Beyond the Uniform Carbon Price

Topic: Input-Output Analysis: Price evolution and policies (2)
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Research Question: How might we use input output techniques to estimate the marginal abatement cost for carbon by industry sector in an economy?

Methods Used: Structural Decomposition Analysis (SDA) Combined with Partial Hypothetical Extraction (PHE)

Data Used: IMPLAN Data for creation of input output models for the states of Louisiana, Mississippi, and Florida as well as the United States. Z matrix data are exported from IMPLAN and custom input output tables are created in Python.

Novelty of Research: Using the combination of SDA and PHE to estimate marginal abatement cost of carbon by sector.

Designing efficient carbon pricing policies requires accounting for the heterogeneity in mitigation costs across economic sectors and regions. This study provides a comprehensive analysis of carbon abatement costs for 85 sectors (approximately three digit NAICS) across Louisiana, Mississippi, Florida, and the United States, combining Structural Decomposition Analysis with Partial Hypothetical Extraction methods to capture both direct and indirect economic effects.

The approach works as follows: First, we use Structural Decomposition Analysis (SDA) (Miller and Blair 2022) to decompose total carbon emissions into their constituent driversâ€”emission intensity, technology (captured by inter-industry relationships), and final demand. Second, we apply Partial Hypothetical Extraction (PHE) by Dietzenbacher and Lahr (2013) to simulate what happens when we constrain a specific sectorâ€™s output to achieve a target emission reduction. This allows us to calculate the total value-added loss across the entire economy resulting from that constraint. The ratio of this economic loss to the emission reduction gives us the marginal abatement cost for that sector.

To analyze carbon emissions, we extend this framework by introducing e, a vector of carbon emission coefficients (COâ‚‚ per dollar of output). Total emissions E can be expressed as eâ€™x, where the prime denotes transpose and x represents a vector of industry outputs. Applying the three-factor decomposition method from Miller and Blair (2022, p. 353), we obtain

Î”E=1/2 Î”e(L^0 f^0+L^1 f^1)+1/2 [e^0 Î”Lf^1+e^1 Î”Lf^0]+1/2 (e^0 L^0+e^1 L^1)Î”f   (1)

An analogous equation is also created for value added where Î”V is the total change in value added based on substituting v, a vector of value added coefficients in place of e.

To estimate the cost of emission reductions, we employ the partial extraction technique developed by Dietzenbacher and Lahr (2013). This method allows us to constrain a sectorâ€™s output by a factor Î± (where Î± = 1 means no constraint and Î± = 0 means complete extraction). The constrained Leontief inverse becomes:

(Â¯L=L-(Î±Le_k b'_k L)/(1+Î±b'_k Le_k)â€•#(2))

Where e_k is a unit vector with 1 in position k (the constrained sector) and 0 elsewhere; b'k is the kth row of the direct requirements matrix A, with the diagonal element set to zero; Î± is the constraint parameter controlling the degree of extraction. Similarly, final demand for sector k is constrained as:
(Â¯f_k=(1-Î±) f_kâ€•#(3))

The key innovation in our approach is using partial extraction to create the â€œchangesâ€• analyzed in SDA. We reinterpret the decomposition equations by setting:
(Î”L=L^0-Â¯Lâ€•#(4))

(Î”f=f^0-Â¯fâ€•#(5))

This transforms equation (1) from a historical decomposition into a projection tool. By adjusting Î± for sector k, we can determine the constraint level needed to achieve a specific emission reduction target.

The marginal abatement cost for sector k is then calculated as:

(MAC_k=(Î”V_k (Î±))/(Î”E_k (Î±))â€•#(8))

where Î”V_k (Î±) and Î”E_k (Î±) are the value-added loss and emission reduction, respectively, when sector k is constrained by factor Î±.
In practice, we calibrate Î± to achieve a one-ton reduction in COâ‚‚ emissions (Î”E=1), allowing direct interpretation of the resulting value-added loss as the marginal abatement cost per ton of COâ‚‚.

Results reveal substantial variation in marginal abatement costs, ranging from $43/ton for utilities to over $38,000/ton for lessors of nonfinancial intangible assets. We categorize sectors into four cost groups: low ($0-$300/ton), medium ($300-$800/ton), high ($800-$1,500/ton), and very high (above $1,500/ton). A critical finding for policy targeting emerges: the top five emitting sectorsâ€”utilities, government enterprises, nonmetallic mineral product manufacturing, truck transportation, and air transportationâ€”account for 74.2% of total U.S. carbon emissions, with utilities alone representing 53.5%. Importantly, these high-emission sectors predominantly fall within low to medium mitigation cost categories, presenting significant opportunities for cost-effective decarbonization. Regional analysis reveals substantial state-level variations even within sectors, with Florida consistently showing lower utility sector costs ($35/ton) compared to Louisiana ($66/