Symposium:
International Trade and the Environment

Offshoring Pollution: Is the United States Increasingly Importing Polluting Goods?

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Introduction

International trade has environmental consequences, and environmental policy can have international trade consequences. So it is not surprising that trade economists and environmental economists increasingly find their fields overlapping in academic and policy discussions. For this symposium on International Trade and the Environment, we have chosen three topics from the list of countless issues that span both disciplines. Each of the three articles addresses a fundamental question about the trade–environment link for which there seems to be no consensus answer, despite considerable recent research. Josh Ederington (2010) asks whether trade–environment linkages necessitate negotiating international treaties that address trade and the environment together, as opposed to holding separate negotiations for each issue. Carolyn Fischer (2010) examines the relationship between international trade and exhaustible natural resources, where the intertemporal nature of resource problems (i.e., using more now means less for the future) adds an extra layer of complexity to the standard trade–environment discussion. In this article I ask the simplest question of all—but one that arguably forms the heart of the trade–environment policy debate: Does international trade enable the United States to enjoy a cleaner environment at home by importing goods whose manufacturing process creates pollution abroad? That is, is the United States "offshoring" pollution?

Although this question seems simple enough, economics journals and the popular press are filled with different and often contradictory answers. Sometimes the contradictions stem from subtle differences in the way the question is posed and how one defines polluting goods. In other cases, the contradictions arise from fundamental differences in how the international trade and pollution data have been used to answer the question.

What I mean by "offshoring pollution" is analogous to the well-known concept of offshoring labor, or exporting jobs. When a U.S. business decides to produce some component

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overseas, the labor input is said to have been offshored, exported, or outsourced. We would measure the lost jobs as the reduction in U.S. labor employed by the offshoring industry, regardless of how many workers are hired abroad to produce the offshored component. Similarly, if production of that offshored component generates pollution, I am interested in how much pollution would have been emitted in the United States had the component been manufactured here, regardless of how much pollution is actually emitted by manufacturing it overseas.

Why is the amount of pollution that would have been emitted in the United States important? Many people have speculated that U.S. pollution regulations have reduced the comparative advantage of U.S. industries that pollute, and have thus *caused* those industries to relocate overseas. This is the so-called "pollution haven" effect, that stringent environmental regulations in "strict" places result in increased pollution in "lax" places.[1] But assessing whether regulations actually cause offshoring is much more difficult than simply asking whether offshoring exists. Demonstrating the causation requires knowing the counterfactual: what would have happened to the pollution composition of U.S. imports without the U.S. regulations? What the pollution haven literature asks, in this context, is whether offshoring of U.S. pollution has been increasing faster, or decreasing more slowly, as a consequence of increasing U.S. regulatory stringency. What I am asking here is a much less complicated question, but one that is a necessary first step toward determining whether the United States is offshoring pollution: has the composition of U.S. imports shifted toward more polluting goods?

There has also been a lot of research on whether international trade agreements have increased the flight of polluting U.S. industries to locations overseas and increased U.S. imports of polluting goods. This more complex question requires knowing a slightly different counterfactual: how much pollution offshoring would there have been without those trade agreements? Again, my question here is a simpler but necessary first step: are we importing proportionally more or fewer polluting goods, regardless of the cause (e.g., tighter regulations, lower tariffs, other regulatory changes)? I suspect the conventional wisdom would say we are importing more polluting goods.

Answering these questions requires surmounting two obstacles: defining what we mean by "polluting goods" and obtaining adequate data on the concept. Some studies have used data on U.S. pollution abatement costs, based on the assumption that those industries that spend a lot on pollution abatement are the ones that emit a lot of pollution. Other studies have used industry-by-industry accountings of emissions of various pollutants, "emissions inventories," which can differ by pollutant and tell different stories depending on when the inventories were compiled.

Finally, many prominent recent studies have not addressed the fact that relatively clean industries may use relatively pollution-intensive inputs. Manufacturing automobiles is relatively clean; producing the steel and rubber used in automobile manufacturing is more polluting. If some automobile production moves offshore, domestic pollution from steel and rubber manufacturing will decline. But that steel and rubber offshoring will not appear directly in the trade data, because these intermediate inputs (steel and rubber) are never

[1] See Levinson and Taylor (2008) for a formal model and some empirical evidence.

traded internationally; they are embodied in the clean final products (cars). Thus, to be done correctly, the analysis must take into account not only the pollution emitted by the manufacture of the final product, but also the pollution emitted by the manufacture of that product's intermediate inputs, those intermediate products' inputs, those inputs' inputs, and so on. Although this type of life-cycle analysis can be done using a Leontief-style input–output analysis, with a few exceptions this approach has largely been overlooked.

The purpose of this article is to examine whether the United States is increasingly offshoring pollution-intensive manufacturing, taking account of the intermediate inputs to each industry. I first describe the history of U.S. policy, which appears to take as a given that offshoring occurs, and that it is a problem requiring legislative solutions. Then, in the following section, I discuss recent empirical research that has used pollution abatement expenditures as a proxy for pollution, and the reasons why such research has been inconclusive. Next I discuss research that has used industry-specific measures of pollution. I argue that this research either fails to account for polluting intermediate inputs or asks questions that differ subtly from the one posed here. In the following section I answer the question posed by the title of this article. Using a 1987 emissions inventory created by the World Bank from U.S. EPA data, and adjusting that inventory to account for polluting intermediate inputs, I find that, contrary to the conventional wisdom, the U.S. imports proportionally more clean goods and proportionally fewer polluting goods than it did thirty years ago. The final section summarizes the findings and presents some conclusions.

History of U.S. Policy Against Industrial Flight and Pollution Offshoring

Perhaps the biggest irony concerning the pollution offshoring issue, and one that makes correct analysis urgent, is that despite all of the uncertainty and contradictory evidence, U.S. policymakers of various political perspectives seem convinced that U.S. offshoring of pollution occurs and have proposed legislation to counteract it.

Early Concerns and Legislation Regarding Industrial Flight

Early fears about industrial flight from strict pollution regulations concerned cross-state movements within the United States rather than international industry migration—outsourcing within the United States rather than offshore. Both the 1970 Clean Air Act and the 1977 Clean Water Act Amendments were designed, in part, to set uniform federal standards so that states would not compete to attract polluting industries by setting lax local standards (Portney 1990). Not surprisingly, the uniform national ambient standards were tougher to attain in densely populated, industrial Northeastern states, raising fears among legislators from those states that they would lose their employment bases—and pollution—to the South and West. Pashigian (1985) documented this sentiment in the congressional vote on the 1977 Prevention of Significant Deterioration (PSD) amendment to the Clean Air Act. The amendment modified the uniform national ambient air quality rules to prevent the air quality of jurisdictions that were already cleaner than the national standard from deteriorating. Not surprisingly, the amendment garnered the most support from representatives of the most polluted Northeastern states. Presumably, these legislators hoped the PSD amendment would prevent industry from relocating to other parts of the United States as a way to avoid compliance costs in the Northeast.

The Focus Shifts to Pollution Offshoring

During the late 1980s and early 1990s, concerns were raised at the United Nations Conference on Environment and Development (UNCED) in Rio, the Uruguay round of the General Agreements on Tariffs and Trade (GATT), and the North American Free Trade Agreement (NAFTA) negotiations about the relationship between pollution and international trade. Violent demonstrations at the World Trade Organization (WTO) meetings in Seattle in 1999 and the G-8 summit in Genoa in 2001 made the issue front-page news. Those protests appear to have been motivated partly by concerns about the impacts of increased world trade on the environment in developing countries due to the offshoring of pollution by developed countries.

Starting sometime in the 1980s, the U.S. concerns about the effect of environmental regulations on competitiveness also seem to have shifted from interstate to international competition. For example, one of the main concerns of Vice President Quayle's Council on Competitiveness was to ensure that stringent U.S. standards did not cause industry to avoid domestic locations. Similarly, President Clinton's support for NAFTA came with the caveat that Mexico improve its environmental quality, and late in his presidency Clinton signed Executive Order 13141, which requires U.S. agencies to conduct quantitative evaluations of the environmental effects of proposed trade agreements. The order requires that "the focus of environmental reviews will be impacts in the United States." However, if trade allows the United States to offshore polluting goods, the environmental impact in the United States will be unambiguously positive.

In the legislative branch, senators from both major U.S. political parties have introduced bills to try to stop the perceived offshoring. Slade Gorton (R.-WA) proposed an amendment to the 1990 Clean Air Act, levying a duty on "any product imported into the United States that has not been subject to processing . . . which does not comply with the air quality standards of the Clean Air Act." The amendment lost narrowly, 52–47 (Vogel 1995). On the other side of the aisle, Senator David Boren's (D.-OK) Pollution Deterrence Act of 1991 would have required the U.S. EPA to construct an "International Pollution Control Index" for the top fifty trading partners of the United States, comparing each country's pollution standards to those in the United States. Tellingly, the bill failed to indicate how the EPA was to accomplish this difficult task.

Recently, offshoring has been labeled "leakage" in the context of discussions about climate change policies. The concern is that if some countries enact strict carbon emissions limits, carbon-intensive industries will respond by simply migrating to nonparticipating countries, thus offsetting the efforts of participating countries. If industries are mobile enough, and the nonparticipating countries have lower baseline levels of regulation than the participants, strict emissions limits in participating countries could actually exacerbate climate change.

Perhaps the most notorious incident in the policy realm concerning offshoring involved a 1991 internal World Bank memo signed by then-Chief Economist Lawrence Summers.

The controversial memo asked rhetorically "shouldn't the World Bank be encouraging more migration of the dirty industries to the [less-developed countries]?" (*Economist* 1992). This question presumed that such migration was already happening; I am asking here whether that presumption is valid.

All of these concepts—industrial flight, pollution havens, leakage, dirty industry migration—depend on the existence of offshoring. In order to answer the questions about whether the United States is offshoring polluting industries and has been increasingly importing pollution-intensive goods, we must first identify and assess which industries emit relatively more pollution. How such analyses have been conducted in the past is the focus of the next two sections.

Pollution Abatement Costs as a Proxy for Pollution

Before decent data on pollution by industry existed, researchers relied on a sensible proxy for pollution: pollution abatement costs. Starting in 1973, the United States began collecting and reporting what are now called the PACE data: industry-specific data on pollution abatement capital expenditures and operating costs (U.S. Bureau of the Census, various years). Thus, even without the specific data needed to determine whether the United States is increasingly importing polluting goods, researchers could answer the closely related question: does the United States increasingly import goods that face high pollution-abatement costs in the United States?

Among the first such studies is Walter (1973), who estimated pollution abatement costs for 1971—before the PACE data were collected. For each of eighteen manufacturing industries, as well as several other large aggregates such as mining, transportation, utilities, and commercial services, Walter calculates the environmental costs per dollar of gross sales. He then uses U.S. Bureau of Economic Analysis (BEA) input–output tables to construct what he calls the "overall" environmental cost loading for each sector. Walter shows that in 1971, "1.75 percent of the value of U.S. exports consisted of pollution-related costs, which is about 15 percent higher than the 1.52 percent estimated for U.S. imports." These results suggest that in 1971 the U.S. economy specialized in the production of goods facing high U.S. pollution costs.

To see whether this situation changed over time, Robison (1988) used PACE time-series data on pollution abatement costs. He showed that the ratio of abatement costs per dollar of value added for imports relative to exports rose from 1.15 in 1973 to 1.39 in 1982. One could infer from this result that the United States was increasingly importing, or decreasingly exporting, goods that pollute. However, there are other possible interpretations. It is not clear from Robison's results whether during this time period the United States increasingly imported polluting goods or the abatement costs imposed on goods competing with imports rose. In this symposium, Ederington (2010) discusses the possibility that the United States may have been reluctant to impose large environmental costs on exporting industries, for fear that they would become less competitive in world markets, a possibility supported by evidence in Ederington and Minier (2003). Nevertheless, Robison's finding is at least consistent with the idea that the United States was increasingly importing polluting goods over that period.

Leonard (1988) also defines pollution-intensive industries in terms of spending on pollution abatement capital by U.S. plants, but comes to a different conclusion. He focuses on two particularly high-cost industries (mineral processing and chemicals), and finds no evidence that these sectors were increasing their foreign direct investment (FDI) faster than other sectors, shifting their FDI to developing countries, increasing imports faster than other products, or increasingly importing from developing countries. However, the results for two industries do not prove the point, and these two industries in particular may have other sources of comparative advantage in the United States, or may be geographically immobile for other reasons.

In a similar spirit, Low (1992) examines U.S. trade with Mexico, and finds that the forty-eight industries that spent the most on pollution abatement in the United States accounted for 12 percent of Mexico's exports to the United States, but that these exports were growing at 9 percent annually compared to 3 percent for all exports. So Low sides with Robison in finding evidence suggesting that the United States is increasingly importing polluting goods, in this case from Mexico.

Perhaps the most widely known paper in the literature that uses pollution abatement cost data and trade flows is Grossman and Krueger (1993), who also focus on U.S.–Mexico trade patterns. The authors run a simple cross-section regression of 1987 U.S. industry-level imports from Mexico on industry characteristics, including pollution abatement costs in the United States. The coefficient on U.S. pollution abatement costs is positive, as would be expected if the U.S. imports polluting goods from Mexico, but it is both qualitatively and statistically insignificant. Moreover, as a cross-sectional analysis, their regression says nothing about whether U.S. imports of polluting goods are increasing or decreasing. Levinson and Taylor (2008) rerun Grossman and Krueger's regression in a panel context and show that U.S. imports increase when environmental costs increase. Of course, this does not mean that the United States increasingly imports polluting goods. It only indicates that the United States increasingly imports those goods whose pollution abatement costs are increasing.

In the end, the use of pollution abatement costs as a proxy for pollution fails to definitively answer the question of whether the United States increasingly imports polluting goods. But one consistent pattern does stand out: researchers examining cross-sections of data (e.g., Walter 1973; Grossman and Krueger 1993) find that the United States does not appear to specialize in goods facing high pollution abatement costs in the United States. By contrast, researchers using panels of data (e.g., Robison 1988; Low 1992; Levinson and Taylor 2008) find that the United States increasingly imports goods whose environmental costs are increasing in the United States (Brunnermeier and Levinson 2004). However, to determine directly whether the United States increasingly imports polluting goods, we need data on pollution, not pollution abatement costs. We turn to this issue in the next section.

Direct Measures of Pollution by Industry

To assess whether the United States has been increasingly importing polluting goods, as opposed to those goods whose industries spend more on pollution abatement, we need a metric for categorizing industries' pollution intensities. That is, we need an "inventory" of how much pollution each individual industry emits per dollar of output. Over the years, several such inventories have been constructed, including: (a) a 90-sector inventory for 1967 compiled by Leontief and Ford (1974); (b) the World Bank's Industrial Pollution Projection System (IPPS), a 448-sector inventory created using 1987 data (Hettige et al. 1995); (c) the U.S. EPA's Trade and Environmental Assessment Model (TEAM), a 1099-sector inventory using 1997 data (Creason et al. 2005); and (d) the Carnegie Mellon Economic Input–Output Life Cycle Assessment (EIOLCA) inventory, which contains 491 sectors and data from 1999 (Carnegie Mellon University Green Design Institute 2008). Until recently, only the World Bank's IPPS has been publicly available and widely used.

The IPPS Inventory and Its Drawbacks

In 1987, World Bank staff constructed the IPPS inventory of pollution intensities for the manufacturing sector, which covered fourteen different emissions coefficients: six air pollutants, two measures of water pollution, and toxic and metal releases to air, water, and land. Air pollution emissions are reported for 448 industries, water pollution emissions are reported for 321 industries, toxic releases are reported for 434 industries, and metals releases are reported for 317 industries (Hettige et al. 1995).

To construct emissions coefficients, the IPPS authors matched facility-level data from the United States Census of Manufactures to facility-level data from three environmental datasets: the Aerometric Information Retrieval System (AIRS) for the air pollutants; the National Pollution Discharge Elimination System (NPDES) for water pollution; and the Toxics Release Inventory (TRI) for toxic chemicals and metals. While every facility reports to the Census of Manufactures, not every facility reports to the environmental databases. For example, in 1987, manufacturers were only required to report toxic releases to the TRI if they used more than 75,000 pounds of the particular toxic chemical. To address the issue of some plants being omitted from the environmental data but included in the census data, the IPPS documentation discusses two potential emissions coefficients (Hettige et al. 1995). The first coefficient is total reported emissions divided by total economic activity in each industry, but only for those facilities that appear in both datasets. This is described as an "upper bound" on the emissions intensities, assuming that the less pollution-intensive facilities are the ones omitted from the environmental data. The second coefficient is total reported emissions divided by total economic activity for each industry. In this case, the numerator (pollution) contains fewer reporting facilities than the denominator (economic activity). This is described as a "lower bound" on emissions intensities. Most users of the IPPS focus on this lower bound estimate of pollution intensity.

A fundamental problem with the IPPS is that it reports the pollution emitted by each industry directly, thus ignoring the pollution that may be emitted by intermediate inputs to that industry. For studies of U.S. industrial composition, where all output is included, this omission is irrelevant because all manufactured output is reported, whether it is a final product or an input to another industry. For studies of trade flows, however, the omission of intermediate inputs is problematic. For example, manufacturing automobiles causes far more pollution than just the emissions from the automobile sector itself. Steel, rubber, glass, plastics, and many other polluting industries manufacture inputs to automobiles. If, over time, the United States increasingly imports final products, as opposed to intermediate goods, it could spuriously appear as though the pollution content of U.S. imports is decreasing over time. Unfortunately, early studies that used the IPPS did not address this issue.

Early Studies That Used the IPPS

The first analysis to use the IPPS to assess whether the United States is increasingly importing polluting goods (Schatan 2003) was written for the Commission for Environmental Cooperation, the international organization established by NAFTA to expressly address issues of industrial flight and pollution havens. Schatan ranks industries according to their emissions as reported in the IPPS, and finds that the fifteen most polluting industries' share of exports from Mexico to the United States fell from 25 percent in 1990 to 12 percent in 1998. At the same time, these industries' share of exports from Canada to the United States fell from 31 percent to 28 percent. These trends would appear to indicate that the United States is *not* increasingly importing polluting goods, at least not from its NAFTA partners.

Kahn (2003) does not use the IPPS directly, but rather one of its components—the TRI. He calculates the pollution content of an industry as the sum total of its carcinogenic toxic releases, based on the 1994 TRI, and examines the implied pollution content of U.S. exports and imports from 1958 to 1994. Kahn finds that, according to this measure, the pollution content of U.S. imports in 1958 was nearly twice the pollution content of U.S. exports. By 1994, however, the two series converge, as the pollution content of imports drops much faster than the pollution content of exports. Kahn concludes that fears about pollution havens are misplaced, although an alternative interpretation could be that the United States is increasingly importing finished goods rather than intermediate inputs, and that any pollution from those inputs is not included in the TRI and IPPS measures.

Cole (2004) uses the IPPS to calculate emissions embodied in U.S. imports and exports from 1974 to 2001, where "embodied" refers to the emissions that would have been emitted in the United States in 1987 if imports had been produced in the United States rather than abroad, and if exports had been produced abroad rather than in the United States. In other words, Cole simply multiplies each industry's imports and exports by its corresponding IPPS emissions per dollar in the United States, and sums across industries. He shows that the pollution per dollar of exports fell over this period, and that the pollution per dollar of imports fell even faster. Consistent with Kahn (2003) and Schatan (2003), Cole finds that the ratio of pollution embodied in imports to pollution embodied in exports fell over time, even when the focus is on trade with one developing country, Mexico. Thus Cole concludes that the results "provide no evidence to suggest that the United States is increasingly displacing [offshoring] its pollution."

Ederington et al. (2004) begin by multiplying each industry's domestic production for each year from 1972 to 1994 by its 1987 IPPS emissions coefficient, yielding an estimate for how much pollution that industry would have emitted in each year had it used the 1987 production technology. They then sum across all industries in each year, yielding a prediction for how much total pollution would have been emitted by the U.S. manufacturing sector each year, given its concurrent scale and industry composition, but using 1987 production technologies. While manufacturing output grew about 50 percent in real terms over this period, for most of the fourteen pollutants tracked by the IPPS, the predicted growth in pollution—based on the 1987 IPPS emissions coefficients—would have been significantly less. Since technology does not change in this calculation, the difference between real manufacturing growth and predicted pollution growth must be due to a shift in the composition of U.S. industries toward goods that polluted less in 1987. Ederington et al. (2004) then perform the same calculation for imports, showing that while imports to the United States grew by over 300 percent from 1972 to 1994, the pollution predicted to be embodied in those imports grew by much less. Emissions of most of the fourteen pollutants grew by less than 150 percent; none grew by 200 percent or more. Moreover, even if the analysis is limited to imports from developing countries, U.S. imports shifted toward cleaner goods faster than U.S. domestic production.

None of the four studies above finds evidence that the United States is increasingly offshoring pollution. However, they all share the same fundamental problem, which causes them to overstate their conclusion. They ignore the fact that calculations of the overall pollution intensity of domestic production include many goods that are used as intermediate inputs into other industries, while calculations of the pollution intensity of imported goods ignore those intermediate inputs because the inputs are not internationally traded. Thus it is unclear from these studies whether the United States is increasingly importing goods whose production generates less pollution, or increasingly importing finished goods that use polluting intermediate inputs that have been omitted from the calculation because they are not imported directly.

Accounting for Intermediate Inputs

As discussed above, the biggest drawback to using emissions inventories to assess the changing pollution content of trade is their omission of the pollution content of intermediate inputs. An example may help clarify the issue. Suppose that the United States produces automobiles, that each car requires one ton of steel as its only input, and that steel is entirely produced domestically. Then suppose the United States increases its automobile imports by one car and produces one fewer at home. Pollution in the United States will decline because the United States will produce fewer cars and less steel. How much of the U.S. pollution reduction can be accounted for by the increase in imports? In this example, the answer is 100 percent. But if we merely multiply the change in imports by the respective direct emissions coefficients (one car times pollution per car), we would understate the pollution displaced by imports because the steel produced abroad and used to make the car is embedded in the car and never directly imported. If producing steel generates more pollution per dollar of output than producing cars (i.e., if steel has higher IPPS emissions coefficients than cars), then ignoring the pollution generated by this intermediate input makes it appear that the import composition is shifting toward cleaner goods faster than it actually is. More generally, ignoring intermediate inputs will understate the pollution content of U.S. imports, and if U.S. imports are increasingly composed of final products, ignoring their intermediate inputs will understate the offshoring of U.S. pollution.

To correct this problem, we need to account for not only the pollution embodied in the intermediate inputs to imports, but also the pollution embodied in the intermediate inputs to those intermediate inputs, and so on *ad infinitum*.[2] Fortunately, translating the *direct*

[2]For example, the steel used to make cars itself requires inputs that may produce pollution, and so on.

emissions coefficients in the standard emissions inventory into *total* emissions coefficients that include pollution caused by intermediate inputs is a well understood, if data-intensive, task. Leontief (1970) laid out the procedure, which requires knowing the input–output matrix for the whole U.S. economy (i.e., how many dollars of each industry are required to produce one dollar's worth of output for every other industry). The BEA produces these input–output matrices periodically. With these in hand, transforming the direct emissions coefficients into total emissions coefficients becomes straightforward.[3]

There is, however, one additional complication in this example. If the steel used to produce automobiles domestically in the United States is entirely imported, then automobile imports displace no U.S. steel pollution. In this case, the appropriate emissions coefficient is the direct one contained in the emissions inventories. However, if some fraction—say 20 percent—of the steel used in U.S. automobile production is imported, and the United States imports one more car and produces one fewer, then U.S. steel production declines by only 80 percent of the amount necessary to build one car. This means that pollution in the United States would decline by the amount emitted from manufacturing one car plus 80 percent of the amount emitted from producing the steel required to make that car. This issue can be addressed, at least approximately, by adjusting the pollution coefficients to account for the imported fraction of each good (see the Appendix). What we are left with is an inventory of *total domestic requirements emissions coefficients*: how much pollution is emitted in the United States in the process of producing one dollar's worth of each industry's output, including all of the inputs to that industry that are themselves produced domestically, as well as those inputs' domestic inputs, and so on.

Studies That Use Emissions Inventories and Account for Intermediate Inputs

One study put almost all of the pieces of the puzzle together 35 years ago. Koo (1974) used an early emissions inventory compiled by Leontief and Ford (1972) that assembled engineering estimates of 1967 emissions per million dollars of output for ninety industrial sectors, and for five common air pollutants (particulates, SO_x, hydrocarbons, carbon monoxide (CO), and NO_x). Because this inventory predates the establishment of systematic pollution monitoring, Leontief and Ford note that "these technical coefficients were derived from sampling estimates that in many cases cannot be considered to be truly representative." The Leontief and Ford emissions inventory accounts for intermediate inputs, using a 370-sector input–output matrix for 1963 published by the U.S. Department of Commerce.

Aside from possibly being unrepresentative, there is an additional drawback to using the Leontief and Ford index for this purpose: its level of aggregation. The IPPS disaggregates the manufacturing sector alone into 448 industries, but the Leontief and Ford index covers the entire economy with only ninety sectors. This means that more different goods are aggregated into fewer categories. Any measure of the changing pollution content of trade based on fewer sectors will understate changes, because any changes that occur within sectors will be lost in the aggregation.

Koo multiplies the dollar amount of exports from each industry by its corresponding Leontief and Ford emissions coefficient to find out how much pollution was generated

[3]See Levinson (2009) or the Appendix for the methodology.

in the United States in order to manufacture those exports, including the pollution from manufacturing intermediate inputs. He repeats the exercise for imports in order to calculate how much pollution would have been generated in the United States had those imports been manufactured domestically. He then sums the total pollution across industries, and poses a simple thought experiment. What would happen to pollution in the United States if imports and exports were each reduced by one million dollars, and export-competing domestic industries increased their output by one million dollars? He estimates that, in total, U.S. emissions of airborne particulates would increase by 394,000 tons, U.S. emissions of CO would decrease by 378,000 tons, and U.S. emissions of NO_x, SO_x, and hydrocarbons would on balance remain unchanged. In other words, in 1967, U.S. foreign trade resulted in a reduction of some pollutants in the United States and an increase in others, with essentially no net offshoring of pollution.

But that only answers the static question: does the current (1967) trade balance offshore pollution? Koo's thought experiment asks what would happen if foreign trade changed *proportionally*. However, people concerned about industrial flight, pollution havens, and carbon leakage are implicitly worried about *disproportional* changes in trade, with the developing countries increasingly specializing in polluting goods, and the United States increasingly offshoring production of those goods. Thus, Koo does not really ask (or answer) the question posed by the title of this article, whether the United States is increasingly importing polluting goods.

The Carnegie Mellon Economic Input–Output Life Cycle Assessment (EIOLCA) Model

Most recently, researchers at Carnegie Mellon's Green Design Institute have created a publicly accessible version of their EIOLCA emissions inventory.[4] It starts with an emissions inventory of toxic releases from the 2000 TRI and air pollutants from 1999 for each Standard Industrial Classification (SIC) code. These are aggregated up to the level of the 491 BEA commodity codes. In addition, the inventory reports commodity-specific energy use and greenhouse gas emissions.

Weber and Matthews (2007) use the EIOLCA model to answer a question that is close to, but not precisely, the one posed here. They ask whether U.S. trade increasingly embodies more pollution, based on the pollution emitted by the traded industries in their countries of origin. Rather than asking about "offshored" pollution, they are asking about the pollution in the exporting countries. The analog would be to ask how offshoring U.S. jobs affects employment in countries manufacturing products for export to the United States. To answer their question, Weber and Matthews combine the EIOLCA emissions inventory with similar input–output-based emissions inventories for the six top U.S. trading partners (Canada, China, Mexico, Japan, Korea, and the UK). Note that for each country, they need a separate input–output table and a country-specific emissions inventory. Moreover, countries tabulate their emissions and input–output tables using different industry definitions and different local currencies, so a whole set of concordances needs to be applied to weave together these various sources.

[4]See www.eiolca.net.

Weber and Matthews (2007) find that from 1997 to 2004, the United States imported more pollution (NO_x, SO_2, and CO_2) than it exported, and that the gap between imports and exports is growing. Though on the surface this result seems to contradict prior work, because it shows that the United States is increasingly importing (offshoring) pollution, the results are not inconsistent with each other, for two reasons. First, overseas producers generally emit more pollution per dollar of production than U.S. producers. Since Weber and Matthews are comparing the pollution produced overseas to the pollution produced domestically, they could show an increasing pollution content of imports even if on average the imported goods are drawn from relatively clean industries in the United States. Second, Weber and Matthews correctly account for intermediate inputs embodied in imports, while much recent previous work has not. So on the one hand they ask a different question, which leads to higher import pollution content and growth. But on the other hand, they properly account for inputs, which may also lead to a higher measured pollution content of imports. Thus it is not clear whether their result shows more imported pollution because they ask a different question or because they properly account for intermediate inputs.

Is the United States Increasingly Importing Polluting Goods?

Clearly, all the pieces exist to answer this question. We can start with the World Bank's inventory of industry-by-industry pollution coefficients (the IPPS), which tells us how much pollution was required in the United States in 1987 to produce one dollar's worth of each manufacturing industry's product, but excludes the pollution caused by the inputs used to manufacture those products. Next we can use the BEA's input–output tables, along with industry trade data, to transform those IPPS coefficients into "total domestic requirements coefficients." These coefficients tell us how much pollution is necessary to produce one dollar's worth of each industry's product, and also include the pollution caused by domestic intermediate inputs, the pollution caused by domestic inputs to those inputs, and so on. Let's start with an early year, say 1972. If we multiply the total amount of imports for each industry by the corresponding total domestic requirements coefficient, and then sum across industries for 1972, we can find out how much pollution would have been emitted in the United States if all of the imports in 1972 had been produced domestically (ignoring general equilibrium consequences). Repeating the calculations for each year, we arrive at a time series of the pollution content of imports.

Results of Analysis

Figure 1 presents the results. Line 1 in Figure 1 plots the real value of manufacturing imports to the United States, adjusted for inflation using the producer price index, and indexed so that the 1972 value equals 100. It shows that real imports grew 536 percent between 1972 and 2001. If every industry's imports grew by the same amount (536 percent), then we might say that the pollution embodied in those imports (ignoring their intermediate inputs) also grew 536 percent. But of course imports of some industries grew more than others, and if imports of relatively polluting industries grew more, then the pollution embodied in imports could

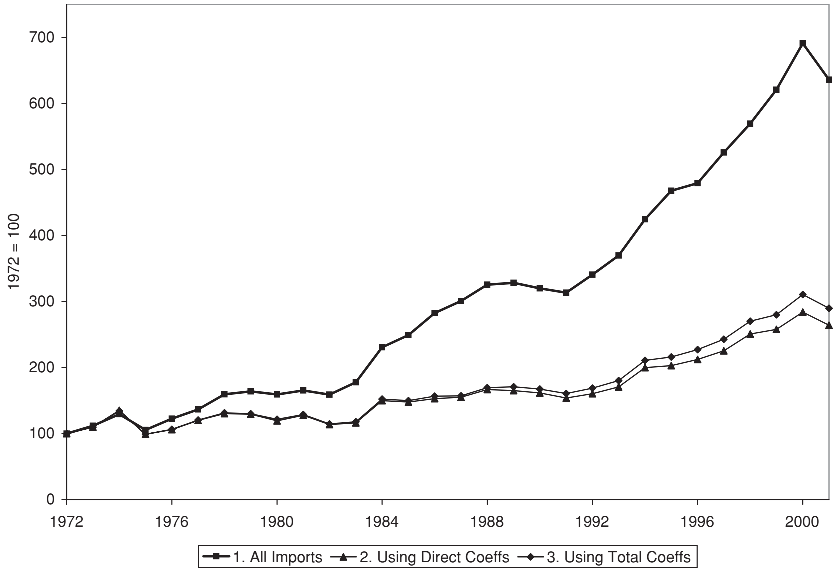

Figure 1. Trends in the value and pollution content of U.S. imports.
Source: Author's calculations based on World Bank's Industrial Pollution Projection System (Hettige et al. 1995), the U.S. Bureau of Economic Analysis benchmark input–output tables for 1987, and import data from Feenstra (1996).

be said to have grown more than 536 percent. If imports of relatively polluting industries grew less, then pollution embodied in imports also grew less.

Line 2 makes this calculation precise. First, I multiply each industry's imports by the World Bank's IPPS coefficient (which ignores inputs) for the unweighted sum of four common air pollutants: SO_2, NO_x, CO, and volatile organic compounds (VOCs).[5] This gives me the total amount of those pollutants embodied in each industry's imports in each year. I then sum across all industries in each year, yielding the total pollution embodied in all imports each year. Next I index the figures so that their 1972 values equal 100 to make them comparable to the import numbers in line 1. That indexed figure is plotted as line 2 in Figure 1. The large difference between lines 1 and 2 indicates a dramatic shift in the composition of imports away from pollution-intensive goods. If imports had been shifting toward more polluting goods—which seems to be most people's intuition—then line 2 would lie above line 1; instead, it drops far below line 1. This is essentially the methodology often used to claim that the pollution embodied in U.S. trade is decreasing. However, because it ignores inputs, it potentially exaggerates the green shift of imports.

Line 3 of Figure 1 addresses this issue by multiplying each industry's imports by the World Bank's IPPS coefficient, which has been transformed using the Leontief input–output procedure to account for domestic intermediate manufacturing inputs, and then aggregating across inputs. Thus line 3 indicates how the pollution embodied in imports has changed over time, based on the changing industrial composition of those imports. Accounting for

[5]Figures for the individual pollutants, for other air pollutants, and for water pollution look similar.

Table 1. The shifting pollution content of U.S. imports and domestic production (in percent)

	1972–2001				1987–2001
Pollutant	**Green shift of imports ignoring inputs (1)**	**Green shift of imports including inputs (2)**	**Pollution added by including intermediate inputs (3)**	**The green shift of U.S. manufacturing including inputs (4)**	**Green shift of imports including inputs (5)**
All four air pollutants	−58	−54	16	−27	−13
Each pollutant individually					
SO_2	−59	−56	15	−28	−15
NO*x*	−58	−54	17	−23	−13
CO	−64	−61	13	−36	−18
VOC	−40	−32	24	−09	3

Source: Author's calculations are based on World Bank's Industrial Pollution Projection System (Hettige et al. 1995), the U.S. Bureau of Economic Analysis benchmark input–output tables for 1987, and import data from Feenstra (1996).

imports shifts up the pollution content of imports, but not dramatically, as line 3 lies only slightly above line 2.

The most striking feature of Figure 1 is the shifting composition of imports away from polluting goods—the "green shift" of imports—shown as the degree to which lines 2 and 3 fall below line 1 starting in 1972. Had production by each of the industries increased by the same overall proportion, the pollution embodied by those imports would have risen 536 percent, the same percentage increase as overall imports. Had imports shifted toward more pollution-intensive goods, line 3 would rise even faster than line 1. Instead, imports have shifted toward less pollution, so that the pollution embodied in imports increased 190 percent rather than 536 percent. Put differently, the green shift of imports reduced embodied pollution by 54 percent relative to a proportional increase in all industries' imports.

Table 1 presents another way of looking at these data. Column 1 measures the green shift of imports, ignoring intermediate inputs. This is the percentage difference in 2001 between the pollution embodied in imports if all imports increased proportionally (line 1 of Figure 1) and embodied pollution predicted by the IPPS coefficients (line 2 of Figure 1). Column 1 indicates that for the sum of all four air pollutants, the predicted embodied pollution in 2001 lies 58 percent below the growth of imports (line 1). For each of the four pollutants, this green shift ranges from 40 percent for VOCs to 64 percent for CO. Column 2 performs this same calculation, but uses the Leontief input–output calculation to include intermediate inputs. In this case, the green shift for the sum of all four pollutants is 54 percent in 2001 (i.e., line 3 in Figure 1 lies 54 percent below line 1), and the green shift for individual pollutants ranges from 32 percent for VOCs to 61 percent for CO.

Column 3 of Table 1 shows how much pollution is added by including intermediate inputs using the Leontief input–output adjustment. It compares the total amount of predicted embodied pollution in 1972 using the unadjusted and adjusted methods. The predicted embodied pollution is 16 percent higher using the Leontief calculation, ranging from 13 percent for CO to 24 percent for VOCs. In Figure 1, line 3 rises only slightly faster than line 2. However, this small difference is not related to the fact that including intermediate inputs raises the amount of pollution embodied in imports, because Figure 1 indexes both lines 2 and 3 so that their 1972 values equal 100. Rather, there is a small difference because this Leontief adjustment becomes larger over the time period, which means that U.S. imports are shifting toward final products, where the adjustment matters, and away from intermediates, where it does not. Thus the direct pollution coefficients (line 2) increasingly understate the pollution embodied in imports, an error that is corrected by line 3.

Finally, it is useful to compare the green shift of imports to the shift of U.S. domestic manufacturing. From 1972 to 2001, the real value of U.S. manufacturing increased 60 percent, but the air pollution embodied in that production increased only 17 percent.[6] In other words, air pollution embodied in 2001 U.S. manufacturing output was 27 percent lower due to the green shift of manufacturing toward clean goods (see column 4, Table 1). However, the green shift of imports, at 54 percent (see column 2, Table 1), was even larger than the green shift in U.S. domestic manufacturing.

In sum, although previous studies that ignored intermediate inputs may have slightly exaggerated the extent of the green shift of imports, the basic finding remains unchanged: imports have been shifting toward cleaner goods, not more polluting goods. Perhaps more surprisingly, imports have been shifting toward cleaner goods even faster than U.S. domestic manufacturing.

Limitations and Implications of the Analysis

One possible criticism of the analysis above is that I have focused only on four air pollutants, ignoring water pollution, hazardous waste, and toxic air pollution. Partly, I have limited the analysis this way for data reasons. The IPPS data document air pollution from 448 manufacturing industries, while the coverage for water pollution is limited to 321 industries. Moreover, past attempts to analyze this issue have been conducted using only air pollution data. Thus, focusing only on air pollutants makes this analysis more directly comparable to previous analyses.[7]

A second possible criticism is that the World Bank's IPPS dates from 1987, the middle of the time span depicted in Figure 1. If the pollution regulations enacted in the 1970s dramatically changed the industry emissions inventories, making the industries that were polluting in 1972 much cleaner by 1987, but not doing much to change the pollution intensity of industries that were already clean in 1972, then Figure 1 may exaggerate the green shift of imports. That is, imports may only be shifting toward goods that *were* pollution intensive in 1972, but became relatively cleaner by 1987, at great cost. If this is the case, then those imposed pollution abatement costs may be the cause of the increased imports.

To address this issue, I conducted the same analysis, but starting in 1987 rather than 1972 (see column 5 of Table 1). Real U.S. manufacturing imports grew 111 percent between 1987 and 2001, and the sum of the four common air pollutants embodied in those imports grew

[6]Calculations based on NBER/CES Manufacturing Productivity Database (Bartelsman and Gray 1996) and IPPS coefficients.

[7]As some have noted (Hahn et al. 1990; Sigman 1996), manufacturers can sometimes substitute across media—polluting in water when confronted with air pollution regulations, or vice versa. This cross-media substitution would pose a problem if the United States increasingly imports goods that pollute water instead of air. However, that does not seem to be the case.

84 percent.[8] This means that by 2001, the pollution embodied in imports was 13 percent lower than it would have been without the change in the composition of imports away from polluting goods (column 5, Table 1). So the same green shift of importing industries is apparent whether we start the analysis in 1987 or 1972.

Before attempting to draw any broad conclusions from this result, it is important to point out that this analysis has deliberately taken a U.S. perspective, because the United States has both the earliest and most comprehensive industry-specific pollution inventory and the most detailed input–output tables. Thus we are only able to say that the composition of imports to the United States has shifted away from manufacturing goods that would have emitted more pollution had they been produced domestically. We can say nothing about whether the composition of U.S. imports is shifting toward industries that produce more or less pollution in their countries of origin without comprehensive emissions inventories for those countries that are at the same level of disaggregation as for the United States. This issue was studied by Weber and Matthews (2007), who used country-specific emissions inventories and input–output tables that are more aggregated than what is available for the United States, and focused on the overall level of greenhouse gas emissions embodied in U.S. imports, including both the scale and composition of trade. They find that the "CO_2 embodied in U.S. imports doubled . . . between 1997 and 2004," while U.S. imports grew 67 percent. Their analysis counts pollution emitted abroad, rather than pollution that would have been emitted in the United States.

Could it be that the composition of exports to the United States is shifting toward more polluting industries, when measured using the exporting countries' emissions inventories, even though Figure 1 shows that the composition of imports to the United States is shifting toward less polluting industries, when measured using the U.S. emissions inventories? That seems unlikely. For that to be the case, the emissions inventories for the United States and its trading partners would have to be negatively correlated. That is, goods that are relatively clean to produce in the United States would be relatively dirty if produced elsewhere, and vice versa.[9] While the pollution regulations enacted in the United States prior to 1987 may have compressed the U.S. emissions inventory, it seems unlikely that they would have inverted the order of industries, making dirty industries relatively clean and vice versa.

Summary and Conclusions

Most readers will not be surprised to learn that over the past 30 years, the composition of goods manufactured in the United States has changed, and that today we produce domestically a higher proportion of goods whose manufacturing generates relatively *less* pollution, and a lower proportion of goods whose manufacturing generates relatively *more* pollution. One possible explanation for this green shift in U.S. manufacturing is that we are increasingly importing the goods that generate the most pollution, perhaps due to the

[8]Author's calculations not shown here.

[9]Gamper-Rabindran (2006) compares the World Bank's 1987 IPPS inventory (used here) to a 1993 emissions inventory constructed for twenty Mexican manufacturing industries, and finds "moderate" rank correlations between the two of 0.54 and 0.62, depending on how emissions intensity is calculated.

rise in environmental compliance costs in the United States. Thus many readers may be surprised to learn that this same green shift also appears to be happening with imports. Today the United States imports proportionally more clean goods and proportionally fewer polluting goods than was the case 30 years ago. Perhaps even more surprisingly, the green shift in imports is even larger than the green shift in domestic production. In other words, the analysis here finds that the United States has not been offshoring pollution.

This finding, that the composition of imports is becoming less polluting more quickly than is the composition of domestic production, may contradict the intuition behind claims of industrial flight, pollution havens, leakage, and dirty industry migration, but it does not necessarily disprove those claims. Perhaps the green shift in U.S. manufacturing is larger and the green shift in imports smaller than it would have been without U.S. regulatory changes and without trade liberalization. The observed green shift in imports just means that if there is a pollution haven effect, or industrial flight from strict U.S. regulations, it has been overwhelmed by other forces.

What forces might be driving the green shift in imports? Answering this question thoroughly is beyond the scope of this paper, but some hints lie in the data. For the most pollution-intensive industries, imports grew faster than domestic production, but the difference was not as large as that between overall imports and overall domestic production. For example, paper imports grew in real terms at an annual average of 3.5 percent from 1972 to 2001, 1.6 times as fast as domestic paper production. Petroleum product imports grew 2.6 percent annually, 2.4 times as fast as domestic petroleum production. Overall, however, manufactured imports grew 6.6 percent annually, four times faster than domestic production. So while imports of highly polluting industries such as paper and petroleum products grew faster than domestic production, they grew more slowly than imports in general.

For the least pollution-intensive industries, the pattern largely reverses. Clean imports grew faster than domestic production, but clean imports also grew faster than overall manufactured imports, and in many cases domestic manufacturing of relatively clean industries actually declined. For example, apparel imports grew 9.8 percent annually, while domestic apparel production declined by 0.4 percent. Shoe imports grew 6.2 percent annually, while domestic production declined 4.8 percent. Imports of games and toys grew 12 percent annually, while domestic production declined 1.1 percent. So imports of relatively clean industries such as apparel and toys grew faster than domestic production, and faster than imports in general.

What is different about paper and petroleum, on the one hand, and apparel, shoes, and toys on the other? The former are pollution intensive, and imports grew more slowly than domestic production. The latter are relatively clean, and imports grew faster than domestic production. The relatively clean industries also happen to be relatively labor intensive and geographically mobile, suggesting that other factors may be correlated with pollution emissions and trade growth, and may overwhelm any causal effect of pollution intensity on import patterns. Labor-intensive, geographically mobile industries may simply have been more likely to relocate overseas during the last 30 years to take advantage of lower wages, and such relocation may have been enabled by trade liberalization and lower transport costs. Since those industries also happen to be relatively clean, the result is a green shift in the composition of manufacturing imports.

If nothing else, the magnitude of the green shift illustrated in Figure 1 should help illustrate the enormous obstacle confronting researchers trying to estimate a causal relationship between environmental regulations and trade flows. Such a causal relationship, if it exists, has been masked by forces working in the opposite direction, causing imports to shift to cleaner rather than dirtier industries. Whatever forces have been at work over the past 30 years, the data and analysis presented here appear to indicate that, on balance, the United States has not been offshoring pollution.

Appendix: Accounting for Pollution Caused by Intermediate Inputs Using Leontief Input–Output Analysis

To properly account for the pollution embodied in U.S. imports, we need to include the pollution created by inputs to those imports. Moreover, those inputs may use polluting inputs themselves, which we would also need to account for, and so on. Fortunately, there is a relatively simple algebra, developed by Leontief (1970), that allows us to untangle this infinite chain of inputs and to derive the total amount of pollution generated by any one industry, including its inputs.[10] Suppose that x_i represents the total output of sector i, including intermediate inputs to other industries and final output to either consumption or export. The total dollar amount of good i required directly in the production of one dollar's worth of good j is c_{ij}. Final output is y_i. Total output, $\mathbf{x}$, which is a vector of n outputs—one from each industry—is the sum of output used as intermediate goods and final output:

$$\begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ c_{n1} & \cdots & c_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} + \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix}. \tag{1}$$

Or, in vector notation:

$$\mathbf{x} = \mathbf{C}\mathbf{x} + \mathbf{y}, \tag{2}$$

where $\mathbf{C}$ is an $n \times n$ matrix of direct requirements coefficients with elements c_{ij} representing the dollar value of input industry i used to produce one dollar of output industry j.

For U.S. production, where we observe $\mathbf{x}$, the value of all shipments, including both intermediate inputs and final products, we can appropriately estimate pollution by multiplying $\mathbf{x}$ by a vector of direct emissions coefficients $\mathbf{z}$, such as those from the IPPS. But when we examine imports, we see only the final product $\mathbf{y}$, without all of the intermediate production. In this case, we need a set of "total" pollution coefficients. These coefficients must embody all the pollution generated by all of the inputs to $\mathbf{y}$, all the inputs to those inputs, and so on. To calculate this, we can solve equation (2) for $\mathbf{x}$ to get

$$\mathbf{x} = [\mathbf{I} - \mathbf{C}]^{-1}\mathbf{y}, \tag{3}$$

[10]See Leontief (1970) for the application most closely related to pollution. See Miller and Blair (1985) for a textbook explanation.

where **I** is the identity matrix. The matrix $\mathbf{T} = [\mathbf{I}\text{–}\mathbf{C}]^{-1}$ is the Leontief total requirements matrix. Each element t_{ij} contains the dollar amount of industry i necessary to produce one dollar's worth of output from industry j, including the amount of i used in all other industries that are used in j, as well as the amount of i used in the inputs to those industries, and so forth. The vector **x** represents the total amount of manufactured goods necessary to produce output **y**. To generate the total pollution coefficients, premultiply the Leontief total requirement matrix by the **z** vector from IPPS as follows:

$$\tilde{\mathbf{z}} = \mathbf{z}'\mathbf{T} = \mathbf{z}'[\mathbf{I} - \mathbf{C}]^{-1}. \tag{4}$$

The only new piece of information needed to construct $\tilde{z}$ is **C**, the matrix of direct requirements coefficients. The BEA publishes an input–output table for the United States that can be used to construct **C**. The BEA tables are organized by commodity rather than industry, but, for the manufacturing sector, commodity codes mostly map one to one into industry codes. For example, the 469 1997 North American Industrial Classification System codes map into 344 BEA commodity codes. The 453 1987 SIC codes can be aggregated into 353 commodity codes.

Using the total emissions coefficients $\tilde{z}$ in place of the direct emissions coefficients **z** captures all of the pollution generated by intermediate goods, and does not understate displaced pollution. However, it overstates the pollution caused by intermediate inputs if some of those inputs are imported to the United States (e.g., if the steel used to make cars in the United States is itself imported). The final step thus involves adjusting pollution coefficients to account for any imported fraction. We must multiply the direct requirements coefficients by the fractions of goods in each industry that are produced domestically. In other words, we need to replace the **C** matrix in the inverse Leontief calculation with $diag(\mathbf{d})\mathbf{C}$, where **d** is an $n \times 1$ vector whose elements are the share of each industry supplied by domestic production:[11]

$$\mathbf{z}^* = \mathbf{z}'[\mathbf{I} - diag(\mathbf{d})\mathbf{C}]^{-1}$$

$$[\, z_1^* \cdots z_n^{**} \,] = [\, z_1 \cdots z_n \,] \left(\mathbf{I} - \begin{bmatrix} d_1 c_{11} & \cdots & d_1 c_{1n} \\ \vdots & \ddots & \vdots \\ d_n c_{n1} & \cdots & d_n c_{nn} \end{bmatrix} \right)^{-1}. \tag{5}$$

These emissions coefficients, $\mathbf{z}^*$, are *total domestic requirements emissions coefficients*. We can then multiply each industry's imports by the appropriate z_i* to get the amount of pollution that would have been generated in the United States had those imports been produced domestically, including the pollution generated from manufacturing all of the inputs to those imported goods.

[11]The domestic share of supply is defined as 1 – imports/(domestic production + imports – exports). Note that this assumes that the fraction of any input that is imported is the same, regardless of which industry uses it.

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