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Spatial Structural Path Analysis – Analysing the Greenhouse impacts of trade substitution.

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Abstract

In a recent submission, Wood & Lenzen elucidate a means for analysing the key determinants of change of greenhouse emissions within an economy by combining the methods of Structural Path Analysis (SPA) and Structural Decomposition Analysis (SDA) (then referred to as T-SPA). This enabled the examination of the temporal changes in greenhouse emissions within a full production chain perspective. Much as SDA has been applied in a geographic as opposed to a temporal context, T-SPA can also be applied in a similar manner, with important results for the analysis of trade substitution, particularly in relation to reducing greenhouse emissions.

With greenhouse emissions now being given an economic imperative, there is increased desire within industry and government to substitute greenhouse intensive production chains with less intensive production. Rather than changing actual processes, an alternate option is utilising trade with lower embodied emissions. A simple example of this may be the growing of tomatoes in warm regions for consumption in the UK, rather than the use of heated greenhouses to produce the tomatoes domestically.

The application of T-SPA to such a problem hence provides economic managers with a ranked assessment of the production chains that would cause the greatest reduction in greenhouse emissions. For a given country's final consumption, all first order and above production paths are encompassed.

In this paper, the method, application and need for the method is examined before a case study is presented with analysis performed on three world regions: EU, Non-EU OECD and Rest of the World. A ranking of production chains that would have the greatest greenhouse benefit under trade substitution is given for each region. Effects on GDP components, easily extracted within the method, are given.

Keywords: Structural decomposition analysis, Structural path analysis, Trade substitution, Greenhouse.

1. Introduction

Trade liberalisation is occurring at a rapid pace, and with growing emphasis being placed on greenhouse gas mitigation, there is increasing emphasis being placed on tracing embodied greenhouse gas emissions through trade flows (Shui and Harriss 2006; Li and Hewitt 2008; Peters 2008). Input-output analysis is often used to capture the embodied content of imported and exported products, as it necessarily delineates exports as a component of final demand and imports as an input into production (Peters and Hertwich 2006; Rhee and Chung 2006; Ackerman, Ishikawa et al. 2007; Ipek Tunç, Türüt-AsIk et al. 2007; Mäenpää and Siikavirta 2007; Wiedmann, Lenzen et al. 2007; Peters 2008). Most of the above analyses have concentrated on calculating net (and/or gross) embodied emissions. Peters (2008) has gone one step further by applying structural path analysis techniques in a multi-regional input-output setting to trace and rank the production chains containing the highest embodied emissions.

This work seeks to extend on the application of structural path analysis in a multi-regional context by incorporating aspects of structural decomposition analysis to enable the examination of the scope for reducing global greenhouse emissions by accelerating trade substitution of particular production chains. The concepts behind this work also draw heavily from the elucidation of Temporal Structural Path Analysis.

The popular media has recently focussed on the humble tomato to demonstrate the point that it is, or at least might, be better in terms of global greenhouse emissions for a consumer in the U.K. to eat a tomato grown in Spain rather than a tomato grown in the U.K., due to the requirements of heating greenhouses in the U.K. Taken further, substitution of imported goods or services, to intermediate or final demand, can have a significant effect on global greenhouse balances (Li and Hewitt 2008). By so doing, the greenhouse gas efficiency of production on a global scale could be improved[1].

This paper proceeds with an introduction to the method, followed by a mathematical derivation. A case study for a three region MRIO model is undertaken, before conclusions are drawn.

[1] Provided countries are held accountable for imported emissions, as discussed in Peters (2008)

2. Methods

Structural Path Analysis (SPA) was introduced in the early 1980s by (Defourny and Thorbecke 1984). It has seen increasingly widespread use, both in an LCA context (Treloar 1997; Treloar, Love et al. 2001; Lenzen 2002; Lenzen 2003; Wood and Lenzen 2003; Suh 2004; Wood, Lenzen et al. 2006; Llop 2007), and in more general areas such as trade modelling (Peters and Hertwich 2006; Peters and Hertwich 2006; Lenzen, Wiedmann et al. 2007) and in trophic systems (Suh 2005; Lenzen 2006).

The basic idea behind a Structural Path Analysis is the unravelling of the Leontief inverse by means of a series expansion of the direct requirements matrix (Waugh 1950). This allows the analyst to investigate impacts that are caused directly by final consumption (such as emissions from gas cooking) to those caused in the first order away from the consumer (such as emissions in electricity generated for the consumer) to those in higher orders (for example, emissions from agriculture embodied in food products embodied in a beer drunk by a consumer).

By allowing substitution of production chains from region 2 to region 1, the differences in factor inputs can be calculated. In this paper, the substitution of production chains is done within the scope of a decomposition analysis. However, a full structural decomposition analysis is not performed, as of interest is only the change in the trade substituted production chain. That is, differences are not calculated for the remainder of the domestic economy or in final demand. In essence, this is keeping the domestic component of the economy stable, whilst analysing change of a single production chain.

Place Figure 1 here

2.1 Mathematical derivation

Beginning from the basic Leontief model, total output can be expressed as:

$$\mathbf{x} = \mathbf{L}\mathbf{y}, \quad (1)$$

where **x** is a vector of total output, **L** is the Leontief inverse $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ of the direct requirements matrix **A**, and **y** is a vector of final demand (Leontief 1966) or comparable). Whilst decomposition can be applied to this purely monetary equation, a physical production factor such as carbon emissions or energy consumption is the objective of this study. Hence, expand equation 1 to:

$$C = \mathbf{cLy} = \mathbf{c}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \qquad (2)$$

where:

C: Total CO_2 emissions (1×1)	**I**: Unity matrix ($n\times n$)
c: Carbon intensity of n sectors ($1\times f$)	**A**: Direct requirements matrix ($n\times n$)
L: Leontief inverse ($n\times n$)	**y**: Final demand (n)

Of interest, is replacing domestic production chains with high greenhouse content, with foreign production chains with lower greenhouse content. Hence, applying the Taylor series expansion of SPA to trace production chains,

$$\mathbf{L} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots \qquad (3)$$

becomes

$$C = \mathbf{cy} + \mathbf{cAy} + \mathbf{cAAy} + \mathbf{cAAAy} + \mathbf{cAAAAy} + \ldots \qquad (4)$$

And so forth.

Change between two economies is measured by:

$$dC = \partial\mathbf{c} + \partial\mathbf{A} + \partial\mathbf{y}. \qquad (5)$$

In the application of this paper, we are interested, however, only in the substitution of production paths into a domestic economy, i.e. the issue of import or technological substitution, rather than the disparate issue of addressing consumptive practices of different countries. In mathematical terms $\partial\mathbf{A} = 0$ and $\partial\mathbf{y}=0$. Hence:

$$\partial \mathbf{c} = d\mathbf{c}\mathbf{y} + d\mathbf{c}\mathbf{A}\mathbf{y} + d\mathbf{c}\mathbf{A}\mathbf{A}\mathbf{y} + d\mathbf{c}\mathbf{A}\mathbf{A}\mathbf{A}\mathbf{y} + .. \qquad (6)$$

Alternatively, for substitution of second order production chains, differentiate with respect to a combined variable **cA**

$$dC = \partial \mathbf{c} + \partial(\mathbf{cA}) + \partial \mathbf{A} + \partial \mathbf{y}. \qquad (7)$$

Thus substitution at the second order of the production chain,

$$\partial(\mathbf{cA}) = d(\mathbf{cA})\mathbf{y} + d(\mathbf{cA})\mathbf{A}\mathbf{y} + d(\mathbf{cA})\mathbf{A}\mathbf{A}\mathbf{y} + ... \qquad (8)$$

Similarly for imports at the third order of the production chain,

$$\partial(\mathbf{cAA}) = d(\mathbf{cAA})\mathbf{y} + d(\mathbf{cAA})\mathbf{A}\mathbf{y} + ... \qquad (9)$$

And so on

In this formulation, the assumption is made that the domestic co-efficient, **A**,is stable, i.e. $\partial\mathbf{A} = 0$, whilst imported production chains differ, $\partial\mathbf{c} \neq 0$, $\partial(\mathbf{cA}) \neq 0$, $\partial(\mathbf{cAA}) \neq 0$, etc.

Feedback loops within the imports and exports of the two countries are possible, however, such a situation is currently beyond the scope of this analysis, and is not likely to be significant (compare (Lenzen, Pade et al. 2004)).

2.1.1 Margins

This analysis assumes the free and easy substitution of a domestic product for a imported product. In reality, such a substitution will be subject to the application of import duties (no impact on greenhouse) and transport and trade margins - which will engender a greenhouse impact. The inclusion of such effects is theoretically readily done by defining a vector $\mathbf{c}_p$ of carbon intensity of international trade with dimension *n*, and a margins matrix **P** showing international transport and trade margins with dimension *n* x *n*. Equations 6-9 can then be adjusted to include these margin flows, much as imports are often included in standard input-output analysis. However, due to data on international transport and margins being not readily available, for this paper, we are excluding these effects.

3. Case Study

For the case study, three world regions are utilised – EU, non-EU OECD and Rest of World (RoW). The Netherlands Environmental Assessment Agency (MNP) (Wilting 2007) courteously allowed use of the input-output tables for 2001 used in the studies by (Nijdam, Wilting et al. 2005) and (Wiedmann, Wood et al. 2007) which are based on the GTAP 6. The technological matrices were derived from GTAP coefficient 'cost structure of firms' and distinguish 30 economic sectors. This data was generalised for greenhouse gas emissions from fuel combustion from the IEA database, taken from the study by (Wiedmann, Wood et al. 2007).

Equation 7 is calculated for both CO_2-eq emissions and Value added, such that the effect of trade substitution can be assessed from the view point of the global issue of greenhouse emissions, and the local issue of GDP. As value added is a local issue, instead of the standard differential of factor inputs $\Delta c = c_2 - c_1$, only the loss of value added for country 1 is included, i.e. $\Delta c = -c_1$.

Place Table 1 here

A ranking of the top 30 paths by magnitude is presented in Table 1 for Country 1 as the Rest of World, and Country 2 non-EU OECD. The interpretation is that in order to satisfy Rest of World final demand, the substitution of these production chains could theoretically occur. For example, 499 Mt of CO_2-eq would be saved if electricity was produced in the OECD rather than the Rest of World. This is due to cleaner production of electricity, and is a 1st order path – that is, it is direct consumption of electricity by consumers. The differential term “Sc1” refers to the location of the trade substitution – in this case, in the first sector, electricity production. It would also have ramifications for GDP in the loss of US$45b in value added from this sector. For another example, the 6th path: an additional 120 Mt of CO_2-eq would be saved if the second order path, Mineral products -> Construction -> final demand was undertaken in the non-EU

OECD rather than the Rest of World. The differential (Sc2 – meaning Sector 2) shows that the trade substitution takes place within the outputs of the construction industry rather than mineral products nec. Value added loss for Rest of World would be US$38b. Hence, a Rest of World consumer, purchasing outputs of the construction industry from the non-EU OECD, with embodied emissions from mineral products nec also produced in the non-EU OECD would have a net impact of negative 120 Mt CO2-eq.

Place Table 2 here

In reality, not all of these production paths are feasible – it is generally not the case that electricity can be imported. Of the 30 sectors, I hence flag which sectors are likely to be available for import (Table 2), and exclude infeasible production chains. Table 3 shows the top 20 production chains that could reasonably be expected to be substituted for imports in order to lower global greenhouse gas emissions. Importing other manufacturing products tops the list for a moderately large reduction in GDP. Probably of more interest, is the second path – importing government and similar services from the EU rather than using domestic ones. Whilst possibly politically popular, it is principally due to the much lower use of electricity within the sector, and the lower embodied emissions in the electricity. The path Machinery and Equipment to Metals to Electricity is the only 3rd order path in the list, and is possibly a good candidate for import substitution.

Place Table 3 here

Whilst this presentation shows impacts to serve total final demand, it is possibly more interesting to analyse impacts per unit of final demand such that maximum change for dollar of expenditure is achieved. This is done by setting final demand of the consuming region to unity, i.e.

$$\hat{\mathbf{y}}_1 = \mathbf{I}$$

Results are presented in Table 4, again for non-EU OECD serving Rest of World consumption. First order paths dominate, principally in the manufacturing sector, with significant scope for a range of product substitution. General manufacturing products would have a greenhouse benefit of over 1.6kg/$ spent for a loss of GDP of less than 0.4 $/$ final demand.

Place Table 4 here

Top ranked tables for each region by unitary final demand are presented in Tables 5 to 9. It is clear that the EU generally has the cleanest methods of production, simply by noting that almost any major trade substitution by the EU for RoW or non-EU OECD products would have an increasing effect on emissions. Similarly, the non-EU OECD generally has cleaner production methods from the RoW, noted by the positive changes in emissions for the import substitution. Large changes can be made though, with up to 2kg CO_2-eq/$ of final demand potentially being offset by the trade substitution of other manufacturing products from the EU for the RoW. Many other significant trade substitutions could be made, particularly for mineral, chemical, plastic and metal products, with changes in the order of 0.5 kg CO_2-eq/$. For comparison, the average multiplier of the three regions was 0.6, 1.0 and 1.9, EU, non-EU OECD and RoW respectively.

4. Conclusion

This paper has introduced a method for using structural path analysis to estimate possible savings of greenhouse gas emissions from trade substitution. Combining structural path analysis with components of structural decomposition analysis, it is possible to disaggregate and differentiate likely changes in emissions from following spatially different production routes.

A case study on a MRIO model was undertaken, with calculations performed for total and unitary final demand of the reference country. Results generally showed potentially significant savings of greenhouse gas emissions, particularly in manufacturing goods. The Rest of the World region could benefit most from trade substitution, and developed nations could not only follow methods of joint implementation for reducing global emissions, but also discounting non-emissions-intensive trade links.

The next step in this work is to include data on margins, particularly transport margins in order to give a reasonable analysis between the benefits of trade, and the costs of increased transport. Manually flagging possible and unlikely production chains for import could also be replaced by utilising existing imports matrices of a country. Where non-zero cells exist, there is obviously potential for imports at this stage in the production chain, whilst where zero cells exist, imports could be seen as unlikely.

Acknowledgements

Thanks to Tommy Weidmann and Harry Wilting for permitting use of MRIO data.

Tables:

Table 1

Rank	kT CO2	VA m$US	Order	Differential	Sector 1	Sector 2	Sector 3
1	-498,771	-44,584	1	Sc1	Electricity		
2	-231,603	-53,900	1	Sc1	Other manufacturing		
3	-194,668	-140,836	1	Sc1	Transport		
4	-157,482	-9,462	2	Sc2	Electricity	Govt, Public and Rec services	
5	-124,936	-22,170	1	Sc1	Metals		
6	-120,061	-37,997	2	Sc2	Mineral products nec	Construction	
7	116,151	-134,200	1	Sc1	Oil and gas		
8	-105,847	-9,462	2	Sc1	Electricity	Govt, Public and Rec services	
9	-83,531	-37,997	2	Sc1	Mineral products nec	Construction	
10	-83,331	-20,348	2	Sc2	Transport	Trade	
11	-71,875	-4,489	2	Sc2	Electricity	Metals	
12	-68,887	-4,441	2	Sc2	Electricity	Chemical, plastic products	
13	-64,155	-730,719	1	Sc1	Govt, Public and Rec services		
14	-62,315	-10,198	2	Sc2	Metals	Machinery and equipment	
15	-60,720	-59,011	1	Sc1	Chemical, plastic products		
16	-58,667	-3,077	2	Sc2	Electricity	Commun, finan and bus services	
17	-57,466	-10,198	2	Sc1	Metals	Machinery and equipment	
18	56,705	-12,151	1	Sc1	Petroleum and coal products		
19	-55,860	-4,103	2	Sc2	Electricity	Trade	
20	-50,216	-4,489	2	Sc1	Electricity	Metals	
21	-49,686	-4,441	2	Sc1	Electricity	Chemical, plastic products	
22	-48,231	-3,196	2	Sc2	Electricity	Machinery and equipment	
23	-45,903	-4,103	2	Sc1	Electricity	Trade	
24	-40,037	-6,209	2	Sc2	Metals	Construction	
25	-37,920	-2,065	3	Sc3	Electricity	Metals	Machinery and equipment
26	-35,758	-3,196	2	Sc1	Electricity	Machinery and equipment	
27	-35,537	-432,960	1	Sc1	Commun, finan and bus services		
28	-34,989	-6,209	2	Sc1	Metals	Construction	
29	-34,426	-3,077	2	Sc1	Electricity	Commun, finan and bus services	
30	-33,180	-362,543	1	Sc1	Trade		

Results of SSPA for RoW to non-EU OECD. Changes show effects of import substitution from non-EU OECD to service RoW final demand.

Table 2

#	Industry	Abr	Import Avail?
1	Grains	Grs	Yes
2	Horticulture	Hor	Yes
3	Livestock	Liv	Yes
4	Forestry	For	Yes
5	Fishing	Fis	Yes
6	Oil and gas	Oil	Yes
7	Coal and minerals	Col	Yes
8	Meat and dairy	Mea	Yes
9	Other food products	Ofd	Yes
10	Beverages and tobacco products	Bev	Yes
11	Clothing and textiles	Tex	Yes
12	Leather products	Lea	Yes
13	Wood products	Wod	Yes
14	Paper products, publishing	Pap	Yes
15	Petroleum and coal products	Pet	Yes
16	Chemical, plastic products	Chm	Yes
17	Mineral products nec	Min	Yes
18	Metals	Met	Yes
19	Metal products	Mpd	Yes
20	Machinery and equipment	Mac	Yes
21	Motor vehicles and other transport equipment	Veh	Yes
22	Other manufacturing	Man	Yes
23	Electricity	Ele	No
24	Gas	Gas	Yes
25	Water	Wat	No
26	Construction	Con	No
27	Trade	Tde	No
28	Transport	Tpt	No
29	Commun, finan and bus services	Bus	Yes
30	Govt, Public and Rec services	Gov	Yes

Sector classification and import availability.

Table 3

kT CO2	VA m$US	Order	Differential	Sector 1	Sector 2	Sector 3
-231,603	-53,900	1	Sc1	Other manufacturing		
-157,482	-9,462	2	Sc2	Electricity	Govt, Public and Rec services	
116,151	-134,200	1	Sc1	Oil and gas		
-83,531	-37,997	2	Sc1	Mineral products nec	Construction	
-68,887	-4,441	2	Sc2	Electricity	Chemical, plastic products	
-64,155	-730,719	1	Sc1	Govt, Public and Rec services		
-62,315	-10,198	2	Sc2	Metals	Machinery and equipment	
-60,720	-59,011	1	Sc1	Chemical, plastic products		
-58,667	-3,077	2	Sc2	Electricity	Commun, finan and bus services	
56,705	-12,151	1	Sc1	Petroleum and coal products		
-48,231	-3,196	2	Sc2	Electricity	Machinery and equipment	
-37,920	-2,065	3	Sc3	Electricity	Metals	Machinery and equipment
-35,537	-432,960	1	Sc1	Commun, finan and bus services		
-30,650	-13,942	1	Sc1	Mineral products nec		
-30,277	-10,861	2	Sc2	Transport	Govt, Public and Rec services	
-30,053	-1,316	2	Sc2	Electricity	Grains	
-29,698	-1,331	2	Sc2	Electricity	Horticulture	
-25,041	-1,866	2	Sc2	Electricity	Other food products	
23,027	-26,606	2	Sc1	Oil and gas	Petroleum and coal products	
-21,621	-178,391	1	Sc1	Machinery and equipment		

Condensed results of SSPA for demand of RoW to production by non-EU OECD. Only changes where trade substitution is possible are shown.

Table 4

kT CO2/m$US	VA $/$	Order	Differential	Sector 1	Sector 2	Sector 3
-1.66	-0.39	1	Sc1	Other manufacturing		
-0.69	-0.31	1	Sc1	Mineral products nec		
0.54	-0.12	1	Sc1	Petroleum and coal products		
0.53	-0.61	1	Sc1	Oil and gas		
-0.32	-0.02	2	Sc2	Electricity	Chemical, plastic products	
0.31	-0.63	1	Sc1	Fishing		
-0.29	-0.01	2	Sc2	Electricity	Metal products	
-0.28	-0.27	1	Sc1	Chemical, plastic products		
-0.28	-0.05	2	Sc2	Metals	Metal products	
-0.24	-0.01	2	Sc2	Electricity	Grains	
0.22	-0.25	2	Sc1	Oil and gas	Petroleum and coal products	
-0.20	-0.01	2	Sc2	Electricity	Wood products	
-0.20	-0.02	2	Sc2	Electricity	Coal and minerals	
-0.19	-0.02	2	Sc2	Electricity	Paper products, publishing	
-0.17	-0.01	3	Sc3	Electricity	Metals	Metal products
-0.15	-0.01	2	Sc2	Electricity	Horticulture	
-0.14	-0.01	2	Sc2	Electricity	Petroleum and coal products	
-0.14	-0.01	2	Sc2	Electricity	Govt, Public and Rec services	
-0.12	-0.04	2	Sc2	Mineral products nec	Mineral products nec	
-0.12	-0.25	2	Sc2	Oil and gas	Petroleum and coal products	
-0.11	-0.05	2	Sc1	Mineral products nec	Construction	

Condensed results of SSPA for demand of RoW to production by non-EU OECD. Units per dollar of RoW final demand, top 20 paths.

Table 5

kT CO2	VA m$US	Order	Differential	Sector 1	Sector 2	Sector 3
2.75	-0.40	1	Sc1	Other manufacturing		
1.16	-0.47	1	Sc1	Mineral products nec		
-0.76	-0.07	1	Sc1	Petroleum and coal products		
-0.76	-0.60	1	Sc1	Oil and gas		
0.59	-0.02	2	Sc2	Electricity	Chemical, plastic products	
0.53	-0.01	2	Sc2	Electricity	Metal products	
-0.52	-0.62	1	Sc1	Fishing		
0.47	-0.38	1	Sc1	Chemical, plastic products		
0.46	-0.06	2	Sc2	Metals	Metal products	
0.44	0.00	2	Sc2	Electricity	Grains	
0.37	-0.03	2	Sc2	Electricity	Coal and minerals	
0.37	-0.01	2	Sc2	Electricity	Wood products	
0.35	-0.02	2	Sc2	Electricity	Paper products, publishing	
0.30	-0.01	3	Sc3	Electricity	Metals	Metal products
0.27	-0.01	2	Sc2	Electricity	Petroleum and coal products	
0.27	0.00	2	Sc2	Electricity	Horticulture	
0.25	-0.01	2	Sc2	Electricity	Govt, Public and Rec services	
0.23	-0.14	2	Sc2	Oil and gas	Petroleum and coal products	
0.20	-0.04	2	Sc2	Mineral products nec	Mineral products nec	
0.19	-0.02	2	Sc2	Electricity	Mineral products nec	

Condensed results of SSPA for demand of non-EU OECD to production by RoW. Units per dollar of non-EU OECD final demand, top 20 paths.

Table 6

kT CO2/m$US	VA $/$	Order	Differential	Sector 1	Sector 2
0.60	-0.09	1	Sc1	Petroleum and coal products	
0.48	-0.67	1	Sc1	Oil and gas	
0.46	-0.40	1	Sc1	Other manufacturing	
0.29	-0.05	2	Sc2	Oil and gas	Petroleum and coal products
0.19	-0.59	1	Sc1	Fishing	
0.15	0.00	2	Sc2	Transport	Gas
0.11	-0.02	2	Sc1	Petroleum and coal products	Petroleum and coal products
0.11	-0.36	1	Sc1	Chemical, plastic products	
0.10	0.00	2	Sc2	Electricity	Oil and gas
0.09	-0.01	2	Sc2	Electricity	Chemical, plastic products
0.09	-0.02	2	Sc2	Electricity	Mineral products nec
0.08	-0.01	2	Sc2	Transport	Livestock
0.07	-0.01	2	Sc2	Electricity	Petroleum and coal products
0.07	-0.04	2	Sc2	Electricity	Coal and minerals
0.07	-0.02	2	Sc2	Electricity	Paper products, publishing
0.07	-0.02	2	Sc2	Transport	Coal and minerals
0.07	0.00	2	Sc2	Petroleum and coal products	Fishing
0.07	0.00	2	Sc2	Electricity	Other manufacturing
0.06	-0.03	2	Sc2	Transport	Mineral products nec

Condensed results of SSPA for demand of EU to production by non-EU OECD. Units per dollar of non-EU OECD final demand, top 20 paths.

Table 7

kT CO2/m$US	VA $/$	Order	Differential	Sector 1	Sector 2
-0.60	-0.07	1	Sc1	Petroleum and coal products	
-0.48	-0.60	1	Sc1	Oil and gas	
-0.46	-0.40	1	Sc1	Other manufacturing	
-0.29	-0.14	2	Sc2	Oil and gas	Petroleum and coal products
-0.19	-0.62	1	Sc1	Fishing	
-0.15	-0.04	2	Sc2	Transport	Gas
-0.11	-0.14	2	Sc1	Oil and gas	Petroleum and coal products
-0.11	-0.38	1	Sc1	Chemical, plastic products	
-0.10	-0.01	2	Sc2	Electricity	Oil and gas
-0.09	-0.02	2	Sc2	Electricity	Chemical, plastic products
-0.09	-0.02	2	Sc2	Electricity	Mineral products nec
-0.08	-0.03	2	Sc2	Transport	Livestock
-0.07	-0.01	2	Sc2	Electricity	Petroleum and coal products
-0.07	-0.03	2	Sc2	Electricity	Coal and minerals
-0.07	-0.02	2	Sc2	Electricity	Paper products, publishing
-0.07	-0.03	2	Sc2	Transport	Coal and minerals
-0.07	-0.01	2	Sc1	Petroleum and coal products	Petroleum and coal products
-0.07	0.00	2	Sc2	Petroleum and coal products	Fishing
-0.07	-0.01	2	Sc2	Electricity	Other manufacturing

Condensed results of SSPA for demand of non-EU OECD to production by EU. Units per dollar of non-EU OECD final demand, top 20 paths.

Table 8

kT CO2/m$US	VA $/$	Order	Differential	Sector 1	Sector 2	Sector 3
2.12	-0.40	1	Sc1	Other manufacturing		
0.73	-0.42	1	Sc1	Mineral products nec		
0.41	-0.01	2	Sc2	Electricity	Chemical, plastic products	
0.41	-0.05	2	Sc2	Oil and gas	Petroleum and coal products	
0.39	-0.36	1	Sc1	Chemical, plastic products		
0.32	-0.01	2	Sc2	Electricity	Metal products	
0.31	-0.03	2	Sc2	Metals	Metal products	
0.27	-0.04	2	Sc2	Electricity	Coal and minerals	
0.26	-0.02	2	Sc2	Electricity	Paper products, publishing	
0.22	-0.01	2	Sc2	Electricity	Petroleum and coal products	
0.22	0.00	3	Sc3	Electricity	Metals	Metal products
0.21	-0.01	2	Sc2	Electricity	Grains	
0.21	-0.01	2	Sc2	Electricity	Wood products	
0.19	-0.02	2	Sc2	Electricity	Mineral products nec	
0.18	0.00	2	Sc2	Electricity	Govt, Public and Rec services	
0.16	-0.03	2	Sc1	Other manufacturing	Other manufacturing	
0.15	0.00	2	Sc2	Electricity	Other manufacturing	
0.13	-0.38	1	Sc1	Paper products, publishing		
0.12	-0.04	2	Sc2	Mineral products nec	Mineral products nec	
0.12	-0.01	2	Sc2	Electricity	Horticulture	

Condensed results of SSPA for demand of EU to production by RoW. Units per dollar of EU final demand, top 20 paths.

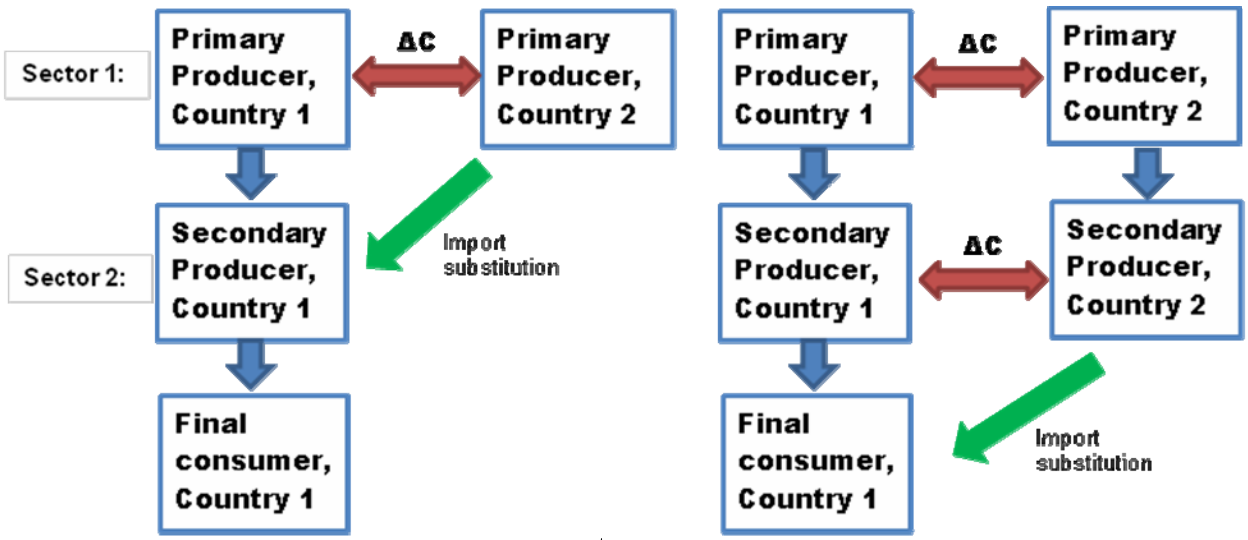
Table 9

kT CO2/m$US	VA $/$	Order	Differential	Sector 1	Sector 2	Sector 3
-2.12	-0.39	1	Sc1	Other manufacturing		
-0.73	-0.31	1	Sc1	Mineral products nec		
-0.41	-0.02	2	Sc2	Electricity	Chemical, plastic products	
-0.41	-0.25	2	Sc2	Oil and gas	Petroleum and coal products	
-0.39	-0.27	1	Sc1	Chemical, plastic products		
-0.32	-0.01	2	Sc2	Electricity	Metal products	
-0.31	-0.05	2	Sc2	Metals	Metal products	
-0.27	-0.02	2	Sc2	Electricity	Coal and minerals	
-0.26	-0.02	2	Sc2	Electricity	Paper products, publishing	
-0.22	-0.01	2	Sc2	Electricity	Petroleum and coal products	
-0.22	-0.01	3	Sc3	Electricity	Metals	Metal products
-0.21	-0.01	2	Sc2	Electricity	Grains	
-0.21	-0.01	2	Sc2	Electricity	Wood products	
-0.19	-0.01	2	Sc2	Electricity	Mineral products nec	
-0.18	-0.01	2	Sc2	Electricity	Govt, Public and Rec services	
-0.15	-0.01	2	Sc2	Electricity	Other manufacturing	
-0.13	-0.33	1	Sc1	Paper products, publishing		
-0.12	-0.04	2	Sc2	Mineral products nec	Mineral products nec	
-0.12	-0.01	2	Sc2	Electricity	Horticulture	
0.12	-0.63	1	Sc1	Fishing		

Condensed results of SSPA for demand of RoW to production by EU. Units per dollar of RoW final demand, top 20 paths.

Figures:

Figure 1



Two examples of import substitution for 1st order production chains. Left, import substitution occurs for secondary producers, Right, import substitution occurs for final demand. Total ΔC is the difference between production practices of country 1 and country 2 for all activity upstream of import substitution.

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