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AN INTERREGIONAL INPUT-OUTPUT ANALYSIS OF THE POLLUTION CONTENT OF TRADE FLOWS AND ENVIRONMENTAL TRADE BALANCES BETWEEN FIVE STATES IN THE US MID-WEST

BY

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An interregional input-output analysis of the pollution content of trade flows and environmental trade balances between five states in the US Mid-West

by

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Abstract

In this paper we attempt an empirical application of the multi-region input-output (MRIO) method in order to enumerate the pollution content of interregional trade flows between five Mid-West regions/states in the US –Illinois, Indiana, Iowa, Michigan and Wisconsin – and the rest of the US. This allows us to analyse some very important issues in terms of the nature and significance of interregional environmental spillovers within the US Mid-West and the existence of pollution 'trade balances' between states. Our results raise questions in terms of the extent to which authorities at State level can control local emissions where they are limited in the way some emissions can be controlled, particularly with respect to changes in demand elsewhere in the Mid-West and US. This implies a need for policy co-ordination between national and state level authorities in the US to meet emissions reductions targets. The existence of an environmental trade balances between states also raises issues in terms of net losses/gains in terms of pollutants as a result of interregional trade within the US and whether, if certain activities can be carried out using less polluting technology in one region relative to others, it is better for the US as a whole if this type of relationship exists.

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Keywords: Multi-region input-output models, environmental trade balance, air pollution

JEL Codes: C67, Q53 and Q56

1. Introduction

Input-output techniques are frequently used to account for emissions related to sectoral economic activity an, increasingly (see Wiedmann *et al*, 2007, and Wiedmann, 2009, for reviews) to and estimate the pollution content of trade flows and emissions 'trade balances' between regions/countries in a multi-sector, multi-region context. Our focus in the current ESRC Climate Change Leadership Fellowship Project is the application of such techniques at a sub-national regional level and secondly, to develop appropriate modelling frameworks to analyse the impacts of *changes* in policy and other disturbances on pollution trade balances. We follow Turner *et al* (2007), who propose the empirical application of the multi-region input-output (MRIO) method of accounting for pollution trade balances and McGregor *et al* (2008), who provide an empirical application for the UK, focussing on the two region case of Scotland and the rest of the UK (RUK), analyzing the CO2 trade balance between these regions.

In this paper, we apply Turner *et al*'s method (2007) to the case of the Midwest states within the US. We extend the analyses of McGregor *et al.* (2008) in two respects. First, we introduce a greater level of sectoral disaggregation, identifying 13 production sectors. Second, we introduce a greater degree of spatial disaggregation, identifying 5 Midwest regions and the rest of the US (RUS). We focus on the emission pollutant, carbon monoxide (CO). The process of working on developing interregional models for the US Midwest for this purpose is likely to be beneficial in terms of considering interregional interaction and providing opportunities for comparative analysis with the UK cases. Therefore, as the first step of attempting to develop a general equilibrium analytical framework for US Midwest framework, the research constructs the structure of a Midwest Input-output Model using the 1992 dataset from MWREIM (Midwest Regional Econometric Input-output Model) for the Midwest economy (developed by Regional Economics Application Laboratory) and analyzes the interaction between the economy and CO emission inventory and illustrate CO emission attribution analysis to examine the interdependence between regions of the Midwest in terms of environmental spillover effects. However, we are currently in the process of updating this dataset to 2007 in order to make the framework more empirically useful. At this stage our main focus is explaining the potential information and analytical content of the environmental interregional input-output framework.

2. A Midwest environmental input-output

2.1. The accounting framework

We apply the multi-region environmental input-output framework from Turner *et al.* (2007) to the case of the US Midwest. Their exposition is given in terms of the 2-region case and applied it as the empirical example of Scotland and the rest of UK. Here we extend the 2-region framework to 6-region case for Midwest in USA. 6 regions are composed of 5 MW states (Illinois, Indiana, Michigan, Ohio, and Wisconsin) and the rest of US (RUS). Each region has *i*=1,…, N=13 production sectors producing *j*=1,…., N=13 commodities according to MWREIM structure.

The traditional input-output approach can be written in matrix form:

(1) $X = AX + Y$

(2) $X = (I - A)^{-1} Y$

where *A* is the input-output matrix, *Y* is a vector of aggregated final demand, and *X* is the output.

By multiplying emission intensity coefficient generated per unit of output *X*, the amount of emission pollution can be written;

(3) $P = E\ (I - A)^{-1} Y = EX$

As a extended form;

$$(4)\quad \begin{pmatrix} p_{11}^y & p_{12}^y & p_{13}^y & p_{14}^y & p_{15}^y & p_{16}^y \\ p_{21}^y & p_{22}^y & p_{23}^y & p_{24}^y & p_{25}^y & p_{26}^y \\ p_{31}^y & p_{32}^y & p_{33}^y & p_{34}^y & p_{35}^y & p_{36}^y \\ p_{41}^y & p_{42}^y & p_{43}^y & p_{44}^y & p_{45}^y & p_{46}^y \\ p_{51}^y & p_{52}^y & p_{53}^y & p_{45}^y & p_{55}^y & p_{56}^y \\ p_{61}^y & p_{62}^y & p_{63}^y & p_{46}^y & p_{56}^y & p_{66}^y \end{pmatrix} = \begin{pmatrix} e_1^x & 0 & 0 & 0 & 0 & 0 \\ 0 & e_2^x & 0 & 0 & 0 & 0 \\ 0 & 0 & e_3^x & 0 & 0 & 0 \\ 0 & 0 & 0 & e_4^x & 0 & 0 \\ 0 & 0 & 0 & 0 & e_5^x & 0 \\ 0 & 0 & 0 & 0 & 0 & e_6^x \end{pmatrix} \begin{pmatrix} I-A_{11} & -A_{12} & -A_{13} & -A_{14} & -A_{15} & -A_{16} \\ -A_{21} & I-A_{22} & -A_{23} & -A_{24} & -A_{25} & -A_{26} \\ -A_{31} & -A_{32} & I-A_{33} & -A_{34} & -A_{35} & -A_{36} \\ -A_{41} & -A_{42} & -A_{43} & I-A_{44} & -A_{45} & -A_{46} \\ -A_{51} & -A_{52} & -A_{53} & -A_{54} & I-A_{55} & -A_{56} \\ -A_{61} & -A_{62} & -A_{63} & -A_{64} & -A_{65} & I-A_{66} \end{pmatrix}^{-1} \begin{pmatrix} y_{11} & y_{12} & y_{13} & y_{14} & y_{15} & y_{16} \\ y_{21} & y_{22} & y_{23} & y_{24} & y_{25} & y_{26} \\ y_{31} & y_{32} & y_{33} & y_{34} & y_{35} & y_{36} \\ y_{41} & y_{42} & y_{43} & y_{44} & y_{45} & y_{46} \\ y_{51} & y_{52} & y_{53} & y_{54} & y_{55} & y_{56} \\ y_{61} & y_{62} & y_{63} & y_{64} & y_{65} & y_{66} \end{pmatrix}$$

p_{rs}^y is a scalar of the amount of CO generated in production activities in region *r* to support regions *s*. e_r^x is a $1\times$ N vector of emission intensity coefficient for a single pollutant, CO, showing the physical amount of CO directly generated per unit of output, x_i, produced by sector *i* in region *r*. $(I\text{-}A)^{-1}$ is the interregional Leontief inverse matrix. The A matrix is defined as $a_{ij}^{rs} = x_{ij}^{rs} / X_j^s$, i.e., the amount of output produced by each sector *i* in region *r* and used as input by sector *j* in region *s*, x_{ij}^{rs}, divided by total output in consuming sector *j* in region s, X_j^s. Hence, the interregional Leontief inverse matrix is 78×78 (13 production sectors$\times$6 regions) representing a conventional 'Type I' analysis. In this study, we only carry out conventional 'Type I' 6 region input-output attribution analyses (McGregor *et al* 2008). Our treatment of trade between MW and RUS follows the 'consumption accounting principle' (Munksgaard and Pederson, 2001). Due to a lack of appropriate data, we do not extend our framework for direct emissions generation by household as final consumers or endogenise trade to close the system at the national level by following McGregor *et al* (2008) in their analysis using what they refer to as a trade endogenised linear attribution system (TELAS) in the analyses of McGregor *et al.* (2008). Therefore, the total emissions generated in region 1(Illinois), p_1 are given by summing along the first row of each P matrix so that

$$(5)\quad p_1 = p_{11}^y + p_{12}^y + p_{13}^y + p_{14}^y + p_{15}^y + p_{16}^y$$

while the total emission in all regions of MW and RUS that are supported by region 1(Illinois) final consumption demand are given by summing down the first column of each P matrix so that

$$(6)\quad p_1^y = p_{11}^y + p_{21}^y + p_{31}^y + p_{41}^y + p_{51}^y + p_{61}^y$$

According to Munksgaard and Pederson (2001) method, region 1 (Illinois)'s CO trade balance with other US regions would be calculated by the difference between eq (5) and eq (6).

2.2. Construction of MW interregional IO table

The Regional Economics Applications Laboratory (REAL) at the University of Illinois has constructed a number of impact and forecasting models for Midwest area that cover Illinois, Indiana, Michigan, Ohio, Wisconsin and Rest of US (The Midwest Regional Econometric Input-output Model, MWREIM). This model, based on the initial formulation of Conway (1990, 1991), and further developed by Israilevich *et al.* (1996, 1997) integrates econometric and input-output components, enabling impact analysis to be conducted as well as annual forecasts for a 30-year horizon for 13 different SIC (Standard Industrial Classification) based industrial sectors (production, employment and income) and several major economic aggregates (such as gross regional product, wage rates, unemployment). This model allows for the extraction and forecasting of input-output tables on an annual basis (See Israilevich *et al*. (1997) for more details). In MWREIM, there are 456 endogenous variables and 192 exogenous variables from 1969 to 2020 based on 1992 Input-Output table. Endogenous variables are composed of employment, income, output variables by 13 industry sectors and final demand, income, employment related variables for 5 States and Rest of US. There are also Data Resources Inc (DRI) and WEFA (Wharton Economic Forecasting Associates) variables and MW variables as exogenous variables.

Figure 1 shows the provisional structure of an interregional MW IO table with 6 regions, 13 sectors and final demand (consumption, investment and government) for 1992. In order to construct an interregional MW IO table, first of all, an interregional *A* coefficient (78x78) and total final demand (78x3) for 5 MW states and RUS are extracted from MWREIM by the extraction method (Israilevich *et al*., 1997). This allows us to determine the interregional intermediate demands matrix (78x78) by 6 regions and 13 production sectors.

However, total final demand is necessary to split into the sub-matrices to identify final consumption of local state and imported goods and services from other states. Not only there is no available data to identify them but also each state REIM only explains their final consumptions from their own industry sectors.

Figure 1. Structure for actual MW region IO table

	IL		IN		MI		OH		WI		RUS		Total Final Demand z=1-3	Gross Output
	Intermediate Demand sector i=1-13	Final Demand z=1-3	Intermediate Demand sector i=1-13	Final Demand z=1-3	Intermediate Demand sector i=1-13	Final Demand z=1-3	Intermediate Demand sector i=1-13	Final Demand z=1-3	Intermediate Demand sector i=1-13	Final Demand z=1-3	Intermediate Demand sector i=1-13	Final Demand z=1-3		
IL i=1-13	X_{IL}^{IL}	F_{IL}^{IL}	X_{IL}^{IN}	F_{IL}^{IN}	X_{IL}^{MI}	F_{IL}^{MI}	X_{IL}^{OH}	F_{IL}^{OH}	X_{IL}^{WI}	F_{IL}^{WI}	X_{IL}^{RUS}	F_{IL}^{RUS}	F_{IL}^{US}	
IN i=1-13	X_{IN}^{IL}	F_{IN}^{IL}	X_{IN}^{IN}	F_{IN}^{IN}	X_{IN}^{MI}	F_{IN}^{MI}	X_{IN}^{OH}	F_{IN}^{OH}	X_{IN}^{WI}	F_{IN}^{WI}	X_{IN}^{RUS}	F_{IN}^{RUS}	F_{IN}^{US}	
MI i=1-13	X_{MI}^{IL}	F_{MI}^{IL}	X_{MI}^{IN}	F_{MI}^{IN}	X_{MI}^{MI}	F_{MI}^{MI}	X_{MI}^{OH}	F_{MI}^{OH}	X_{MI}^{WI}	F_{MI}^{WI}	X_{MI}^{RUS}	F_{MI}^{RUS}	F_{MI}^{US}	
OH i=1-13	X_{OH}^{IL}	F_{OH}^{IL}	X_{OH}^{IN}	F_{OH}^{IN}	X_{OH}^{MI}	F_{OH}^{MI}	X_{OH}^{OH}	F_{OH}^{OH}	X_{OH}^{WI}	F_{OH}^{WI}	X_{OH}^{RUS}	F_{OH}^{RUS}	F_{OH}^{US}	
WI i=1-13	X_{WI}^{IL}	F_{WI}^{IL}	X_{WI}^{IN}	F_{WI}^{IN}	X_{WI}^{MI}	F_{WI}^{MI}	X_{WI}^{OH}	F_{WI}^{OH}	X_{WI}^{WI}	F_{WI}^{WI}	X_{WI}^{RUS}	F_{WI}^{RUS}	F_{WI}^{US}	
RUS i=1-13	X_{RUS}^{IL}	F_{RUS}^{IL}	X_{RUS}^{IN}	F_{RUS}^{IN}	X_{RUS}^{MI}	F_{RUS}^{MI}	X_{RUS}^{OH}	F_{RUS}^{OH}	X_{RUS}^{WI}	F_{RUS}^{WI}	X_{RUS}^{RUS}	F_{RUS}^{RUS}	F_{RUS}^{US}	
VA														

1) White cells : existing data in MWREIM

2) Grey cells : estimated data

Three steps are involved in estimating final demands by 13 sectors by 6 regions. The first step is initially to estimate final demands using REIM for 5 states (Illinois, Indiana, Michigan, Ohio and Wisconsin) and the rest of the U.S. (RUS). And we calculate the fixed ratio of consumption, property type income and government final demand by industry and by state in order to estimate consumption, investment, and government final demand from other state's industry sectors, respectively.

Hence, our assumption is that the proportion of each final demand of imported goods and services from other states has the same sectoral structure as their own final demand of local goods and services. For example, in the case of other state's final demand consumption from IL goods and services, firstly we need to get the rest of final demand consumption by total consumption minus IL own consumption and then apply each state *r*'s consumption ratio excluding IL consumption by industry *i*.

$$consumption^{i}_{IL\rightarrow r} = \left(total\ consumption^{TOT}_{IL} - consumption^{IL}_{IL}\right) \times \frac{consumption^{i}_{r}}{\sum_{r\neq IL} consumption^{i}_{r}}$$

$$investment^{i}_{IL\rightarrow r} = \left(total\, investment^{TOT}_{IL} - investment^{IL}_{IL}\right) \times \frac{investment^{i}_{r}}{\sum_{r\neq IL} investment^{i}_{r}}$$

$$goverment^{i}_{IL\rightarrow r} = \left(total\ government^{TOT}_{IL} - government^{IL}_{IL}\right) \times \frac{government^{i}_{r}}{\sum_{r\neq IL} government^{i}_{r}}$$

The next step is to estimate each state's primary input matrix $VA_{i,r}$ which is not provided from MWREIM. Therefore, we calculated the ratio of compensation of employee, taxes on production and imports less subsidies, and other value added by industry and state from Regional Economic Information System (REIS) in Bureau of Economic Analysis (BEA) and applied the ratio to total primary input value that is able to get by subtracting total industry output and total estimated interregional intermediate demands.

It is necessary to point out that we have not considered either region's import or export with the rest of world (ROW) in our MW IO construction. There are two reasons we have not included ROW trade between MW and/or RUS. First is that MW imports from ROW and export to 5 MW states and RUS broken down by commodity are not readily available. Second is that our main purpose of this exercise focuses on which state in Midwest region has a responsibility for emissions generated within Midwest regional economy although each region's trade with the rest of world should be considered in more comprehensive analysis (McGregor *et al*, 2008). This exercise is one of the key objectives of our ongoing research. In the current application, therefore, we focus on interregional trade between MW states with the effective assumption of a closed US economy.

2.3. Emission Intensity (EMI) coefficients

The development of EMI for Midwest is derived from the REAL research funded by the US EPA STAR program (more detailed methodology can be found in Tao *et al*., 2007). Under the Clean Air Act, US EPA (Environmental Protection Agency) has set the criteria emission pollutants, carbon monoxide (CO), nitrogen oxide (NOx), sulfur dioxide (SO_2), particular organic compound (PM10 and PM2.5 with diameter less than 10 and 2.5μm), volatile organic compound (VOC) and ammonia (NH_3) as a air quality standard. We focus our attention here on CO EMI as a first attempt to do our environmental trade balance analysis since CO produces the highest proportion, 40% of total 7 emission pollutants in terms of physical volume (tons) in 1999. The development of emission inventory is similar to traditional approaches, in which emissions are determined by emission intensity and levels of emission activities:

E (EMI) = P (Emission, tons per year) / X (sectoral output , 92 constant millions $)

where EMI is defined by the emissions per unit of activity (ton/92 constant million $)

The general approach is to formulate the emission intensity from the 1999 National Emissions Inventory (NEI99). First, the emissions from NEI99 inventories based on SCC (National Emission Intensity based on Source Classification Code) are mapped into MW IO's SIC code (13 sectors). All point source SCCs and approximately 16% of area source SCCs have their associated SIC. The remaining 80% area source SCC are assigned to a particular SIC following the EGAS mapping (Economic Growth Analysis System)[1] developed by US EPA and some allocation through analysis of SCC and SIC coding. Note that the remaining 4% of the area sources related to household activities (e.g., space heating/cooling, solvent usage, and yard-waste burning etc) and on-road mobile sources are excluded in developing EMI.

The main problem is that emission data are not available for 1992. This is because EPA has developed NEI from 1999. Therefore, we assume the emissions per real unit of activity in 1992 is constant with 1999 level and all emission changes result from only activity changes under the fixed EMI condition assuming no

[1] http://www.epa.gov/ttn/chief/emch/projection/index.html

emission technology changes in order to calculate environmental trade balance with 1992 MWIO table. The resulting set of CO emission intensity coefficients for MW and RUS are shown in Table 1.

Within the 13 sectors, sector 1 (agriculture, forestry and fisheries) has the largest CO EMI for all MW states and RUS. Sector 2 (mining), sector 6 (primary metal products) and sector 12 (other durable manufacturing) are in top three EMI (table 2). But the sectors with large EMI are not necessarily the ones with large total emissions since economic activity plays its role of producing total emissions.

Table1. CO emission intensity coefficients for MW and RUS

Ton of CO per $1 million real output

Sector	IL	IN	MI	OH	WI	RUS
1. Agriculture, Forestry and Fisheries	54.93	57.84	130.76	96.26	71.86	43.27
2. Mining	1.80	1.87	7.45	3.50	1.54	4.56
3. Construction	1.23	1.68	1.34	1.83	1.43	1.55
4. Food and Kindred Products	0.77	0.57	0.47	0.44	0.56	0.75
5. Chemicals and Allied Products	1.38	0.93	0.51	3.24	0.57	2.30
6. Primary Metals Industries	5.71	18.98	3.98	8.93	2.18	6.84
7. Fabricated Metal Products	0.51	0.53	0.42	0.44	0.54	0.57
8. Industrial Machinery and Equipment	0.46	0.54	0.43	0.43	0.63	0.56
9. Electronic and other Electric Equipment	0.45	0.54	0.42	0.48	0.54	0.64
10. Transportation Equipment	0.47	0.52	0.48	0.44	0.54	0.57
11. Other Non-durable Manufacturing Products	0.55	1.31	0.78	0.52	1.56	1.49
12. Other Durable Manufacturing	0.55	2.72	0.88	0.62	0.76	2.86
13. TCU, Service, and Government Enterprises	1.08	1.66	2.26	1.46	2.61	1.40

Table 2. Top three sectoral CO EMI

IL	IN	MI	OH	WI	RUS
sector 1	sector 1	sector 1	sector 1	sector 1	sector 1
sector 6	sector 6	sector 2	sector 6	sector 13	sector 6
sector 2	sector 12	sector 6	sector 2	sector 6	sector 2

3. CO attribution analysis for MW and the rest of US

Firstly, we can estimate direct CO emissions generation by sector in each region with the MW environmental IO system under Muskgaard and Pedersen(2001)'s 'production accounting principle'. The direct CO generation in each sector is calculated by multiplying the direct EMI (eq. (7)) against the gross sectoral outputs from the MW interregional IO tables and shown in Table 3.

$$P = EX$$

$$\begin{pmatrix} p^y_{11} & p^y_{12} & p^y_{13} & p^y_{14} & p^y_{15} & p^y_{16} \\ p^y_{21} & p^y_{22} & p^y_{23} & p^y_{24} & p^y_{25} & p^y_{26} \\ p^y_{31} & p^y_{32} & p^y_{33} & p^y_{34} & p^y_{35} & p^y_{36} \\ p^y_{41} & p^y_{42} & p^y_{43} & p^y_{44} & p^y_{45} & p^y_{46} \\ p^y_{51} & p^y_{52} & p^y_{53} & p^y_{45} & p^y_{55} & p^y_{56} \\ p^y_{61} & p^y_{62} & p^y_{63} & p^y_{46} & p^y_{56} & p^y_{66} \end{pmatrix} = \begin{pmatrix} e^x_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & e^x_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & e^x_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & e^x_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & e^x_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & e^x_6 \end{pmatrix} \begin{pmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} & x_{36} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} & x_{46} \\ x_{51} & x_{52} & x_{53} & x_{54} & x_{55} & x_{56} \\ x_{61} & x_{62} & x_{63} & x_{64} & x_{65} & x_{66} \end{pmatrix} \quad (7)$$

Table 3. Direct CO pollution generated in MW and RUS in 1992 (tonnes)

Sector	IL	IN	MI	OH	WI	RUS	Total
1	429291.74	183393.23	446183.05	523784.51	313736.76	9750601.99	11646991.29
2	6697.91	2677.60	12173.20	10514.67	620.55	621282.60	653966.52
3	34391.89	21389.64	22431.77	39580.34	16619.12	719076.26	853489.01
4	20898.06	5268.71	5758.46	7288.11	10474.49	228587.68	278275.49
5	23541.31	9472.37	5381.96	50925.87	1865.93	559667.12	650854.56
6	52064.63	290553.37	28403.82	144915.97	6084.25	588005.86	1110027.89
7	6436.06	3970.95	6052.58	7480.22	3314.21	60122.07	87376.08
8	8319.42	4522.05	6512.89	7457.79	8250.73	98834.00	133896.87
9	5245.90	4652.10	1150.09	5515.63	3428.58	107701.67	127693.95
10	5858.83	9845.07	30420.70	19976.42	3996.08	135045.97	205143.08
11	19807.51	22044.05	15883.97	15226.14	32200.97	960966.69	1066129.33
12	7117.73	27094.65	10905.57	8620.95	7726.44	858193.52	919658.86
13	313380.51	156789.59	371864.87	292564.97	223103.31	6615965.18	7973668.44
Total	933051.49	741673.37	963122.92	1133851.57	631421.42	21304050.61	25707171.38
Total contribution of US	(3.63%)	(2.89%)	(3.75%)	(4.41%)	(2.46%)	(82.87%)	(100.00%)
Total contribution within MW	(21.19%)	(16.84%)	(21.87%)	(25.75%)	(14.34%)		(100.00%)
Total output (92 millions $)	486957	216624	345389	412899	190636	7806899	
(%)	(5.15%)	(2.29%)	(3.65%)	(4.36%)	(2.02%)	(82.53%)	(100.00%)
Total employment (thousands)	6406	3144	4789	5907	2917	116248	
(%)	(4.60%)	(2.26%)	(3.44%)	(4.24%)	(2.09%)	(83.39%)	(100.00%)

Table 4. Top three sectoral CO emitters

IL	IN	MI	OH	WI	RUS
sector 1	sector 6	sector 1	sector 1	sector 1	sector 1
sector 13	sector 1	sector 13	sector 13	sector 13	sector 13
sector 6	sector 13	sector 10	sector 6	sector 11	sector 11

Table 3 shows that total direct CO pollution generated from MW states is 17.13% of total CO pollution in US. Within MW states, Ohio directly generates 25.75% of CO pollution, the largest CO pollution generator in MW. Michigan and Illinois are second and third contributor of CO pollution, respectively. The smallest proportion, 14.34%, of CO pollution in MW is produced from Wisconsin. In terms of sectoral level emission, sector 1 (agriculture, forestry and fisheries) ranks first as a direct CO emitter, followed by sector 13 (TCU, services, and government enterprises) except Indiana where sector 6 (primary metal products) contributes the biggest CO emission (refer to table 4).

This direct analysis explains total direct CO emissions through the purchase of goods and services in each state. However, from the consumption accounting perspective that is gaining increasing attention in the public, policy and academic arenas, we are likely to be more interested in what share of pollution generation in each state is indirectly attributed to the final demands of other states or RUS. That is, how economic activity in one region affects pollution generation in others.

Table 5 shows how CO spillover or trade occurs between MW and RUS as accounted for in a conventional Type I attribution analysis using the accounting framework. In equations (4) to (6). The results suggest that (in our accounting year of 1992) 55.9% of CO pollution generated in MW is to support, directly or indirectly, RUS final demand. On the other hand, only 9.6% of CO pollution generated in RUS is explained as a result of MW final demand expenditure. Consequently, there is a positive CO trade balance for MW, 405,365 tonnes of CO pollution; CO pollution generated in MW by production supporting RUS final demands is bigger than the pollution generated in RUS by production supporting MW final demands.

Table 5. The CO trade balance between MW states and RUS (tonnes) : Type I input-output

CO pollution supported by final consumption demand:							
	IL	IN	MI	OH	WI	RUS	Total regional emission of CO
Pollution generated in :							
IL	391390.72 (41.95%)	24126.07 (2.59%)	15582.00 (1.67%)	21192.06 (2.27%)	6701.58 (0.72%)	474059.05 (50.81%)	933051.49 (100.00%)
IN	44783.94 (6.04%)	209627.49 (28.26%)	26633.28 (3.59%)	34536.04 (4.66%)	6420.14 (0.87%)	419672.48 (56.58%)	741673.37 (100.00%)
MI	39928.92 (4.15%)	37769.79 (3.92%)	268649.08 (27.89%)	68167.10 (7.08%)	5897.78 (0.61%)	542710.26 (56.35%)	963122.92 (100.00%)
OH	35181.79 (3.10%)	33928.50 (2.99%)	42191.82 (3.72%)	404360.45 (35.66%)	6805.24 (0.60%)	611383.77 (53.92%)	1133851.57 (100.00%)
WI	114373.63 (18.11%)	11679.84 (1.85%)	15889.58 (2.52%)	20963.82 (3.32%)	56960.82 (9.02%)	411553.73 (65.18%)	631421.42 (100.00%)
RUS	711739.26 (3.34%)	276263.52 (1.30%)	410997.38 (1.93%)	509706.27 (2.39%)	145307.33 (0.68%)	19250036.84 (90.36%)	21304050.61 (100.00%)
Total	1337398.27 (5.20%)	593395.22 (2.31%)	779943.12 (3.03%)	1058925.75 (4.12%)	228092.89 (0.89%)	21709416.13 (84.45%)	25707171.38 (100.00%)

Looking at each Midwest state, Table 5 shows that Wisconsin is the state with the highest share of its CO emissions (91%) produced to meet external (other MW and RUS) final demand – i.e. it has the highest outward trade in CO (reading along with WI row, where only 9% of CO emissions generated in Wisconsin are associated with production to supports final demand in Wisconsin). On the other hand, in the case of Illinois, only 58.1% of locally generated CO pollution supports external consumption – i.e. reading along the Il row, 42% of CO emissions generated in Illinois are generated to support final consumption demand in Illlinois.

Table 6. CO trade balance between MW and RUS

Environmental trade balance	
MW CO pollution supported by RUS demand	2459379.29 (55.9%)
RUS CO pollution supported by MW demand	2054013.86 (9.6%)
MW CO trade surplus with RUS	405365.43 (9.2%)
IL CO pollution supported by other MW and RUS's demand	541660.84 (58.1%)
IN CO pollution supported by other MW and RUS's demand	532045.97 (71.7%)
MI CO pollution supported by other MW and RUS's demand	694473.96 (72.1%)
OH CO pollution supported by other MW and RUS's demand	729491.19 (64.3%)
WI CO pollution supported by other MW and RUS's demand	574460.82 (91.0%)
RUS CO pollution supported by other MW and RUS's demand	2054013.86 (9.6%)

Table 6 summarises this information for each state in turn. In Table 7 we go onto to examine the CO trade balance between MW states. There is a negative CO trade balance for Illinois with all of other MW states.

This implies that the pollution generated in Illinois in production to support final consumption demands in other MW states is less than the pollution generated in other MW states in production to supporting Illinois final demands. Meanwhile, note that CO generated in Wisconsin in production to support other MW states final demands is greater than the pollution generated in other MW states in production supporting Wisconsin final demands. For example, the Wisconsin CO trade surplus with Illinois, 107,672.05 tonnes (i.e. the figure of 114373 tonnes from the Illinois entry of the Wisconsin row of Table 5 – 'exports' of CO to Illinois – minus the 6701.58 Wisconsin entry in the Illinois row – 'imports' of CO from Illinois) is relatively big, accounting for 17.05% of total CO emission generated in Wisconsin. However, note that 84% of the CO emissions in Wisconsin that are supported by Illinois final demands are generated in the Sector 1, Agriculture, Forestry and Fishing. However, this transaction only accounts for 10% of the output in Wisconsin supported by Illinois. It is relatively high direct CO-intensity of production (71.86 tonnes of CO per $1million output from Table 1) that underlies this core element of the CO trade balance between Wisconsin and Illinois.

Table 7. CO trade balance between MW states

Environmental trade balance between MW states		
(IL→IN)-(IN→IL)	-20657.87	2.79% of total CO emission in IN
(IL→MI)-(MI→IL)	-24346.92	2.53% of total CO emission in MI
(IL→OH)-(OH→IL)	-13989.73	1.23% of total CO emission in OH
(IL→WI)-(WI→IL)	-107672.05	17.05% of total CO emission in WI
(IN→MI)-(MI→IN)	-11136.51	1.16% of total CO emission in MI
(IN→OH)-(OH→IN)	607.54	0.08% of total CO emission in IN
(IN→WI)-(WI→IN)	-5259.71	0.83% of total CO emission in WI
(MI→OH)-(OH→MI)	25975.29	2.70% of total CO emission in MI
(MI→WI)-(WI→MI)	-9991.80	1.58% of total CO emission in WI
(OH→WI)-(WI→OH)	-14158.58	2.24% of total CO emission in WI

More detailed interregional CO trade is shown by household, investment and government final demands in table 8 (e.g. the three Illinois-Illinois entries in the top left of the table sum to the single top left entry in Table 5). There is a difference in the extent of interregional CO spillover between these final demand types. CO emissions in Indiana, Wisconsin and RUS generate relatively bigger amount of CO to supply their productions for all three final demands (household, capital investment, and government consumption) in Illinois than other MW states do. CO emission generated in Michigan is largely associated with all three final demands in Ohio and vice versa. On the other hand, 2.13% of CO emission in Illinois is generated as a result of Indiana household consumption, which is the biggest proportion among other MW household consumption supported by Illinois. For investment and government consumption, 0.22% and 0.29% of CO emission in Illinois are related with Ohio's investment and government consumption.

Table 8. The CO trade balance by three final demands between MW and RUS (continued over page)

	IL			IN			MI		
	HH	Investment	Govt	HH	Investment	Govt	HH	Investment	Govt
IL	318998.73 (34.19%)	28031.14 (3.00%)	44360.86 (4.75%)	**19886.62 (2.13%)**	1926.30 (0.21%)	2313.15 (0.25%)	11641.70 (1.25%)	1765.55 (0.19%)	2174.75 (0.23%)
IN	**28138.41 (3.79%)**	**9344.29 (1.26%)**	**7301.25 (0.98%)**	142397.66 (19.20%)	39191.88 (5.28%)	28037.95 (3.78%)	17725.75 (2.39%)	5079.10 (0.68%)	3828.43 (0.52%)
MI	32838.33 (3.41%)	2684.06 (0.28%)	4406.52 (0.46%)	32583.26 (3.38%)	2033.11 (0.21%)	3153.42 (0.33%)	208986.57 (21.70%)	20396.55 (2.12%)	39265.96 (4.08%)
OH	27461.74 (2.42%)	3311.00 (0.29%)	4409.05 (0.39%)	28311.31 (2.50%)	2511.41 (0.22%)	3105.77 (0.27%)	**33944.46 (2.99%)**	**3550.52 (0.31%)**	**4696.83 (0.41%)**
WI	**102968.15 (16.31%)**	**3579.77 (0.57%)**	**7825.71 (1.24%)**	8949.26 (1.42%)	1328.68 (0.21%)	1401.90 (0.22%)	11961.81 (1.89%)	1699.08 (0.27%)	2228.68 (0.35%)
RUS	**535613.85 (2.51%)**	**62626.17 (0.29%)**	**113499.24 (0.53%)**	196174.49 (0.92%)	31841.68 (0.15%)	48247.35 (0.23%)	289678.93 (1.36%)	40381.62) (0.19%)	80936.82 (0.38%)

Table 8. The CO trade balance by three final demands between MW and RUS (cont.)

	OH			WI			RUS			Total
	HH	Investment	Govt	HH	Investment	Govt	HH	Investment	Govt	
IL	16401.92	**2087.85**	**2702.29**	4392.77	1451.48	857.32	361588.48	38920.73	73549.85	933051.49
	(1.76%)	**(0.22%)**	**(0.29%)**	(0.47%)	(0.16%)	(0.09%)	(38.75%)	(4.17%)	(7.88%)	(100.00%)
IN	23704.16	6162.70	4669.18	2795.54	2641.54	983.06	264204.13	67526.72	87941.63	741673.37
	(3.20%)	(0.83%)	(0.63%)	(0.38%)	(0.36%)	(0.13%)	(35.62%)	(9.10%)	(11.86%)	(100.00%)
MI	**58912.46**	**3129.45**	**6125.20**	3964.93	1154.57	778.28	407889.11	43056.50	91764.65	963122.92
	(6.12%)	**(0.32%)**	**(0.64%)**	(0.41%)	(0.12%)	(0.08%)	(42.35%)	(4.47%)	(9.53%)	(100.00%)
OH	301820.09	45410.77	57129.58	4443.65	1511.32	850.27	459875.39	51447.66	100060.72	1133851.57
	(26.62%)	(4.01%)	(5.04%)	(0.39%)	(0.13%)	(0.07%)	(40.56%)	(4.54%)	(8.82%)	(100.00%)
WI	16385.80	1921.40	2656.62	42693.69	7862.47	6404.66	306212.85	37839.17	67501.71	631421.42
	(2.60%)	(0.30%)	(0.42%)	(6.76%)	(1.25%)	(1.01%)	(48.50%)	(5.99%)	(10.69%)	(100.00%)
RUS	355686.79	51151.53	102867.95	93015.12	27419.34	24872.87	14207051.88	1349213.22	3693771.73	21304050.61
	(1.67%)	(0.24%)	(0.48%)	(0.44%)	(0.13%)	(0.12%)	(66.69%)	(6.33%)	(17.34%)	(100.00%)

4. Summary and further research

We use an interregional input-output framework for the Midwest regional environmental attribution and trade balance analysis in this study. The construction of Midwest interregional input-output table is provisional at this moment due to availability of appropriate data. Thus, the results of our environmental trade balance analysis should be regarded as an example of how we can examine environmental spillovers between Midwest states using the environmental IO framework. However, our main finding from the empirical analysis here is that 55.9% of CO emission generated in Midwest supports consumption in RUS while only 9.6% of CO emission generated in RUS supports consumption in Midwest. There is a CO trade surplus between Midwest and RUS, 9.2% of the total CO generated in Midwest. We find out that Wisconsin is a biggest net loser in terms of CO emission pollutants within the Midwest region (due to the importance of Wisconsin's very CO-intensive Agriculture, Forestry and Fishing sector in interregional trade) and, comparatively, Illinois is a net gainer. Another key finding is that Michigan and Ohio are very closely related to each other in terms of CO emission trade by production supporting each other's consumption. For more accurate analysis, we are setting up a more updated and detailed system of MW IO table with improved interregional trade flow data (for 2007). We will also develop this through construction of an interregional SAM system for the Midwest and application of this as the core database of an interregional CGE modeling framework.

Appendix 1. Mnemonics of industry sectors and final demands

Industry sector i=1~13

1. Agriculture, Forestry and Fisheries
2. Mining
3. Construction
4. Food and Kindred Products
5. Chemicals and Allied Products
6. Primary Metals Industries
7. Fabricated Metal Products
8. Industrial Machinery and Equipment
9. Electronic and other Electric Equipment
10. Transportation Equipment
11. Other Non-durable Manufacturing Products
12. Other Durable Manufacturing
13. TCU, Service, and Government Enterprises

Final demand z=1~3

1. Consumption (Autos and Parts, Other Durables, Nondurables, and Service)
2. Investment (Residenatial + Nonresidential and Equipment)
3. Government Expenditure

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