations.

Table 2. Predicted impacts of a $15/ton CO2 price on various manufacturing sectors

Industry	(1) Energy intensity	(2) Domestic Supply	(3) Demand	(4) Demand - Supply	(5) Corrected Comp. Effect	(6) CE as share of Supply
Chemicals	0.11	-3.4	-2.2	1.2	1.3	0.37
Paper	0.08	-3.2	-2.1	1.1	1.0	0.32
Iron and Steel	0.07	-3.0	-1.9	1.0	1.0	0.34
Aluminum	0.24	-4.4	-2.8	1.6	1.2	0.28
Cement	0.20	-4.2	-2.7	1.5	1.3	0.32
Bulk Glass	0.08	-3.2	-2.1	1.1	1.2	0.38
Industry average	0.02	-1.4	-0.4	1.0	1.0	0.73

Notes:

1. Columns (2) and (3) reflect estimated elasticities from Figures 4 and 5 based on the energy intensity in Column (1) (measured over 1985-1994 for each industry).
2. Corrected competitiveness effect reflects the adjustment in Equation (11); namely, adding (NI/S) × (demand effect in Column 2) to the measured "demand – supply" effect in Column (4). NI/S ranges from about 3 percent for steel and chemicals to 12 percent for aluminum, so the correction tends to be small for these industries.
3. Column (6) shows the competitiveness effect (5) as a share of the overall supply effect (2).
4. Chemicals includes industrial inorganic chemicals, SIC codes 2812-2819. Paper includes pulp, paper, and paperboard mills, SIC codes 2611, 2621, and 2631. Iron and steel includes SIC codes 3312, 3321-3325. Aluminum includes primary production, SIC code 3334. Cement includes hydraulic cement, SIC code 3241. Bulk glass includes flat glass, SIC code 3211.
5. The $15/ton effect is translated into an 8% increase in electricity prices predicted under a carbon pricing policy in EIA (2008).
6. For multi-industry aggregates, results are weighted by the average value of shipments (1985-1994) among constituent 4-digit SIC industries.
7. Due to rounding, the values in Column (4) may not exactly equal the apparent difference in Columns (2) and (3).

Figures

Figure 1: Effect of global carbon regulation on domestic price, domestic supply, and net imports

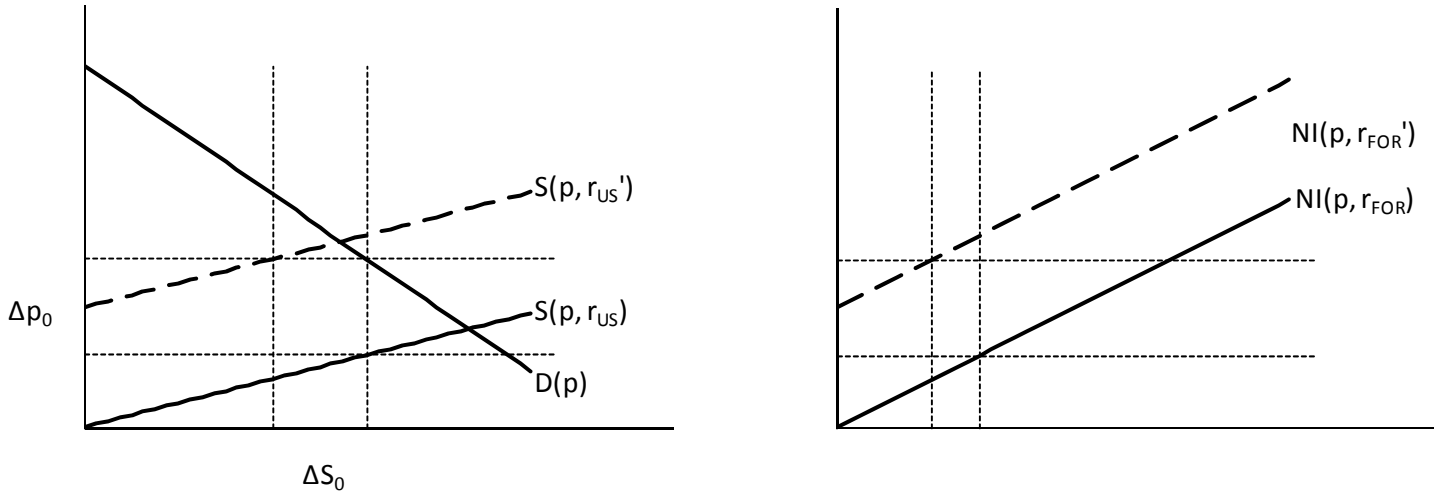


Figure 2. Effect of U.S.-only regulation on domestic price, domestic supply, and net imports

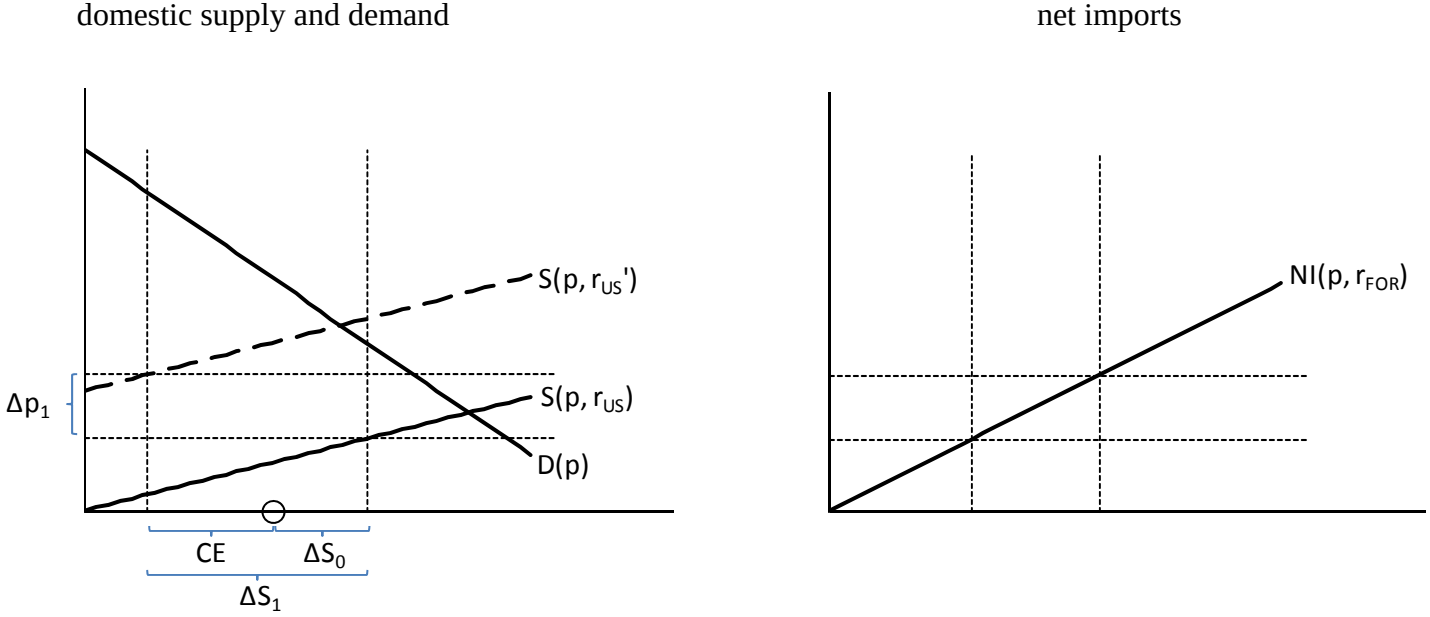
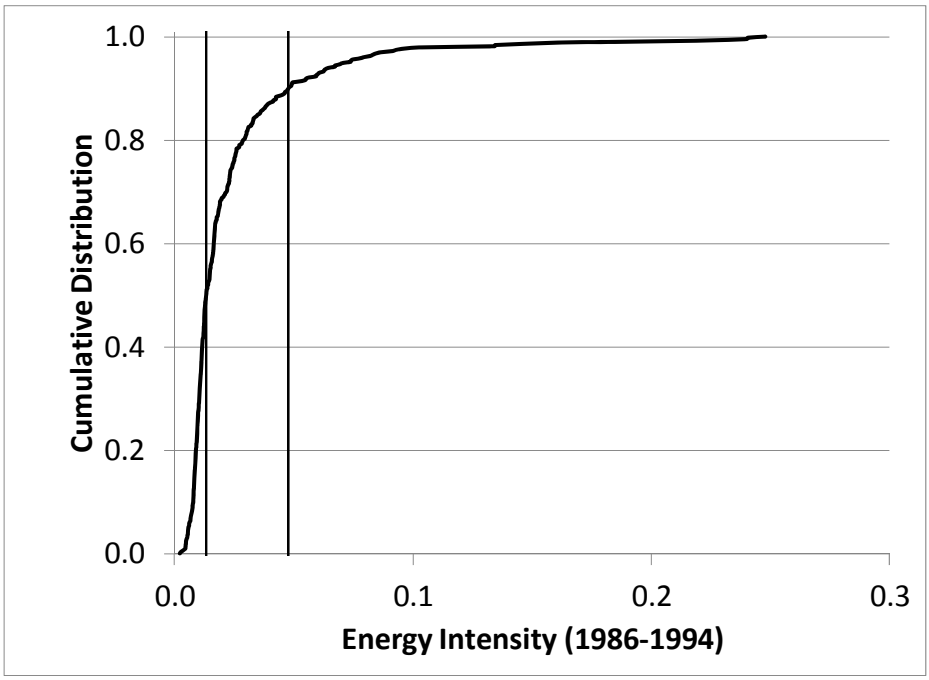
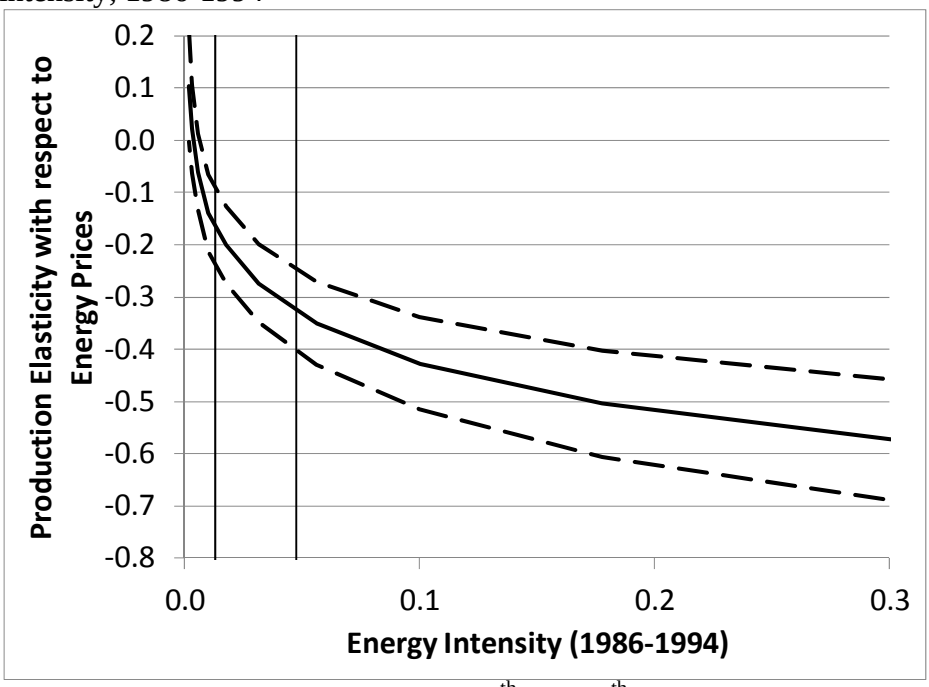


Figure 3. Distribution of 400+ industry classifications by energy intensity



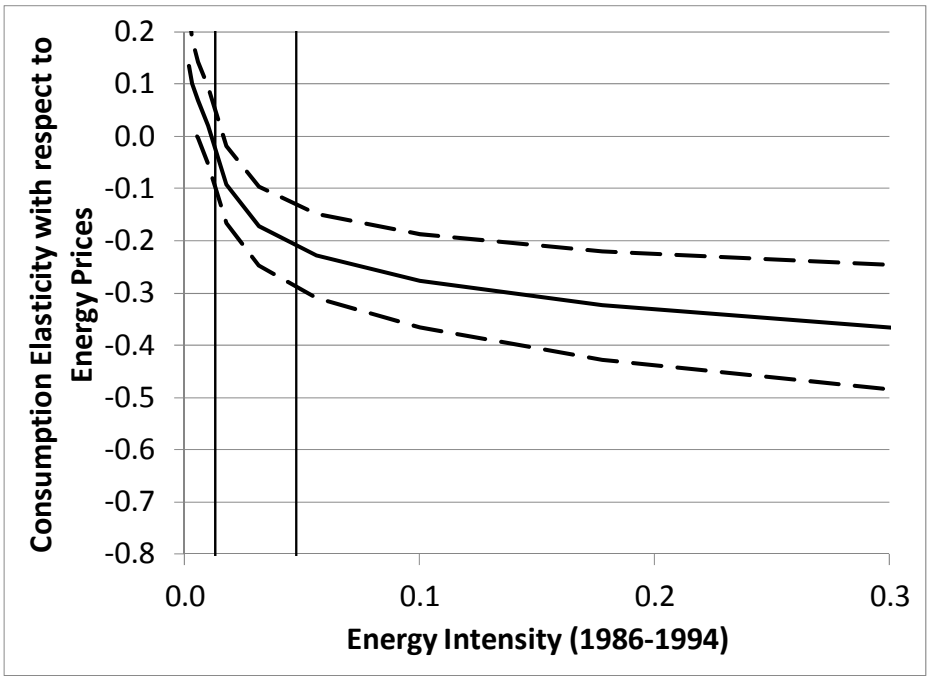
Notes: The vertical lines present the 50th and 90th percentiles of the manufacturing sector energy intensity distribution.
Source: Constructed by authors from Annual Survey of Manufactures.

Figure 4. Estimated domestic supply-energy price elasticities as a function of energy intensity, 1986-1994



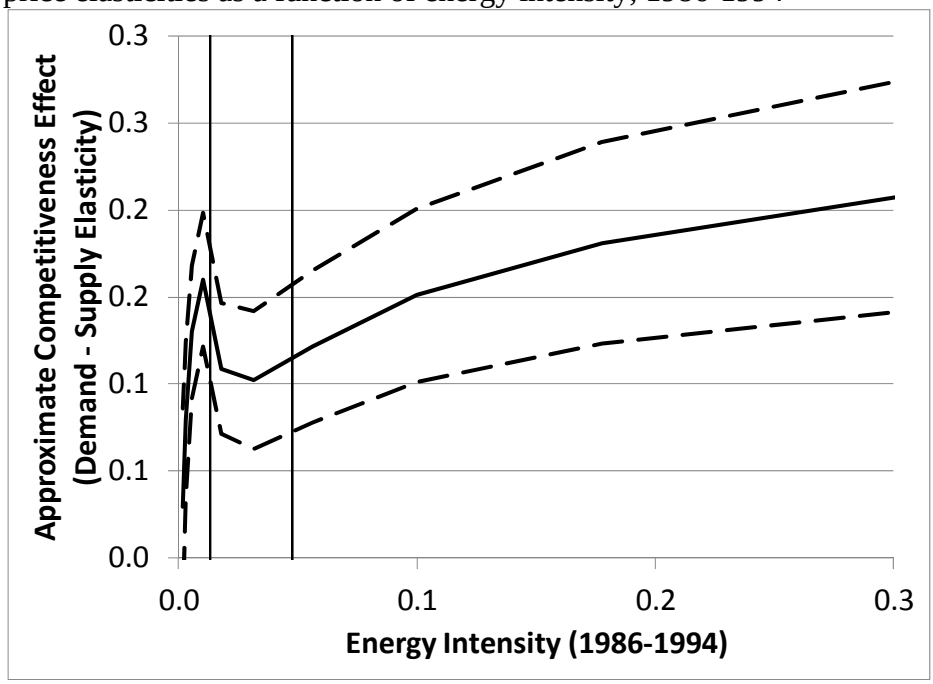
Notes: The vertical lines present the 50th and 90th percentiles of the manufacturing sector energy intensity distribution. The dashed lines present the 95 percent confidence interval.

Figure 5. Estimated demand-energy price elasticities as a function of energy intensity, 1986-1994



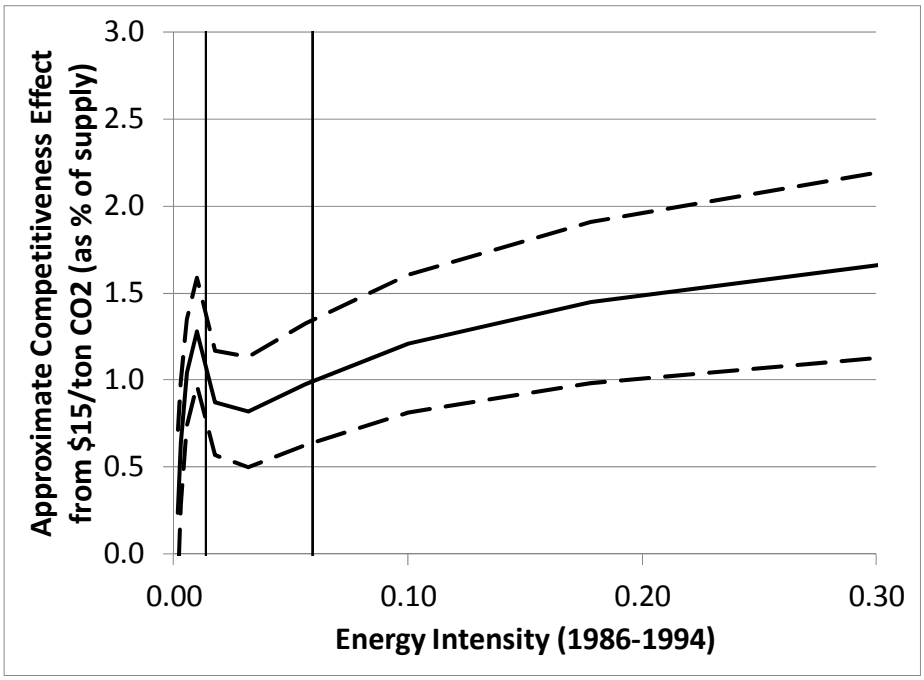
Notes: The vertical lines present the 50th and 90th percentiles of the manufacturing sector energy intensity distribution. The dashed lines present the 95 percent confidence interval.

Figure 6. Approximate competitiveness effect / estimated (demand – supply)-energy price elasticities as a function of energy intensity, 1986-1994



Notes: The vertical lines present the 50th and 90th percentiles of the manufacturing sector energy intensity distribution. The dashed lines present the 95 percent confidence interval.

Figure 7. Simulated competitiveness effects of a $15 per ton CO_2 price, based on 1986-1994 model



Notes: The vertical lines present the 50th and 90th percentiles of the manufacturing sector energy intensity distribution. The dashed lines present the 95 percent confidence interval.