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Abstract

Using input–output tables and data on wastes from the Japanese industrial sectors, we have provided empirical evidence that, in Japan environmental performance of their upstream suppliers contributes positively to the performance of their final product assembly firms or economic sectors. In this paper, we propose to investigate the same hypothesis for firms and other establishments in manufacturing and other sectors in India. Indian supplier firms that sell goods and services to their client assembler firms are not generally structured in the form of efficient supply chains as in advanced economies. So, the environmental performance of these suppliers may not have positive impacts on the performance of their assembler firms or economic sectors, but this is yet to be verified empirically.

In our study on Japan, we measured supply chains' environmental performance using various amounts of waste materials and also CO$_2$-equivalent greenhouse gas emissions generated in their production processes. Unfortunately, the only environmental performance data we have for the Indian economic sectors is their CO$_2$ emissions. So, we investigate the impact of CO$_2$ emissions by supplier firms on the economic performance of their assembler firms in India.

Keywords: greenhouse gas emissions, supply chains, environmental management, firm performance, India
1. Introduction

Limiting the amounts of industrial wastes generated in firms’ manufacturing processes has been of policy interest in recent years. A type of waste of our interest in this paper is greenhouse gases (represented by the carbon dioxide equivalent below). Even though it is not harmful to human health, CO₂ is being regulated like toxic industrial wastes in many developed countries including Japan. More recently, the importance of limiting CO₂ emissions globally has been recognized by both developed and developing nations, and an international treaty to strengthen the former Kyoto protocol was signed in Paris.¹

One of the topics of research interest, which has not received much empirical attention, is the extent to which CO₂ emissions, as an industrial waste, are generated along firms’ supply chains. Although we see large corporations (e.g., 3M, Sony) promoting green procurement policies and claiming to use environment-friendly suppliers, we have little empirical evidence yet to suggest how such environmental management methods based on supply chains might benefit large downstream firms economically. We do not have much empirical evidence either about the impacts on final products of environmental management policies conducted by firms in their supply chains emerging in developing countries like India.

In this paper we present empirical estimates for the amounts of greenhouse gas (GHG) emissions generated by Indian manufacturing and other economic sectors, and their supply chains. (GHG emissions are measured in carbon dioxide (CO₂) equivalent in this paper.) We then estimate their contributions to firm performance measured in terms of value added. Figures 1 and 2 show CO₂ emissions per person and per income, respectively, in India and Japan.

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¹ The 2015 United Nations Climate Change Conference, held in Paris, France, from November to December 2015 was the 21st yearly session of the Conference of the Parties (COP) to the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and the 11th session of the Meeting of the Parties to the 1997 Kyoto Protocol. The Paris Agreement, a global agreement on the reduction of climate change, the text of which represented a consensus of the representatives of the 196 parties attending it, was signed. It needs to be ratified to become a world treaty [1].
Japan over time. We see from these figures that while Japan emits more CO$_2$ than India per capita, Japan generates less CO$_2$ emissions per dollar than India does.

Figure 2. CO$_2$ emissions per GNI (gross national income): India and Japan, 1990–2011. Source: Prepared by the authors using figures in [2–5].

The rest of the paper is organized as follows. After a brief review of earlier studies in Section 2, we discuss our method and approach toward the analysis of the generation of industrial waste (CO$_2$ emissions here) by supply chains in Section 3. Our data are briefly introduced in Section 4. We show and analyze certain patterns that are found in the generation of CO$_2$ emissions in Indian and Japanese industries in Sections 5 and 6. Section 6 presents our empirical results that relate the value added to the generation of wastes by downstream and upstream firms. Section 7 concludes.

2. Literature

There are relatively few research studies that use nations’ input–output (I–O) tables as the data source for analyzing the relationships between supply chains and firms’ environmental performance. Hayami et al. [6] present a framework in which I–O tables can be used for analyzing the effects, at the sector level, of the environmental management performance of firms in supply chains on their downstream assembly firms’ performance. They present references on the literature that discusses many aspects of environmental management at upstream supply chains as related to their downstream customer firms [7,8]. Discussions on supply chains in India are also found [9–11]. Details of I–O analysis and applications to the Indian economy and environmental management are found in papers contained in [12].

3. Our approach to estimating output and waste along the stages of a supply chain

As noted earlier, certain downstream producers in developed countries are beginning to practice “green procurement,” by which upstream suppliers with greener production proc-
%esses become the preferred suppliers of their downstream customer firms. For example, Cisco, NEC, Sony, and Toshiba discuss their corporate green procurement guidelines in [13–16]. We apply this notion to India and investigate empirically the extent to which the same notion holds in India.

In order for the government to evaluate the potential benefits (i.e., the greening) of upstream firm production processes resulting from promoting downstream instruments, it is essential that we estimate relationships that describe the generation of waste materials at both upstream and downstream firms in a national economy. However, to our knowledge, only Hayami et al. present an empirical framework to achieve this objective using available data [6]. They also present an empirical model that allows us to estimate downstream firms’ benefits of reduction of their suppliers’ environmental wastes.

We apply the above model to India and derive some preliminary empirical estimates that evaluate the relative importance of the waste materials generated along the supply chain. Our findings in this chapter provide complementary evidence to the importance of environmental management in supply chains reported, for example, for individual firms, obtained using survey data and methodologies different from ours [8,17].

3.1. Estimation of output along a supply chain

Our methodology is based on the input–output (I–O) analysis originally developed by Leontief [19,20]. (Applications of the I–O analysis to waste management and other environmental issues are found, for example, in [12,21–23]. Additional uses of input–output analysis in environmental management are found in [24]. We divide an economy into industrial and other economic sectors where production of goods and services takes place. We define I–O technical coefficients $a_{ij}$ ($i, j = 1,2,\ldots,n$) to be the amount of input from sector $i$ per unit amount of output from sector $j$. To ensure positive output values, it is customary to assume the Hawkins–Simon condition [25] that $a_{ij}$ lie between 0 and 1 and their column sums are less than 1.

Suppose $x_j$ denotes the output from sector $j$. Then $a_{ij}$ are estimated as follows:

$$a_{ij} = \left( \frac{X_{ij}}{x_j} \right),$$

where $X_{ij}$ denotes the amount of input from sector $i$ that is required for the production of $x_j$. Using supply chain terms, we say $a_{ij}$ connect downstream output from sector $j$ to its immediate predecessor upstream input from sector $i$.

We denote by $A$ an $n \times n$ matrix with elements $a_{ij}$ and by $x$ an $n \times 1$ vector in which each component $x_j$ represents domestic production (output) of sector $j$ ($j = 1,2,\ldots,n$). We also denote

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1. A questionnaire-based survey across 124 companies from eight industrial sectors in Taiwan was used [17] in one study, while survey data on a sample of 122 firms drawn from electronics manufacturers listed on the database of the Taiwan Stock Exchange Corporation (TWSE) market and the Gre Tai Securities Market (GTSM) in Taiwan was used in another study [8].

2. See [18] where Indian manufacturers’ approaches to green supply chain management are explained.
by \( f_i \) the final downstream demand for sector \( i \). We denote by \( f \) the corresponding \( n \times 1 \) final downstream demand vector. For example, \( f_i = 1 \) means a unit final downstream demand for output from sector \( i \). (For simplicity, we ignore the impacts of international trade.)

In order to produce the final downstream demand \( f \), the total amount of input required from sector \( i \) in the immediate predecessor stage (denoted by \( k = 1 \)) is given by

\[
x^{(k=1)} = Af.
\]

\( x^{(1)} \) is also interpreted to be the indirect demand for the previous stage (\( k = 1 \)) production process, which is induced by final demand \( f \), because without the production of \( x^{(1)} \), the final demand cannot be met. In order to produce \( x^{(1)} \), the total amount of input required from sector \( i \) in the immediate predecessor stage (denoted by \( k = 2 \)) in the supply chain is given by the \( i \)th element of the following vector:

\[
x^{(2)} = Ax^{(1)} = A^2 f.
\]

Generally, we can trace production activities along the supply chain backward, starting from the final demand, and we get

\[
x^{(k)} = Ax^{(k-1)} = A^k f, \quad k = 1, 2, \ldots
\]

We call \( x^{(k)} \) the \( k \)th stage indirect effect of final demand \( f (k = 1, 2, \ldots) \) in the supply chain.

In order to be able to produce final demand \( f \), the following total indirect output must be produced:

\[
x^{(\text{indirect})} = Af + A^2 f + \ldots + A^k f + \ldots = A(I - A)^{-1} f,
\]

where \( (I - A)^{-1} \) is the Leontief inverse matrix which exists provided that the \( a_{ij} \) satisfy the Hawkins–Simon condition given above.

We have shown that our input–output analysis identifies the successive upstream production processes that are followed by the average supply chain for the final demand vector \( f \). This is summarized as follows. The input–output analysis describes all economic activities of the average supply chain in a national economy by following input–output transactions for all goods and services. The analysis typically starts from the final stage of downstream demand as shown above and moves backward by backtracking all predecessor upstream stages of production.

In this paper, we consider CO\(_2\) (defined here to be the combined greenhouse gases measured in CO\(_2\) equivalent) as a waste material associated with industrial production activities.
3.2. Graphical representation of connectedness of I–O sectors

Different sectors tend to be more connected in modern developed economies than in developing economies. This is because, in a modern economy, unproductive sectors will become more productive, with inputs from more productive sectors to survive. In addition, primary sectors and supplier sectors of manufacturing are connected to assembly sectors of manufacturing in a functional and efficient manner in supply chains. These functional connections are often missing in developing economies. Figures 3–5 show the degrees of 35 I–O sectors’ connectedness to each other in India and Japan. These 35 sectors are as follows:

| No. | Name                                                        |
|-----|-------------------------------------------------------------|
| 1   | Agriculture, Hunting, Forestry, and Fishing                 |
| 2   | Mining and Quarrying                                       |
| 3   | Food, Beverages, and Tobacco                               |
| 4   | Textiles and Textile Products                              |
| 5   | Leather and Footwear                                       |
| 6   | Wood, and Products of Wood and Cork                        |
| 7   | Pulp, Paper, Printing, and Publishing                      |
| 8   | Coke, Refined Petroleum, and Nuclear Fuel                  |
| 9   | Chemicals and Chemical Products                            |
| 10  | Rubber and Plastics                                        |
| 11  | Other Nonmetallic Minerals                                 |
| 12  | Basic Metals and Fabricated Metals                         |
| 13  | Machinery, NEC                                             |
| 14  | Electrical and Optical Equipment                           |
| 15  | Transport Equipment                                        |
| 16  | Manufacturing, NEC, Recycling                              |
| 17  | Electricity, Gas, and Water Supply                         |
| 18  | Construction                                               |
| 19  | Sales, Maintenance, and Repair of Motor Vehicles and Motorcycles, Retail Sale of Fuel |
| 20  | Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles |
| 21  | Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods |
| 22  | Hotels and Restaurants                                     |
| 23  | Inland Transport                                           |
| 24  | Water Transport                                            |
| 25  | Air Transport                                              |
| 26  | Other Supporting and Auxiliary Transport Activities, Activities of Travel Agencies |
| 27  | Posts and Telecommunications                                |
| 28  | Financial Intermediation                                   |
| 29  | Real Estate Activities                                     |
| 30  | Renting of mdoq and Other Business Activities              |
| 31  | Public Administration and Defense; Compulsory Social Security |
| 32  | Education                                                  |
| 33  | Health and Social Work                                     |
| 34  | Other Community, Social, and Personal Services             |
| 35  | Private Households with Employed Persons                   |

Source: [5,32].

List of 35 aggregate I–O sectors used in Figures 3–5
Figure 3. Degrees of connectedness of 35 I–O sectors: India, 1995. Note: The size of each square represents the amount of relevant input for the cell measured in terms of US $million dollars at current price. Numbers on vertical and horizontal axes represent 35 I–O sectors for India and Japan defined in the text.

Figure 4. Degrees of connectedness of 35 I–O sectors: India, 2003. Note: The size of each square represents the amount of relevant input for the cell measured in terms of US $million dollars at current price. Numbers on vertical and horizontal axes represent 35 I–O sectors for India and Japan defined in the text.
Intuitively speaking, Figures 3–5 show the degrees of connectedness between sectors in terms of economic transactions. For example, sectors whose transactions are mostly within themselves are depicted as single dots. On the other hand, if two different sectors have more transactions with each other, then those two sectors are connected by a box. Multiple sectors with transactions, such as sectors that define supply chains, are shown with larger boxes containing them. As expected, Figures 3 and 4 show that sectors of the Indian economy are not much connected to each other, though there are considerably more connectedness observed during 2003 than during 1995. This implies that there are increasingly more supply chain type relationships emerging in the Indian economy in recent years. The Japanese economy has developed well-defined supply chain based relationships among sectors in many industries [6]. This is clearly observed in Figure 5. We speculate from these figures, for example, that environmental management performance of upstream suppliers affect the performance of downstream firms much more in Japan than in India.

3.3. Estimation of wastes along a supply chain

In the I–O analysis presented in Section 3.1, it is customary to include output which has economic value. It is also customary to assume that industrial waste has no economic value in the form it is generated. For these reasons, industrial wastes are not included in our analysis

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4 Waste here denotes CO₂, but our formulation applies to other waste materials as well.
5 In reality, most waste materials have positive or negative economic value. For example, CO₂ has economic value in the GHG market currently [26].
We treat waste materials separately here. Suppose we have estimated $E_j$, the amount of waste generated per unit of output produced in sector $j$ ($j = 1, 2, \ldots, n$). We denote by $E$ the corresponding $n \times n$ diagonal matrix with $E_j$ in the $j$th diagonal position. Then the amounts of waste produced by the output of sector $j$ along the successive stages of a supply chain are given as follows:

Denote by $w_j$ the amount of waste generated in sector $j$, and denote by $w$ an $n \times 1$ vector consisting of $w_j$ ($j = 1, 2, \ldots, n$).

Then in the final stage, stage $0$ ($k = 0$), of a supply chain, the demand is $f$, and the waste generated is $w^{(0)} = EA^0f = Ef$, which is the waste generated from assembly operations of final output $f$.

In the immediate predecessor upstream stage, stage $1$ ($k = 1$), of the supply chain, the amount of waste generated (called indirect output for stage 1) is

$$w^{(1)} = EAx^{(0)} = Ef.$$

Similarly, we can derive the amount of waste generated along the upstream stages ($k = 2, 3, \ldots$) of the supply chain as follows:

$$w^{(k)} = EAx^{(k-1)} = A^k f, k = 2, 3, \ldots$$

This is shown in the last row of Table 1.

---

| Upstream Stages of a supply chain (→ → closer to the final demand → →) | Downstream: final stage of a supply chain (final demand) |
| --- | --- |
| Total indirect output for the $n$-th and waste stage in upstream stages ($k = 1, 2, \ldots$) | Indirect output for the first stage in upstream stages ($k = 2$) |
| Indirect output for the second stage in upstream stages ($k = 1$) | |

Production output along the stages of a supply chain

$$x^{(direct)} = Af + A^2f + \ldots + A^{k-1}f = A^k f = f$$

Actual statistical treatment of industrial waste materials depends on the nature of each waste material, which we will not discuss here.
Upstream Stages of a supply chain (*→ → →* closer to the final demand *→ → →*)

Downstream: final stage of a supply chain (final demand)

\[
\cdots + Af + \cdots = A (I - A)^{-1} f
\]

Waste output generated along the stages of a supply chain

\[
W^{\text{direct}} + A \cdots + A^2 f + \cdots = A (I - A)^{-1} f
\]

Table 1. Production and waste output along the stages of a supply chain.

3.4. Output along a firm-specific supply chain and statistically obtained average output along the average supply chain

We do not have data on individual firm-specific supply chains that expand from downstream to upstream stages of production. However, element \( a_{ij} \) of input–output matrix \( A = [a_{ij}, i, j = 1,2,...,n] \) is in fact the statistically estimated average fraction of output of sector \( i \) that goes to sector \( j \). This statistical method of obtaining matrix \( A \) (called the commodity flow method) thus allocates input \( X_{ij} \) from the data of total output \( x_j \) [27], that is, \( a_{ij} \) connects downstream sector \( j \) to its immediate upstream sector \( i \) statistically. We have used this property of matrix \( A \) to obtain the average production and waste output along the stages of the average supply chain, \( x^{(k)} \) and \( w^{(k)}, k = 1,2,\ldots, \) given downstream demand vector \( f \). If we had data on production and waste output for the stages of all firm-specific supply chains for given \( f \), then our I–O based estimates give the first-order approximation to the average output of the quantities for all such firm-specific supply chains. (The first-order approximation arises because of the linearity of \( a_{ij} \), which defines the I–O matrix \( A \).)

4. Data

4.1. Input–output matrix

As we have noted in Section 3.1, our estimation methodology uses an \( n \times n \) matrix \( A \) consisting of

I–O technical coefficients \( a_{ij} (i,j = 1,2,...,n) \), where \( n \) is the number of economic sectors being considered. Since 1973, estimated values for \( a_{ij} (i,j = 1,2,...,n) \) are published every 5 years as I–O tables by the Government of India [9,28]. In this paper, we primarily use the Indian I–O tables for the years 1998–1999 and 2003–2004, with 130 sectors \( (n = 130) \). The I–O sectors consist of 37 primary sectors, 68 secondary (manufacturing) sectors, and 25 service sectors.
In addition to the I–O matrix $A = \{a_{ij} \ (i,j = 1,2,\ldots,n)\}$, the Indian I–O table includes additional information on relevant economic quantities for each of the 130 sectors including final demand $f$ for the Indian economy (see Appendix A1).

4.2. Waste and y-products surveys, and I–O matrix $A$

The environmental input–output table that we use here, based on greenhouse gas emission estimates (GOI, 2010), I–O table, material table, calorific table, combustion ratio table, and other data, was constructed by [9,12,29,30].

4.3. Calculating the amounts of waste materials

Using application of the input-output analysis described above, we used the estimated quantities of CO$_2$ for each of the 130 Indian I–O sectors, which we use in our regression analyses. We also used value-added estimations for each of these I–O sectors.

Using I–O analysis, we estimated the amounts of CO$_2$ generated per unit output for each of the 130 I–O sectors.

We are interested in studying the behavior of CO$_2$ emissions in firms’ decision processes. In this paper, we denote by CO$_2$ emissions the total emissions in carbon dioxide equivalents of all greenhouse gases. CO$_2$ has certain characteristics in common in terms of their implications for firms’ own economic incentives and government regulations. For example, CO$_2$ emissions, like some other nontoxic wastes, are harmless to human health. On the other hand, CO$_2$ emissions, like some other waste materials, may also mean firms’ excessive use of costly inputs (fossil fuels in case of CO$_2$). (Note that CO$_2$ emissions and fossil energy use are highly correlated [32, 33].)

5. Waste output along supply chains: example of an auto industry

One topic of research interest is to evaluate the relationships that might exist between downstream and upstream firms in terms of their waste behavior. Input–output analysis identifies statistically average economic relationships that exist between upstream and downstream firms. It is then possible to use input–output analysis also to find the average amounts of wastes that are generated by upstream firms in supply chains in response to production activities for the final products of downstream firms.

5.1. Example of an auto industry example

Table 1 illustrates how our production of output and waste takes place along a supply chain starting from the final downstream demand. By tracing backward, final assembly plant
receives inputs from suppliers in upstream stage 1, who in turn receive their inputs from 
suppliers in upstream stage 2. As we have shown, I–O analysis allows us to estimate inputs 
between two successive stages of production along a supply chain.

5.2. A numerical example, India and Japan

This example illustrates the supply chain effects in the propagation of waste (CO₂) generation 
along supply chains in India and Japan.

| Amounts generated (tons) | Cumulative amounts (tons) | Ratio to total |
|-------------------------|---------------------------|---------------|
| Direct                  | 0.107625                  | 0.020439      |
| Indirect (first stage)  | 0.706568                  | 0.15462       |
| Indirect (second stage) | 1.205888                  | 0.383625      |
| Indirect (third stage)  | 1.151894                  | 0.602376      |
| Indirect (fourth stage) | 0.896974                  | 0.772717      |
| Total (all stages)      | 5.26577                   | 1             |

Source: Authors' calculations.

Table 2. Supply chain effects, auto industry in Japan: CO₂ emissions generated by production of one passenger car 
with a 2000 cc engine.

| Amounts generated (tons) | Cumulative amounts (tons) | Ratio to total |
|-------------------------|---------------------------|---------------|
| Direct                  | 0.1346605                 | 0.03002061    |
| Indirect (first stage)  | 1.919879                  | 0.4580298     |
| Indirect (second stage) | 1.238733                  | 0.7341874     |
| Indirect (third stage)  | 0.6406156                 | 0.8770033     |
| Indirect (fourth stage) | 0.3034687                 | 0.9446573     |
| Total (all stages)      | 4.485602                  | 1             |

Source: Authors' calculations.

Table 3. Supply chain effects, auto industry in India: CO₂ emissions generated by production of one passenger car with a 2000 cc equivalent engine.

Tables 2 and 3 show how much CO₂ emissions occur along the auto supply chains in producing 
passenger cars with certain characteristics: median size cars in India and cars with 2000 cc 
engines in Japan.
We see from Table 2 that firms along the auto supply chain in Japan generate 5.26577 tons of CO₂ emissions, but only 2% of this amount is generated by the final assembler firms. The remaining 98% of CO₂ emissions are generated by suppliers and other upstream firms in the supply chain. In comparison, the corresponding figures for India are: 4.485602 tons of total CO₂ emissions per car are generated in total, of which 3% is generated by the final assembler firms and the rest (97%) of the emissions are generated by suppliers (Table 3). This similarity in the patterns of CO₂ emissions along auto supply chains between India and Japan suggests that production technology of autos is reasonably standardized, perhaps due to the fact that many auto plants in India are owned and operated to a large extent by Western automakers. Another noteworthy point is that total CO₂ emissions per car produced is somewhat lower in India than in Japan. This difference occurs in part because of the sizes of passenger cars considered here that are different between India and Japan, and also in part because of the difference between India and Japan in the amounts of CO₂ emissions induced by imported car parts. The use of more imported parts implies lower levels of domestic CO₂ emissions, which is the case for India. For passenger car production, this ratio is 0.05846 for India and 0.02316 for Japan.

Based on the results given in Tables 2 and 3, we conclude that government environmental regulations about greenhouse gas emissions need to include not only the final auto producers but also many upstream suppliers, in order to be effective.

We noted that our results in Tables 2 and 3 are consistent with the possibility that downstream firms might be able to upload the processing of CO₂ in particular to their upstream suppliers, while processing relatively large amounts of nonenergy-intensive tasks themselves in-house. This could easily happen in practice, since processing energy-intensive tasks is generally expensive.

We also note that this hierarchical structure of processing of the waste materials emitted by firms in assembly-based industries is likely to be typical. This is because of the nature of the types of assembly-based industries, which are most efficiently done by streamlining their supply chains so that assembly operations come last. In addition, assembly firms are generally more powerful than suppliers in their supply chains and hence have the most bargaining power.

Detailed processes of generation of CO₂ emissions by upstream and downstream firms are presented in Tables 4 and 5.
Tables 4 and 5 show the amounts of CO₂ emissions generated by the final auto producers, as well as their suppliers and other upstream firms, in producing a passenger car with a 2000 cc engine. These tables provide details on the amounts of waste materials generated by each of the industrial sectors, based on which figures reported in Tables 2 and 3 were obtained.
6. Estimating the contributions of direct and indirect CO₂ emissions

6.1. Relative contributions of direct and indirect CO₂ emissions to the total sectorial emissions

It is intuitively clear that final output (called output from downstream sectors), whether assembled manufactured products, or output from primary sectors such as mining and agriculture, uses much output produced in their predecessor sectors including suppliers (upstream sectors). It is then likely that the total emissions attributable to any final product (e.g., a passenger car) consist of significant amounts of indirect emissions from upstream sectors and direct emissions which are emitted from the final car assembly stage in the downstream part of the supply chains. Figures 6 and 7 show the breakdown of direct and indirect emissions for 16 sectors. Industries 9–13 with asterisks are thought to be assembly-based manufacturing industries.

We see in these figures that CO₂ emissions are skewed toward upstream firms in manufacturing supply chains. This is particularly evident for Japan (Figure 7). Figure 7 also shows that proportions of toxic wastes show a similar pattern.

Figure 6. CO₂ emissions by industry: proportions of indirect emissions for India.
Figure 7. CO₂ emissions by industry: proportions of indirect emissions for Japan. Notes: In this graph for Japan, proportions of indirectly generated amounts of toxic waste (solid and liquid) materials other than CO₂ are also shown.

| Industry | Description |
|----------|-------------|
| 1        | Mining      |
| 2        | Food production |
| 3        | Textiles    |
| 4        | Pulp/paper |
| 5        | Chemicals |
| 6        | Petrol/Coal production |
| 7        | Basic metals |
| 8        | Nonferrous metals production |
| 9*       | General machinery |
| 10*      | Electric machinery |
| 11*      | Auto |
| 12*      | Transportation machinery |
| 13*      | Precision machinery |
| 14       | Electric power |
| 15       | Public utility |
| 16       | Service |

*A* Assembly-based manufacturing industries.

List of industries used in Figures 6 and 7
Are the patterns of CO\textsubscript{2} emissions across upstream and downstream economic sectors that we observed in Figures 6 and 7 consistent with downstream firms’ profit maximization behavior? We are interested in testing the following hypothesis:

H1: Downstream firms’ performance (measured by their value added) is affected by their upstream firms’ CO\textsubscript{2} emissions as well as their own.

In general, we expect upstream firms’ generation of toxic wastes such as CO\textsubscript{2} to be a negative factor in firms’ value added, but generation of nontoxic wastes may not be, since most nontoxic wastes have commercial value. We first focus on the impacts of downstream firms’ immediate predecessor upstream firms on downstream firm performance, because the impacts, if any, of downstream firms’ environmental management policies such as green procurement can extend most effectively to their immediate predecessor upstream suppliers.

| A     | B     | C     | D     |
|-------|-------|-------|-------|
| India | Japan |       |       |
| Dependent variable | Value added | Value added | Value added | Value added |
| Constant         | 0.5213***  | 0.6965*** | 0.4640*** | 0.5087***  |
|                  | (0.0415)   | (0.0578)  | (0.0099)  | (0.0204)   |
| Direct CO\textsubscript{2} waste (downstream) | −0.0043    | 0.0649**  | −0.0018    | −0.0016    |
|                  | (0.0034)   | (0.0194)  | (0.0011)  | (0.0011)   |
| Indirect CO\textsubscript{2} waste (upstream total, all stages) | −          | −0.1266*** | −          | −0.0150*   |
|                  |           | (0.0347)  |          | (0.0070)   |
| Indirect CO\textsubscript{2} waste (upstream, first stage) | −0.0107*** | −        | −0.0115*** | −          |
|                  | (0.0115)  |          | (0.0030)  |            |
| Adjusted R\textsuperscript{2} | 0.01846  | 0.27258  | 0.04373   | 0.12097    |
| No. of observations | 130     | 130     | 396       | 396        |

*Significance level at 10%.
**Significance level at 5%.
***Significance level 1%.

Notes: The dependent variable (value-added) is measured per sector output. Neither Harisson-McCabe nor Breusch-Pagan tests for heteroskedasticity detected statistically significant level in the regressions reported above. We have also run regressions with log of value-added as the dependent variable. We obtained estimation results which are qualitatively the same. Further, we experienced considerable multicollinearity when indirect emissions from both first and all stages entered regressions. Therefore, we only report regressions with either one of the indirect emission variables here. These regression results were calculated by the authors. Results for Japan in columns E and F are also reported in [6].

Table 6. Determinants of downstream firms’ value added: effects of direct and indirect CO\textsubscript{2} emissions by upstream firms, India and Japan.

We test this hypothesis empirically by estimating the following regressions using a sample of economic sectors corresponding to Indian input–output sectors for which usable data are
available. The data used includes value added and the amounts of CO₂ emissions generated during direct and indirect stages of production for each of the input-output sectors in the sample. (Descriptive statistics for these variables for India and Japan are presented in Appendix 2.)

In our specification, we regress value added on the amounts of CO₂ generated directly by downstream firms as well as the amounts of CO₂ generated indirectly by their upstream producers. Our OLS regression results for India are given in columns A and B of Table 6. Columns C and D show the corresponding results for Japan.²

Even though CO₂ is not thought to be one of the industrial wastes in a traditional sense, the amounts of CO₂ emissions represent the levels of firms’ inputs of fossil fuels. As such, like some other toxic wastes, firms have economic incentives, even without government regulations, to reduce such emissions of CO₂, since the cost of energy can be a significant portion of firms’ production costs. Furthermore, from policy perspectives, some policies introduced by the governments of developed countries have been promoting energy-efficient production processes for many years (e.g., beginning in the late 1970s, after the second oil crisis in Japan). And also, in recent years, CO₂ emission quota policies of various sorts are being introduced in Japanese, EU, and other nations’ industries.

From Column C of Table 6, we see that 1 ton of direct waste output of CO₂ contributes to −0.0018 of firms’ value added per yen of firms’ output. On the other hand, contribution to firms’ value added of the indirect waste output of CO₂ from their immediate upstream predecessor suppliers is −0.0115, which is numerically much larger and statistically more significant than our direct waste output. We conclude that firms face significant financial losses, measured by value added, when direct and indirect generation of CO₂ occurs in their own production processes. Generation of CO₂ emissions by firms’ immediate upstream predecessor suppliers seems to have much larger negative effects on their value added than their own direct waste output. This suggests that downstream firms may have economic incentives to reduce waste output by their immediate predecessor upstream suppliers.

Comparing columns A (India) and C (Japan), we see similar patterns on how CO₂ emissions along supply chains affect final sectors’ value added. As far as final sectors’ direct emissions are concerned, direct CO₂ emissions have no impact on value added for India, since its coefficient (−0.0043) is statistically not significant. On the other hand, their immediate predecessor CO₂ emissions negatively affect final sectors’ value added (with statistically significant coefficient (−0.0107). But direct emission coefficients in Column B are positive and statistically significant (0.0649), suggesting that the more fossil energy is used by the final sector, the more productive (in terms of value added) final sectors become. This might indicate inefficient use of fossil energy, but this is not clear, since the same coefficient in column A is statistically insignificant. In all cases, indirect emissions from all supplier stages combined are statistically

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² Various tests of heteroskedasticity and specification tests that we have done, respectively, show little heteroskedasticity and little specification errors.

³ We speculate that there are multiple channels through which downstream and upstream firms’ environmental policies affect downstream firms’ value added.
significant and negative. From these results, we tentatively conclude that, for India, environmental management policies encouraging suppliers in supply chains to reduce their CO$_2$ emissions will likely improve final sector firms’ performance measured in terms of value added. These results for India are consistent with but are not as strong as the policy conclusions obtained for Japan [6].

7. Concluding remarks

Recent advances in supply chain based management methods have made it possible for many firms to organize their production and other business activities as part of the supply chains they belong to. Efficiency gains are realized in terms of reduced inventories, reduced lead times for new product development, and shorter delivery lags, among many other benefits. Our results suggest that including certain supply chain level environmental management schemes, such as “how to manage toxic and nontoxic wastes, as well as CO$_2$ emission for a supply chain as a whole,” in such supply chain management methods might improve not only downstream firms’ economic performance but also advanced economies’ environmental performance significantly.

Consideration of such schemes may underlie some firms’ proposals for green procurement policies. In many sectors of an advanced economy, as supply chain management becomes more sophisticated in pursuing economic efficiency, larger downstream firms tend to become more dominant as the primary driver of management decisions associated with their supply chains. (Note, however, that this phenomenon is not limited to assembly-based manufacturing industries. In retail industries, Walmart and the like have become the primary decision makers for their entire global supply chains.) It is possible that, as a national economy develops and increases its sophistication in logistic capabilities, organic connections between upstream and downstream firms become more prevalent, as we see in Japan. This might make it easier for some downstream firms to adopt green procurement policies.

Another factor that might be important to consider in supply chain based environmental policies is firm ownership structures. Ownership structures of firms involved in supply chains are complex but tend to share some systematic patterns. Dominant downstream firms generally influence business decisions of their upstream suppliers via some forms of partial ownership and/or certain guaranteed purchase agreements. Dominant firms do not necessarily extend their partial ownership to all other firms in their supply chains, but, nevertheless, dominant firms often have significant influence over smaller upstream firms through various sorts of business relationships.

Current public policies on waste management in Japan focus on firms and/or establishments. Because of the reasons stated above, this is not appropriate for an advanced economy in which many firm decisions are made at their supply chain levels in interrelated ways. Our empirical results present limited evidence, for both India and Japan, that downstream firms’ economic performance is affected not only by their own environmental policies but also by the environmental behavior of their upstream suppliers. Some profit-maximizing firms may see
it to their advantage to implement green procurement policies. As we have shown, improving suppliers’ environmental performance may lead to immediate improvements in downstream firms’ economic performance. We suppose that government environmental policies need to accommodate this supply chain effect as well. As of now, few environmental regulations for downstream firms have serious implications for upstream firms’ environmental behavior.

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Appendix A1. 130 Sectors of the input–output Table: India, 2003

| Code | Name        | Code | Name                                                      |
|------|-------------|------|-----------------------------------------------------------|
| 1    | Paddy       | 41   | Edible oils other than vanaspati                         |
| 2    | Wheat       | 42   | Tea and coffee processing                                 |
| 3    | Jowar       | 43   | Miscellaneous food products                               |
| 4    | Bajra       | 44   | Beverages                                                 |
| 5    | Maize       | 45   | Tobacco products                                          |
| 6    | Gram        | 46   | Khadi and cotton textiles in handlooms                    |
| 7    | Pulses      | 47   | Cotton textiles                                           |
| 8    | Sugarcane   | 48   | Woolen textiles                                           |
| 9    | Groundnut   | 49   | Silk textiles                                             |
| 10   | Coconut     | 50   | Art silk and synthetic fiber textiles                    |
| No. | Category                        | Code |
|-----|---------------------------------|------|
| 11  | Other oil seeds                | 51   |
| 12  | Jute                           | 52   |
| 13  | Cotton                         | 53   |
| 14  | Tea                            | 54   |
| 15  | Coffee                         | 55   |
| 16  | Rubber                         | 56   |
| 17  | Tobacco                        | 57   |
| 18  | Fruits                         | 58   |
| 19  | Vegetables                     | 59   |
| 20  | Other crops                    | 60   |
| 21  | Milk and milk products         | 61   |
| 22  | Animal services (agricultural) | 62   |
| 23  | Poultry and eggs               | 63   |
| 24  | Other livestock products       | 64   |
| 25  | Forestry and logging           | 65   |
| 26  | Fishing                        | 66   |
| 27  | Coal and lignite               | 67   |
| 28  | Natural gas                    | 68   |
| 29  | Jute hemp and mesta textiles   |      |
| 30  | Carpet weaving                 |      |
| 31  | Ready-made garments            |      |
| 32  | Miscellaneous textile products |      |
| 33  | Furniture and fixtures (wooden)|      |
| 34  | Wood and wood products         |      |
| 35  | Paper, paper products, and newsprint | |
| 36  | Printing and publishing        |      |
| 37  | Leather footwear               |      |
| 38  | Leather and leather products   |      |
| 39  | Rubber products                |      |
| 40  | Plastic products               |      |
| 41  | Petroleum products             |      |
| 42  | Coal products                  |      |
| 43  | Inorganic heavy chemicals      |      |
| 44  | Organic heavy chemicals        |      |
| 45  | Fertilizers                    |      |
| 46  | Pesticides                     |      |

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| Code | Name                                                   | Code | Name                                                   |
|------|--------------------------------------------------------|------|--------------------------------------------------------|
| 29   | Crude oil                                              | 69   | Paints, varnishes, and lacquers                       |
| 30   | Iron ore                                               | 70   | Drugs and medicines                                  |
| 31   | Manganese ore                                          | 71   | Soaps, cosmetics, and glycerin                       |
| 32   | Bauxite                                                | 72   | Synthetic fibers and resin                            |
| 33   | Copper ore                                             | 73   | Other chemicals                                       |
| 34   | Other metallic minerals                                | 74   | Structural clay products                              |
| 35   | Limestone                                              | 75   | Cement                                                |
| 36   | Mica                                                   | 76   | Other nonmetallic mineral products                    |
| 37   | Other nonmetallic minerals                             | 77   | Iron, steel, and ferroalloys                          |
| 38   | Sugar                                                  | 78   | Iron and steel casting and forging                    |
| 39   | Khandari and boora                                     | 79   | Iron and steel foundries                              |
| 40   | Hydrogenated oil (vanaspati)                          | 80   | Nonferrous basic metals                               |
|      |                                                        |      |                                                        |
|      | Code                                                   | Name                        |
| 81   | Hand tools and hardware                               | 116 | Trade                                                   |
| 82   | Miscellaneous metal products                          | 117 | Hotels and restaurants                               |
| Code | Description |
|------|-------------|
| 83   | Tractors and agricultural implements |
| 84   | Industrial machinery for food and textiles |
| 85   | Other industrial machinery |
| 86   | Machine tools |
| 87   | Other non-electrical machinery |
| 88   | Electrical industrial machinery |
| 89   | Electrical cables and wires |
| 90   | Batteries |
| 91   | Electrical appliances |
| 92   | Communication equipment |
| 93   | Other electrical machinery |
| 94   | Electronic equipments including TV |
| 95   | Ships |
| 118  | Banking |
| 119  | Insurance |
| 120  | Ownership of dwellings |
| 121  | Education and research |
| 122  | Medical and health |
| 123  | Business services |
| 124  | Computer-related services |
| 125  | Legal services |
| 126  | Real estate |
| 127  | Renting of machinery and equipment |
| 128  | Community, social, and personal services |
| 129  | Other services |
| 130  | Public administration |
| Code | Description                             |
|------|----------------------------------------|
| 96   | Rail equipment                         |
| 97   | Motor vehicles                         |
| 98   | Motor cycles and scooters              |
| 99   | Bicycles and cycle-rickshaw            |
| 100  | Other transport equipment              |
| 101  | Watches and clocks                     |
| 102  | Medical precision and optical instruments |
| 103  | Gems and jewelry                       |
| 104  | Aircraft and spacecrafts               |
| 105  | Miscellaneous and manufacturing        |
| 106  | Construction                           |
| 107  | Electricity                            |
| 108  | Water supply                           |
| 109  | Railway transport services             |
| 110  | Land                                   |
| 121  | Education and research                 |
| 122  | Medical and health                     |
| 123  | Business services                      |
| 124  | Computer-related services              |
| 125  | Legal services                         |
| 126  | Real estate                            |
| 127  | Renting of machinery and equipment     |
| 128  | Community, social, and personal services |
| 129  | Other services                         |
| 130  | Public administration and defense      |
| 131  | Sustainable Supply Chain Management    |
| Code | Description                                      | Code | Description                                      |
|------|-------------------------------------------------|------|-------------------------------------------------|
| 111  | Water transport including pipelines             | 126  | Real estate                                     |
| 112  | Air transport                                   | 127  | Renting of machinery and equipment              |
| 113  | Supportive and auxiliary transport activities   | 128  | Community, social, and personal services        |
| 114  | Storage and warehousing                         | 129  | Other services                                  |
| 115  | Communication                                   | 130  | Public administration and defense               |

**Final Demand**

- **PFCE**: Private final consumption expenditure
- **GFCE**: Government final consumption expenditure
- **GFCF**: Gross fixed capital formation
- **CIS**: Changes in stocks
- **EXP**: Exports
- **IMP**: Imports
- **COMOUT**: Domestic output (product)
- **VA**: Value added
- **NIT**: Net
Appendix A2. Descriptive statistics for regression variables: India, 2003 and Japan, 2000

### India

| Variables                                              | Mean    | Std. dev. | Median  | Minimum | Maximum | No. obs. |
|--------------------------------------------------------|---------|-----------|---------|---------|---------|----------|
| Value added (dep. variable)                            | 0.47978 | 0.23504   | 0.38890 | 0.00908 | 1       | 130      |
| GHG emissions (CO₂ equivalent): India, ton-CO₂ per million Rupees |         |           |         |         |         |          |
| Direct emissions (from current sector)                 | 1.4699  | 5.4709    | 0.1885  | 0.0000  | 48.1495 | 130      |
| Indirect emissions (emissions from all previous sectors/stages combined) | 2.4667  | 3.2255    | 1.9813  | 0.0000  | 27.4213 | 130      |
| Indirect emissions (emissions from immediate predecessor sector/stage) | 3.2817  | 2.5990    | 2.9807  | 0.0000  | 18.5870 | 130      |

### Japan

| Variables                                              | Mean    | Std.dev.  | Median  | Minimum | Maximum | No. obs. |
|--------------------------------------------------------|---------|-----------|---------|---------|---------|----------|
| Value added (dep. var.)                                | 0.444286| 0.180905  | 0.408066| 0       | 0.929868| 396      |
| GHG emissions (CO₂ equivalent): Japan, ton-CO₂ per million Yen |         |           |         |         |         |          |
| Direct emissions (from current sector)                 | 1.81488 | 8.02313   | 0.24814 | 0       | 104.2946| 396      |
| Indirect emissions (emissions from all previous sectors/stages combined) | 2.99029 | 3.99268   | 1.98527 | 0       | 52.4513 | 396      |
| Indirect emissions (emissions from immediate predecessor sector/stage) | 1.42372 | 2.99584   | 0.71593 | 0       | 44.9873 | 396      |

Source: India—The dataset is compiled by the authors using The Central Statistical Organisation, India at current million Indian Rupees [28]. Japan—The dataset is compiled by the authors using data available from http://www.stat.go.jp/english/data/io/index.htm and Ministry of Economy, Trade and Industry.

Notes. Value added and direct waste outputs are measured per sector output. Indirect waste output for each stage is measured per total indirect output (all stages combined).
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