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Waste Accounting within an Input-Output Framework: Strengths and Weaknesses

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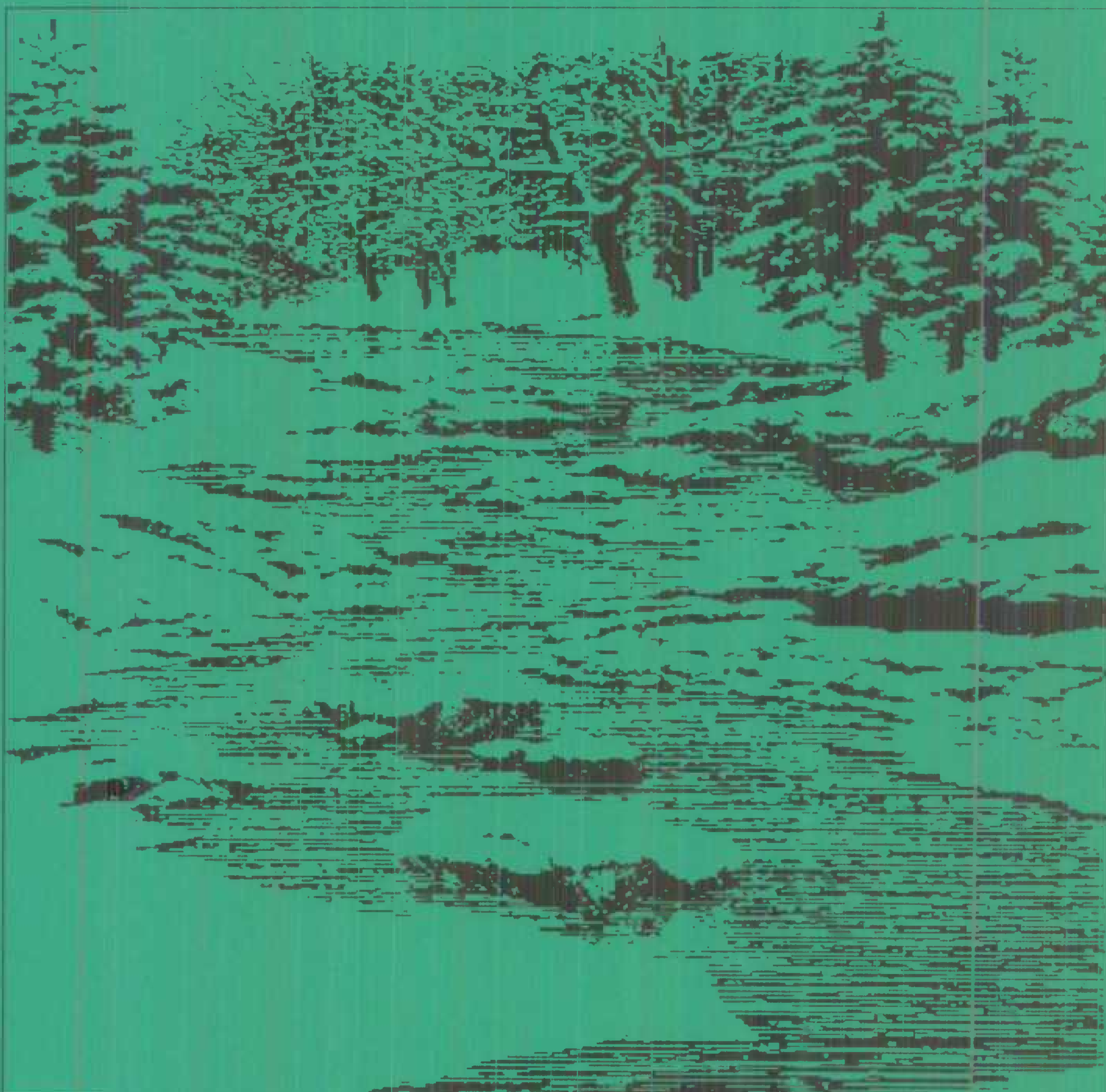

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Waste Accounting within an Input-Output Framework: Strengths and Weaknesses[1]

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1. This paper was presented at the second meeting of the 'London Group' on environmental accounting held at the United States Bureau of Economic Analysis, Washington, D.C., March 15 - 17, 1995.
2. The author has benefited greatly from discussions with Cynthia Baumgarten, Gerry Gravel and Philip Smith of National Accounts and Environment Division, Statistics Canada, and Tony Johnson of the Australian Bureau of Statistics. Any errors that remain in spite of their insight are his alone.

Introduction

Statistics Canada is currently developing a set of accounts that will form an environmental component of the Canadian System of National Accounts. Four accounts will comprise this component: a natural resource stock account, a natural resource use account, an environmental expenditure account, and a waste account.[1]

Focusing on concepts rather than results, this paper presents and discusses the input-output framework that forms the basis for the waste account that is currently under development at Statistics Canada. The paper begins with a brief discussion of the general characteristics of waste accounts. This is followed in Section 2 by an overview of Statistics Canada's standard input-output accounting framework. The modifications to this framework necessary to incorporate waste flows are detailed in Section 3. The fourth section is devoted to a discussion of the ways in which waste statistics and economic data can be integrated within the input-output framework. The paper concludes with a discussion of the strengths and weaknesses of the framework and some indications of future work.

1 Waste Accounts: Consistent and Comprehensive Data

A number of sources of waste data exist in Canada. These include governmental sources such as published waste inventories, unpublished results from regulatory monitoring programs, and research studies. University and consulting firm studies, corporate reports from environmentally progressive companies, and environmental organisations are also useful sources of waste data.

Generally speaking, the data available from these sources share the following characteristics:

- the data represent only a sub-set of all waste production; this can mean that they do not cover all sectors of the economy, that they represent only certain regions of the country, that they focus only on a specific range of wastes, or any combination of these;
- in most cases the data are not published regularly;
- the data are not usually compatible with one another, either because different classifications have been used to report them, or because different methodologies have been used to collect the same set of data in different time periods;
- the data lack any integration with economic statistics.

The above is not meant as a criticism of basic waste data or of the agencies that collect them. There are very good reasons why such data have the characteristics they do, as each agency has a different need to fulfill with the data it collects. The point is simply that no consistent and comprehensive accounting of waste production in Canada exists. More importantly, no accounting of waste production exists within a framework that relates waste production to the economic activity that is its cause. The principle purpose of Statistics Canada's waste account is to provide this missing context by creating a consistent and comprehensive account of waste data cast within the framework of the Canadian System of National Accounts (CSNA). The linkage of these two data

1. Smith (1994) provides an overview of this project.

sets, one environmental and the other economic, within the well-established framework of the CSNA represents a powerful analytical tool for understanding the relationship between economic activity and waste production.

Key concepts

Before moving further, some key concepts are defined to prevent confusion later in the paper.

> **Waste** is any material that is unwanted by its producer and is disposed of, either directly to the environment, or through another economic agent without, or with only nominal, remuneration to the producer.

By this definition a material need only be unwanted by the producer for it to be waste, even though it may serve a purpose to some other agent in the economy. Empty aluminum beverage cans are thus considered waste, because recycling companies collect them for conversion back into raw aluminum but do not pay the beverage consumers for the cans. Likewise, even though a nominal price is usually paid for scrap automobiles, these are considered wastes here as well.

The definition of waste given above encompasses *all* unwanted materials, be they gaseous, liquid or solid. This is in contrast to the more common use of the term to mean only solid waste; other types of waste are usually referred to by other terms. Airborne wastes, for example, are commonly referred to as 'emissions' and water borne wastes as 'effluents'. The use of different terms to refer to what is conceptually the same thing is unnecessarily confusing, particularly for the non-professional user of waste statistics. Thus, the broader definition of 'waste' as all unwanted material has been chosen for its greater clarity.

It should be noted that waste, as defined here, corresponds to the use of the term 'residual' in the United Nations System of Integrated Environmental and Economic Accounting (SEEA) (United Nations, 1993; 85). The decision to use 'waste' in favour of 'residual' in Statistics Canada's waste accounting work is based on the belief that the former is intuitively clearer than the latter for most Canadian users of environmental statistics.

For the purposes of this paper, the **economy** is defined broadly as:

> the collection of production and consumption activities that occur within a nation's boundaries, including activities that occur outside of the marketplace.

This broadening of the economy to include extra-market activity is necessary because, as will be seen, waste production is related to more than just production and consumption activity as usually defined in the national accounts.

From the perspective of the national accountant, a **waste account** can be defined as:

> an organised data set describing the production and disposition of wastes within a framework that allows their integration with the economic data held in System of National Accounts.

Regardless of how the integration of waste data with the national accounts is effected, there are certain characteristics that a comprehensive waste account should possess.

- The account should be structured in such a way that it is suitable for recording *all* waste production, regardless of source, destination or relationship to economic activity.

- The account should record both the production of waste and its subsequent disposition to the environment, to other economic agents (domestic and foreign) and to waste inventories.[2] In doing so, the traditional accounting identity between production and disposition should be respected.
- All sectors of the economy should be covered in the account. The definitions of these sectors should adhere to the national accounts' definitions.[3]
- The account should allow the integration of waste data with the economic statistics held in the national economic accounts, with the aim of developing measures of the relationship between economic activity and waste production.
- As a minimum, the account should measure waste flows at the national level. Regional waste accounts are useful as well, if there exist regional economic accounts with which to link them.
- The account should be compiled on an on-going basis, using a frequency that is compatible with the national accounts to which it is linked.

Within the framework of the Canadian System of National Accounts, the Input-Output Accounts represent the most sensible choice of framework for compiling a waste account with the above characteristics. This is so for several reasons. The input-output framework is the most detailed representation of the economy available. It describes all sectors of the economy, including the foreign sector, within an integrated, well-established framework. Highly detailed input-output accounts based on the framework are produced annually by Statistics Canada in current and constant dollars.[4] And, as will be seen in Section 4, derivation of a number of interesting measures of the relationship between waste production and economic activity is possible within the input-output framework.

Having defined some key concepts and discussed in general terms what a waste account is and why one is useful, the paper turns to a brief overview of the standard input-output accounting framework used by Statistics Canada, followed by presentation of the modifications necessary to turn it into the waste accounting framework proposed by Statistics Canada.

2 Statistics Canada's Input-Output Accounting Framework

Statistics Canada's input-output accounting framework (Table 1) uses industry-by-commodity, or rectangular, input-output matrices. Unlike the industry-by-industry input-output framework used by many countries, industries in the Canadian framework may produce more than one output. The number of commodities represented in the framework therefore exceeds the number of industries, giving the matrices their rectangular shape.

2. Waste inventories are agglomerations of materials that result from the disposal of waste from economic activity: landfill sites, mine-tailing piles, spent nuclear fuel rod stores and warehoused toxic wastes are all examples.
3. This is not to say that waste data must never be aggregated according to a sectoring of the economy other than that of the national accounts. However, the most important linkage of waste account data is with the national accounts and, therefore, the basic structure of the waste account must always be compatible with them first.
4. Over 600 commodities, 200 industries and 130 categories of final expenditure are represented in the accounts at their most detailed level.

Statistics Canada has produced input-output matrices in current and constant dollars on a yearly basis since 1961. Three different levels of aggregation are maintained. At the most detailed level they include data on the production and consumption of 627 commodities by 216 industries and 136 categories of final demand. Many data at this detailed level are not publicly available due to the need to protect confidential business information. Thus, two higher levels of aggregation (100 commodities, 50 industries, 28 final demand categories; 49 commodities, 16 industries and 14 final demand categories) are also produced. The input-output data regularly published by Statistics Canada are released at the second (medium) level of aggregation.

Using input-output data arranged according to Table 1, it is possible to define a basic *model* that specifies industrial production in terms of final demand for commodities and some simple input-output relationships.

Derivation of the basic input-output model first requires specification of the base period[5] relationship between the commodity inputs used by a given industry and the commodities marketed by that industry. In the Statistics Canada model it is assumed (as is commonly the case in input-output modelling) that the value of each commodity purchased as an input by a given industry is fixed in linear proportion to the total value of that industry's output. This assumption can be stated in matrix form as follows:

$$\bar{U} = Bg \qquad \text{Eq. 1}$$

where matrix $\bar{U}$ is the column summation of matrix U[6] from Table 1, vector g is as defined in Table 1 and:

> matrix B is an (m x n) matrix in which an element, b_{ij}, is defined to represent the quantity of commodity i used per unit of total output of industry j in the base year. Elements in this matrix are referred to as technical coefficients and are calculated as in Eq. 2.

$$b_{ij} = \frac{u_{ij}}{g_j} \qquad \text{Eq. 2}$$

Second, it is necessary to define the relationship between the total industrial production of a given commodity and the share of the market for this product held by each industry. In the basic model it is assumed that each industry preserves the market shares that it held in the base year. This assumption has the following matrix form:

$$g = Dq \qquad \text{Eq. 3}$$

where vectors g and q are as defined above in Table 1, and:

> matrix D is an (n x m) matrix in which an element, d_{ji}, is defined to represent the base year share of the total marketed output of commodity i held by industry j. Elements in this matrix, referred to as market share coefficients, are calculated as in Eq. 4.

$$d_{ji} = \frac{v_{ji}}{q_j} \qquad \text{Eq. 4}$$

5. The base period in an input-output model is the period for which the input-output relationships are specified.
6. A horizontal bar above a matrix is used throughout this paper to represent the column summation of that matrix.

Table 1

Statistics Canada's Input-Output Accounting Framework

	Commodities 1,...,m	Industries 1,...,n	Final Demand (*F*) 1,...,f									Total
Commodities 1,...,m		*U*	*PE* 1,...,p	*FCF* 1,...,c	*vpcw*	*vpca*	*GGCE* 1,...,g	x_d	x_r	less *m*	less *gr*	*q*
Primary inputs 1,...,m*		*YI*	*YF*									*e*
Industries 1,...,n	*M*											*g*
Total	*q´*	*g´*	*e*									

Notes:

Capital letters indicate matrices and small letters indicate vectors or scalars.

matrix *M* (make matrix) - an (n x m) matrix in which an element, m_{ji}, represents the value of the production of commodity *i* by industry *j* in the accounting period

matrix *U* (use matrix) - an (m x n) matrix in which an element, u_{ij}, represents the value of the use of commodity *i* by industry *j* in the accounting period

matrix *YI* - an (m* x n) matrix in which an element, yi_{ij}, represents the use of primary input *i* by industry *j* in the accounting period

matrix *YF* - an (m* x f) matrix in which an element, yi_{ij}, represents the use of primary input *i* by final demand category *j* in the accounting period

matrix *F* (final demand matrix) - an (m x f) matrix in which an element, f_{ij}, represents the value of purchases of commodity *i* by final demand sector *j*; the final demand matrix comprises the following consumption categories:

- matrix *PE* - personal sector expenditures
- matrix *FCF* - expenditures on fixed capital formation
- vector *vpcw* - withdrawals of inventoried goods
- vector *vpca* - additions to inventoried goods
- matrix *GGCE*- gross government current expenditures
- vector x_d - domestic exports
- vector x_r - re-exports of previously imported goods
- vector *m* - imports
- vector *gr* - revenues from government sales of goods and services

vector *q* - an (m x 1) vector in which an element, q_i, represents the value of the total use of commodity *i* by industries and final demand sectors; elements in this vector are formed from the row sums of matrices *U* and *F*

vector *q´* - a (1 x m) vector formed from the transpose of vector *q*

vector *g* - an (n x 1) vector in which an element, g_j, represents the value of the total production of industry *j* in the base year; elements in this vector are formed from the row sums of matrix *M*

vector *g´* is a (1 x n) vector formed from the transpose of vector *g*

scalar *e* - gross domestic product at market prices for the whole economy

One final element is required before the full input-output model can be derived - an accounting expression of the balance between the total annual supply of commodities (from domestic industrial production, imports, withdrawals from inventories and government production) and the annual consumption of these commodities by industries and the various categories of final demand. This is represented in Eq. 5.

$$q + m + vpcw + gr = \bar{U} + \overline{PE} + \overline{FCF} + vpca + \overline{GGCE} + x_d + x_r \quad \text{Eq. 5}$$

The left-hand-side of Eq. 5 represents the supply of commodities from domestic production (*q*), imports (*m*), withdrawals from inventories (*vpcw*) and government production (*gr*). The right-hand-side represents the consumption of commodities by industries ($\bar{U}$), persons (*PE*), capital formation (*FCF*), additions to inventories (*vpca*), governments (*GGCE*), and as exports ($x_d + x_r$).

The basic input-output model can now be derived in two steps. Substitution first for $\bar{U}$ in Eq. 5 from Eq. 1 yields:

$$q = Bg + \tilde{f} + x_D + x_R - m - vpcw - gr \qquad \text{Eq. 6}$$

$$\text{where} \quad \tilde{f} = \overline{PE} + \overline{FCF} + vpca + \overline{GGCE} \qquad \text{Eq. 7}$$

Next, substitution for *q* from Eq. 3 into Eq. 6 yields Eq. 8, which upon rearrangement yields the desired input-output model (Eq. 10).

$$Dq = g = DBg + D\left(\tilde{f} + x_d + x_r - m - vpcw - gr\right) \qquad \text{Eq. 8}$$

$$g(I - DB) = D\left(\tilde{f} + x_d + x_r - m - vpcw - gr\right) \qquad \text{Eq. 9}$$

$$g = (I - DB)^{-1}D\left(\tilde{f} + x_d + x_r - m - vpcw - gr\right) \qquad \text{Eq. 10}$$

The input-output model in Eq. 10 specifies industry output (vector *g*) in terms of the market share and technical coefficient matrices (*D* and *B* respectively) and the various elements of final demand. Matrices *D* and *B* are both easily derived from base year economic data organised according to the accounting framework presented in Table 1. Once these coefficient matrices are known, Eq. 10 can be used to estimate the value of the total output required from each industry to meet any specified final demand for commodities, net of imports, government production and withdrawals from inventories. If the final demand matrix supplied to the model is the one that prevailed during the base year for which *D* and *B* have been derived, then the model will reproduce exactly the vector of industrial output that obtained in the base year. If some other final demand vector is supplied to the model, say an estimate of final demand for some future year, then the model will estimate the industrial output necessary to meet the estimated future demand for commodities given the assumption of fixed technical coefficients (matrix *B*) and market shares (matrix *D*).

3 Waste in the Input-Output Framework

Researchers have been suggesting the use of input-output techniques for environment-economy analysis since the late 1960s. Several economists at that time recognised that the basic input-output framework could be extended beyond monetary flows within the economy to include physical flows of materials - including wastes - between the economy and the environment (Cumberland, 1966; Daly, 1968; Isard, 1969; Ayres and Kneese, 1969; Leontief, 1970 and Victor, 1972). It is the work of one of these authors (Victor, 1972) that forms the basis for the input-output-based waste account that is presented in this paper.

Although interest in the use of input-output techniques for environmental analysis waned somewhat following the burst of research in the 1960s, some economists continued to publish in the field (Anderson and Manning, 1983; Ayres, 1978; Johnson and Bennett, 1981; Murck et al., 1985). With the re-emergence of environmental issues on the international agenda in the mid 1980s, and the emphasis placed on economy/environment linkages by the Brundtland Commission (World Commission on Environment and Development, 1987), interest in the use of input-output techniques for environmental analysis has once again grown (Baines and Peet, 1991; Proops et al., 1993). According to a recent survey of environmental accounting by EuroStat (Hahn, 1995), at least four nations have explicitly adopted the input-output framework for use in the development of their environmental accounts (Denmark, Germany, Finland and Canada). As well, the National Accounting Matrix including Environmental Accounts (NAMEA) developed by the Netherlands Central Bureau of Statistics is at least partly based on an input-output framework (de Haan et al., 1994). The UN SEEA also notes that 'a wide variety of environment-related input-output analyses can be conceived', including the 'analysis of physical flows of raw materials, produced goods and [wastes]' (United Nations, 1993; 144).

In this section the details of the input-output-based waste accounting framework proposed by Statistics Canada are presented and discussed, beginning with the units of measure to be used in the account.

3.1 Units of measure

Two types of measurement units can be employed in the waste account: a standard physical unit of some kind (the kilogram, for example), or a hybrid measurement unit designed specifically for reporting waste flows.[7]

Of the two, physical units are certainly the easiest to apply. A physical unit can be found to measure any waste flow, and it is often, although not always, possible to measure different waste flows using the same unit of measure. A basic physical unit such as the kilogram or cubic metre can be used to measure a wide range of wastes. Some wastes cannot be measured easily using weight or volume units however. Although scrapped cars are made up of steel, plastic, fabric, rubber and a variety of other materials, it may be difficult to measure the exact quantities of each of these materials in a scrap car. In such cases, it might be necessary simply to record the number of items scrapped.[8]

Hybrid measurement units are an interesting possibility for recording waste flows. These allow different wastes to be recorded on a comparable basis by taking advantage of similarities between the wastes in terms of environmental effects. In their NAMEA, the Netherlands Central Bureau of Statistics use hybrid units to compile statistics according to 'environmental themes' such as the greenhouse effect, ozone depletion and acidification (de Haan, et al., 1994). Global warming potential provides an interesting example of a hybrid waste measurement unit.

The relative contribution of different gases to global warming is known from scientific studies. Scientists have developed the concept of global warming potential (GWP) to represent these contributions. Carbon dioxide is arbitrarily assigned a GWP of 1 and the other greenhouse gases are assigned values proportional to their contribution to global warming relative to that of carbon dioxide (Houghton *et al.*, 1990). Thus, GWP represents a hybrid unit of measure for greenhouse gas emissions.

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7. Some might argue that prices represent a third possibility. For example, the cost of the environmental and economic damage likely to result from global warming could be used as a basis for estimating the per-unit cost (price) of carbon dioxide emissions. This cost could be then be introduced into the market by a tax system forcing producers to pay for each unit of carbon dioxide they produce. In principle, the same method could be used to estimate a cost for each and every waste produced in the economy. Suffice it to say that the practical difficulties involved in such an undertaking are enough to preclude the use of prices to measure waste flows. Furthermore, the estimation of prices for every waste in the economy demands a parallel re-estimation of the prices for all economic goods as well, as the internalisation of previously external waste costs would create substantial shifts in the relative prices of all goods produced in the economy. Thus, the waste prices (if they could be calculated) would not be comparable with the actual prices of produced goods used to measure production and consumption in the input-output accounts.
8. An alternative method would be to estimate the waste content of an item using information on the composition of an 'average' unit. For example, the average material composition of automobiles could be estimated from data on a representative sample of cars. This average composition could then used to estimate the waste flows associated with scrapped cars without having to know the material content of each and every car sent to the junkyard.

Obviously, the same unit of measure cannot be used to record all wastes. It is very important though that the same unit be used to measure all flows of a *given* waste. Without this minimum level of consistency, the waste account cannot be used to assess the relative contributions of various producers of a given waste, either within a period or over time.

3.2 Wastes in the input-output framework

Table 2 shows the standard input-output framework (Table 1) transformed into the waste accounting framework proposed by Statistics Canada. Any new matrices required to represent waste flows are shown in shaded cells. Where dashed lines have been used to divide cells, this represents the partitioning of the production or consumption space from Table 1 as necessary to accommodate these new flows.

The most fundamental change to the standard framework is expansion of the commodity matrix to include wastes. This has been accomplished through the division of the commodity row- and column-space from Table 1 into the two portions seen in Table 2. In one of these is presented just the same commodity classification that was used in the standard framework. The other (shaded) portion represents a classification of 'k' waste types for which data may be recorded in the waste account.[9]

Households and governments in the waste account

Several modifications to the standard framework are necessary to allow the production and disposition of wastes to be recorded. The most significant of these modifications from a conceptual point of view is the treatment of the household and government sectors. In standard input-output accounts, these two sectors are seen exclusively as consumers of goods and services.[10] From a waste accounting perspective, however, this is an incomplete conception. It disregards the fact that large quantities of waste materials result from the consumption activities of both households and governments. Thus, the accounting framework must be modified to allow the inclusion of these sectors in the production portion of the account.[11] To allow this, two new partitions have been added to the production space in Table 2, one in which the waste production associated with the personal sector can be recorded and another where waste production of the government sector may be shown. New matrices have been defined to represent the waste production associated with these sectors:

> matrix W^{hs} is a (p x k) matrix of waste production by the household sector, in which an element, w_{ij}^{hs}, represents the quantity of waste type *j* produced by household sector consumption activity *i* in the accounting period;

and

9. Since this paper is concerned with the general concepts of waste accounting rather than with the specific details of an actual waste account, no classification of wastes is presented here. Conceptually speaking, a waste classification should cover the entire range of wastes that are produced in an economy. In practice, the degree of detail of the waste classification will be determined in large part by the data available to the accountant.
10. This is not strictly true. Allowance is made in the standard (and waste accounting) framework for government sector revenue from the production and sale of goods and services that compete directly with commodities offered for sale by the business sector (this is represented by vector *gr* in tables 1 and 2). In practice, this production is very small and it is ignored in the text for the sake of simplicity.
11. Note that it is only wastes that the government and personal sectors are allowed to produce. As in the standard framework, they are not seen to produce goods and services for sale on the open market (aside from the small amount of government sector production that is represented by vector *gr*).

Table 2

Waste Accounting Framework

		Commodities 1,...,m	Wastes 1,...,k	Industries 1,...,n		Final Demand (F) 1,...,f									Waste sinks		Total	
				Non-waste management industries 1,...,(n-c)	Waste management industries (n-c)+1,...,n										Environment 1,...,z	Inventories 1,...,v	Commodity disposition	Gross waste disposition
Commodities 1,...,m				U		PE 1,...,p	FCF 1,...,h	vpcw	vpca	GGCE 1,...,g	x_d	x_r	less m	less gr			q	
Wastes 1,...,k					U_{wm}						x^w_d		less m^w		E	V		w
Primary inputs 1,...,m'				YF		YI											e	
Industries 1,...,n	Non-waste management industries 1,...,(n-c)	M	W^{bs}_{nwm}														g	
	Waste menegement industries (n-c)+1,...,n		W^{bs}_{wm}															
Household sector 1,...,p			W^{hs}															
Government sector 1,...,g			W^{gs}															
Waste sources not related to current economic activity 1,...,s			W^s															
Total	Commodity production	q´		g´		e												
	Gross waste sources		w´															

matrix W^{gs} is a (g x k) matrix of waste production by the government sector, in which an element, w_{ij}^{gs}, represents the quantity of waste type *j* produced by government sector consumption activity *i* in the accounting period.

The same classifications of 'p' household sector and 'g' government sector activities used in the final demand portion of the account are used in the waste production portion. This is done so that waste production by these sectors may be easily linked with economic data relating to their consumption activity. Wastes associated with burning gasoline, for example, would be recorded in the W^{hs} matrix in a row labelled 'motor fuels and lubricants' corresponding to the household sector consumption category of the same name.

Waste sinks

Another addition to the framework is the column labelled 'waste sinks'. A waste sink is any repository in which waste is discarded for long-term storage or assimilation. The most important waste sink is, of course, the environment. Although it is difficult to define the environment in strict physical terms, a useful definition can be proposed by thinking of the environment in terms of its role as a sink.

Waste that is disposed of in such a way that it is not maintained under active human control is said to have been disposed of in the **environment**.

This broad definition of the environment includes any area where wastes are discarded and left entirely subject to natural processes without further human intervention. The atmosphere, bodies of water, and most of the planet's surface are all part of the environment by this definition. Excluded from the environment are only those areas where wastes are managed on an on-going basis, such as modern sanitary landfill sites, nuclear fuel storage sites and toxic waste warehouses. The environment is represented as comprising 'z' sub-categories in Table 2. These might be as simple as 'air, land and water', or they might represent some more detailed classification of the environment based on ecozones, watersheds or another spatial unit.

Waste disposition into the environment from the economy is represented in Table 2 by:

matrix *E*, a (k x z) matrix of waste disposition to the environment, in which an element, e_{ij}, represents the quantity of waste type *i* emitted into environmental sink *j* from economic activities in the accounting period.

The other group of sinks represented in Table 2 is that of waste inventories. As defined above (Footnote 2), waste inventories are agglomerations of materials that result from the disposal of waste from economic activity. Disposition into 'v' waste inventories is represented in the framework by:

matrix *V*, a (k x v) matrix of waste disposition in inventories, in which an element, v_{ij}, represents the quantity of waste type *i* placed in inventory *j* in the accounting period.

Waste imports and exports

Since domestic wastes may be shipped abroad for disposal, and vice versa, waste imports and exports must be included in the accounting framework. Otherwise the balance between supply and disposition of wastes is not respected. These flows are represented by:

vector x_d^w, a (k x 1) vector of waste exports from the domestic economy to the rest-of-the-world, in which an element, $x_{d_i}^w$, represents the quantity of waste type i exported to the rest-of-the-world in the accounting period;

and

vector m^w, a (k x 1) vector of waste imports from the rest-of-the-world to the domestic economy, in which an element, m_i^w, represents the quantity of waste type i imported from the rest-of-the-world in the accounting period.

Business sector wastes

There is no difficulty accounting for the waste production of most industries, as nearly all of them behave only as waste producers. However, a few industries, collectively referred to here as the waste management industries, are both producers and consumers of wastes. The accounting for these industries is slightly more complicated. Before discussing it, the relatively simple treatment of the non-waste management industries can be quickly described.

The industry output space from Table 1 has been partitioned into two sections in Table 2, one in which to record the waste flows of the waste management industries and the other for the waste production of the non-waste management industries.[12] The waste production of the latter group is represented in the accounting framework by:

matrix W_{nwm}^{bs}, an (n-c x k)[13] matrix of waste production by the non-waste management industries, in which an element, $W_{nwm_{ij}}^{bs}$, is defined to represent the production of waste type j by non-waste management industry i in the accounting period.

The waste management (WM) industries are defined as those enterprises that collect, treat, dispose and/or recycle wastes produced by other economic agents. In carrying out these activities, the WM industries act as both producers and consumers of wastes. They are, in fact, the only economic agents that behave in this manner; all other economic agents produce waste but none other also consumes it. Two WM industries are defined in the accounting framework: one industry devoted to pre-disposal waste treatment and the other to recycling wastes into new commodities. These are referred to below as the treatment industry and the recycling industry respectively.[14]

The WM industries use wastes as inputs into their production activities. Waste is said to have been 'used' only if its physical/chemical form has been changed by the activity of a WM industry. By this definition, waste is not considered to be used if the WM industry simply collects it from the producer and deposits it directly in a waste sink (most likely a landfill site) without any intermediate processing. To avoid double counting, waste managed in this way is not recorded as waste use by the WM industries. Instead, it is recorded as though disposed of directly by its producer with

12. It is only the *waste flows* of the two groups of industries that are treated separately in the waste accounting framework. Their economic activity continues to be treated integrally in matrices M and U.
13. There are 'n' industries in total in the framework, of which 'c' are defined as being waste management industries. Therefore, there are n-c non-waste management industries.
14. It is recognised that some WM companies will carry out both of these functions. This problem of classification, which the statistician faces with respect to all industries, is ignored here for the sake of simplicity.

no intermediation by the WM industries.[15] This is in contrast to the suggestion in the UN SEEA that it is 'adequate...in physical accounts' to double count wastes that are collected by the WM industry for direct disposal (United Nations, 1993; 87).

The WM industries also produce wastes as a result of their activities. These wastes can be of three types. There is that created by the treatment industry when it processes wastes from other producers into less harmful forms. The second type is the residual material left over from the processing of wastes into new commodities by the recycling industry. The final type, which can be produced by either of the WM industries, is waste that is materially independent of the waste collected for treatment/recycling/disposal. A good example of this third waste type is the exhaust gas produced by the trucks used in the collection of wastes by the recycling industry.

The consumption and production of wastes by the WM industries are represented in the accounting framework as follows:

> matrix U_{wm} is an (k x c) matrix of waste consumption by the WM industries, in which an element, $u_{wm_{ij}}$, is defined to represent the consumption of waste type i by WM industry j in the accounting period;

and

> matrix W_{wm}^{bs} is a (c x k) matrix of gross waste production by the WM industries, in which an element, $w_{wm_{ij}}^{bs}$, is defined to represent the gross production of waste type j by WM industry i in the accounting period.

Gross versus net waste production

Total waste production in the economy is represented in the accounting framework on a gross basis:

> vector w' is a (1 x k) vector of gross total waste production, in which an element, w'_j, represents the gross production of waste type j produced from all economic activity in the accounting period.

Vector w' is *gross* of the waste consumption of the WM industries. Subtracting this consumption from gross production yields net waste production. The difference between gross and net waste production is the waste that is prevented from leaving the domestic economy as a result of the activities of the WM industries. Net waste production can be calculated as $w' - \overline{U_{wm}}'$.

15. This treatment is analogous to that of the retail trade industry in the standard input-output accounts. Retail trade companies purchase two types of commodities: those commodities that they require in order to run their businesses (supplies, trucks, display space, etc.) and those commodities that they resell to consumers. Only the first type is shown in the input vector for the retail trade industry. Because commodities of the second type are not consumed by retail industry itself, they are not recorded in its input vector. Rather, only the original production of these commodities and their subsequent purchase by final consumers is recorded in the input-output accounts, as though consumers dealt directly with producers. The accounting is done in this way to avoid double counting the production of the retailed goods, once for the original producer and again for the retail trade industry.

Waste disposition routes

An important dimension of waste production is the route by which producers dispose of their wastes. Five possibilities exist: disposal by the producer directly to the environment (env); disposal by the producer directly into a waste inventory (inv); disposal through the treatment industry (treat); disposal through the recycling industry (recycle); and, finally, disposal by exportation to another country (exp). All waste must be discarded through one these routes.

Waste disposal route is captured in the account by adding a third dimension to the waste production matrices.[16] Each slice in this third dimension represents one of the possible disposal routes. Total waste production is recorded in the top 'slice', and its disposition among the six routes is recorded in lower slices. Summation over the six disposal routes yields total waste production. The waste production matrices in Table 2 can be rewritten as follows to incorporate this extra dimension:

$$W_{nwm}^{bs} = \sum_{\gamma} W_{nwm_{\gamma}}^{bs}$$

$$W_{wm}^{bs} = \sum_{\gamma} W_{wm_{\gamma}}^{bs}$$

$$W^{ps} = \sum_{\gamma} W_{\gamma}^{ps}$$

$$W^{gs} = \sum_{\gamma} W_{\gamma}^{gs}$$

$$W^{v} = \sum_{\gamma} W_{\gamma}^{v}$$

where $\gamma \equiv$ env, inv, treat, recycle, exp .

3.3 Asset-discard waste

Considered in terms of its temporal relationship with economic activity, waste production is of two types. First, there is waste that results directly from current economic activity. Carbon dioxide emissions from fossil fuel combustion are a good example, since the consumption activity and waste production occur simultaneously. The second category is waste created when worn-out capital or durable household goods are discarded. This type of waste is not related to current activity, but instead to production and consumption that occurred in previous periods.

Since the input-output accounts represent current economic activity, a direct temporal relationship exists between wastes of type one and the economic activity measured in the accounts. This means that wastes of type one can be recorded in the waste account and easily linked with the economic data recorded there.

In contrast, a straightforward temporal relationship between input-output data and wastes of the second type does not exist. For example, the number of cars scrapped each year has nothing to do with the current value of car production (or consumption) that is measured in the accounts. Rather, it is a function of size and age-structure of the stock of cars that has resulted from pur-

16. To keep the presentation of the framework in Table 2 simple, this third dimension has not been represented in the table.

chases in earlier periods. Likewise, other wastes result from disposals out of stocks of capital or durable household goods; household appliances, clothing, industrial machinery, and building demolition waste are but a few. These wastes are referred to below as asset-discard wastes.

One cannot simply record current period asset-discard wastes as though they are the direct result of the economic activity measured in the input-output accounts. Doing so would be conceptually incorrect, as it would attribute wastes to current activity that are properly associated with historical activity. Some alternative treatment of these wastes is needed.

Asset discards in the business sector

An interesting solution to the problem of accounting for asset-discard wastes in the business sector is to consider them in parallel with the economic treatment of capital consumption. Just as the national accounts allocate the cost of using capital to production activity over an asset's life, an argument can be made that the waste created by the ultimate disposal of the asset should be accrued to production activity in each of the periods in which the asset is employed. In other words, while an economic good is depreciating in value, there is a corresponding appreciation of an environmental 'bad' in the form of accrued - but not yet produced - waste. This has conceptual appeal in two ways.

First, the internal consistency of the waste accounting framework is enhanced when capital depreciation and the associated waste production are treated in parallel. The value of economic output measured in the input-output accounts includes the cost of capital, as well as the costs of current operating expenditures. Thus, it is appropriate that the waste production measured in the waste account should include both the accrued waste from future capital disposal plus the waste that results directly from current operating activities. In doing so, the value of economic output and the quantity of waste production in a given period are placed on an equivalent basis.

Second, the idea that some portion of the waste associated with disposal of capital assets should be attributed to production in each period in which the assets are used seems just. This is particularly true when the life of the asset is long. Treatment of asset-discard waste on an accrual basis ensures that current production activity is 'held responsible' for its share of the waste that will ultimately result, perhaps far in the future, from the disposal of the capital it uses.

To give an example of how the accounting of asset-discard waste on an accrual basis might work, consider a purchase in the current period of 100 units of capital good K with a useful life of 10 years. Ten years hence the purchasing industry will dispose of this asset, creating 100 units of waste. In the meantime, the industry makes on-going use of the asset in its production processes. Assuming a straight-line waste accrual schedule, one tenth of the waste associated with this asset's ultimate disposal (10 units) accrues to the industry's production in each of the subsequent 10 accounting periods. This accrual would be represented in the waste account of each period as an entry of 10 units of waste 'K' in waste production matrix for the business sector (W^{bs}). The 'flow' of this waste is entered in an 'accrued asset-discard waste inventory' (a vector defined in matrix V). Of course, no such inventory exists in the real world; it is simply an accounting construct that allows the accrued waste to be 'absorbed' until the asset is actually discarded. When disposal does take place, the account would show a release of 100 units of waste 'K' from the accrued waste inventory. This flow would be recorded in matrix W^{v} (defined below). Accounting for asset-discard waste in this way serves the dual purpose of justly distributing asset-discard waste to production activity over all periods in which the capital is employed, as well as recording the physical waste flow when the capital item is discarded.

The quantity of asset-discard waste accruing to current production activity must be calculated for each accounting period. This can be done by considering the stock of capital assets extant in the period, the age-structure of this stock, the expected lives of the assets, and choosing a waste accrual rate. In other words, it can be calculated analogously to the estimation of capital depreciation. If the chosen waste accrual rate is the same as the depreciation rate used in the economic calculation, the two measures become parallel; waste accrual becomes the physical analogue of economic depreciation. There is much to be gained from this treatment. For one, the internal consistency of the waste accounting framework is further enhanced if asset-discard waste accrual is calculated like capital depreciation. The value of economic output as measured in the account reflects the rate of depreciation of the various capital assets used in production. Thus, when the rate of waste accrual is analogous to the rate of depreciation, the correspondence between current period economic output and waste production is as complete as it can be. Equally importantly, the choice of existing rates of capital depreciation for use in estimating waste accrual precludes the need to develop separate rates for waste accrual. Thus, efficient use is made of an existing and well-established set of statistics.[17]

Asset-discard waste in the household sector

The proposal made above to treat asset-discard wastes analogously to the consumption of capital on an accrual basis is not appropriate for the household sector. Like industries, households make use of 'capital', or durable assets, in their activities. Unlike industries, the value of these assets is not capitalised in the input-output accounts, nor are the household production activities in which they are employed measured in the accounts. Rather, only the current consumption of the household sector is recorded in the accounts, and all purchases of durable assets are treated as current consumption of the purchase period. Thus, although it is possible to estimate the waste accruing in the current period from past purchases of household durables (in the same manner as for businesses), there is little point in doing so. No meaningful relationship exists between current household consumption and the disposal (accrued or actual) of previously purchased durable goods.

A relationship does exist, however, between current purchases of durable goods and the waste attributable to their future disposal. The treatment suggested for asset-discard wastes in the household sector, then, is to accrue *all* future waste associated with the ultimate disposal of a durable asset to the period in which it is purchased. Symmetry is thus achieved between the treatment of durable asset purchases and the treatment of asset-discard wastes for the household sector. As well, inter-period equity is served, as the ultimate waste burden associated with current levels of household consumption is clearly represented in the account. The accounting for the household sector on this basis is similar to that for asset-discard wastes in the business sector.[18]

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17. Having made this point, it is worth considering the possibility that waste accrual rates should differ from depreciation rates. For example, it could be argued that no matter how depreciation is calculated, waste accrual should always be on estimated a straight-line basis because goods produced in the last year of an asset's life are equally responsible for the ultimate waste as are goods produced in the first year. Alternatively, it could be argued that waste should accrue at a greater rate in the last years of an asset's life, in line with the increasing probability of the asset being scrapped.
18. Although household purchases of durable goods are not capitalised in the input-output accounts, they are treated as capital assets in the Canadian National Balance Sheet Accounts. This asymmetry means that a linkage between asset-discards in the household sector and the depreciation of household 'capital' could be made within the framework of the CSNA, just not within the framework of the input-output accounts. The decision to remain within the input-output framework in treating asset-discards for the household sector is based on the desire to maintain the waste account entirely within one framework and notion that it is the relationship between current consumption and waste production that is most interesting.

In the year in which a durable asset is purchased, the W^{hs} matrix would report waste production by the household sector equal to the future waste associated with the asset's ultimate disposal. This waste flow is 'absorbed' in the current period by the 'accrued asset-discard waste inventory'. In the future period when the asset is actually discarded, the accrued waste inventory 'releases' the waste associated with the asset, which appears as a flow in the W^{r} matrix.

Asset-discard waste in the government sector

The foregoing discussion of asset-discard wastes in the household sector can be applied in all respects except one to the government sector. The single difference between the two sectors is the fact that government purchases of durable goods are in fact capitalised in the input-output accounts rather than treated as current consumption. This does not change the suggested treatment of asset discards for the government, but it does mean that the implied waste-economy relationship is between capital formation and asset-discards in the government sector, rather than current consumption and asset-discards as in the household sector.

The treatment of asset-discard wastes suggested here has several points to recommend it:

- it is in line with the accepted treatment of capital in the national accounts, thus improving the internal consistency of the input-output based waste accounting framework;
- it respects inter-period equity, as current economic activity today is held accountable for the future wastes that are its inevitable result;
- it allows the possibility of using existing capital stock data to aid in estimating waste flows.

3.4 Wastes outside the framework

Much waste production is not directly related to the economic activity measured in the input-output accounts. Yard wastes, cooking vapours, waste from 'junk' mail, and sewage are examples of wastes that are not direct functions of current economic activity. While not entirely independent of this activity, such wastes are related as much, or more, to individual choices made outside the marketplace (how often to tend one's garden, what type of cooking processes to use) or factors beyond individual control (junk mail delivery, rates of bodily functions).

Catastrophic spills[19] and natural disasters are also sources of 'wastes' that are not related to current activity.[20] Huge quantities of waste can be created as a result of these events, often with severe consequences for human and environmental health. Events of these types are not related straightforwardly with economic activity in any particular period. In the case of catastrophic spills, there is a probabilistic relationship with economic activity over long periods of time, but the events themselves are random. Natural disasters are, of course, not a function of economic activity at all. Wastes associated with either type of event should not be recorded as current waste production in the waste account.[21]

19. Catastrophic spills are very large spills that occur on a random basis. Oil tanker spills are a good example.
20. Waste is in quotations in this case because spilled material does not fit the definition of waste given in the opening section. By that definition, waste is material intentionally discarded because it is 'unwanted by its producer'. Wastes created as a result of catastrophic spills or natural disasters clearly do not fit this definition.

A third waste source that is not related to current activity is waste inventories. As well as acting as waste sinks, inventories also leak wastes; they are never perfect storehouses.[22] Moreover, the wastes that leak from inventories are often not the same as the wastes they store, as chemical/physical transformations of wastes can take place within the inventory. Indeed, these transformations are often themselves the cause of the leakages. In the case of landfill sites, for example, the action of bacteria on buried organic material results in the production of methane gas which leaks from the site. Inventory leakages can be either continual (such as landfill gas) or discreet (fires in toxic waste warehouses for example).

Since none of the waste sources discussed above have any direct relationship to current economic activity, the input-output accounts do not offer a very useful framework for studying them.[23] But because the material quantities involved can be large, these sources must be included in the account if it is to be comprehensive. A matrix has been defined outside the input-output portion of the account to allow this to be done:

> matrix W^s is an (s x k) matrix of wastes from sources not directly related to current economic activity, in which an element, w_{ij}^s, represents the quantity of waste type *j* released by non-economic source *i* in the accounting period.

4 Putting the Waste Account to Use

Using the waste account implies exploiting the linkages between the waste data and the economic statistics recorded in the input-output account. The goal to produce is a set of statistical measures that highlight the relationship between waste production and economic activity.

Before presenting these measures, it is worth pointing out that summation across different waste types is not usually appropriate when aggregating waste statistics. In doing so, one necessarily mixes wastes with dissimilar characteristics. The result is an aggregate measure that masks the relationship between the waste production and its potential impact on environmental quality or human health. 'Total waste production per industry' as a measure, for example, reveals nothing of the make-up of industrial waste production and, therefore, reveals little about the potential impact of industrial activity. In contrast, 'total industrial sulphur dioxide production' is useful because it gives an indication of the contribution of industrial activity to an identifiable problem (acid rain in this case).

There are some instances, however, when it is legitimate to aggregate over different waste types. When a hybrid unit of measure allowing wastes to be measured in terms of equivalent environmental impact is available, wastes may be aggregated to produce summary statistics. The global warming potential unit that was described earlier is a practical example.

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21. There is a parallel here with the standard national accounts treatment of capital write-offs resulting from natural disasters. Just as the national accounts do not show write-offs of capital assets due to natural disasters as charges against current production (they are shown instead as 'other changes in the volume of assets'), the waste account should not 'charge' wastes resulting from natural disasters (or catastrophic spills) against current production.
22. The amount of waste leaked from some inventories might be extremely small. Highly controlled sites for storing nuclear fuel wastes are probably the 'tightest' of all waste inventories.
23. It is somewhat unfair to focus only on the limitations of the input-output framework in this regard. In fact, the limitation is really one of the System of National Accounts in general, not of the input-output accounts specifically.

4.1 Industrial waste coefficients

Most of the interesting statistical measures that can be developed using data in the waste account are related to industrial activity. These range from simple aggregations of waste production to sophisticated coefficients that make use of the input-output model developed above (Eq. 10).

As for simple aggregations, a number of these are possible. Measures such as 'total industrial waste production by waste type' and similar aggregations for sub-sets of industries are useful. These simple aggregations are suitable for comparing the relative importance of different industry groups in contributing to waste production. Caution should be employed when interpreting changes in these measures over time however. Many factors can affect waste production by a given industry, including the mix of commodities produced during the period, the material efficiency of technology employed in production, the waste controls in use, and the level of economic output during the period. The influence of any of these factors on waste production can be difficult to study in isolation from the others.

While simple aggregations are useful, they fail to take full advantage of the framework because they ignore its economic dimension. Coefficients that combine waste *and* economic data represent the real strength of the waste accounting framework.

The most basic industrial coefficient that can be produced is waste production per unit of economic output. This is defined by the following relationship:

$$\overline{W^{bs'}} = \Delta g \qquad \text{Eq. 11}$$

where $\overline{W^{bs'}}$ is column summation of the transpose of matrix W^{bs} from Table 2, vector g is as defined above and:

> Δ is a (k x n) matrix of **industrial direct waste coefficients**, in which an element, $\delta_{ij,}$ is defined as the quantity of waste type *i* produced per unit value of output by industry *j* during the accounting period. These coefficients are calculated as:

$$\delta_{ij} = \frac{w_{ij}^{bs}}{g_j} \qquad \text{Eq. 12}$$

A similar coefficient could be produced using value-added rather than total output as the denominator in Eq. 12.[24]

The great advantage of a waste coefficient such as δ_{ij} over simple aggregations of waste data is the common basis of comparison provided by the economic dimension. Waste coefficients can be meaningfully compared between industries, allowing an assessment of the relative 'waste intensiveness' of production in each industry. Inter-temporally, waste coefficients allow the waste intensity of production for a given industry to be compared with the influence of the business cycle removed (assuming that the coefficients are derived using a constant dollar measure of production). This allows the researcher to focus on the effects of changing technology and/or industrial structure on waste production.

The direct waste coefficients derived in Eq. 12 are useful in their own right, but also because they can be used to derive a waste input-output model. This is easily done by substituting for *g* in Eq. 10 from Eq. 11 and rearranging terms:

24. Value-added for each industry can be directly calculated from the use (U) matrix as the sum of primary inputs (indirect taxes less subsidies, labour income and operating surplus).

$$g = (I-DB)^{-1}D\left(\bar{f} + x_d + x_r - m - vpcw - gr\right) \qquad \text{Eq. 13}$$

$$\overline{W^{bs'}} = \Delta g = \Delta(I-DB)^{-1}D\left(f^{*}\right) \qquad \text{Eq. 14}$$

where all elements are as defined above and

f^{*} is an abbreviation for $\bar{f} + x_D + x_R - m - vpcw - gr$ from Eq. 10.

The waste input-output model (Eq. 14) represents industrial waste production in terms of an exogenously supplied vector of final demand (f) and the D, B and Δ matrices calculated from data recorded in the waste account. The model can be used to estimate waste production for different levels of final demand, or under different assumptions about the technological structure in the economy (i.e. changes in the D, B or Δ matrices).

A measure of waste production that falls out of Eq. 14 is the **industrial total waste impact matrix**. This is the environmental counterpart to the standard (economic) impact matrix that is well known to users of input-output tables. The industrial waste impact matrix is defined as:

$$\Phi_{bs} = \Delta(I-DB)^{-1} \qquad \text{Eq. 15}$$

where all elements are as defined above, except:

> matrix Φ_{bs}, a (k x n) matrix of **industrial total waste impact coefficients**, in which an element, $\phi_{bs_{ij}}$, is defined as the total[25] production of waste type i per unit of output by industry j during the accounting period.

This matrix is easily recognised as being equivalent to part of Eq. 14.

The total waste impact matrix has a very interesting property. It captures not only the direct wastes associated with a given industry's activity, but also the wastes indirectly associated with this activity. The distinction between direct and of indirect waste production is most easily explained by an example.

All industries produce a certain amount of waste from economic activities; this is referred to as their *direct* waste production (it is only this waste production that is captured in the direct waste coefficient (δ_{ij}) defined above). For example, carbon dioxide emissions from electric power stations are 'direct' emissions associated with the electric power industry. The waste associated with this industry is not just that from power stations however. In order to make electricity, power utilities must first purchase machinery, fuel, and a variety of other inputs from suppliers, all of which produce waste. This waste can be *indirectly* attributed to the electric power industry in proportion to its purchases of each supplier's products. If, for example, power utilities purchase 15 percent of the natural gas industry's production, then 15 percent of the waste emissions associated with natural gas production can be indirectly attributed to the electric power industry.

By including both direct and indirect waste production, total waste impact coefficients yield a more complete picture of the waste associated with a given industry's activities than do direct waste production coefficients (δ_{ij}). Consideration of the two measures in parallel provides an interesting view of industrial waste production that allows industries with low direct waste production but high total (direct plus indirect) production to be identified.

25. Total waste production includes direct and indirect waste production as defined below.

With a slight modification, the industrial total waste impact matrix just presented can be transformed into a **commodity** total waste impact matrix. All that is necessary is post-multiplication of equation 15 by matrix *D*:

$$\Phi_{com} = \Delta(I - DB)^{-1}D \qquad \text{Eq. 16}$$

> Matrix Φ_{com} is a (k x m) of **commodity total waste impact coefficients**, in which an element, $\phi_{com_{ij}}$, is defined as the total production of waste type *i* per unit of output by commodity *j* during the accounting period.

The ϕ_{com} coefficients are simply weighted averages of the industry total impact coefficients, with market share coefficients (matrix *D*) used as the weights. As such, they are not reflective of the actual wastes associated with commodity production. In cases where two or more commodities are produced by the same industry and that industry holds the entire market for those commodities, the total impact coefficients will be exactly the same for each of the commodities.

4.2 Who carries the waste burden

Since industrial activity takes place to meet the demand for goods and services from final consumers, it is legitimate to wonder, 'who is ultimately responsible for the creation of industrial wastes, businesses or their customers?' The answer to this question lies of course outside the realm of national accounting. Nevertheless, it is interesting to note that the waste account allows the calculation of the amount of industrial waste production attributable to each of the categories of final demand. This is very easily determined by post-multiplying Eq. 16 by the appropriate vector of final consumption by commodity. For example, the waste associated with the production of goods and services to meet the demand from households can be calculated by multiplying the commodity total waste impact matrix (Eq. 16) by the summation of the matrix of personal expenditures (matrix *PE*) across consumption categories:

$$w_{bs}^{pe} = \Delta(I - DB)^{-1}D(\overline{PE}) \qquad \text{Eq. 17}$$

> Vector w_{bs}^{pe} is a (k x 1) vector of industrial waste production associated with the production of goods and services to meet household demand.

A similar calculation can be carried out for any category of final demand. One interesting possibility is the comparison of 'imports' and 'exports' of industrial waste production.

When commodities are produced in one country for export to another, the exporting country can be seen to 'import' the waste associated with this production from the other country. That is, it assumes the waste burden that would have been assumed by the other country had it produced the commodities itself. Likewise, when a country imports commodities from abroad, it 'exports' the wastes associated with producing these commodities to the producing country.[26] The quantities of wastes thus 'imported' and 'exported' can be calculated by post-multiplying Eq. 16 by the vectors of domestic exports (x_d) and imports (m). Post-multiplication by the export vector yields the wastes created by domestic industries in producing commodities for exports. Post-multiplication by the import vector gives an estimate of the wastes created in other countries in producing the

26. The waste 'imports' and 'exports' in question here are merely conceptual; they do not occur in actual fact. Care should be taken not to confuse them with the real waste imports and exports (vectors m^w and x_d^w respectively) that are measured in the waste account.

commodities imported into domestic consumption, *assuming* that the economic structure in other countries is the same as that domestically. To the extent that this assumption is inaccurate, the estimate of wastes produced in associated with the production of the domestic import vector will be inaccurate as well.

4.3 Household and government waste coefficients

The waste coefficients derived above for the business sector are based on the linkage of its waste production with its economic output as measured in the input-output accounts. This same linkage cannot be developed for the household or government sectors. These sectors are not seen as productive in the national accounts. Instead, they are viewed only as consumers of commodities produced by the business sector. Waste coefficients developed for them must then rest on the linkage of their waste production with their consumption activities.

Many wastes produced by the household/government sectors are easily related to the consumption of specific goods by these sectors. For example, wastes from the combustion of fossil fuels for heating purposes are a direct function of real value of expenditures on heating fuels. Likewise, newspaper disposal is related to expenditures on newspapers and the junking of cars is, as was argued in Section 4, related to the purchases of cars. For such wastes a simple relationship between production and household/government expenditure can be formulated:

$$\overline{W_{sc}^{hs\prime}} = \Omega_{sc}^{hs}(\overline{PE}') \text{ (household sector)} \qquad \text{Eq. 18}$$

$$\overline{W_{sc}^{gs\prime}} = \Omega_{sc}^{gs}(\overline{GGCE}') \text{ (government sector)} \qquad \text{Eq. 19}$$

where:

vectors $\overline{W_{sc}^{hs\prime}}$ and $\overline{W_{sc}^{gs\prime}}$ are the column summations of the transposes of matrices W^{hs} and W^{gs}, and the subscript 'sc' refers to wastes that can be associated with specific categories of household consumption;

vector $\overline{PE}'$ is the summation across commodities of the transpose of matrix *PE* (the matrix of household expenditure), and vector $\overline{GGCE}'$ is the summation across commodities of the transpose of matrix *GGCE* (the matrix of government current expenditure);

and

matrix Ω_{sc}^{x} is a (k x p) matrix of household waste coefficients (x=hs), or a (k x g) matrix of government (x=gs) waste coefficients, for wastes related to specific categories of household/government consumption, in which an element, $\omega_{sc_{ij}}^{x}$, represents the production of waste type *i* per unit of household/government consumption category *j* in the accounting period.

Not all household and government wastes are easily linked to a specific category of consumption however. Packaging waste is the best example. Many goods, ranging from breakfast cereal to computers, are sold in some type of plastic, cardboard, paper, metal or glass packaging. Canadian waste statistics do not differentiate packaging wastes according to their product of origin; only the total quantities of wastes are reported. It is therefore difficult to record packaging wastes according to the consumption category with which they are related. While this a weakness of the statistical system more than of the waste accounting framework, it nevertheless poses a limitation on the usefulness of the framework for measuring household and government waste production.

For these wastes, all that can be done is to define a relationship with total consumption:

$$\overline{W_{nc}^{hs\prime}} = \omega_{nc}^{hs}\left(\underline{PE}\right) \text{ (household consumption)} \qquad \text{Eq. 20}$$

$$\overline{W_{nc}^{gs\prime}} = \omega_{nc}^{gs}\left(\overline{\underline{GGCE}}\right) \text{ (government consumption)} \qquad \text{Eq. 21}$$

where:

> vectors $\overline{W_{nc}^{hs\prime}}$ and $\overline{W_{nc}^{gs\prime}}$ are the column summations of the transposes of matrices W^{hs} and W^{gs}, and the subscript 'nc' refers to waste that can be associated with no specific category of consumption;
>
> scalar $\underline{PE}$ is the column and row summation of matrix *PE* (the total value of household expenditure), and scalar $\overline{\underline{GGCE}}$ is the column and row summation of matrix *GGCE* (the total value of government expenditure);

and

> vector ω_{nc}^{x} is a (k x 1) matrix of household (x=hs) or government (x=gs) waste coefficients for wastes not related to any specific category of consumption, in which an element, $\omega_{nc_i}^{x}$, represents the production of waste type *i* per unit of total household/government consumption in the accounting period.

The specification of the household and government waste coefficient matrices (Ω_{sc}^{hs}, Ω_{sc}^{gs}, Ω_{nc}^{hs} and Ω_{nc}^{gs}) using data for a given period allows the estimation of household and government waste production associated with any other level of current expenditure that the researcher cares to specify, assuming that the relationship between expenditure and waste production that held in the period is constant.

Conclusion

Several strengths of the input-output framework can be stated in conclusion:

- the framework has been shown to be flexible - it can be modified to incorporate all waste sources and disposition in the economy;
- the framework is capable of accounting effectively for all waste production for which a direct relationship with current economic activity exists;
- the framework has analytical power, in that it allows the calculation of several measures of the relationship between economic activity and waste production (this is particularly noteworthy for the business sector).

The weaknesses of the framework should be recognised as well. In particular, it is not very useful for studying the waste production of the household and government sectors. Nor does it aid in analysing waste production for which there is no (or little) relationship to marketplace activity. Neither of these limitations is a weakness of the input-output framework alone however. Rather, both are inherent to the System of National Accounts as a whole. The SNA does not represent the household and government sectors as fully as the business sector, so it stands to reason that it does not provide as useful a framework for studying the waste production of these sectors. Likewise, the SNA is not intended to measure activity outside the marketplace, and thus is not very useful for analysing wastes that are not directly related to this activity.

Data requirements

It almost goes without saying that the data requirements of the waste accounting framework proposed above are well beyond the scope of the waste statistics currently available in Canada. This is not to be lamented however. One of the purposes served in setting out a conceptual framework is the identification of data gaps in existing statistical systems. Once identified, these can be used as a guide to data development.

The major gaps in Canadian waste data preventing a full implementation of the proposed waste account are as follows.

- Data on asset-discards are almost entirely lacking for all three sectors of the economy. The possibility does however exist to build these from existing data on the investment in and consumption of fixed capital.
- Data on leakages from waste inventories are sparse. Estimates have been made of methane emissions from landfill sites, but these are all that are available.
- Data on government sector waste production are almost entirely lacking.
- Waterborne waste data are weak for all sectors, particularly for the business sector. Most data report only the major constituents of waterborne waste (BOD, suspended solids, grease and oil), although there exist some data sets for particular industries with greater levels of detail.
- Data on airborne emissions of toxic wastes are not widely available. This situation will improve with the release of Canada's first National Pollutant Release Inventory in the summer of 1995.

Future work

To date, the focus of the empirical development of the waste account has been on greenhouse gas emissions. Some data development has been carried out for the household sector and for water- and airborne wastes of the business sector. This work is on-going. The goal for the first official release of Statistics Canada's waste account planned for 1997 is a comprehensive account of the major solid, liquid and gaseous wastes from all sectors of the economy, including the wastes associated with asset-discards treated according to the proposal in Section 3.3 above.

With some straightforward modifications, the waste accounting framework that has been presented here can be transformed into a complete materials flow framework showing the extraction of raw materials from the environment, the disposition of this material among the various sectors of the economy, and the production, recycling and disposition of wastes. Such an account would be a useful tool for studying the material efficiency with which the economy operates and how this efficiency changes over time. Future work will be aimed at the development of such an integrated account.

Bibliography

Anderson, A. W. and T. W. Manning. 1983. 'The Use of Input-output Analysis in Evaluating Water Resource Development,' in **Canadian Journal of Agricultural Economics**, 31 (March): 15-26.

Ayres, R. U. and A. V. Kneese. 1969. 'Production, Consumption and Externalities,' in **American Economic Review**, 59 (June): 282-97.

Ayres, R. U. 1978. *Resources, Environment and Economics: Applications of the Materials/Energy Balance Principle*. New York: John Wiley and Sons.

Baines, J. and J. Peet. 1991. *Input-output Based Resource Accounting as a Practical Tool to Assist those Responsible for Developing and Evaluating Greenhouse Policy*. New Zealand: Taylor Baines and Associates.

Cumberland, J. H. 1966. 'A Regional Inter-industry Model for Analysis of Development Objectives,' in **Regional Science Association Papers**, 17: 65-95.

Daly, H. E. 1968. 'On Economics as a Life Science,' in **The Journal of Political Economy**, 76 (May/June): 392-406.

de Haan, M., S. J. Keuning, and P. R. Bosch. 1994. 'Integrating Indicators in a National Accounting Matrix including Environmental Accounts (NAMEA): An Application to the Netherlands', *in* **National Accounts and the Environment: Papers and Proceedings from a Conference**. Ottawa: Statistics Canada, National Accounts and Environment Division.

Hahn, Angela. 1995. *Green Accounting: an Agenda for Action, The Status of Environmental Accounting in European and non-European Countries*. Eurostat.

Houghton, J. T., G. J. Jenkins and J. J. Ephraums. 1990. *Climate Change: The IPCC Assessment*. Cambridge: Cambridge University Press.

Isard, W. 1969. 'Some Notes on the Linkage of the Ecologic and Economic Systems,' paper delivered to the Regional Science and Landscape Analysis Project, Harvard University, June 27.

Johnson, M. H. and J. T. Bennett. 1981. 'Regional Environmental and Economic Impact Evaluation,' in **Regional Science and Urban Economics**, 11: 215-230.

Leontief, W. 1936. 'Quantitative Input-Output Relations in the Economic System of the United States,' in **Review of Economics and Statistics**, 18, 3 (August): 105-25.

Leontief, W. 1970. 'Environmental Repercussions and the Economic Structure: An Input-output Approach,' in **Review of Economics and Statistics**, 52 (August): 262-71.

Miller, R. E. and P. D. Blair. 1985. *Input-output Analysis: Foundations and Extensions*. Englewood Cliffs, New Jersey: Prentice Hall, Inc.

Murck, B. W., C. M. Dufournaud and J. B. R. Whitney. 1985. 'Simulation of a Policy Aimed at the Reduction of Wood Use in the Sudan,' in **Environment and Planning A**, 17: 1231-42.

Pearce, D. and R. K. Turner. 1990. *Economics of Natural Resources and the Environment*. Hertfordshire, U.K.: Harvester Wheatsheaf.

Proops, J.L.R., M. Faber and G. Wagenhals. 1993. *Reducing CO2 emissions: A comparative Input-Output Study for Germany and the U.K.* Berlin: Springer-Verlag.

Smith, P. 1994. 'The National Accounts Environmental Component: A Status Report', *in* **National Accounts and the Environment: Papers and Proceedings from a Conference**. Ottawa: Statistics Canada, National Accounts and Environment Division.

United Nations. 1993. *Integrated Environmental and Economic Accounting (Interim Version).* New York: United Nations.

Victor, P. A. 1972. *Pollution: Economy and Environment.* Toronto: University of Toronto Press.

World Commission on Environment and Development. 1987. *Our Common Future*. Oxford: Oxford UP.

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