Swedish Footprints: Policy-Relevant Indicators for Consumption and Environment

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This presentation[1] introduces the input-output relevant work of PRINCE (Policy-Relevant Indicators for Consumption and Environment). PRINCE is a multi-partner, cross-disciplinary project aiming to develop a sound and repeatable methodology to monitor the environmental impacts of Swedish consumption, both inside and outside Sweden's borders.

Sweden has set itself the ambitious goal of handing over to the next generation "a society in which the major environmental problems in Sweden have been solved". Significantly, this is to be achieved "without increasing environmental and health problems outside Sweden's borders". This so-called Generational Goal constitutes the overarching goal of current Swedish environmental policy. Yet measuring the diverse environmental impacts of a country's consumption, particularly beyond its borders, is extremely challenging. These impacts may be spread along a myriad of long, complex and very fluid global supply chains.

PRINCE responds to a call from the Swedish Environmental Protection Agency (Naturvårdsverket) for a pioneering monitoring framework for its consumption-based accounting, based on the latest modelling and statistical techniques. The framework will cover a uniquely broad range of environmental pressures, including: Emissions of greenhouse gases and traditional air pollutants (SO_2, NOx, NH_3, VOCs) from fossil fuel burning, manufacturing processes, livestock production and land-use change Impacts of the consumption of resources such as water and land. Exploratory indicators for use or emission of hazardous chemical substances.

PRINCE will develop an economic-environmental monitoring framework based on multiregional input-output (MRIO) analysis. The research will have four main strands and outputs: Evaluation of existing consumption-based accounting models and calculations, to identify those most appropriate to integrate with Swedish national accounting data. Identification and quantification of a range of environmental pressures from Swedish consumption. Identification of those product groups with the largest environmental impacts, and where those impacts take place. Development of a sound, repeatable methodology for monitoring, in line with official statistical criteria.

This presentation covers the overall goals of the project. It concentrates on methods used to operationalize the accounts – especially the link between the MRIO models, and the available Swedish IO tables.

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1. Introduction

The UN System of Environmental and Economic Accounts (SEEA) provides the current standard for measurement and monitoring of environmental impacts. The SEEA has a purpose to describe the inputs from the environment to the economy (e.g. through the use of raw materials, water, energy and land) and the pressures from the economy on the environment (such as emissions from fuel use and from industrial processes). As an economy requires both domestic and international inputs in a linked global economic system, it is a natural progression to understand not only the national contribution of the environment to the economy, but also the international contribution.

Consumption-based indicators are used to capture this international perspective. To fully understand the pressures and impacts that a whole nation places on the environment overseas it is necessary to consider the consumption of all goods and services within an economy, as some goods that may initially appear unrelated to the environmental impact of interest may in fact generate large impacts throughout their production and processing. This leads to a full-supply chain approach to consumption-based accounting, taking into account all goods and services consumed within an economy. A commonly applied technique that provides this information is input-output analysis (IOA). IOA has now become well-established for the calculation of the impacts of nations, sub-national entities and socio-economic groups (Ewing et al. 2012; Hertwich and Peters 2009; Moran et al. 2013; Wiedmann 2009; Wiedmann et al. 2015; Wood and Dey 2009).

As research in the field has progressed a variety of IO models have been developed and their data and capabilities have grown and improved. During the last years models have moved from representing just the economic flows in one country, to models of many countries, known as global multiregional input-output (MRIO) models. These global models are able to trace environmental impacts through complex global supply chains, linking between production and consumption in different parts of the world.

MRIO analysis, in combination with the system of environmental accounting, has been suggested to be best suited for this type of consumption-based analysis (Wiedmann 2009). Similarly, Brolinson et al. (2010) discussed different methods, highlighting the usefulness of MRIO over other approaches. However, MRIO is limited by the fact that currently large investments are needed to produce MRIO tables that can result in temporal delays in availability (see Tukker et al. 2015 for a discussion), and national tables need to be harmonised against other countries' input-output tables (Wood et al. 2014). As such, there may be discrepancy between official tables, and between MRIO models (Edens et al. 2015; Moran and Wood 2014; Owen et al. 2016).

The difference in resultant environmental footprints between MRIO models and official national tables are due to the differing data used in official national tables (Edens et al. 2015), and the way impacts embodied in trade are addressed (Andrew et al. 2009). Most importantly, is the mechanics of the integration, and the potential empirical effect of assumptions implicit in integration. The latter is discussed by Moran, Rodrigues, and Wood (forthcoming), the former is the focus of this work.

2. Calculation of impacts embodied in consumption by applying multipliers to trade

Starting with a two-region economic balance, where total output is the sum of intermediate output and final demand

$$\begin{bmatrix}\mathbf{x_r}\\ \mathbf{x_s}\end{bmatrix} = \begin{bmatrix}\mathbf{Z_{rr}} & \mathbf{Z_{rs}}\\ \mathbf{Z_{sr}} & \mathbf{Z_{ss}}\end{bmatrix} + \begin{bmatrix}\mathbf{y_{rr}} + \mathbf{y_{rs}}\\ \mathbf{y_{sr}} + \mathbf{y_{ss}}\end{bmatrix} \qquad \text{Equation 1}$$

This can be converted into coefficient form (**A**) by dividing intermediate flows (**Z**) by output (**x**)

to give a model for calculations of impacts embodied in final demand:

$$\begin{bmatrix}\mathbf{x_r}\\ \mathbf{x_s}\end{bmatrix} = \begin{bmatrix}\mathbf{A_{rr}} & \mathbf{A_{rs}}\\ \mathbf{A_{sr}} & \mathbf{A_{ss}}\end{bmatrix}\begin{bmatrix}\mathbf{x_r}\\ \mathbf{x_s}\end{bmatrix} + \begin{bmatrix}\mathbf{y_{rr}} + \mathbf{y_{rs}}\\ \mathbf{y_{sr}} + \mathbf{y_{ss}}\end{bmatrix} \qquad \text{Equation 2}$$

We have thus endogenised the intermediate component of trade (the off-diagonal blocks of the A matrix), when we solve for **x**

$$\begin{bmatrix}\mathbf{x_r}\\ \mathbf{x_s}\end{bmatrix} = \left(\begin{bmatrix}\mathbf{I} & \mathbf{0}\\ \mathbf{0} & \mathbf{I}\end{bmatrix} - \begin{bmatrix}\mathbf{A_{rr}} & \mathbf{A_{rs}}\\ \mathbf{A_{sr}} & \mathbf{A_{ss}}\end{bmatrix}\right)^{-1}\begin{bmatrix}\mathbf{y_{rr}} + \mathbf{y_{rs}}\\ \mathbf{y_{sr}} + \mathbf{y_{ss}}\end{bmatrix} \qquad \text{Equation 3}$$

We can specify the Leontief inverse L as

$$\begin{bmatrix}\mathbf{L_{rr}} & \mathbf{L_{rs}}\\ \mathbf{L_{sr}} & \mathbf{L_{ss}}\end{bmatrix} = \left(\begin{bmatrix}\mathbf{I} & \mathbf{0}\\ \mathbf{0} & \mathbf{I}\end{bmatrix} - \begin{bmatrix}\mathbf{A_{rr}} & \mathbf{A_{rs}}\\ \mathbf{A_{sr}} & \mathbf{A_{ss}}\end{bmatrix}\right)^{-1} \qquad \text{Equation 4}$$

Noting that the elements of L respond to the elements of the full matrix inverse, and not the inverse of elements of A. This gives:

$$\begin{bmatrix}\mathbf{x_r}\\ \mathbf{x_s}\end{bmatrix} = \begin{bmatrix}\mathbf{L_{rr}} & \mathbf{L_{rs}}\\ \mathbf{L_{sr}} & \mathbf{L_{ss}}\end{bmatrix}\begin{bmatrix}\mathbf{y_{rr}} + \mathbf{y_{rs}}\\ \mathbf{y_{sr}} + \mathbf{y_{ss}}\end{bmatrix} \qquad \text{Equation 5}$$

Generalising the 2 region model for environmental inputs, we calculate the environmental account by normalising environmental pressures $\mathbf{F}_{r,s}$ by gross output $\mathbf{x}_{r,s}$ to give environmental intensities $\mathbf{S}_{r,s}$,

$$\begin{bmatrix} \mathbf{S}_r & \mathbf{0} \\ \mathbf{0} & \mathbf{S}_s \end{bmatrix} = \begin{bmatrix} \mathbf{F}_r & \mathbf{0} \\ \mathbf{0} & \mathbf{F}_s \end{bmatrix} \begin{bmatrix} \mathbf{x}_r & \mathbf{0} \\ \mathbf{0} & \mathbf{x}_s \end{bmatrix}^{-1}$$ Equation 6

And multiplying Equation 5 by Equation 4, we obtain:

$$\begin{bmatrix} \mathbf{D}_r \\ \mathbf{D}_s \end{bmatrix} = \begin{bmatrix} \widehat{\mathbf{S}_r} & \mathbf{0} \\ \mathbf{0} & \widehat{\mathbf{S}_s} \end{bmatrix} \begin{bmatrix} \mathbf{x}_r & \mathbf{0} \\ \mathbf{0} & \mathbf{x}_s \end{bmatrix} = \begin{bmatrix} \mathbf{S}_r & \mathbf{0} \\ \mathbf{0} & \mathbf{S}_s \end{bmatrix} \begin{bmatrix} \mathbf{L}_{rr} & \mathbf{L}_{rs} \\ \mathbf{L}_{sr} & \mathbf{L}_{ss} \end{bmatrix} \begin{bmatrix} \mathbf{y}_{rr} + \mathbf{y}_{rs} \\ \mathbf{y}_{sr} + \mathbf{y}_{ss} \end{bmatrix}$$ Equation 7

Impacts of regional consumption can be calculated by delineating y:

$$\begin{bmatrix} \mathbf{D}_{rr} & \mathbf{D}_{rs} \\ \mathbf{D}_{sr} & \mathbf{D}_{ss} \end{bmatrix} = \begin{bmatrix} \mathbf{S}_r & \mathbf{0} \\ \mathbf{0} & \mathbf{S}_s \end{bmatrix} \begin{bmatrix} \mathbf{L}_{rr} & \mathbf{L}_{rs} \\ \mathbf{L}_{sr} & \mathbf{L}_{ss} \end{bmatrix} \begin{bmatrix} \mathbf{y}_{rr} & \mathbf{y}_{rs} \\ \mathbf{y}_{sr} & \mathbf{y}_{ss} \end{bmatrix}$$ Equation 8

The meaning of the variables is as follows: $\mathbf{D}_{rr} + \mathbf{D}_{sr}$ is the environmental pressure from consumption in region r from production in both region r and region s.

If we focus now purely on the footprint of region *r*:

$$\mathbf{D}_r = \mathbf{SL} \begin{bmatrix} \mathbf{y}_{rr} \\ \mathbf{y}_{sr} \end{bmatrix}$$ Equation 9

We now seek to include total imports and exports as exogenous variables by defining total imports $\mathbf{m}$ as the sum of the intermediate imports and the final imports. For region 1, the intermediate imports is the flow matrix $\mathbf{Z}_{sr} = \mathbf{A}_{sr}\mathbf{x}_r$, and imports direct to final demand are $\mathbf{y}_{sr}$

$$\mathbf{m}_r = \mathbf{A}_{sr}\mathbf{x}_r + \mathbf{y}_{sr}$$ Equation 10

And equivalently, exports **e** can be expressed as the sum of the intermediate exports and the final imports. For region 1, the intermediate exports is the flow matrix $\mathbf{Z}_{rs} = \mathbf{A}_{rs}\mathbf{x}_s$, and exports direct to final demand are $\mathbf{y}_{rs}$

$$\mathbf{e}_r = \mathbf{A}_{rs}\mathbf{x}_s + \mathbf{y}_{rs}$$ Equation 11

Adding and subtracting both equations from Equation 9 gives

$$\mathbf{D_r} = \mathbf{SL}\begin{pmatrix}\mathbf{y_{rr}} - \mathbf{e_r} + \mathbf{A_{rs}x_s} + \mathbf{y_{rs}} \\ \mathbf{y_{sr}} + \mathbf{m_r} - \mathbf{A_{sr}x_r} - \mathbf{y_{sr}}\end{pmatrix} \quad \text{Equation 12}$$

Now we know that from Equation 2

$$\mathbf{x_r} = \mathbf{A_{rr}x_r} + \mathbf{y_{rr}} + \mathbf{A_{rs}x_s} + \mathbf{y_{rs}} \quad \text{Equation 13}$$

So,

$$\mathbf{x_r} - \mathbf{A_{sr}x_r} = \mathbf{y_{rr}} + \mathbf{A_{rs}x_s} + \mathbf{y_{rs}} \quad \text{Equation 14}$$

And substituting Equation 14 into Equation 12, and cancelling $\mathbf{y_{sr}}$ in the demand denominator:

$$\mathbf{D_r} = \mathbf{SL}\begin{pmatrix}\mathbf{x_r} - \mathbf{A_{rr}x_r} - \mathbf{e_r} \\ \mathbf{m_r} - \mathbf{A_{sr}x_r}\end{pmatrix} \quad \text{Equation 15}$$

$$\mathbf{D_r} = \mathbf{SL}\begin{pmatrix}(\mathbf{I} - \mathbf{A_{rr}})\mathbf{x_r} - \mathbf{e_r} \\ -\mathbf{A_{sr}x_r} + \mathbf{m_r}\end{pmatrix} \quad \text{Equation 16}$$

$$\mathbf{D_r} = \mathbf{SL}\left(\begin{bmatrix}\mathbf{I} \\ \mathbf{0}\end{bmatrix} - \begin{bmatrix}\mathbf{A_{rr}} \\ \mathbf{A_{sr}}\end{bmatrix}\right)\mathbf{x_r} + \begin{pmatrix}-\mathbf{e_r} \\ \mathbf{m_r}\end{pmatrix} \quad \text{Equation 17}$$

Which is equivalent to (adding region *s* A matrices):

$$\mathbf{D_r} = \mathbf{SL}\left(\begin{bmatrix}\mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{I}\end{bmatrix} - \begin{bmatrix}\mathbf{A_{rr}} & \mathbf{A_{rs}} \\ \mathbf{A_{sr}} & \mathbf{A_{ss}}\end{bmatrix}\right)\begin{bmatrix}\mathbf{x_r} \\ \mathbf{0}\end{bmatrix} + \begin{pmatrix}-\mathbf{e_r} \\ \mathbf{m_r}\end{pmatrix} \quad \text{Equation 18}$$

Substituting Equation 4

$$\mathbf{D_r} = \mathbf{S}\begin{bmatrix}\mathbf{x_r} \\ \mathbf{0}\end{bmatrix} + \mathbf{SL}\begin{pmatrix}-\mathbf{e_r} \\ \mathbf{m_r}\end{pmatrix} \quad \text{Equation 19}$$

And expanding **S**

$$\mathbf{D_r} = \mathbf{S_r x_r} + \mathbf{SL}\begin{pmatrix}-\mathbf{e_r} \\ \mathbf{m_r}\end{pmatrix} \quad \text{Equation 20}$$

We can now split up the impacts due to domestic production $\mathbf{S_r x_r}$, from those in imports $D^m = \mathbf{SL}\begin{pmatrix}\mathbf{0} \\ \mathbf{m_r}\end{pmatrix}$ and those in exports $\mathbf{SL}\begin{pmatrix}-\mathbf{e_r} \\ \mathbf{0}\end{pmatrix}$.

Thus far we have an internally consistent model to analyse the supply chain effects in a certain region ***r***. Of note is that the analysis per se is an imputation analysis, not an impact analysis. This because there is a dependency between m and L as well as e and L (see Equation 10, Equation 11 and Equation 4). In other terms, traded goods for intermediate consumption are represented in both **L** and **m**/**e**.

Mathematically, it has been shown that the equations are consistent, as long as footprints of imports and exports are considered alongside domestic impacts. Next, we can discuss whether, conceptually, representing traded goods for intermediate consumption as both an endogenous and exogenous variable is reasonable.

3. Double counting?

Oosterhaven and Stelder (2002) clearly point to a number of cases where in applied work, users seek to use methods that calculate the total indirect impact of a certain unit of output rather than final demand. The fundamental difference being that, in comparison to final demand, output is a partially endogenous variable in the Leontief inverse, such that the contribution of output in both endogenous variables (intermediate demand) and as an exogenous variable amounts to double counting.

Oosterhaven and Stelder (2002) come up with a concept of net-multipliers that looks at scaling contributions to factor requirements in order to give an index of importance, without double counting. They consider two aspects, firstly, that they weight the impacts to add to 100% in equilibrium, and secondly, that the exogenous output is rescaled by the relative contribution of final demand to output (fi/xi). This adjustment essentially shifts the analysis back to a demand based assessment (fi/xi * xi(exog)) if the exogenous output is equivalent to equilibrium output.

Oosterhaven and Stelder (2002), however, intend for the analysis to be applied to one sector, with a non-equilibrium output. De Mesnard (2002) relaxes the assumption of fixed final demand to output ratios, and instead goes back to the production layer effects of an exogenous shock, but still with the net concept of multipliers, such that the overall impact excludes the impact of the original shock (shown by utilizing the production layer decomposition from $A+A^2+A^3+\ldots$, which condenses to (L-I), given standard Leontief accounting, which can also be represented as LA by taking the A term out of the Taylor series expansion of the production layer decomposition.

Dietzenbacher (2005) extends the discussion to incorporate direct effects into the de Mesnard multipliers, and by so doing, ending again with gross multipliers L. A key point of discussion of Dietzenbacher (2005) is the economic meaning and suitability of gross multipliers L, even for analysis of gross output. It seems this is disputable in the literature still, with Oosterhaven (2007) making the point that is hopefully clear in IOA, that the standard gross multiplier is a didactical device suitable for demonstrating linkages in a “comparative static equilibrium model”. That is, it is not appropriate to use gross multipliers when looking at the expansion of the economy (dynamic changes), but that it is acceptable to use them for analysing the structure of the economy – what we consider imputation analysis, and what we focus on in the calculation of environmental footprints, and environmental or social impacts embodied in trade. As De Mesnard (2002) and Dietzenbacher (2005) show, gross multipliers can be applied to an endogenous variable (output), given that correct interpretation is applied. As traded goods reflect gross output in being partially represented in the Leontief inverse, the same conclusions can be made for traded goods, without repeating the derivations of the papers.

4. Linking domestic and global models

However, what if we would like to use different data to inform the calculation of domestic production from that of imports?

From the standpoint of a national statistical agency, they will have own data in own classification (denoted with a star) on $\mathbf{S}_r^*$, $\mathbf{A}_{rr}^*$, $\mathbf{A}_{sr}^*$, $\mathbf{m}_r^*$ and $\mathbf{e}_r^*$. Whilst data on $\mathbf{S}_s$, $\mathbf{A}_{ss}$, $\mathbf{A}_{\mathrm{rs}}$ must be informed from other statistical agency data, or multiregional input-output models.

There are many potential ways of linking data across models, remapping classifications is necessary, but rebalancing is optional (Wiebe and Lenzen 2016). Hence, we propose a linked IO model where a concordance matrix $\mathbf{G}$ is introduced to map from classification of imported commodities. $\mathbf{G}$ must be a weighted concordance matrix, such that column sums equal 1. Imports is the most straightforward case, where it is assumed the MRIO model data is used:

$$D^m = \mathbf{SLG}\begin{pmatrix}\mathbf{0}\\ \mathbf{m}_r^*\end{pmatrix} \qquad \text{Equation 21}$$

Moving to calculation of impacts in domestic production and exports

$$\mathbf{D}_r^{\sim m} = \mathbf{S}_\mathrm{r}\mathbf{x}_\mathrm{r} + \mathbf{SL}\begin{pmatrix}-\mathbf{e}_\mathrm{r}\\ \mathbf{0}\end{pmatrix} \qquad \text{Equation 22}$$

As Equation 23

$$\mathbf{x}_\mathrm{r} = \mathbf{A}_\mathrm{rr}\mathbf{x}_\mathrm{r} + \mathbf{y}_\mathrm{rr} + \mathbf{e}_\mathrm{r}$$

or Equation 24

$$\mathbf{x}_\mathrm{r} = (\mathbf{I} - \mathbf{A}_\mathrm{rr})^{-1}(\mathbf{y}_\mathrm{rr} + \mathbf{e}_\mathrm{r})$$

We can rewrite this as:

$$\mathbf{D}_r^{\sim m} = \mathbf{S}_\mathrm{r}(\mathbf{I} - \mathbf{A}_\mathrm{rr})^{-1}(\mathbf{y}_\mathrm{rr} + \mathbf{e}_\mathrm{r}) - (\mathbf{S}_\mathrm{r}\mathbf{L}_\mathrm{rr} + \mathbf{S}_\mathrm{s}\mathbf{L}_\mathrm{rs})\mathbf{e}_\mathrm{r} \quad \text{Equation 25}$$

Decomposing the terms, we can arrive back at the classic Leontief equation for domestic emissions in domestic consumption:

$$\mathbf{D}_r^r = \mathbf{S}_\mathrm{r}(\mathbf{I} - \mathbf{A}_\mathrm{rr})^{-1}\mathbf{y}_\mathrm{rr} \quad \text{Equation 26}$$

And a slightly more complex disposition for the contribution of impacts embodied in exports that are present in region *r*'s footprint:

$$\mathbf{D}_r^e = \mathbf{S}_\mathrm{r}(\mathbf{I} - \mathbf{A}_\mathrm{rr})^{-1}\mathbf{e}_\mathrm{r} - (\mathbf{S}_\mathrm{r}\mathbf{L}_\mathrm{rr} + \mathbf{S}_\mathrm{s}\mathbf{L}_\mathrm{rs})\mathbf{e}_\mathrm{r} \quad \text{Equation 27}$$

When does $\mathbf{D}_r^e = \mathbf{0}$? Well the simplest and cleanest answer is when $\mathbf{A}_\mathrm{rs}$ and $\mathbf{A}_\mathrm{sr} = \mathbf{0}$. In this case, we denote $\mathbf{L}_{rr}^d$ as

$$\begin{bmatrix} \mathbf{L}_{rr}^d & \mathbf{0} \\ \mathbf{0} & \mathbf{L}_{ss}^d \end{bmatrix} = \left(\begin{bmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} \end{bmatrix} - \begin{bmatrix} \mathbf{A}_\mathrm{rr} & \mathbf{0} \\ \mathbf{0} & \mathbf{A}_\mathrm{ss} \end{bmatrix} \right)^{-1} \quad \text{Equation 28}$$

Which is equivalent to $\mathbf{L}_{rr}^d = (\mathbf{I} - \mathbf{A}_\mathrm{rr})^{-1}$ by rules of matrix inverse. This corresponds to the EEBT approach (Peters 2008), where feedback effects from international trade are ignored, and all trade is considered exogenous. The contribution of those feedback effects can then be quantified as those originating from the domestic territory, $\mathbf{S}_\mathrm{r}\mathbf{L}_\mathrm{rr}\mathbf{e}_\mathrm{r}$, and those originating on foreign territory, $\mathbf{S}_\mathrm{s}\mathbf{L}_\mathrm{rs}\mathbf{e}_\mathrm{r}$:

$$\mathbf{S}_\mathrm{r}\mathbf{L}_{rr}^d\mathbf{e}_\mathrm{r} - \mathbf{S}_\mathrm{r}\mathbf{L}_\mathrm{rr}\mathbf{e}_\mathrm{r} - \mathbf{S}_\mathrm{s}\mathbf{L}_\mathrm{rs}\mathbf{e}_\mathrm{r} \quad \text{Equation 29}$$

It should be noted that impacts embodied in exports are not required to calculate the impacts of consumption if consumption vectors are available (and under the assumption that feedback effects, $\mathbf{D}_r^e = \mathbf{0}$)

$$\mathbf{D}_r = \mathbf{D}_r^r + \mathbf{D}_r^m \quad \text{Equation 30}$$

Maintaining the assumption that feedback effects are negligible, impacts embodied in exports can be calculated from the domestic balance, exogenous to the above equation:

$$\mathbf{D}_{rs} = \mathbf{S}_{\mathrm{r}}(\mathbf{I} - \mathbf{A}_{\mathrm{rr}})^{-\mathbf{1}}(\mathbf{e}_{\mathrm{r}}) \qquad \text{Equation 31}$$

5. Conclusion

This paper outlines the context of the project on Swedish environmental accounts, in which progress to achieve the Swedish generational goals should not come at the expense of off-shoring environmental impacts. Because the project wants to have a reproducible, frequently updated procedure going forwards, and because it wants to respect Swedish data where available, the discussion in this work has been to focus on linking domestic models with global multiregional models. Because of the central discussion about treatment of traded goods, the work has focussed on mathematically deriving the relationships necessary to include traded goods as exogenous parameters to the Leontief inverse. This breaks with the literature on emissions embodied in bilateral trade and multiregional input-output. However, it opens up a significant opportunity to simplify the modelling frameworks used in linked models, whilst still using consumption based frameworks and best quality data available.

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