Reliability of using Periodic IO Data to Identify High Return Investments in Efficiency and Environmental Sustainability: An Examination of US Manufactured Tech Products

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Abstract

This paper identifies industries within the supply chain for 50 high-tech assembly-centric commodities that have pervasive costs and environmental impacts. Previous examinations have shown that expenditures for research and development in high economic cost areas (e.g., the cost of metal for producing a vehicle) tend to have a higher return on investment than expenditures on low cost areas. Public entities and trade associations could achieve a high return on investment by targeting research and development expenditures in such areas. The results of this analysis show that a minimum of 90.1 % of industries in the supply chain, above the 80th percentile for environmental impact, appear in 2007 and 2012 for each of the 50 commodities. For value added it is 86.4 %. Moreover, high-impact high-cost items are pervasive over time. Eleven industries in the supply chain are above the 80th percentile in both value added and environmental impact for all 50 commodities. These items affect numerous industries and people. Four industries in the supply chain are pervasive over time and across commodities: "Electric power generation…," "Oil and gas extraction," "truck transportation," and "Iron and steel mills…" These 4 represent industries in the supply chain that are high environmental impact (above the 95th percentile), high cost (above the 95th percentile in value added), and span across numerous commodities while stretching over at least a 5-year period. Research that reduces the consumption of these items or improves the efficiency of producing them will, likely, result in a high return on investment.

Introduction

Currently, there are limited studies on identifying the research efforts that might have the largest possible return on investment for public research in manufacturing.[1,2,3] The consequence is that research areas in manufacturing are frequently selected based on anecdotal evidence, intuition, and other non-scientific criteria, potentially resulting in suboptimal return on investment. Although data limitations make it infeasible or difficult to identify those investments that have the highest return, research can identify those areas that have the characteristics of a potentially high return investment. Among the few studies that examine this issue is an article by Thomas and Kandaswamy, which uses input-output analysis to identify high cost supply chain points in US manufacturing.[4] This paper builds on those findings using newly released data to examine the pervasiveness of high impact/cost industries in the supply chain.

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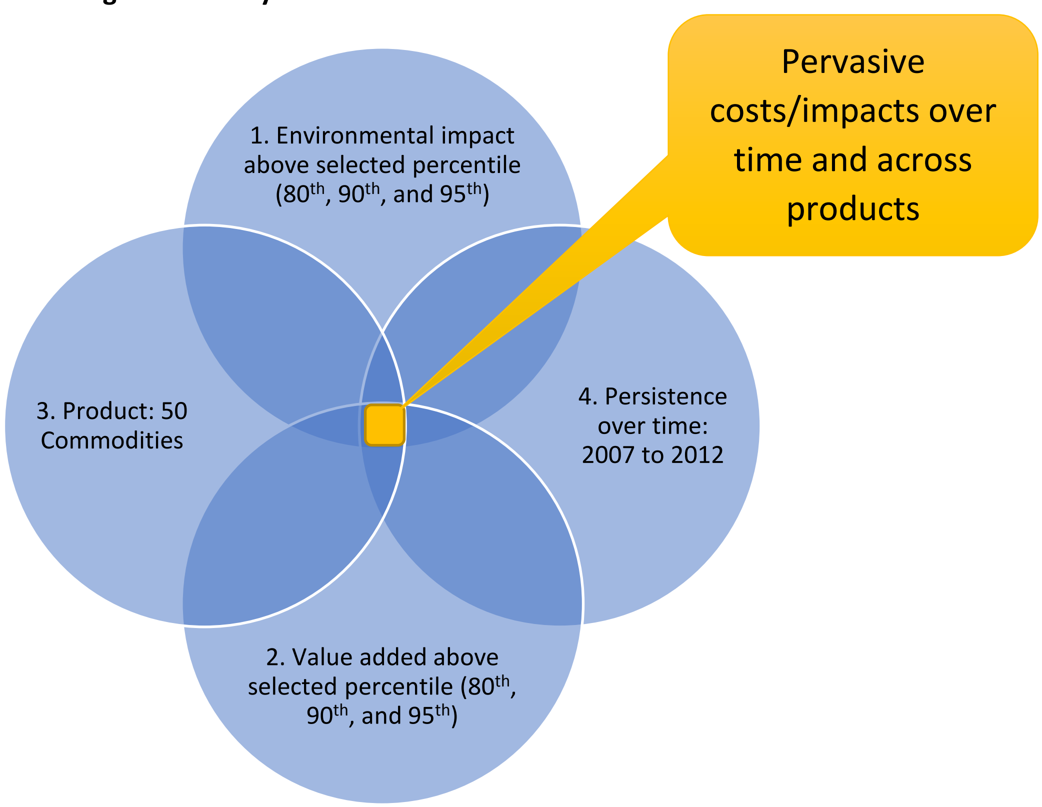
[1] Thomas, Douglas and Anand Kandaswamy. "Identifying High Resource Consumption Areas of Assembly-Centric Manufacturing in the United States." Journal of Technology Transfer. (2017).
[2] Thomas, Douglas and Anand Kandaswamy. "An Examination of National Supply-Chain Flow Time." Economic Systems Research. Vol 30, no. 3 (2017): 359-379.
[3] Thomas, Douglas. "Life-Cycle Cost of Manufactured Goods: A Case Study in US Ground Passenger Transportation." 26th International Input-Output Conference (June 2018). https://www.iioa.org/conferences/26th/papers/files/3165.pdf
[4] Thomas, Douglas Anand Kandaswamy. "Identifying High Resource Consumption Areas of Assembly-Centric Manufacturing in the United States." Journal of Technology Transfer. (2017): 1-48. https://doi.org/10.1007/s10961-017-9577-9

Trade associations along with public and private research efforts in manufacturing aim to advance efficiency by reducing inputs (e.g., material costs) and negative externalities (e.g., environmental impacts). These efforts have benefits for owners, employees, consumers, and the general public. Owners seek to increase their profits, employees wish to increase compensation, and consumers desire lower prices for higher quality products. Public entities and trade associations seek to advance those efficiency efforts that, for a variety of reasons, private entities struggle to achieve. Research by Thomas has shown that research in high cost areas tend to have a higher return on investment than research on low cost areas.[5]

This paper seeks to identify those industries in the supply chain that have the potential for a high return on investment for improving efficiency and reducing environmental impact. It not only seeks to identify those investment areas that have a large impact, but also have widespread impact across industries. It further aims to establish the reliability of using 5-year increment data to make this assessment. Detailed input-output tables are published in 5-year increments by the US Bureau of Economic Analysis (BEA) and the release of the data is 5 years after the data collection period; thus, analyses utilizing this data should be applicable over, at least, a 5-year period. This paper examines 50 finished goods and compares the results of using 2007 BEA data to that of 2012.[6] In addition to revealing the reliability, the results will reveal supply-chain industries that have a high impact across multiple industries that have been sustained over a five-year period. As illustrated in Figure 1, this

Figure 1: Venn Diagram of Analysis



[5] Thomas, Douglas. "The Effect of Flow Time on Productivity and Production." (2018). Unpublished. In Review.
[6] NAICS: The North American Industry Classification System (NAICS) is the standard used in the US for classifying business establishments.

amounts to examining the overlap of four items: environmental impact, value added (i.e., cost), commonality among commodity types, and persistence over time.

Data

Two datasets are used for this analysis. The first is the US BEA Benchmark Input-Output data. Every five years the BEA computes benchmark input-output tables, which tends to have over 350 industries.[7] The data is provided in the form of Make and Use tables, with their corresponding matrices replacing the Leontief method.[8] In the US, industries are categorized by NAICS codes. There are two types of Make and Use tables: "standard" and "supplementary." Standard tables closely follow NAICS and are consistent with other economic accounts and industry statistics, which classify data based on establishment. Note that in this context an "establishment" is a single physical location where business is conducted. This should not be confused with an "enterprise" such as a company, corporation, or institution. Establishments are classified into industries based on the primary activity within the NAICS code definitions; however, establishments often have multiple activities. An establishment is classified based on its primary activity. Data for an industry reflects all the products made by the establishments within that industry; therefore, secondary products are included. Supplementary Make-Use tables reassign secondary products to the industry in which they are primary products. This paper utilizes the industry by commodity (after redefinitions) total inputs matrix calculated by the BEA for 2007 and 2012. This is combined with data from the Make and Use tables to calculate the industry inputs required to produce a selection of 50 commodities shown in Table A1 in the Appendix.

The second data set used in this analysis is the US environmentally-extended input-output (USEEIO) data assembled by Yang et al.[9, 10, 11] This dataset provides the environmental impacts associated with the production of goods and services. A selection of the measures of impact were used in this analysis (see Table 1), which are consistent with metrics used by the US Environmental Protection Agency's TRACI tool.[12]

A single metric of environmental impact was created using weights, which are shown in Table 1. Published analyses often focus on individual environmental impacts such as water consumption or carbon emissions while others use weighted environmental effect indices that create an overall

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[7] Bureau of Economic Analysis. Input-Output Accounts Data. November 2014. Accessed September 2016. http://www.bea.gov/industry/io_annual.htm.
[8] A System of National Accounts, Studies in Methods, Series F/No. 2/Rev. 3, New York, United Nations (1968).
[9] Yang, Yi, Wesley W. Ingwersen, Troy R. Hawkins, Michael Srocka, David E. Meyer. "USEEIO: A New and Transparent United States Environmentally-Extended Input-Output Model." Journal of Cleaner Production. Vol 158, no. 1 (2017): 308-318. https://doi.org/10.1016/j.jclepro.2017.04.150
[10] US Environmental Protection Agency. USEEIO Elementary Flows and Life Cycle Impact Assessment Characterization Factors. (2018). https://catalog.data.gov/dataset/useeio-elementary-flows-and-life-cycle-impact-assessment-lcia-characterization-factors
[11] US Environmental Protection Agency. USEEIO v1.1. (2018). https://catalog.data.gov/dataset/useeio-v1-1-matrices
[12] Bare, Jane. "TRACI 2.0: The Tool for the Reduction and Assessment of Chemical and other Environmental Impacts 2.0." Clean Technologies and Environmental Policy. Vol 13 no. 5 (January 2011): 687-696.

performance score, such as used by Wier et al. (2005) or Lippiatt et al. (2010).[13, 14] This paper utilizes the overall performance score provided by Lippiatt et al. (2010). Weighted indices can vary significantly;

Table 1: Environmental Impacts Utilized in Analysis

Items to be measured	Units	Weights
Global Warming	kg CO2 eq	0.30
Acidification	H+ moles eq	0.03
HH Criteria Air	kg PM10 eq	0.09
Eutrophication	kg N eq	0.06
Ozone Depletion Air	kg CFC-11 eq	0.02
Smog Air	kg O3 eq	0.04
ecotox	CTUe	0.07
HH_can	CTUHcan	0.08
HH_noncan	CTUHnoncan	0.05
Primary Energy Consumption	thousand BTU	0.10
Land Use	acre	0.06
Water Consumption	kg	0.08

therefore, we incorporate these weights into a Monte Carlo analysis, which is discussed in the methods section.

Methods

Input-Output Analysis: This paper utilizes input-output analysis along with Monte Carlo simulation to examine 50 finished goods. An input-output analysis develops a total requirements matrix that when multiplied by the vector of final demands equals the output needed for production. The total requirements matrix is developed using the methods outlined in Horowitz and Planting:[15]

Equation 1

$$X = W(I - BW)^{-1} * Y$$

Where:
$X =$ Vector of output required to produce final demand
$Y =$ Vector of final demand, as defined in the BEA Input-Output data
$W = (I - \hat{p})D$
$B = U\hat{g}^{-1}$
$I =$ Identity matrix

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[13] Wier, Mette, Line Block Christoffersen, Trine S. Jensen, Ole G. Pedersen, Hans Keiding, and Jesper Munksgaard. "Evaluating Sustainability of Household Consumption – Using DEA to Assess Environmental Performance." Economic Systems Research. Vol 17 no. 4 (2005): 524-447. <http://dx.doi.org/10.1080/09535310500284276>
[14] Lippiatt, Barbara, Anne Landfield Greig, and Priya Lavappa. Building for Environmental and Economic Sustainability. National Institute of Standards and Technology. (2010). <http://www.nist.gov/el/economics/BEESSoftware.cfm>
[15] Horowitz, Karen J. and Mark A. Planting. Concepts and Methods of the US Input-Output Accounts. Bureau of Economic Analysis. (September 2006). <http://www.bea.gov/papers/pdf/IOmanual_092906.pdf>

$D = V\hat{q}^{-1}$

$p =$ "A column vector in which each entry shows the ratio of the value of scrap produced in each industry to the industry's total output."

$U =$ "Intermediate portion of the use matrix in which the column shows for a given industry the amount of each commodity it uses—including noncomparable imports, scrap, and used and secondhand goods. This is a commodity-by-industry matrix."

$V =$ "Make matrix, in which the column shows for a given commodity the amount produced in each industry. This is an industry-by-commodity matrix. V has columns showing only zero entries for noncomparable imports and for scrap."

$g =$ "A column vector in which each entry shows the total amount of each industry's output, including its production of scrap. It is an industry-by-one vector."

$q =$ "A column vector in which each entry shows the total amount of the output of a commodity. It is a commodity-by-one vector."

$\widehat{\ }$ "A symbol that when placed over a vector indicates a square matrix in which the elements of the vector appear on the main diagonal and zeros elsewhere."

In Equation 1, a total requirements matrix $W(I - BW)^{-1}$ is multiplied by a vector of final demand for commodities Y to estimate the total output X. The total requirements matrix provided by the BEA was used in this analysis. All variables in Equation 1 have known values in the input output data. The output X required to produce an alternate level of final demand can be calculated by altering the final demand vector from the actual final demand Y in the input output data to Y'. For this analysis, Y' has the actual final demand for the 50 selected commodities and zero for other commodities. This alteration reveals the output needed to produce only assembly-centric commodities.

Environmental Impact Categories: The TRACI 2 impact categories are each an aggregation of multiple emissions converted to a common physical unit. For example, the global warming impact category includes impacts of many pollutants, such as carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (NO_X), and fluorinated gases, which are converted to their carbon dioxide equivalent (CO_2e) impact and aggregated to estimate the total impact for that impact category. The environmental impacts are measured in terms of the common physical unit per dollar of output. The impact can be calculated by multiplying the output in the Input-Output analysis by the impact categories.

Impact Category Weights: Having 12 impact categories makes it difficult to rank industry environmental activity; therefore, the 12 impact categories have been combined into one using the Analytical Hierarchy Process (AHP). AHP is a mathematical method for developing weights using normalized eigenvalues. It involves making pairwise comparisons of competing items. The weights used in this paper were developed for the BEES software and can be seen in Table 1.[16] This paper uses 12 of the 13 impact categories for which weights were developed. Indoor Air Quality (IAQ) is excluded because it is more applicable to the design of buildings and ventilation systems rather than to manufacturing activities. The weight of IAQ is proportionally allocated to the other 12 categories. The final metric for each industry or industry/commodity combination is the proportion of the total impact from assembly-centric products.

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[16] Lippiatt, Barbara, Anne Landfield Greig, and Priya Lavappa. Building for Environmental and Economic Sustainability. National Institute of Standards and Technology. (2010). <http://www.nist.gov/el/economics/BEESSoftware.cfm>

The percent of environmental impacts, based on the weights, are calculated using the following equation:

Equation 2

$$Env_{z,Y'} = \frac{x_{z,Y'} * GWP_z}{\sum_{i=1}^{n} x_{i,Y'} * GWP_i} * 0.30 + \frac{x_{z,Y'} * Acid_z}{\sum_{i=1}^{n} x_{i,Y'} * Acid_i} * 0.03 + \frac{x_{z,Y'} * HHA_z}{\sum_{i=1}^{n} x_{i,Y'} * HHA_i} * 0.09 + \frac{x_{z,Y'} * Eut_z}{\sum_{i=1}^{n} x_{i,Y'} * Eut_i} * 0.06 + \frac{x_{z,Y'} * OD_z}{\sum_{i=1}^{n} x_{i,Y'} * OD_i} * 0.02 + \frac{x_{z,Y'} * Sm_z}{\sum_{i=1}^{n} x_{i,Y'} * Sm_i} * 0.04 + \frac{x_{z,Y'} * Eco_z}{\sum_{i=1}^{n} x_{i,Y'} * Eco_i} * 0.07 + \frac{x_{z,Y'} * HHC_z}{\sum_{i=1}^{n} x_{i,Y'} * HHC_i} * 0.08 + \frac{x_{z,Y'} * HHNC_z}{\sum_{i=1}^{n} x_{i,Y'} * HHNC_i} * 0.05 + \frac{x_{z,Y'} * PE_z}{\sum_{i=1}^{n} x_{i,Y'} * PE_i} * 0.10 + \frac{x_{z,Y'} * LU_z}{\sum_{i=1}^{n} x_{i,Y'} * LU_i} * 0.06 + \frac{x_{z,Y'} * WC_z}{\sum_{i=1}^{n} x_{i,Y'} * WC_i} * 0.08$$

Where

$Env_{z,Y'}$ = Environmental impact from industry z for final demand Y'

GWP_z = Global warming potential per dollar of output for industry z

$Acid_z$ = Acidification per dollar of output for industry z

HHA_z = Human health –criteria air pollutants – per dollar of output for industry z

Eut_z = Eutrophication per dollar of output for industry z

OD_z = Ozone depletion per dollar of output for industry z

Sm_z = Smog per dollar of output for industry z

Eco_z = Ecotoxicity per dollar of output for industry z

HHC_z = Human health – carcinogens – per dollar of output for industry z

$HHNC_z$ = Human health – non-carcinogen – per dollar of output for industry z

PE_z = Primary energy consumption per dollar of output for industry z

LU_z = Land use per dollar of output for industry z

WC_z = Water consumption per dollar of output for industry z

$x_{z,Y'}$ = Output for industry z with final demand Y'

Monte Carlo Analysis: There are a few sources of error and uncertainty that might affect the results of this analysis. For instance, Input-Output results can vary depending on the data and methods selected.[17] Additionally, this analysis uses data from previous years to guide investments made in the present. In order to account for this uncertainty, a probabilistic sensitivity analysis was conducted using Monte Carlo analysis. This approach is based on works by McKay, Conover, and Beckman[18] along with work by Harris[19] that involves a method of model sampling. The method was implemented using the Crystal Ball software product[20], a software add-in for spreadsheets. Model specification involves defining which variables to simulate, distribution of each of these variables, and number of iterations performed. The software randomly samples from the probabilities for each input variable of interest.

A Monte Carlo analysis with 100 000 iterations was conducted for this analysis. This analysis varied the AHP weights by +/- 50 % with the constraint that they sum to one being preserved. This level of variation tests the results under significant uncertainty in the weights. Although different levels of variation could be selected, it has been shown that this amount of variation is possible.[21, 22] Additionally, to account for potential error, each of the value-added estimates were varied by +/- 25 % as were the environmental impact estimates. The level of variation used in the Monte Carlo analysis assumes a worst-case scenario for error and uncertainty. The inclusion of these variabilities directly varies the rankings being measured, providing a rigorous test of the results. A triangular distribution is utilized where the base case is used as the most likely value. Each iteration of the Monte Carlo analysis randomly selects among the 50 commodities and examines that commodity.

Results

Table 2 provides a guide to the results tables and figures. There is a combination of static and dynamic analyses. The static analysis examines the base case, where the calculations are made using Equation 1 and Equation 2. The dynamic analysis uses the results from the Monte Carlo analysis. Another variation in the results comes from examining the 50 commodities individually, where the results are calculated for each individual commodity using Equation 1 and Equation 2 versus calculating the results using all 50

Table 2: Guide to Tables and Figures

	Finished Goods Aggregated	Finished Goods Separately Examined
Static	Figure 2, 3, Table A1	Table 3, 4, 5
Monte Carlo	-	Table 6, 7, 8

[17] Zhang, Yi, Erin L. Gibbemeyer, and Bhavik R. Bakshi. "Empirical Comparison of Input-Output Methods for Life Cycle Assessment." Journal of Industrial Ecology. Vol 18 no 5 (2014): 734-746.
[18] McKay, M. C., W. H. Conover, and R.J. Beckman, "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code," Technometrics. Vol. 21 (1979): 239-245.
[19] Harris, Carl M, Issues in Sensitivity and Statistical Analysis of Large-Scale, Computer-Based Models, NBS GCR 84-466, Gaithersburg, MD: National Bureau of Standards (1984).
[20] Crystal Ball, Crystal Ball 11.1.2.3 User Manual. Denver, CO: Decisioneering, Inc. (2013).
[21] European Science and Technology Observatory. Environmental Impact of Products: Analysis of the Life Cycle Environmental Impacts Related to the Final Consumption of the EU-25. (2006). <http://ec.europa.eu/environment/ipp/pdf/eipro_report.pdf>
[22] Temurshoev, Umed. "Uncertainty Treatment in Input-Output Analysis." (2015). <http://loyolaandnews.es/loyolaecon/wp-content/uploads/2015/12/Uncertainty-treatment-in-Input-Output-analysis.pdf>

commodities at once. In the latter case, the results represent the value added and environmental impact of all commodities together.

Results of Static Analysis: Figure 2 compares the percent that each supply chain industry represents as a percent of the total value added for all 50 commodities aggregated for 2012 to that of 2007. Thus, a point on this figure represents the value added needed from one industry to produce all 50 commodities divided by the sum of the total value added from all industries to produce the 50 commodities. The x-axis represents the 2012 value while the y-axis represents the 2007 value. Figure 3 compares the same value for environmental impact. As seen in these figures, the percentages do change slightly from 2007 to 2012. Those that veer from the 45-degree line are not equivalent from one year to the other. Although there is variation, they do correlate strongly with a correlation coefficient of 0.98 for environmental impact and 0.94 for value added. The consistency in rankings and percent of total cost (i.e., value added) have implications for the return on investments aiming to improve efficiency. If a manufacturing cost declines independent of investment, then the return on any investment that might have been made is also likely to decline. Public entities and trade associations need to invest in cost areas that are persistent over time in order to generate a high return. The appendix provides a list of all the industries in the supply chain above the 80th percentile for either environmental impact or value added in 2012. These represent areas that have a disproportional impact on efficiency and/or environmental sustainability.

Table 3 presents the average overlap between 2007 and 2012 for industries in the supply chain above the 80th, 90th, and 95th percentile. Environmental impact and value added are separated; thus, this table examines the overlap in items 1 and 4 (i.e., environmental impact and persistence over time) along with

Figure 2: Supply Chain Industry Value Added as a Percent of Total Value Added, 2007 and 2012

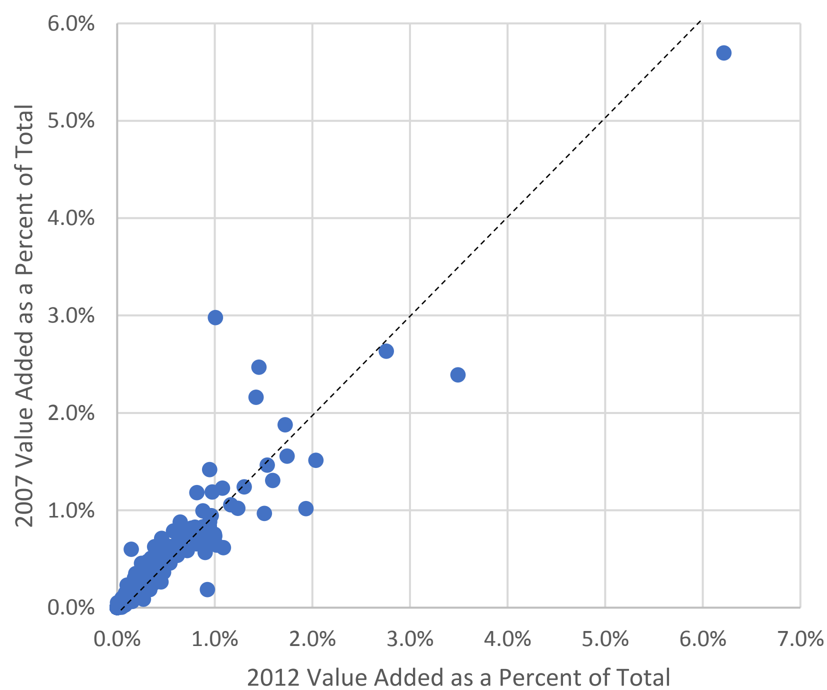

Figure 3: Supply Chain Industry Environmental Impact as a Percent of Total Impact, 2007 and 2012

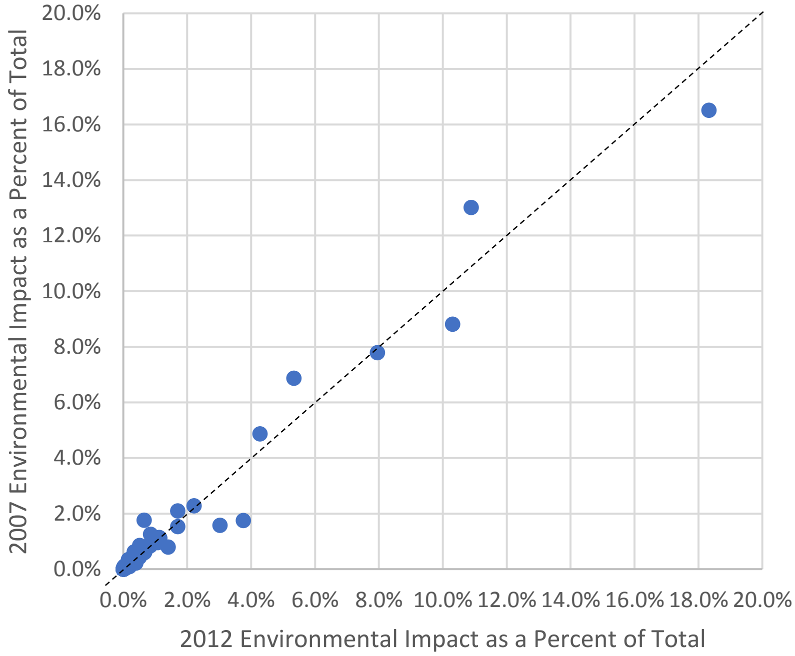

Table 3: Percent of Supply Chain Overlap between 2007 and 2012 for the 80th, 90th, and 95th Percentile of 50 Commodities

	Environmental Impact			Value Added		
Percentile	80th	90th	95th	80th	90th	95th
Mean	95.1%	95.6%	89.0%	91.1%	86.7%	82.2%
Minimum	90.1%	87.8%	71.4%	86.4%	70.7%	52.4%
Maximum	98.8%	100.0%	95.2%	96.3%	97.6%	95.2%
Mode	95.1%	97.6%	90.5%	92.6%	85.4%	85.7%
Median	95.1%	95.1%	90.5%	91.4%	85.4%	85.7%

the overlap in items 2 and 4 (i.e., value added and persistence over time) for each commodity. For instance, on average 95.1 % of the 50 commodities have the same industries in the supply chain appearing above the 80th percentile for environmental impact in 2012 as they did in 2007. In regards to those industries in the supply chain above the 80th percentile in environmental impact, no commodity has less than 90.1 % (i.e., the minimum) of its 2012 supply chain overlap with 2007. In terms of value added, it is no less than 86.4 % with the average being 91.1 %. The implication is that the industries in the supply chain above the 80th percentile for environmental impact or value added are pervasive over time as are those at the 90th and 95th percentile. In terms of overlap between commodity supply chains, there are 11 industries in the supply chain that are in the 80th percentile for all 50 commodities for both impact and value added in 2012:

NAICS 211000 Oil and gas extraction
NAICS 221100 Electric power generation, transmission, and distribution
NAICS 230301 Nonresidential maintenance and repair
NAICS 331110 Iron and steel mills and ferroalloy manufacturing
NAICS 331410 Nonferrous Metal (except Aluminum) Smelting and Refining
NAICS 332800 Coating, engraving, heat treating and allied activities
NAICS 334413 Semiconductor and related device manufacturing
NAICS 324110 Petroleum refineries
NAICS 484000 Truck transportation
NAICS 48A000 Scenic and sightseeing transportation and support activities for transportation
NAICS 531ORE Other real estate

These represent the intersection of items 1, 2, and 3 (i.e., environmental impact, value added, and among 50 commodities).

Table 4 presents the number of industries in the supply chain ranked above the 80^{th}, 90^{th}, and 95^{th} percentile for both environmental impact and value added in both 2007 and 2012. This examines the overlap in items 1, 2, and 4 in Figure 1 (i.e., environmental impact, value added, and persistence over time). On average 33.7 industries in the supply chain appear above the 80^{th} percentile with 10.5 and 5.3 appearing above the 90^{th} and 95^{th} percentile respectively. The minimum is 24, 5, and 2 for the 80^{th}, 90^{th}, and 95^{th} percentile, respectively. The implication is that there are a few select industries ranking above the 80^{th}, 90^{th}, and 95^{th} percentiles for both environmental impact and cost that are pervasive over time.

Table 4: Summary of Industries in the supply chain Ranked Above the 80^{th}, 90^{th}, and 95^{th} Percentile in both 2007 and 2012 for both Value Added and Environmental Impact

Percentile	80th	90th	95th
Mean	33.7	10.5	5.3
Minimum	24	5	2
Maximum	44	17	8
Mode	36	10	6
Median	34	10	6
Total Possible	81	41	21

Table 5 provides the percent of the commodities for which each industry is at the 80^{th}, 90^{th}, and 95^{th} percentile for both environmental impact and value added for both 2007 and 2012. That is, it examines the intersection of all 4 items in Figure 1 (i.e., environmental impact, value added, among 50 commodities, and persistence over time). For instance, for 100 % of all 50 commodities, NAICS code 331110 ranks above the 80^{th} percentile as a cost (i.e. value added) and a source for environmental impact in both 2007 and 2012. For 88 % of all 50 commodities, the same NAICS code ranks above the 90^{th} percentile. As seen in Table 5, only 4 industries in the supply chain have 50 % or more for the 95^{th} percentile: “Electric power generation…,” “Oil and gas extraction,” “truck transportation,” and “Iron and steel mills…” These 4 represent items that are high environmental impact, high cost (measured in value added), and span across numerous commodities while stretching over at least a 5-year period. There are other industries that have high percentages that are related to these. For instance, NAICS 331200 “Steel

Table 5: Percent of Industries in the supply chain Above the 80th, 90th, and 95th Percentile for both Environmental Impact and Value Added for both 2007 and 2012 (i.e., Base Case)

BEA NAICS Code	Description	80th	90th	95th
221100	Electric power generation, transmission, and distribution	100%	100%	98%
211000	Oil and gas extraction	100%	100%	96%
484000	Truck transportation	100%	100%	80%
331110	Iron and steel mills and ferroalloy manufacturing	100%	88%	76%
324110	Petroleum refineries	100%	56%	6%
331410	Nonferrous Metal (except Aluminum) Smelting and Refining	100%	44%	0%
334413	Semiconductor and related device manufacturing	100%	14%	4%
230301	Nonresidential maintenance and repair	100%	2%	0%
48A000	Scenic and sightseeing transportation and support activities for transportation	100%	0%	0%
332800	Coating, engraving, heat treating and allied activities	98%	8%	0%
531ORE	Other real estate	98%	0%	0%
482000	Rail transportation	94%	42%	0%
331490	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	92%	36%	2%
331200	Steel product manufacturing from purchased steel	82%	46%	6%
331510	Ferrous metal foundries	76%	50%	26%
562000	Waste management and remediation services	72%	0%	0%
326190	Other plastics product manufacturing	70%	32%	2%
331520	Nonferrous metal foundries	64%	22%	0%
212100	Coal mining	64%	4%	0%
325211	Plastics material and resin manufacturing	62%	16%	8%
2122A0	Iron, gold, silver, and other metal ore mining	62%	4%	0%
33211A	All other forging, stamping, and sintering	56%	12%	2%
325110	Petrochemical manufacturing	54%	12%	4%
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	54%	2%	0%
33441A	Other electronic component manufacturing	52%	16%	0%
481000	Air transportation	52%	0%	0%
322210	Paperboard container manufacturing	48%	10%	0%
212230	Copper, nickel, lead, and zinc mining	48%	8%	0%
332710	Machine shops	48%	0%	0%
S00203	Other state and local government enterprises	46%	2%	0%
221200	Natural gas distribution	44%	0%	0%
325510	Paint and coating manufacturing	42%	16%	2%
335930	Wiring device manufacturing	36%	0%	0%
423A00	Other durable goods merchant wholesalers	34%	0%	0%
33131B	Aluminum product manufacturing from purchased aluminum	32%	10%	4%
331420	Copper rolling, drawing, extruding and alloying	32%	10%	0%
325190	Other basic organic chemical manufacturing	32%	6%	2%
335312	Motor and generator manufacturing	32%	4%	0%
332720	Turned product and screw, nut, and bolt manufacturing	30%	0%	0%
339990	All other miscellaneous manufacturing	30%	0%	0%

NOTE: Only industries in the supply chain with 30 % or more at the 80th percentile are shown product manufacturing…" has 82 % at the 80th percentile, 46 % at the 90th percentile, and 6 % at the 95 % percentile. This is closely related to NAICS 331110 "Iron and steel mills…", which is above 75 % for all three percentiles.

Results of Monte Carlo Analysis: Table 6 presents results from the Monte Carlo analysis. Similar to Table 3, it presents the average overlap between 2007 and 2012 for industries in the supply chain above the 80th, 90th, and 95th percentile. Environmental impact and value added are separated; thus, this table examines the overlap in items 1 and 4 (environmental impact and persistence over time) along with the

Table 6: Percent of Overlap between 2007 and 2012 for Industries at the 80th, 90th, and 95th Percentile, Monte Carlo Result Summary

	Value Added			Environmental Impact		
	80th	90th	95th	80th	90th	95th
Mean	88.6%	82.2%	77.2%	94.5%	94.5%	88.3%
Minimum	77.8%	58.5%	42.9%	85.2%	82.9%	61.9%
Maximum	97.5%	97.6%	100.0%	100.0%	100.0%	100.0%
Mode	88.9%	82.9%	81.0%	95.1%	95.1%	90.5%
Median	88.9%	82.9%	76.2%	95.1%	95.1%	90.5%

overlap in items 2 and 4 (i.e., value added and persistence over time) from Figure 1. The difference between Table 6 and Table 3 is that in Table 6 the percent is shown from the Monte Carlo analysis. The average overlap remains above 75 % for both value added and environmental impact for all three percentiles. For instance, on average 88.6 % of the 2012 industries in the supply chain above the 80th percentile for value added overlaps with that for 2007. At minimum, the overlap is 77.8 %, as seen in the table. Recall that the Monte Carlo analysis is selecting among the 50 commodities randomly; thus, it is, essentially, the average for the 50 commodities. The average for both value added and environmental impact does not drop below 75 %; however, it drops down to 42.9 % at the 95th percentile for value added. It is important to recall that the Monte Carlo analysis presents a scenario with high levels of error and uncertainty in all value added and environmental impact for all industries along with high variation in the weights for environmental impact. The implication is that the industries in the supply chain above the 80th percentile for environmental impact or value added are pervasive over time as are those at the 90th and 95th percentile even when considering high levels of error.

Table 7 presents Monte Carlo results for the number of industries in the supply chain overlapping between 2007 and 2012 for industries ranked above the 80th, 90th, and 95th percentiles for both environmental impact and value added. That is, it presents the overlap of items 1, 2, and 4 presented in Figure 1 (i.e., environmental impact, value added, and persistence over time) using Monte Carlo analysis. For instance, on average 88.6 % of the 50 commodities have the same industries in the supply chain appearing above the 80th percentile for environmental impact in 2012 as they did in 2007 when considering high levels of error. The implication here is that there are a select number of industries that have both high environmental impact and high cost (i.e., value added) for producing the 50 commodities.

Table 7: Monte Carlo Results Summary of Industries in the supply chain Ranked Above the 80th, 90th, and 95th Percentile in both 2007 and 2012 for both Value Added and Environmental Impact

	80th	90th	95th
Mean	32.8	10.0	5.0
Minimum	19	4	0
Maximum	45	19	10
Mode	35	9	6
Median	33	10	5
Base Case	36	10	6

Table 8 presents Monte Carlo results for the percent of the commodities for which each industry is at the 80th, 90th, and 95th percentile for both environmental impact and value added for both 2007 and 2012. That is, it examines the intersection of all 4 items in Figure 1 (i.e., environmental impact, value added, among 50 commodities, and persistence over time) using Monte Carlo analysis. As can be seen in the table, only 4 items are above 70 % at the 95th percentile: "NAICS 211000 Oil and gas extraction," "NAICS 221100 221100 Electric power generation…," "NAICS 484000 Truck Transportation," and "NAICS 331110 Iron and steel mills." 15 are above the 80th percentile. This table identifies those industries that represent a source of high impact and cost for producing the 50 finished goods. Targeting research towards these areas can, potentially, have a high return on investment.

Summary and Conclusion

This paper identifies those industries in the supply chain that have a high environmental impact and high cost (measured in value added) over time and between commodities. These industries in the supply chain represent high cost/impact areas that are pervasive (i.e., persist over time), affect multiple industries, and affect multiple stakeholder groups. Research in high cost areas (i.e., research to reduce the use of these items or produce them more efficiently) have been shown to, on average, have higher return on investment. Moreover, research in these areas is likely to have a large effect on numerous people at a lower cost than other areas. The paper identifies these cost/impact areas by examining the intersection of 4 items shown in Figure 1. The analysis uses both a static and dynamic approach while examining commodities individually and together as a single unit.

The industries identified can be seen in Table 5, Table 8, and Table A2. Table 5 presents the results of a static examination while Table 8 provides the results of a Monte Carlo Analysis. The tables show nearly the same industries with the exception of 3: NAICS 33131B "aluminum product manufacturing…," NAICS 331420 "copper rolling…," and NAICS 339990 "all other miscellaneous manufacturing," which do not make it onto the list in Table 8. Table A2 presents more than just the industries that overlap in the 4 items in Figure 1. It shows all industries in the supply chain that are above the 80th percentile for either 2012 value added or 2012 environmental impact for the 50 commodities together.

Among the 50 commodities examined, at least 90.1 % of those industries in the supply chain above the 80th percentile for environmental impact appear in 2007 and 2012 for each of the 50 commodities. For value added it is 86.4 %. Moreover, these items are pervasive over time, making them target areas for efficiency improvement with potentially high returns. Eleven industries in the supply chain are above the 80th percentile for both value added and impact for all 50 commodities. These items affect numerous industries and people. Only 4 industries in the supply chain appear in 50 % or more of the commodities at the 90th percentile in both the static analysis (see Table 5) and Monte Carlo analysis (see Table 8):

“Electric power generation…,” “Oil and gas extraction,” “truck transportation,” and “Iron and steel mills…” These 4 represent industries in the supply chain that are high environmental impact (above the 95^{th} percentile), high cost (above the 95^{th} percentile in value added), and span across numerous commodities while stretching over at least a 5-year period. Research that reduces the consumption of these items or improves the efficiency of producing them will, likely, result in a high return on investment. Future research might focus on identifying subcategories of cost/impact areas. These might include identifying maintenance cost areas and the rate of defects. Additional research might focus on providing tools for practitioners to identify high cost/impact areas of manufacturing.

Table 8: Percent of Monte Carlo Iterations where Industries in the supply chain are above the 80th, 90th, and 95th Percentile for Both Environmental Impact and Value Added for both 2007 and 2012

BEA NAICS		80th	90th	95th
211000	Oil and gas extraction	100.0%	100.0%	95.3%
221100	Electric power generation, transmission, and distribution	100.0%	100.0%	89.1%
484000	Truck transportation	100.0%	100.0%	72.4%
324110	Petroleum refineries	100.0%	45.6%	5.3%
331110	Iron and steel mills and ferroalloy manufacturing	99.9%	87.7%	73.3%
331410	Nonferrous Metal (except Aluminum) Smelting and Refining	99.1%	37.9%	1.2%
230301	Nonresidential maintenance and repair	98.7%	2.5%	
334413	Semiconductor and related device manufacturing	98.5%	14.3%	4.0%
531ORE	Other real estate	97.6%	0.0%	
332800	Coating, engraving, heat treating and allied activities	91.8%	6.6%	
482000	Rail transportation	90.6%	30.2%	1.0%
331490	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	90.3%	33.2%	2.0%
48A000	Scenic and sightseeing transportation and support activities for transportation	89.4%	0.0%	
331200	Steel product manufacturing from purchased steel	79.2%	40.1%	6.9%
331510	Ferrous metal foundries	75.3%	49.6%	20.7%
326190	Other plastics product manufacturing	68.9%	28.8%	3.6%
562000	Waste management and remediation services	61.6%	0.0%	
212100	Coal mining	61.3%	4.7%	
331520	Nonferrous metal foundries	58.0%	20.3%	0.2%
2122A0	Iron, gold, silver, and other metal ore mining	57.8%	6.5%	0.1%
325211	Plastics material and resin manufacturing	57.2%	17.2%	7.0%
33211A	All other forging, stamping, and sintering	55.4%	11.7%	1.1%
325110	Petrochemical manufacturing	53.9%	12.1%	3.4%
33441A	Other electronic component manufacturing	51.6%	15.8%	0.4%
212230	Copper, nickel, lead, and zinc mining	49.1%	6.2%	0.0%
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	48.9%	2.2%	
221200	Natural gas distribution	46.5%	0.0%	
332710	Machine shops	43.8%		
481000	Air transportation	41.7%	0.2%	
325510	Paint and coating manufacturing	41.5%	15.1%	2.8%
322210	Paperboard container manufacturing	40.1%	9.3%	0.2%
S00203	Other state and local government enterprises	39.3%	1.9%	0.1%
325190	Other basic organic chemical manufacturing	35.4%	5.3%	0.8%
335930	Wiring device manufacturing	34.6%	0.0%	
335312	Motor and generator manufacturing	32.6%	2.9%	
423A00	Other durable goods merchant wholesalers	32.5%		
332720	Turned product and screw, nut, and bolt manufacturing	30.4%		

Note: Only those industries with 30 % of the iterations are above the 80th percentile are shown

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Appendix

Table A1: Commodities Examined

333111	Farm machinery and equipment manufacturing
333112	Lawn and garden equipment manufacturing
333120	Construction machinery manufacturing
333130	Mining and oil and gas field machinery manufacturing
333242	Semiconductor machinery manufacturing
33329A	Other industrial machinery manufacturing
333314	Optical instrument and lens manufacturing
333316	Photographic and photocopying equipment manufacturing
333318	Other commercial and service industry machinery manufacturing
333414	Heating equipment (except warm air furnaces) manufacturing
333415	Air conditioning, refrigeration, and warm air heating equipment manufacturing
333413	Industrial and commercial fan and blower and air purification equipment manufacturing
333511	Industrial mold manufacturing
333514	Special tool, die, jig, and fixture manufacturing
333517	Machine tool manufacturing
33351B	Cutting and machine tool accessory, rolling mill, and other metalworking machinery manufacturing
333613	Mechanical power transmission equipment manufacturing
333618	Other engine equipment manufacturing
333912	Air and gas compressor manufacturing
33391A	Pump and pumping equipment manufacturing
333920	Material handling equipment manufacturing
333991	Power-driven handtool manufacturing
333993	Packaging machinery manufacturing
333994	Industrial process furnace and oven manufacturing
33399B	Fluid power process machinery
334111	Electronic computer manufacturing
334210	Telephone apparatus manufacturing
334220	Broadcast and wireless communications equipment
334512	Automatic environmental control manufacturing
334513	Industrial process variable instruments manufacturing
334514	Totalizing fluid meter and counting device manufacturing
334515	Electricity and signal testing instruments manufacturing
334516	Analytical laboratory instrument manufacturing
334517	Irradiation apparatus manufacturing
335120	Lighting fixture manufacturing
335210	Small electrical appliance manufacturing
335221	Household cooking appliance manufacturing
335222	Household refrigerator and home freezer manufacturing
335224	Household laundry equipment manufacturing
335228	Other major household appliance manufacturing
336111	Automobile manufacturing
336112	Light truck and utility vehicle manufacturing
336120	Heavy duty truck manufacturing
336211	Motor vehicle body manufacturing
336212	Truck trailer manufacturing
336213	Motor home manufacturing
336411	Aircraft manufacturing
336611	Ship building and repairing
336612	Boat building
336991	Motorcycle, bicycle, and parts manufacturing

Table A2: Percentile of Supply Chain Industry, Aggregated for 50 Finished Goods

BEA NAICS	Industry Description	Value Added 2007	Value Added 2012	Environment Impact 2007	Environment Impact 20012
336112	Light truck and utility vehicle manufacturing	100	100	93	95
333120	Construction machinery manufacturing	98	99	84	85
333130	Mining and oil and gas field machinery manufacturing	95	99	73	80
331110	Iron and steel mills and ferroalloy manufacturing ** ++	98	98	99	99
334413	Semiconductor and related device manufacturing * +	99	97	89	85
211000	Oil and gas extraction *** +++	99	97	100	100
221100	Electric power generation, transmission, and distribution *** +++	96	97	100	100
484000	Truck transportation ** +++	96	96	99	99
33329A	Other industrial machinery manufacturing	97	96	83	82
336120	Heavy duty truck manufacturing	90	96	81	83
531ORE	Other real estate * +	92	95	80	81
33399A	Other general purpose machinery manufacturing	95	94	80	82
336350	Motor vehicle transmission and power train parts manufacturing	94	94	81	81
333618	Other engine equipment manufacturing	91	93	85	86
336390	Other Motor Vehicle Parts Manufacturing	96	91	84	83
331510	Ferrous metal foundries	93	91	94	94
333318	Other commercial and service industry machinery manufacturing	90	89	90	90
336360	Motor vehicle seating and interior trim manufacturing	88	89	77	80
326190	Other plastics product manufacturing	88	88	92	92
33441A	Other electronic component manufacturing	93	87	80	79
333415	Air conditioning, refrigeration, and warm air heating equipment manufacturing	87	87	90	90
331410	Nonferrous Metal (except Aluminum) Smelting and Refining * +	89	86	89	88
331200	Steel product manufacturing from purchased steel +	84	86	98	98
324110	Petroleum refineries * +	89	85	97	97
482000	Rail transportation * +	83	85	97	97
331520	Nonferrous metal foundries	82	85	88	89
336211	Motor vehicle body manufacturing	91	84	79	79
332800	Coating, engraving, heat treating and allied activities * +	84	83	85	84
331490	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying * +	85	83	88	90
3363A0	Motor vehicle steering, suspension component (except spring), and brake systems manufacturing	82	83	82	83
336214	Travel trailer and camper manufacturing	76	81	84	84
33211A	All other forging, stamping, and sintering	77	80	83	84
325110	Petrochemical manufacturing	73	80	92	91
550000	Management of companies and enterprises	99	100	69	73
423A00	Other durable goods merchant wholesalers	99	99	73	75
423100	Motor vehicle and motor vehicle parts and supplies	98	99	64	71
423800	Machinery, equipment, and supplies	97	98	61	65
336412	Aircraft engine and engine parts manufacturing	98	98	78	79
334516	Analytical laboratory instrument manufacturing	95	98	56	59
333920	Material handling equipment manufacturing	97	97	77	78
33451A	Watch, clock, and other measuring and controlling device manufacturing	88	96	52	54

Table A2 Continued

BEA NAICS	Industry Description	Value Added 2007	Value Added 2012	Environment Impact 2007	Environment Impact 20012
334111	Electronic computer manufacturing	100	95	78	56
334515	Electricity and signal testing instruments manufacturing	91	95	67	68
423600	Household appliances and electrical and electronic goods	96	95	60	61
332710	Machine shops	94	94	76	77
334220	Broadcast and wireless communications equipment	97	94	72	63
333611	Turbine and turbine generator set units manufacturing	90	93	70	77
334517	Irradiation apparatus manufacturing	65	93	71	79
334513	Industrial process variable instruments manufacturing	86	93	55	59
336370	Motor vehicle metal stamping	95	92	76	76
52A000	Monetary authorities and depository credit intermediation	94	92	49	46
424A00	Other nondurable goods merchant wholesalers	92	92	55	58
33391A	Pump and pumping equipment manufacturing	91	92	64	66
561300	Employment services	90	91	24	25
332720	Turned product and screw, nut, and bolt manufacturing	93	91	71	73
541100	Legal services	87	90	33	35
333242	Semiconductor machinery manufacturing	92	90	63	59
336310	Motor vehicle gasoline engine and engine parts manufacturing	92	90	72	75
333514	Special tool, die, jig, and fixture manufacturing	87	90	66	64
334112	Computer storage device manufacturing	94	89	52	51
533000	Lessors of nonfinancial intangible assets	93	89	40	38
522A00	Nondepository credit intermediation and related activities	86	88	54	54
33291A	Valve and fittings other than plumbing	89	88	65	67
541200	Accounting, tax preparation, bookkeeping, and payroll services	85	88	28	28
333912	Air and gas compressor manufacturing	83	87	62	63
541300	Architectural, engineering, and related services	86	87	42	40
541800	Advertising, public relations, and related services	86	86	53	52
GSLGO	State and local government other services	80	86	69	72
336991	Motorcycle, bicycle, and parts manufacturing	84	85	53	53
524200	Insurance agencies, brokerages, and related activities	80	84	31	33
561700	Services to buildings and dwellings	88	84	67	62
541610	Management consulting services	81	84	32	33
334514	Totalizing fluid meter and counting device manufacturing	73	83	46	45
333511	Industrial mold manufacturing	82	83	71	72
33399B	Fluid power process machinery	80	82	59	61
335312	Motor and generator manufacturing	79	82	68	70
5419A0	All other miscellaneous professional, scientific, and technical services	80	82	35	35
333517	Machine tool manufacturing	81	82	58	61
424700	Petroleum and petroleum products	83	81	46	46
523A00	Securities and commodity contracts intermediation and brokerage	85	81	44	39
5241XX	Insurance carriers, except direct life	89	81	34	30
423400	Professional and commercial equipment and supplies	83	80	49	49
541512	Computer systems design services	71	80	32	33

Table A2 Continued

BEA NAICS	Industry Description	Value Added 2007	Value Added 2012	Environment Impact 2007	Environment Impact 20012
212100	Coal mining	79	74	99	99
113000	Forestry and logging	63	60	99	99
1111B0	Grain farming	32	46	98	98
S00202	State and local government electric utilities	50	62	97	98
111900	Other crop farming	39	37	98	98
3252A0	Synthetic rubber and artificial and synthetic fibers and filaments manufacturing	50	57	95	97
486000	Pipeline transportation	52	56	96	97
325190	Other basic organic chemical manufacturing	67	74	96	96
322130	Paperboard mills	62	59	96	96
562000	Waste management and remediation services	74	69	97	96
325211	Plastics material and resin manufacturing	77	78	95	96
2122A0	Iron, gold, silver, and other metal ore mining	76	74	94	95
325180	Other Basic Inorganic Chemical Manufacturing	62	67	94	95
S00101	Federal electric utilities	40	38	93	95
221200	Natural gas distribution	79	67	98	94
48A000	Scenic and sightseeing transportation and support activities for transportation * +	74	76	93	94
322120	Paper mills	60	54	95	94
331313	Alumina refining and primary aluminum production	61	57	95	93
212230	Copper, nickel, lead, and zinc mining	75	69	94	93
331314	Secondary smelting and alloying of aluminum	47	48	96	93
1111A0	Oilseed farming	31	35	91	93
321200	Veneer, plywood, and engineered wood product manufacturing	52	51	92	92
327200	Glass and glass product manufacturing	76	76	91	92
483000	Water transportation	41	39	91	92
1121A0	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming	31	33	87	91
325510	Paint and coating manufacturing	72	72	90	91
327400	Lime and gypsum product manufacturing	42	43	91	91
325120	Industrial gas manufacturing	41	38	93	90
481000	Air transportation	70	70	89	89
336612	Boat building	77	78	92	89
S00203	Other state and local government enterprises	68	69	90	89
327310	Cement manufacturing	32	31	89	88
221300	Water, sewage and other systems	36	36	88	88
321100	Sawmills and wood preservation	52	50	88	88
230301	Nonresidential maintenance and repair * +	81	77	87	87
2123A0	Other nonmetallic mineral mining and quarrying	45	47	86	87
33131B	Aluminum product manufacturing from purchased aluminum	69	71	87	87
325310	Fertilizer manufacturing	39	44	83	87
112A00	Animal production, except cattle and poultry and eggs	32	36	82	86
322110	Pulp mills	33	30	86	86
322210	Paperboard container manufacturing	70	68	86	86
3259A0	All other chemical product and preparation manufacturing	69	63	87	85

Table A2 Continued

BEA NAICS	Industry Description	Value Added 2007	Value Added 2012	Environment Impact 2007	Environment Impact 20012
325130	Synthetic dye and pigment manufacturing	43	50	86	85
324190	Other petroleum and coal products manufacturing	60	55	83	84
337110	Wood kitchen cabinet and countertop manufacturing	42	38	85	83
115000	Support activities for agriculture and forestry	45	48	81	83
335222	Household refrigerator and home freezer manufacturing	73	76	85	82
331420	Copper rolling, drawing, extruding and alloying	65	63	84	82
326210	Tire manufacturing	67	67	79	81
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	72	73	81	81
327100	Clay product and refractory manufacturing	53	49	82	80
326120	Plastics pipe, pipe fitting, and unlaminated profile shape manufacturing	51	48	82	80

Note: Industries in the supply chain at the 80th percentile and higher for 2012 value added or environmental impact are shown
* At least 80 % for the 80th percentile in Monte Carlo analysis from Table 8
** At least 80 % for the 90th percentile in Monte Carlo analysis from Table 8
*** At least 80 % for the 95th percentile in Monte Carlo analysis from Table 8
+ 80 % of the industries were above the 80th percentile for both 2007 and 2012 (Table 5)
++ 80 % of the industries were above the 90th percentile for both 2007 and 2012 (Table 5)
+++ 80 % of the industries were above the 95th percentile for both 2007 and 2012 (Table 5)