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Physical input-output tables: Developments and future

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PHYSICAL INPUT-OUTPUT TABLES: DEVELOPMENTS AND FUTURE

Summary: Physical input-output tables (PIOT) enjoyed a certain popularity in the 1990's and beginning of the millennium. The empirical work was followed by articles on PIOT modelling and applications. However, despite the potential benefits for environmental economics, there seems to be no large scale push to produce PIOT at National Statistical Institutes or elsewhere.

This paper provides an overview of the literature on physical accounts (Physical supply and use tables (PSUT) and Physical input-output tables (PIOT)). A rudimentary PSUT for the Netherlands for the year 2006 is also presented as an illustration.

We conclude that momentum has been lost because the literature has generated too few (or visible) applications that justify the large investments which are involved in the production of a PIOT. The paper proposes a number of directions for future research which could help to make the PIOT more relevant and cost-effective.

Keywords: Physical supply and use tables (PSUT), Physical input-output tables (PIOT), Material flow accounts (MFA), recycling, emissions, waste, residuals, natural resources.

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1. Introduction

Many of the most serious environmental and resource problems are related to the extraction and emission of materials and substances. Industrial processes require non-renewable raw materials, such as metal ores and fossil fuels, which leads to the depletion of existing resource stocks. Moreover, excessive use of renewable resources, such as wood and fish, can lead to a collapse of ecosystems and extinction of species. At the same time, the use of resources in the economy results in wastes and emissions, which cause environmental problems such as global warming, acid rain, eutrophication, and the depletion of the ozone layer.

Clarification of the relationship between the economy and materials flows is essential for a good understanding of environmental problems and policies to resolve them. The structure of an economy consists of different elements, such as technology, sector structure, consumption patterns, investments, import and export. Each of these is related, in its own way, to physical flows of raw materials, products and wastes.

From a macro-economic perspective the discussion on physical flows has been dominated by the field of (economy wide) material flow accounting (MFA). This approach has a long history and has been applied widely (Adriaanse et al., 1997; WRI, 2000; Eurostat, 2001; Amann et al., 2004). MFA provides detailed information on the import, export and extraction of materials and goods. Furthermore, these figures are aggregated into indicators which are designed to serve as macro-economic sustainability indicators (e.g. Domestic Material Consumption- DMC). These indicators have received criticism because they aggregate all materials, irrespective of environmental impacts, on the basis of weight.[2] On the other hand it must be said that these indicators have been adopted in quite a few policy frameworks.

MFA data is very useful because it provides very detailed information of the physical flows related to imports, export and extraction. However, MFA does not provide information on flows such as technology, emissions and consumption. These are important aspects in understanding physical flows, and the environmental problems that are related to them. Here, the field of physical input-output tables (PIOT), which is strongly related to MFA, comes into play.[3]

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[2] Note that methods have been developed to weigh MFA indicators based on the environmental damages (van der Voet et al, 2005).

[3] The demarcation of where PIOT starts and MFA ends is not always as clear as is suggested here. For example, MFA studies also provide industry breakdowns, thereby moving beyond the original scope of the economy wide MFA and towards the PIOT framework. One might even define the PIOT as a detailed MFA. For the sake of clarity we have adopted the "original" definitions, without wishing to ignore the fact that these two fields are converging.

A PIOT is the physical equivalent of the monetary input-output table (MIOT) in the National Accounts. All flows in the MIOT which can be measured in mass units are recorded as well as the multiple flows which relate the economy to the environment. Since the PIOT provides a complete overview of physical flows which is consistent to the MIOT it provides a valuable source of information for environmental-economic modelling.

Physical input-output tables (PIOT) enjoyed a certain degree of popularity in the 1990's and beginning of the millennium. PIOT studies were produced for Denmark (Gravgård-Pedersen, 1999; Mulalic, 2007), EU (Giljum and Hubacek, 2001; Hubacek and Giljum, 2003), Germany (Stahmer et al., 1997; Statistisches Bundesambt, 2001), Finland (Mäenpää and Muukkonen, 2001; Mäenpää, 2002; Mäenpää, 2004), Italy (Nebbia, 2000), the Netherlands (Konijn et al., 1997; Hoekstra, 2005) New Zealand (McDonald, 2005; McDonald and Patterson, 2006) and Spain (Gasco et al., 2005). This work on the data also led to articles on a variety of modelling issues concerning the PIOT[4]. Note that a sizeable portion of these papers have dealt with technical modelling issues, while the rest provides applications that could be useful from a scientific or policy perspective

Most of the PIOTs were produced for 1990 or a year in the mid 90s. To our knowledge only Denmark produced an update for 2002 (Mulalic, 2007). Furthermore, physical accounting has failed to spread beyond the countries of the European Union, with the exception of the work in New Zealand. So despite all the potential benefits the PIOTs has not become a standard product of National Statistical Institutes (NSI) or other institutes.[5] Why is this so?

This is a difficult question to answer. However, it seems incontrovertible that an important factor is the large investment which is required to produce a PIOT. In a setting of budget cuts at National Statistical Institutes (NSI) it will need to be clear that the benefits justify the costs. In general terms one might argue that this cost-benefit analysis for PIOTs has not been sufficiently positive so far. Too few applications have been developed, or are visible, that have increased the demand for a regular production of physical accounts.

In this paper we will describe the structure and uses of the PIOT. A rudimentary PSUT for 2006 for the Netherlands is produced as an illustration. However, more importantly we will suggest a couple of directions for future research so that the PIOT can again generate enthusiasm in the environmental-economic and national

[4] Konijn et al., 1995; Konijn et al., 1997; Strassert, 2001; Daniels and Moore, 2002; Strassert, 2002; Hubacek and Giljum, 2003; Giljum and Hubacek, 2004; Suh, 2004a, Suh, 2004b, Weisz and Duchin, 2004; Dietzenbacher, 2005; Dietzenbacher et al., 2005; Gasco et al, 2005; Hoekstra, 2005; Weidema et al. 2005; Hoekstra and van den Bergh, 2006; Schoer, 2006; Weisz, 2006; Suh 2009 (various chapters); and Xu and Zhang, 2009.

[5] MFA is far more successful in this respect. Many NSI’s in Europe have started to produce these figures.

accounting community. We also explore ways in which the PIOT can be produced more cost-efficiently.

The organization of this paper is as follows. In sections 2-5, the monetary supply and use tables (MSUT), monetary input-output tables (MIOT), physical supply and use tables (PSUT) and physical input-output tables (PIOT) are introduced respectively. A “quick and dirty” PSUT for the Netherlands for 2006 is described in section 6. In section 7 the advantages and disadvantages of PIOTs are discussed. In the last section 8, suggestions are made for future work in this field.

2. Monetary supply and use tables (MSUT)

The production accounts of the National accounts provide an overview of production and consumption in an economy. This is usually done using monetary supply and use tables or monetary input-output tables. MSUTs are preferable from an accounting standpoint while a MIOT is required for input-output modelling. This work was of course pioneered by Nobel Prize winner Wassily Leontief (Leontief, 1936; 1941, 1966).

The ‘System of National Accounts’ (SNA) handbook recommends using MSUT rather than MIOT as the statistical basis for the production accounts of the National Accounts (UN, 1968, 1993, 2008). The reason is that MSUT are better suited to the source statistics because this statistical framework has an industry-by-commodity structure. An MSUT is also capable of registering multiple products for a single industry. On the other hand a MIOT has a symmetrical classifications structure which is not suited as well to the source data. Nevertheless, the symmetrical nature of the MIOT means that it is far more useful from a modelling perspective.

In this section, the MSUT is introduced while in the next section the MIOT is discussed. A monetary supply table is shown in Table 1. It records all goods and services that are produced by industries (matrix V').[6] Furthermore, the imports of goods and services are recorded in matrix N. The total supply of each commodity is recorded in *basic prices* and is equal to $V' \cdot i + N \cdot i$. The total supply in *purchaser prices* (q) is equal to the value in basic prices plus the product related taxes less subsidies and the trade and transport margins ($= V' \cdot i + N \cdot i + T \cdot i + M \cdot i$). The total value of the products made in each industry is recorded in vector g ($= V \cdot i$).

Table 2 shows a monetary use table which records the use of commodities (U) and primary inputs (K) by each industry, as well as the consumption of commodities by exports (X) and other final demand categories (Y). The monetary output value of commodities is recorded in vector q ($= U \cdot i + X \cdot i + Y \cdot i$), the total use of primary

[6] Capital letters denote matrices while lowercase letters refer to vectors. Bold font is used for physical variables throughout this report, while normal font indicates monetary values. Vector i denotes a summation vector.

inputs in vector k (= $K \cdot i$), while vector g (= $U' \cdot i + K' \cdot i$) denotes the total inputs required by each industry.

Table 1. A monetary supply table

	Industries	Imports	Product related taxes less subsidies	Trade and Transport margins	Total
Commodities	V'	N	T	M	q
Total	g'				

Table 2. A monetary use table

	Industries	Exports	Other final demand	Total
Commodities	U	X	Y	q
Primary inputs	K			k
Total	g'			

Of course, there is a balancing restriction. This means that commodity (q) and industry totals (g) have to be equal in both tables. The balance equations are provided in equations 1 and 2.

Commodity balance (euro)	$V'i + Ni = Ui + Xi + Yi = q$	(1)
Industry balance (euro)	$i'V' = i'U + i'K = g'$	(2)

MSUT are constructed using information from a variety of sources, such as production statistics, international trade statistics, labour statistics, investment statistics and budget surveys. In the construction process, the balancing restrictions force comparison and adjustment of the data. Expert opinions on the relative quality of the different data sources, as well as mathematical techniques are used to make these balancing adjustments.

3. Monetary input-output tables (MIOT)

MSUT are better for accounting purposes while MIOT are needed for modelling. So how is a MIOT produced? A simple answer to this question is provided in Figure 1. Basically, MSUT can be converted into a MIOT. The result is a table which is very similar to the use table except that it has a symmetrical structure (see Table 3). It can either have industry-by-industry or commodity-by-commodity dimensions.[7] Note that all variables have the same meaning as in the MSUT. One new variable, the intermediate input matrix *Z*, is introduced.

The MIOT is produced by making assumptions about the technological or sales structure of the economy, using additional statistical information or through mathematical procedures (see Almon, 2000). For more information on the production of MIOT from MSUT see Konijn (1994, 1995).

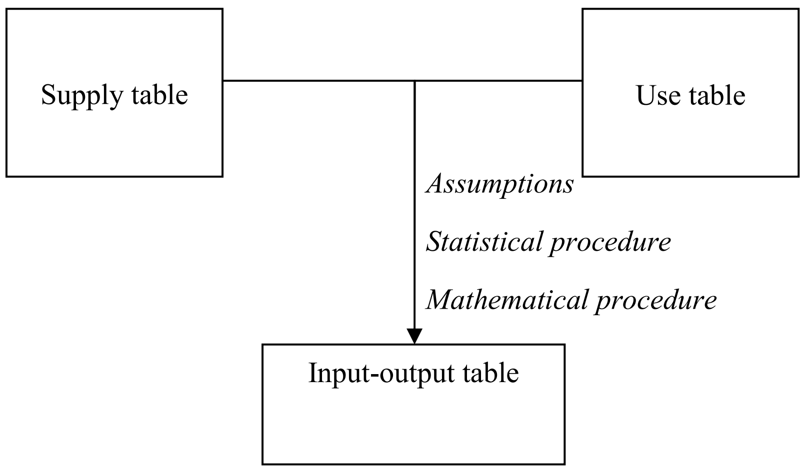

Figure 1. Producing input-output tables from supply and use tables

Table 3. A monetary input-output table

	Industries/ Commodities	Export	Other final demand	Total
Industries/ Commodities	Z	E	Y	q *or* g
Imports	N			n
Primary inputs	K			k
Total	g' *or* q'			

[7] It is beyond the scope of this paper to discuss the activity-by-activity input-output table which provides a MIOT which adheres best to input-output modelling assumptions (Konijn, 1994; 1995).

The balancing restrictions of the MIOT are very similar to those of the MSUT (see equations 3). The row and column totals can be either the industry (g) or commodity totals (q) depending on the type of input-output table which is produced.

Balance (euro)	$Zi + Ei + Yi = Z'i + N'i + K'i = q \quad or \quad g$	(3)

4. Physical supply and use tables (PSUT)

The MSUT and MIOT are in monetary values. However, the accounting system is valid for other units of measurement as well. This paper explores physical supply and use tables (PSUT) and physical input-output tables (PIOT) which are measured in mass units. This section deals with the former type of physical account.

The physical supply table records the physical outputs of industries. These include all physical commodities and residuals, whether they have economic value or not. Table 4 shows such a physical supply table. The total physical output of each commodity is given by vector $\boldsymbol{q}$ $(= \boldsymbol{V'}\cdot\boldsymbol{i} + \boldsymbol{N}\cdot\boldsymbol{i})$, while the total physical output of each industry is equal to vector $\boldsymbol{g}$ $(= \boldsymbol{V}\cdot\boldsymbol{i} + \boldsymbol{W}\cdot\boldsymbol{i} + \boldsymbol{E}\cdot\boldsymbol{i})$. The difference between the supply of residuals $\boldsymbol{w}$ $(= \boldsymbol{W'}\cdot\boldsymbol{i})$ and emissions to nature $\boldsymbol{e}$ $(= \boldsymbol{E'}\cdot\boldsymbol{i})$ is that the former type of waste by-products are supplied to or processed by other industries, while the latter are directly emitted to water, soil, air or landfills. Emissions to nature do not have a market price (although they may represent a social cost), while the residuals supplied usually have a price.

Table 4. A physical supply table

	Industries	Imports	Total
Commodities	$\boldsymbol{V'}$	$\boldsymbol{N}$	$\boldsymbol{q}$
Supply of residuals	$\boldsymbol{W'}$		$\boldsymbol{w}$
Emissions to nature	$\boldsymbol{E'}$		$\boldsymbol{e}$
Total	$\boldsymbol{g'}$		

The physical and monetary supply tables differ in a number of ways. The monetary matrix V' includes all transactions of goods and services in the economy. The physical industrial production matrix $\boldsymbol{V'}$ only records the output of physical commodities. This means that physical goods appear in both tables, while services, which are generally intangible, are only registered in the monetary table. Residuals can sometimes lead to costs, such as collection, landfilling and incineration charges. These costs are recorded as services in the monetary use tables. Eco-taxes, emission charges or permits could be recorded as primary inputs in the use table.

The physical use table records the physical inputs of commodities, residuals and natural resources, as shown in Table 5.[8] The physical output of each commodity is recorded in vector $\boldsymbol{q}$ (= $\boldsymbol{U{\cdot}i}$ + $\boldsymbol{E{\cdot}i}$ + $\boldsymbol{Y{\cdot}i}$), the use of residuals in vector $\boldsymbol{r}$ (= $\boldsymbol{R{\cdot}i}$), the use of natural resources in vector $\boldsymbol{d}$ (= $\boldsymbol{D{\cdot}i}$), while vector $\boldsymbol{g}$ (= $\boldsymbol{U'{\cdot}i}$ + $\boldsymbol{R'\,i}$ + $\boldsymbol{D'{\cdot}i}$) records the mass of physical inputs per industry.

Table 5. A physical use table

Physical use	Industries	Exports	Other final demand	Total
Commodities	$\boldsymbol{U}$	$\boldsymbol{X}$	$\boldsymbol{Y}$	$\boldsymbol{q}$
Use of residuals	$\boldsymbol{R}$			$\boldsymbol{r}$
Natural resources	$\boldsymbol{D}$			$\boldsymbol{d}$
Total	$\boldsymbol{g'}$			

The monetary and physical use tables differ in several ways. Similarly to the supply tables, the monetary use table contains information on all goods and services in matrices U and Y, while the physical use table only includes physical commodities in matrices $\boldsymbol{U}$ and $\boldsymbol{Y}$. Furthermore, the non-industrial inputs are different: primary inputs K in the monetary use table and natural resources $\boldsymbol{D}$ in the physical table. Industries require primary inputs, such as labor and capital goods depreciation, social charges and profits. None of these are recorded in the physical use table. On the other hand, natural resources are not recorded in monetary use tables, since these are supplied by nature. The tables record the use and supply of residuals, which are of course equal, $\boldsymbol{r} = \boldsymbol{w}$. The PSUT has very similar balancing restrictions when compared to the MSUT (compare equations 1 and 2 to equations 4 and 5).

Commodity balance (kg)	$\boldsymbol{V'i} + \boldsymbol{Ni} = \boldsymbol{Ui} + \boldsymbol{Xi} + \boldsymbol{Yi} = \boldsymbol{q}$	(4)
Industry balance (kg)	$\boldsymbol{i'V'} + \boldsymbol{i'W} + \boldsymbol{i'E} = \boldsymbol{i'U} + \boldsymbol{i'R} + \boldsymbol{i'D} = \boldsymbol{g'}$	(5)
Residual balance (kg)	$\boldsymbol{w} = \boldsymbol{r}$	(6)

[8] Stock changes are ignored in the supply and use tables in this section. The use and supply of residuals by final demand categories, as well as the use of natural resources by final demand, are also not included in the tables. The imports and exports are the only transboundary elements in the PSUTs presented here. Other flows such as transboundary flows in rivers are not discussed here.

5. Physical input-output tables (PIOT)

The PSUT are related to the PIOT in a very similar fashion as the relationship MSUT-MIOT which was described in paragraph 2. However, this section will not delve into the production of PIOT from PSUT. Rather, three types of PIOT are proposed. The following aspects have been omitted from the PIOT tables, so that the discussion is not complicated needlessly:

- The transboundary dimension, imports and exports, has been dropped.
- Final demand has been split into two: investment (I) and consumption (C).

Table 6. A physical input-output table: Type 1

	Intermediate demand	Final demand		Total
	Industries	Investment	Consumption	
Industries	$\boldsymbol{Z}$	$\boldsymbol{F}$	$\boldsymbol{C}$	$\boldsymbol{g}$
Natural resources	$\boldsymbol{D}$	$\boldsymbol{D_{inv}}$	$\boldsymbol{D_{cons}}$	$\boldsymbol{d}$
Use of residuals	$\boldsymbol{R}$	$\boldsymbol{R_{inv}}$	$\boldsymbol{R_{cons}}$	$\boldsymbol{r}$
Supply of residuals	$\boldsymbol{-W}$	$\boldsymbol{-W_{inv}}$	$\boldsymbol{-W_{cons}}$	$\boldsymbol{-w}$
Emission to nature	$\boldsymbol{-E}$	$\boldsymbol{-E_{inv}}$	$\boldsymbol{-E_{cons}}$	$\boldsymbol{-e}$
Stock changes	$\boldsymbol{-S}$	$\boldsymbol{-S_{inv}}$	$\boldsymbol{-S_{cons}}$	$\boldsymbol{-s}$
Total	$\boldsymbol{g'}$	$\boldsymbol{0}$	$\boldsymbol{0}$	$\boldsymbol{0}$

The simplest PIOT (Type 1) is shown in table 6. Note that the outputs of residuals, emissions and stock changes are recorded as negatives in the column. Since this is simply and accounting identity they could also have been recorded in the rows. Note that some matrices may have all zeros.

In a PIOT of Type 2, intermediate demand is split into two separate categories: structural demand and auxiliary demand. The difference lies in the function which the inputs have in the production process. In the case of structural inputs, the physical input is needed for the physical product. E.g. Steel plating is needed as a structural input in the production of a car. Auxiliary demand refers to physical input which is used for a different reasons than the physical structure. E.g. fossil fuels are material inputs which are usually used for their energetic content. Note that when fossil fuels are used for production of plastics, this is classified as structural demand.

Table 7. A physical input-output table: Type 2

	Intermediate demand		Final demand		Total
	Structural demand	Auxiliary demand	Investment	Consumption	
	Industries	Industries	Industries		
Industries	$\boldsymbol{Z_{str}}$	$\boldsymbol{Z_{aux}}$	$\boldsymbol{F}$	$\boldsymbol{C}$	$\boldsymbol{g}$
Natural resources	$\boldsymbol{D_{str}}$	$\boldsymbol{D_{aux}}$	$\boldsymbol{D_{inv}}$	$\boldsymbol{D_{cons}}$	$\boldsymbol{d}$
Use of residuals	$\boldsymbol{R_{str}}$	$\boldsymbol{R_{aux}}$	$\boldsymbol{R_{inv}}$	$\boldsymbol{R_{cons}}$	$\boldsymbol{r}$
Supply of residuals	$\boldsymbol{-W_{str}}$	$\boldsymbol{-W_{aux}}$	$\boldsymbol{-W_{inv}}$	$\boldsymbol{-W_{cons}}$	$\boldsymbol{-w}$
Emission to nature	$\boldsymbol{-E_{str}}$	$\boldsymbol{-E_{aux}}$	$\boldsymbol{-E_{inv}}$	$\boldsymbol{-E_{cons}}$	$\boldsymbol{-e}$
Stock changes	$\boldsymbol{-S_{str}}$	$\boldsymbol{-S_{aux}}$	$\boldsymbol{-S_{inv}}$	$\boldsymbol{-S_{cons}}$	$\boldsymbol{-s}$
Total	$\boldsymbol{g'}$	$\boldsymbol{0}$	$\boldsymbol{0}$	$\boldsymbol{0}$	$\boldsymbol{0}$

Table 8. A physical input-output table: Type 3

	Intermediate demand		Final demand		Total
	Structural demand	Auxiliary demand	Investment	Consumption	
	Industries	Industries	Industries		
Industries	$\boldsymbol{Z_{str}}$	$\boldsymbol{Z_{aux}}$	$\boldsymbol{F}$	$\boldsymbol{C}$	$\boldsymbol{g}$
Natural resources	$\boldsymbol{D_{str}}$	$\boldsymbol{D_{aux}}$	$\boldsymbol{D_{inv}}$	$\boldsymbol{D_{cons}}$	$\boldsymbol{d}$
Use of residuals	$\boldsymbol{R_{str}}$	$\boldsymbol{R_{aux}}$	$\boldsymbol{R_{inv}}$	$\boldsymbol{R_{cons}}$	$\boldsymbol{r}$
Supply of residuals	$\boldsymbol{-W_{str}}$	$\boldsymbol{-W_{aux}}$	$\boldsymbol{-W_{inv}}$	$\boldsymbol{-W_{cons}}$	$\boldsymbol{-w}$
Emission to nature	$\boldsymbol{-E_{str}}$	$\boldsymbol{-E_{aux}}$	$\boldsymbol{-E_{inv}}$	$\boldsymbol{-E_{cons}}$	$\boldsymbol{-e}$
Stock changes	$\boldsymbol{-S_{str}}$	$\boldsymbol{-S_{aux}}$	$\boldsymbol{-S_{inv}}$	$\boldsymbol{-S_{cons}}$	$\boldsymbol{-s}$
Total	$\boldsymbol{g'}$	$\boldsymbol{0}$	$\boldsymbol{0}$	$\boldsymbol{0}$	$\boldsymbol{0}$

Materials

All in all this means that there are 3 dimensions (structural demand, auxiliary demand and investment) to the physical balance of industries.

The most complete PIOT (Type 3) also distinguishes a third dimension of the physical balance: the underlying material types. For example, in PIOT-Type 2 the output of the car industries will be the mass of cars. A car is however made up of several materials (iron, plastics, word, rubber) which can be distinguished in PIOT-Type 3. Additional data on the content of products clearly have to be available to make this possible.

6. A tentative PSUT for the Netherlands 2006

As an illustration of physical accounting we have produced a tentative PSUT for the Netherlands for 2006. This is very much a "quick and dirty" effort to show what the numbers look like for a Western country. It is however also aimed at regaining in-house experience because Statistics Netherlands will probably start a physical accounts project in 2011.

Table 10 and 11 show the monetary supply and use table respectively for 2006. The economy has been split into four parts (Agriculture, mining, industry and services) which are relevant for material flows. Note that the monetary source data is available at 200 industries by about 800 commodities. As the tables shows the commodity and industry totals are equal.

Table 10. Monetary supply table for the Netherlands 2006 (1000 million euros)

		Industries				Imports	PRTLS TTM	Total
		Agr.	Min.	Ind.	Serv.			
Commodities	Agricultural. pr.	24	0	0	0	11	8	43
	Mining pr.	0	20	0	0	32	1	54
	Industrial pr.	1	0	326	15	238	112	692
	Services	1	0	35	600	73	-101	609
Total		25	21	362	615	354	21	1398

Table 11. Monetary use table for the Netherlands 2006 (1000 million euros)

		Industries				Final demand			Total
		Agr.	Min.	Ind.	Serv.	Cons.	Exp.	Inv.	
Commodities	Agricultural. pr.	4	0	14	2	6	18	0	43
	Mining pr.	0	2	37	0	0	14	0	54
	Industrial pr.	8	2	152	70	105	280	75	692
	Services	3	1	57	183	266	74	24	609
Value added		10	16	101	360	22	0	10	519
Total		25	21	362	615	391	397	106	1917

The Dutch system of environmental accounts is very elaborate which is why there is already a lot of source data which can be used for the PSUT. Tentative physical supply and use tables (Type 1) are presented in table 12 and 13 respectively. Note that the tables show only 4 industries and commodities, while the source data has about 50-60 industries and many subcategories of wastes, natural resources etc.

The imports and exports of goods are part of the MFA statistics produced by the department of environmental accounts. They are based on calculations on international trade data which includes physical units (and therefore prices per kilogram) (Delahaye and Nooteboom, 2008,2009). Furthermore, the extraction of natural resources for the MFA accounts are used for the physical amount of mined fossil fuels (particularly natural gas in the Netherlands). Other data is derived from the air emission accounts, waste accounts, energy accounts and the water accounts. The other components, for which physical data is not available, are estimated using the monetary values and appropriate prices from the import and export data.

The results show that there is a commodity totals do not match. This can be resolved by adjusting the data until the two commodity totals balance in a similar procedure as in the regular MSUT. The industry totals are far more worrisome than the commodity totals. This is to be expected because the columns of the supply and use tables represent transformative production processes in which several inputs may be converted into several outputs. Also categories such as water, which is often used in cooling, also have to be recorded consistently on the output side. These, and other problems such as biomass, will have to be resolved in future projects.

Table 12. Tentative physical supply table for the Netherlands 2006 (million tonnes)

		Industries				Imports	Cons.	Total
		Agr.	Min.	Ind.	Serv.			
Commodities	Agricultural. pr.	39	0	0	0	24		63
	Mining pr.	0	113	4	4	157		277
	Industrial pr.	0	0	218	6	144		368
	Services	0	0	0	1	0		1
Supply resid.	Waste	4	0	48	7	11	9	69
Emissions	Air emission	10	3	47	107	0	37	203
Total		53	115	317	124	337	46	981

Table 13. Tentative physical use table for the Netherlands 2006 (million tonnes)

		Industries				Final demand			Total
		Agr.	Min.	Ind.	Serv.	Cons.	Exp.	Inv.	
Commodities	Agricultural. pr.	2	0	30	1	6	16	0	56
	Mining pr.	2	8	210	11	1	80	0	312
	Industrial pr.	12	0	127	28	47	183	4	400
	Services	0	0	0	0	0	0	0	0
Use of resid.	Waste	1	0	53	12	0	13	0	67
Raw materials	Ores/fossil fuels		175						
	Water	208	5	3652	11179	729	0	0	15773
Total		226	189	4072	11230	784	293	4	16608

Despite the fact that the PSUT is not yet balanced the tables already show a number of differences in the physical and monetary economies. It clearly shows that services play a huge role in economy (output of service products is 47% of total output) while it barely represents an output of 1 million tonnes of products. Nevertheless, because of the auxiliary demand for energy (particularly in transport) and the processing of waste, the services sector does represent a large share of the air emissions.

As a test of the results the implicit prices have been calculated for the supply and use tables in Tables 14 and 15. In the process of reconciling the physical totals, this data can be used to check where corrections should be made. However, this should be done at a lower commodity level than is published here.

Table 14. Implicit prices in the supply table for the Netherlands 2006 (euro per kg)

		Industries				Imports	Total
		Agr.	Min.	Ind.	Serv.		
Commodities	Agricultural. pr.	0,6		6,9	23,0	0,5	0,7
	Mining pr.		0,2	0,0	0,0	0,2	0,2
	Industrial pr.	2,6	12,0	1,5	2,5	1,7	1,9
	Services	194,4	90,1	273,0	829,6	203,9	499,6

Table 15. Implicit prices in the use table for the Netherlands 2006 (euro per kg)

		Industries				Final demand			Total
		Agr.	Min.	Ind.	Serv.	Cons.	Exp.	Inv.	
Commodities	Agricultural. pr.	2,0		0,4	1,7	0,9	1,1	0,5	0,8
	Mining pr.	0,1	0,3	0,2	0,0	0,1	0,2	-0,3	0,2
	Industrial pr.	0,6	7,3	1,2	2,5	2,2	1,5	19,6	1,7
	Services	269	1989	840	814	9470	879	381	1268

Note: The negative price of mining products is of course an issue which needs to be resolved.

7. Advantages and disadvantages of physical accounts

So far, we have only discussed the structure of the PSUT and PIOT and the literature. But what are the advantages and of these types of accounts? There are three main advantages that can be identified:

1. Integration of physical data. The PSUT is the integration framework for all physical data from emission inventories, energy statistics, waste statistics, water statistics etc. It is not surprising that the System for Environmental and Economic Accounting (SEEA) uses the PSUT as a central account for integration. Similarly to the MSUT, these sources have to be reconciled because they have to adhere to the balancing restrictions. In the process of the confrontation of the data decisions will be made about the relative quality of the data sources, which should in principle lead to a better set of statistics. Note that as the PIOT become more complex (from Type 1 to 3) the number of balancing

restrictions increases as well as the knowledge required about the technological processes. Assuming that the necessary data is available, this means that Type 3 performs best in the integration of physical data.

2. Improvement of monetary statistics. The PSUT partly overlap with the products and residuals in the MSUT which have an economic value. When the two values are divided the result in a price per kilogram. This provides extra dimensions in the balancing process of the National accounts, which can lead to quality improvements. Sometimes the physical data may also simply be better. For example, at the Dutch National accounts, the energy commodities in the MSUT are estimated using the physical data augmented with price information.

3. Environmental-economic modelling. The above two advantages are of a statistical nature. However, one of the most important advantages is the use of the MIOT-PIOT as a data source for environmental economic modelling. Note that use of the PIOT for environmental economic modelling increases as the PIOT becomes more complex (from Type 1 to 3). Type 1 can be used to analyse the changes in the MFA aggregates. Type 2 makes a distinction of the use of the materials in structural demand, auxiliary demand and investments, thereby providing information about the uses of materials in the production process. Type 3 PIOTs make distinctions between the material types and thereby raise the prospect of analysing material substitution and technological changes (see also Hoekstra, 2005).

Of course these advantages come at a price. The data requirements and cost of producing PIOTs are large. As the PIOT becomes more complex, the data and cost also increases.

8. Conclusions and Recommendations

On the basis of our survey of the literature and physical accounting studies it can be concluded that the initial popularity of physical accounting in European countries has not lead to large scale production of these accounts. Modelling applications have appeared in the last decade or so, but apparently these have been insufficient to convince NSIs.

It is striking that an accounting system which provides an integral overview of physical flows and related environmental problems, and which can be coupled to economic data has not been adopted in environmental economics on a larger scale. Technological change, material substitution, shifts in consumption, trade aspects are all highly relevant aspects which could be tackled using PIOTs.

In general we conclude that in a cost-benefit analysis, the literature has not yet conclusively shown that the advantages are sufficient to justify the large investments required to produce a PIOT. In the remainder of this paper a number of directions are suggested which may help to make the PIOT more relevant to the statistical world and the world of environmental economists.

- Statistical world
    - Reduce production costs. One of the primary problems with the PSUT/PIOT is the large investment which is required. So far the PIOT which have been produced have been one-off, large-scale efforts. The field would benefit greatly if this production time could be reduced significantly. Two cost-saving strategies seem fruitful:
        - Mathematical techniques. It would fruitful to apply mathematical techniques in the production of PIOTs. The field of input-output and national accounts includes many RAS and optimisation models which can be easily applied to physical accounting.
        - International sharing of experiences. The production of physical accounts is a specialisation which not many institutes have experience in. Apart from the methodology there may also be opportunities to share data on generic aspects such as standard production technologies or product compositions.
    - Advantage for monetary accounts. Often a satellite account is viewed as a system which is stuck onto the core monetary accounts of the SNA. The latter is considered to be the dominant account to which the satellite has to adhere. In reality, however, it is often found that satellite accounts can help improve the monetary values. This is particularly true for a PSUT which provides a different, but equal, dimension of the flows of goods in the MSUT. The introduction of the physical dimension in monetary accounts has a number of positive spin-offs. Firstly, the number of balancing dimension increases. Secondly, more technological knowledge will have to be used in the used in the confrontation of the data. Finally, the availability of physical data may simply be better.
- Environmental Economists
    - IO models
        - Historical PIOTs. Changes in material use patterns happen over the long term. Material substitution, efficiency or other technological changes take a very long time to materialize. To capture meaningful effects from the PIOTs a long time horizon is required. Annual PIOTs over shorter time periods are less relevant in such a setting.
        - PIOT-Type 2 and 3. So far PIOT-type 1 dominates in the literature. These are the most cost-efficient and the least data intensive. These type of tables allow for analyses which are consistent to MFA assumption that the mass of various products can be aggregated into a meaningful

macro-economic sustainability indicator. However, for researchers that do not subscribe to this point of view, the PIOT-Type 1, provides fairly little analysis possibilities which could not be achieved using a MIOT combined with environmental accounts. Although the PIOT-Type 2 and 3 are more data intensive and costly they do provide the promise of in depth analysis of substitution patterns and technological changes.

- Other models.
    - The PIOT framework is discussed and developed only by input-output researchers and national accountants. Broadening the set of application beyond input-output modelling (for example CGE models) could help to increase the appeal of this accounting framework.

We conclude that PIOT modelling will have to come up with applications which visibly justify the costs which are involved in the production of physical accounts. There will have to be a sharper focus on the potential advantages of the PIOTs as well as research into more cost-efficient production of these costly frameworks.

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