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The creation of a dual Waste and Multi Regional Input-Output model for Australian conditions

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Abstract

Waste is an inevitable part of production and consumption in the Australian economy. However, wastes economic and environmental impact is misrepresented, undervalued, and misunderstood by society at large. In Australia this miscomprehension is deeply engrained with various states having differing conceptions of what waste is and how to manage it.

This paper will lay out the theoretical processes (and problems) of creating and applying both a Waste Input-Output (WIO) and Multi Regional Input-Output (MRIO) model to Australia. After, discussing the developmental histories of both models, this paper will then discuss the operation, creation, and the merging of the two, as well as the particular difficulties that are due to the nature and structure of the Australian economy and government. Specifically, the challenges in applying the WIO methodology to Australia's states and territories will be explored, as this has not previously been attempted to this author's knowledge.

Keywords: Municipal waste, Waste Input-Output, Sustainability, Multi Regional Input-Output, Australia

Introduction

Waste is a large and complex category of items that no longer serve their intended purpose or function. In the present economy of the developed world, the acts of production and consumption create waste products of varying types. From the simple aluminium can or food scrap to bio hazardous material, every type of waste has its own waste cycle and a preferred method of disposal.

Yet, with such large amounts of waste being generated, there are few tools that give us understanding about the environmental, economic and social impacts of waste at a national level, or of how these impacts play out on a regional or local level. This lack of understanding both local and regional waste issues prevents the effective management of waste to the detriment of the environment and public health.

This paper aims to lay out the theoretical processes (and problems) of creating and applying both a Waste Input-Output (WIO) model and Multi Regional Input-Output (MRIO) model to Australia. Firstly, discussing the development and history of both the WIO and MRIO models independently. This paper will then give a developmental and methodological introduction to the Multi Regional Waste Input-Output (MRWIO) as developed by Nakamura, Kondo, Kagawa and colleagues (Kagawa, Inamura et al. 2004; Nakamura and Kondo 2009; Kagawa 2012). This existing framework work will then be applied as a methodology to the Australian condition. Particular note will be taken of the difficulties that are due to the nature and structure of the Australian economy and government in fabricating an Australian MRWIO.

Multi Regional Input-Output

Multi Regional Input-Output (MRIO) models have been developing theoretically and in application since their first use in the 1960s. MRIO models provide a more detailed method for examining and expressing relationships (financial or other) that are usually found in national input-output tables. As Wiedmann et al (Wiedmann, Wilting et al. 2011) indicate, these are complex relationship, with financial transactions between economic sectors, trade flows, and exports and imports all occurring within one set of linked tables.

The two most utilized forms of regional modeling are based upon either the Isard (1951) et al (1960) or the Chenery–Moses (Chenery 1953; Moses 1955) regional models. Miller and Blair (2009) pointing out that the Chenery–Moses model has become known as the multiregional input–output model (MRIO). A degree of its uptake has been earned due to its "consistent estimation of the intra- and interregional transactions required", along with less demanding data requirements on the origins of inputs and their destinations, than an Isard type model.

The Chenery-Moses model assumes that producers in each region understand the imports from a specific region are homogenous, thus "all producers import for a specific region in proportion to their total use patterns rather than importing in different proportion from different regions" (Hartwick 1971). The Isard model requires destination and origin data in order to models these flows (hence needing a higher data requirement).

Yet, it must be noted that the data requirements for both the Isard and the Chenery-Moses style models are large, with Hartwick (1971) stating "the information measure of the Isard model is always at least as great as that of the Chenery-Moses model". Both the Isard and the Chenery-Moses have been applied previously to Australia (and waste management) and thus this paper will consider both methodologies as MRIO and discuss their applicability later in the paper.

Australia has had MRIO models both for individual states (West, Wilkinson et al. 1979; Trendle 1999) and nationally (Jensen, Mandeville et al. 1979; West, Wilkinson et al. 1979; West 1990; Adams, Dixon et al. 2010; Wang 2011). The Australian Bureau of Statistics (ABS) only produces a national IO table, with individual researches either conducting either top down (Jensen, Mandeville et al. 1979) or bottom up (Cooper 1998) approaches to create state based tables. One of the most popular regional models (though not a true IO model—rather CGE) is Monash Universities' model that has been in a state of evolution since the late 1980s (Dixon and Peter 1996; Peter, Horridge et al. 1996; Adams, Dixon et al. 2010). Generation of Regional Input-Output Tables (GRIT) technique pioneered in Australia by West et al (1979) also has a strong following in Queensland.

The ABS not producing regional IO table makes the standardization of data difficult with both bottom up and top down methods utilized by academics. Contemporarily the most practiced method of regionalising Australia in wide-scale regional economic models appears to be an eight region split (six states and two territories (West 1990; Peter, Horridge et al. 1996; West and Gamage 2001; Adams, Dixon et al. 2010)). This layout can be seen most recently in the AUS-MRIO model that has been developed by the CSIRO and the University of Sydney (Wiedmann, Geschke et al. 2012). This model provides an eight region/state and territory MRIO, with a detail of 344 sectors for all states and territories extended with physical-unit satellite accounts, in a time series from 2000-2008.

Waste Input Output

Since its inception by Nakamura, Kondo and colleagues (1999; 2008), Waste Input Output (WIO) has become recognised both as an extension of IO and as a form of Life Cycle Analysis (LCA), due to its ability to account for multiple pollution types and expenses (For example, air and water pollutants, energy and social costs) across an entire economy (Kagawa, Nakamura et al. 2007). WIO is now utilised by scholars to model a plethora of waste types ranging from water and sewage waste (Lin 2009) to ‘smart waste’ from manufactured goods (Nakamura and Yamasue 2010). However, even though there have been WIO investigations into many waste types, there has been little geographical spread of WIO research, with WIO papers predominantly focusing on Japan, the country of the WIOs development. This apparent gap in the literature will become filled as WIO continues to develop.

The theoretical development behind the WIO models application to Japan has been well documented (Nakamura 1999; Nakamura and Kondo 2002; Nakamura and Kondo 2009), with the WIO tables for Japan in 1995 and 2000 now available online (http://www.f.waseda.jp/nakashin/wio.html). In brief, Japans WIO (for the 1995 table) originally consisted of 78 industries, 24 waste types and 9 types of bulky waste, which was then consolidated into 13 industries, 13 wastes and 3 treatment processes. The S allocation matrix assigns waste in this condensed Japanese WIO into three end points, namely, sorting and shredding, incineration, and landfill (Nakamura and Kondo 2002; Nakamura and Kondo

2002). This national model was then disaggregated in to an Isard type regional WIO for nine regions of Japan by Kagawa et al (Kagawa, Inamura et al. 2004; Kagawa, Nakamura et al. 2007). Tsukui et al (Tsukui and Nakamura 2010) have also applied an Isard type regional WIO to Tokyo and the surrounding regions. This model has been developing in complexity over the years and now features the effects of regional transport. Nakamura and Kondo (Nakamura and Kondo 2009) also briefly examine the theory behind Regional WIO discussion both the Isard and Chenery-Moses models.

Kondo et al (Kondo 2007) furthered developed WIO by integrating a consumer behaviour model, describing situations where technological change altered the maximum possible consumption levels. This extended model enabled time and consumption methodology to be investigated and the most efficient forms of consumption and waste disposal to be offered to the consumer. Reynolds, Boland et al (Reynolds, Boland et al. 2011) have begun to expand WIO modelling to Australian waste issues with their current focus on food wastage and the integration of the effects of behavioural change programs (advertising and public education) for waste reduction. However, adapting the WMRIO to Australia faces some challenges. The first of these challenges is that in addition to the regular IO tables, WIO requires additional information on waste disposal and creation. This information ranges from the types and proliferation of waste disposal options, to the type and amounts of waste produced per industry sector (including households). This is a lot of data to gather. In Australia, there is national data available however, 'regional' data is more difficult to acquire.

How does the WIO model work?

WIO models the waste flows of an economy down into observable interactions. Figure 1 and Table 1 represent two methods of displaying the economy and its waste flows. Figure one pictorially represents the flows of waste (solid lines), goods, services and capital (dotted lines) and recycled goods re-entering the economy (dashed lines). Figure 1 also splits landfill, Energy recovery and recycling from other industrial sectors (whether these be primary, secondary, etc) to illustrate where the waste is flowing to for treatment or disposal.

Table 1 also displays the interactions of waste and the economy, but now in an IO format. The WIO table disaggregates the waste sector of the economy into the various treatment types available to that economy (i.e. recycling, landfill, incineration etc). The WIO also disaggregates the waste stream into various waste streams that the modeller wishes to observe. This could be as simple as splitting the waste stream down to Municipal (Household); Commercial and Industrial; and Construction and Demolition sectors or as complex and specific as 'Food waste', 'Old newspaper', 'Tired magazine', and 'Paper drink box' (these were categories found in the Japanese WIO for the year 2000). These productions of waste appear as horizontal 'satellites' at the bottom of the IO table, while the different waste treatment sectors appear separately as columns at the end of the vertical part of the IO table. In tables 1, 3 and 5 below, the grey shaded areas represent the parts of the IO table that have been added onto the table by the introduction of waste data.

Figure 1 Pictorial mapping of economic and waste flows

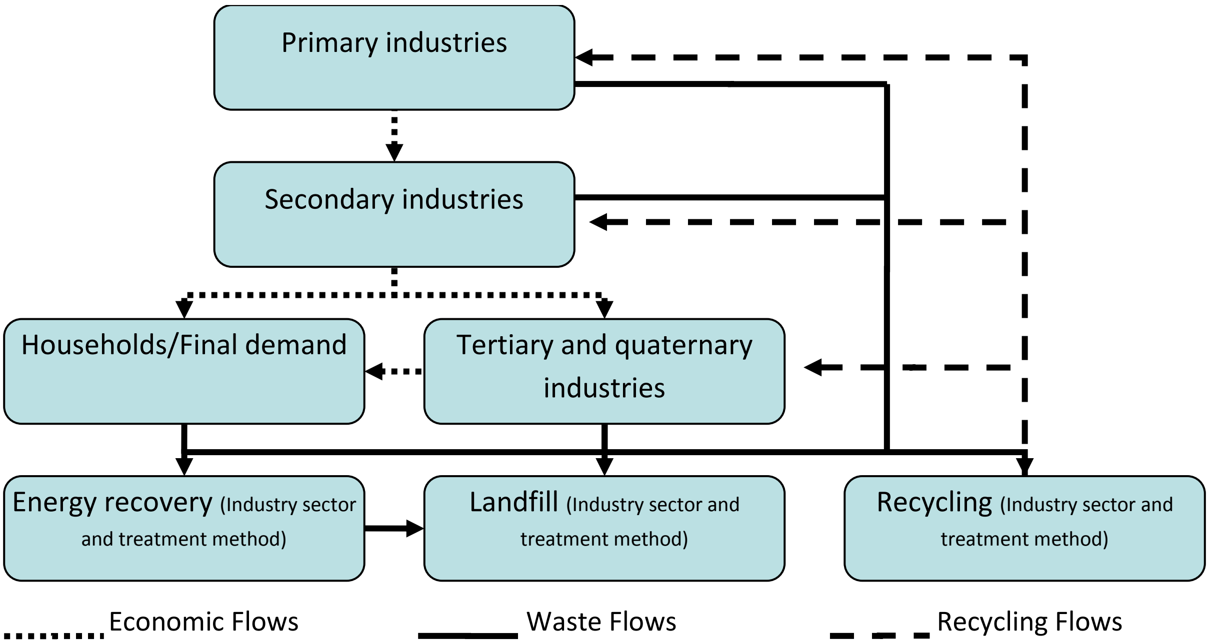

Table 1 The Waste Input-Output model

	Sector 1 ⋮	Waste treatment 1 ⋮ W treatment n	Final Demand	Total
Sector 1 … Sector n	$x_{i,i}$	$x_{i,ii}$	$x_{i,F}$	x_I
Waste generation Wg 1 … Wg n	$w_{w,i}$	$w_{w,ii}$	$w_{w,F}$	w_W
Other Satellite accounts	$I_{\bullet,i}$	$I_{\bullet,ii}$	$I_{\bullet,F}$	

Table 2 Allocation matrix S for Table 1

	Waste type Wg1 … Wg n
Treatment type (ie sector) Wt 1 … Wt n	

Melding WIO and MRIO

Taking into account the above issues posed by the literature, the author feels that the WMRIO presented hereafter will be best suited to follow in the methodological footsteps of Gallego and Lenzen (2009), Lenzen (2009) and Wiedmann, Geschke and Lenzen (2012). in regards to modeling the regions of Australia. While an amalgam of notation and frameworks from Tsukui and Nakamura (2010), Tsukui (2007), Kagawa et al (Kagawa, Inamura et al. 2004; Kondo, Kagawa et al. 2005; Kagawa, Nakamura et al. 2007; Tsukui, Ichikawa et al. 2011), and Nakaumra and Kondo (2009), in addition to Miller and Blair (Miller and Blair 2009), Gallego and Lenzen (2009), and Lenzen (2009) will be employed to construct the WMRIO.

As indicated by Nakaumra and Kondo (2009) and Miller and Blair (2009), the basic two region IRIO is given by

$$\begin{pmatrix} x^a \\ x^b \end{pmatrix} = \left\{ I - \begin{pmatrix} A^{aa} & A^{ab} \\ A^{ba} & A^{bb} \end{pmatrix} \right\}^{-1} \begin{pmatrix} f^{aa} + f^{ba} \\ f^{ba} + f^{bb} \end{pmatrix},$$

Where the first suffix on each vector and matrices refers to the region of origin and the second suffix refers to the region of use. In Gallego and Lenzen this is depicted by slightly different notation with the suffixes *r*, *s* indicating regional flows. Hence,

$$(x^r) = \{I - (A^{rs})\}^{-1}(f^{rs})$$

Waste is incorporated into this model via the extension of x, f , and A to waste and waste treatment. Thus (for a two region model),

$$(x^r) = \begin{pmatrix} x_I^r \\ x_{II}^r \end{pmatrix} \quad (r = a, b),$$

$$(f^{rs}) = \begin{pmatrix} f_I^{rs} \\ S^r \, w_f^{rs} \end{pmatrix} \quad (rs = a, b),$$

$$(A^{rs}) = \begin{pmatrix} A^{rs}_{I,I} & A^{rs}_{I,II} \\ S^r G^{rs}_I & S^r G^{rs}_{II} \end{pmatrix} \quad (rs = a, b),$$

As discussed by Nakamura and Kondo(2009), the ith element w_f^{rs}, $(w_f^{rs})_i$, refers to "the amount of waste i generated by the final demand of region s and treated or recycled in region r". Likewise, the ith row and jth column element of $A^{rs}_{I,II}$, $(A^{rs}_{I,II})_{ij}$ "refers to the input coefficient of good i produced in region r into waste treatment sector j in region s"; $(G^{rs}_{II})_{ij}$ "refers to the amount of waste i that is generated per unit activity of production sector j in region s, and treated or recycled in region r". The matrix G^{rs} also indicates the activity transporting waste from region s to region r, (the "input by regions s of waste management services into region r"). The allocation matrix that applies to region r is represented by S^r.

The S matrix: A short diversion about (waste) diversion

The environmental IO (EIO) model of Leontief (Leontief 1970) and Duchin (Duchin 1990) corresponds to the early development of the WIO model. Implicit in the EIO model is the assumption that there exists for each pollutant (waste) one <u>and only one</u> abatement (treatment) method that treats no other pollutant but that pollutant. This condition is hardly applicable to the reality of waste management because, in general, there is no one-to-one correspondence between a waste and its treatment method. It is usually the case that a multiplicity of treatment methods can be applied to a given solid waste, either separately or jointly. For instance, food waste can be composted, gasified, incinerated, or landfilled. Any of these methods can be applied separately or in combination.

Prior to the introduction of the WIO model, the one to one correspondence ($n^W = n^{II}$) of waste type and treatment methods was a limiting factor, that although enabling the analysis of waste in the economy, it did so at the expense of detailed analysis (Leontief 1970; Duchin 1990). Nakamura and Kondo (2002) overcame this barrier to detailed investigation via the elegant utilisation of an $n^{II} \times n^W$ matrix S. Termed the "allocation matrix", its (i, j) component refers to the share of waste j that is treated by treatment method i (Nakamura and Kondo 2002), with $\sum_i S_{ij} = 1$ due to the percentage like nature of the components of S_{ij}.

By the relaxation of restrictions found in previous EIOA/WIO style models, Nakamura and Kondo (2002) found that multiple pollutants can be treated by a single abatement process and the condition $n^W = n^{II}$ does not hold, rather $n^W \geq n^{II}$.This in turn means that several treatment methods can be utilised in conjunction with a single type of waste as each column can contain more than one non-zero element.

Multiplication from the left by S converts the net waste generation (as seen in the above table) into the net input of waste treatment services $\mathrm{X}_{\mathrm{I,II}} = S\,\mathrm{W}_{\cdot,\mathrm{I}}$ and $\mathrm{X}_{\mathrm{II,II}} = S\,\mathrm{W}_{\cdot,\mathrm{II}}$ and the net amount of waste treated into the n^{II} - vector of output of waste treatment sectors $\mathrm{x}_{\mathrm{II}} = S\,\mathrm{W}$ (Nakamura and Kondo 2008)

Thus, as given by (Nakamura and Kondo 2008) the quantity WIO is given as:

$$\begin{bmatrix}\mathrm{x}_{\mathrm{I}}\\ \mathrm{x}_{\mathrm{II}}\end{bmatrix} = \begin{bmatrix}\mathrm{A}_{\mathrm{I,I}} & \mathrm{A}_{\mathrm{I,II}}\\ \mathrm{SG}_{\cdot,\mathrm{I}} & \mathrm{SG}_{\cdot,\mathrm{II}}\end{bmatrix}\begin{bmatrix}\mathrm{X}_{\mathrm{I}}\\ \mathrm{X}_{\mathrm{II}}\end{bmatrix} + \begin{bmatrix}\mathrm{X}_{\mathrm{I,F}}\\ \mathrm{W}_{\cdot,\mathrm{F}}\end{bmatrix}$$

This can be solved for the net input to waste treatment services, as well giving the waste multipliers (if the inverse matrix exists):

$$\begin{bmatrix}\mathrm{x}_{\mathrm{I}}\\ \mathrm{x}_{\mathrm{II}}\end{bmatrix} = \left(\mathrm{I} - \begin{bmatrix}\mathrm{A}_{\mathrm{I,I}} & \mathrm{A}_{\mathrm{I,II}}\\ \mathrm{SG}_{\cdot,\mathrm{I}} & \mathrm{SG}_{\cdot,\mathrm{II}}\end{bmatrix}\right)^{-1}\begin{bmatrix}\mathrm{X}_{\mathrm{I,F}}\\ \mathrm{SW}_{\cdot,\mathrm{F}}\end{bmatrix}$$

This can be noted as a regional model,

$$\begin{bmatrix}\mathrm{x^r}_{\mathrm{I}}\\ \mathrm{x^r}_{\mathrm{II}}\end{bmatrix} = \left(\mathrm{I} - \begin{bmatrix}A_{I,I}^{rs} & A_{I,II}^{rs}\\ S^r\,G_I^{rs} & S^r\,G_{II}^{rs}\end{bmatrix}\right)^{-1}\begin{bmatrix}f_I^{rs}\\ S^r\,w_f^{rs}\end{bmatrix}$$

WIO and the Isard model

Nakamura and Kondo (2009) give the operational expanded form of the WIO Isard model as:

$$\begin{pmatrix} x_I^a \\ x_{II}^a \\ x_I^b \\ x_{II}^b \end{pmatrix} = \left\{ I - \begin{pmatrix} A_{I,I}^{aa} & A_{I,II}^{aa} & A_{I,I}^{ab} & A_{I,II}^{ab} \\ S^a G_I^{aa} & S^a G_{II}^{aa} & S^a G_I^{ab} & S^a G_{II}^{ab} \\ A_{I,I}^{ba} & A_{I,II}^{ba} & A_{I,I}^{bb} & A_{I.II}^{bb} \\ S^b G_I^{ba} & S^b G_{II}^{ba} & S^b G_I^{bb} & S^b G_{II}^{bb} \end{pmatrix} \right\}^{-1} \begin{pmatrix} f_I^{aa} + f_I^{ab} \\ S^a w_f^{aa} + S^a w_f^{ab} \\ f_I^{ba} + f_I^{bb} \\ S^b w_f^{ba} + S^b w_f^{bb} \end{pmatrix}$$

$$= \begin{pmatrix} B_{I,I}^{aa} & B_{I,II}^{aa} & B_{I,I}^{ab} & B_{I,II}^{ab} \\ H_I^{aa} & H_{II}^{aa} & H_I^{ab} & H_{II}^{ab} \\ B_{I,I}^{ba} & B_{I,II}^{ba} & B_{I,I}^{bb} & B_{I.II}^{bb} \\ H_I^{ba} & H_{II}^{ba} & H_I^{bb} & H_{ii}^{bb} \end{pmatrix} \begin{pmatrix} f_I^{aa} + f_I^{ab} \\ S^a w_f^{aa} + S^a w_f^{ab} \\ f_I^{ba} + f_I^{bb} \\ S^b w_f^{ba} + S^b w_f^{bb} \end{pmatrix}$$

A unique modification of the above is the inclusion of the H matrices (waste treatment activities) and matrices with suffixes of I, II as indicators of relationships and waste flows between regions. Nakamura and Kondo give the examples of $B_{I,II}^{ab}$, which represents "the effects on the production activities in region a of the treatment or recycling of waste in region b", while H_{II}^{ab}, indicates the effects upon region a's waste treatment activities of the treatment or recycling of waste in region b, and, H_I^{ba} shows the effects on the waste treatment activities in region b of the production activities in region a.

WIO and the Chenery-Moses Model

As stated previously, the Isard model requires detailed information on movements between regions of goods in order to operate. With the WIO this need for information is increased as waste flows (the origins of inputs and the destinations of waste) have also to be accounted for. The Chenery-Moses model is less demanding in terms of the information needed for its implementation, however depending on the purpose of analysis, it may not be correct in application.

As Nakaumra and Kondo (2009) indicate, this means that regionally decomposed matrices or vectors (i.e.A^{ab}, A^{ba}, G^{ab}, G^{ba}, and f^{ba} are not required, instead they are estimated "from the matrices and vectors of competitive types A^{a}, A^{b}, G^{a}, G^{b}, and f^{a}, which make no distinction about the origins of inputs or the destination of waste." This estimation is achieved by use of "share coefficients of imports" and "trade coefficients" of waste.

Technically, this means the vectors of d^{a} and m^{a} are now employed to refer to the total demand for input i in region a including imports (from region b), $(d^{a})_{i}$, and the import of i in region a (from region b), $(m^{a})_{i}$ respectively. The coefficients referring to the shares of competitive imports can thus be given as

$$\mu^{a} = m^{a}(\hat{d}^{a})^{-1}, \mu^{b} = m^{b}(\hat{d}^{b})^{-1}$$

Furthermore, the "trade coefficients" of waste between the two regions can be defined as follows:

$$\eta^{a} = h^{a}(\widehat{w}^{a})^{-1}, \eta^{b} = h^{b}(\widehat{w}^{b})^{-1}$$

Where the ith element of $\widehat{w}^{a}$, refers to the amount of waste i generated in region a, and the ith element of h^{a} refers to the portion of $(w^{a})_{i}$ was treated or recycled in region b. The coefficient $(\eta^{a})_{i}$ refers to the share of waste i that was generated in region a, and treated/recycled in region b. In other words, $(\eta^{a})_{i}$shows the extent to which region a depends on waste management service in region b for the treatment of waste i it generated. Assuming the constancy of these coefficients, the following Chenery-Moses version of the WIO model will be obtained (with more information available via Nakamura and Kondo (Nakamura and Kondo 2009)):

$$
\begin{pmatrix} x_I^a \\ x_{II}^a \\ x_I^b \\ x_{II}^b \end{pmatrix} = \left\{ I - \begin{pmatrix} (i-\hat{\mu}^a)A_{I,I}^a & (i-\hat{\mu}^a)A_{I,II}^a & \hat{\mu}^b A_{I,I}^b & \hat{\mu}^b A_{I,II}^b \\ S^a(i-\hat{\eta}^a)G_I^a & S^a(i-\hat{\eta}^a)G_{II}^a & S^a\hat{\eta}^b G_I^b & S^a\hat{\eta}^b G_{II}^b \\ \hat{\mu}^a A_{I,I}^a & \hat{\mu}^a A_{I,II}^a & (i-\hat{\mu}^b)A_{I,I}^b & (i-\hat{\mu}^b)A_{I.II}^b \\ S^b\hat{\eta}^a G_I^a & S^b\hat{\eta}^a G_{II}^a & S^b(i-\hat{\eta}^b)G_I^b & S^b(i-\hat{\eta}^b)G_{II}^b \end{pmatrix} \right\}^{-1}
\times \begin{pmatrix} (i-\hat{\mu}^a)f_I^a + \hat{\mu}^b f_I^b \\ S^a(i-\hat{\eta}^a)w_f^a + S^a\hat{\eta}^b w_f^b \\ \hat{\mu}^a f_I^a + (i-\hat{\mu}^b)f_I^b \\ S^b\hat{\eta}^a w_f^a + S^b(i-\hat{\eta}^b)w_f^b \end{pmatrix}
$$

Consideration upon the choice of Isard versus Chenery-Moses models

Both MRIO model types have qualities that lend themselves to being chosen as the preferred method of modeling waste flows in the Australian situation. However, the ability to accurately map the flows of waste inside Australia requires the use of the Isard model in preference to the Chenery-Moses model. This is due to the Isard's requirement for the origin and destination of waste at a regional level that leads to a better understanding of the flows rather than an estimation of them.

The choice of the Isard over Chenery-Moses choice does require a greater level of data. It is the hope of the author that the 2010 report by the Department of Environment, Water, Heritage and the Arts (2010) with additional data from the Australian Bureau of Statistics (ABS) and industry (2008; 2011; 2011) should provide enough data to trace the origin, processing and destination of the waste produced in Australia per year.

Australian peculiarities and data availability

Australia is a large country with a widely spread population. Sparsely populated regional areas contrast with Australia's state capitals where the greater amount of Australia's population resides. The wide spread of population across Australia has led to the various responsibilities of governing and civic administration being placed within three levels: federal, state or territory, and local (council) government. The management and disposal of waste - though an issue of national importance - is handled primarily by local government due to it being contemporarily understood as a community need, rather than a public health or environmental issue. This distance between major population centers has also led to waste being predominantly treated within the state of production. For example in 2003-4, 91% of Victorian waste was reprocessed within state boundaries (2005). Additionally, in 2006-7, 94% of Queensland's resource recovery was carried out inside state the boundary.

In Australia, the ABS regularly publishes national aggregated data available upon what the Municipal (Household); Commercial and Industrial; and Construction and Demolition sectors produces as waste (Australian Bureau of Statistics 2010; Australian Bureau of Statistics 2010). However, 'regional' data is more difficult to acquire, due to many local government departments having differing mandatory reporting levels and definitions of what is waste. Thus the state level can be seen to be the optimal level (at present) for a regional model for Australia.

Domestic and municipal waste is gathered from municipal curbside garbage and recycling collections, council garbage from litter bins, council waste from parks and gardens, and domestic waste brought to landfills and transfer stations. The greatest source of data on municipal waste is produced by local government bodies. Mason, Boyle et al (2011) wryly suggest that this is because they are the ones who have to actually manage waste. However, Mason, Boyle et al also highlight the problem of each local government body having their own methodology and reporting standards, thus weakening the data's own strength in addition to weakling the validity of the homogenized national data. This can in turn mean a lack of ability to aggregate waste data to achieve an accurate understanding of the entire waste picture of Australia at less than the national level (2010).

Commercial and industrial waste is generated by businesses, state and federal government and education, excluding waste collected by municipal collections. Data on this waste form can be found in State reports but for the most part is highly homogenized and aggregated (as mentioned above). Construction and demolition waste is waste from residential, civil and commercial construction and demolition (e.g. bricks, concrete, rubble, soil, rock). Australian and New Zealand Standard Industrial Classification (ANZSIC) codes are available but not yet matched specifically to waste generation data which poses a problem for ease of WIO implementation upon a general IO framework without assumption based disaggregation.

The end allocation point for waste in Australia differs from Japan. As mentioned by Reynolds (2011) and in the Department of Environment, Water, Heritage and the Arts report (2010) the most common waste disposal options that are utilised in Australia are to either landfill or recycle waste. Incineration has become illegal for most types of waste due to federal and state based environmental legalisation. Another difference is that waste water and liquid waste is categorised, treated and captured differently to Japan, with only 0.69% of the total national waste disposed of in this manner (2004). These variations from the methods for waste collection and treatment in Japan means that the WIO method and results will differ also.

Methodology: building a WMRIO for Australia

Referring to tables 5, 6 and 7 and following the foundations laid in the work of Wiedmann, Geschke and Lenzen (2012). This MRWIO model of waste flows in the Australian economy will be constructed along state and territory lines leading to 9 regions in total (New South Wales (NSW), Victoria (Vic), Queensland (QLD), Western Australia (WA), South Australia (SA), Tasmania (Tas), Northern Territory (NT), Australian Capital Territory (ACT) and Rest of World (ROW)). Both Gallego and Lenzen's (2009) model and the AUS-MRIO (Wiedmann, Geschke et al. 2012) operate with a 344 industry sectors ($n_o = 344$), this MRWIO will expand this with an addition of a minimum of three waste creation/emission (n_W) (Domestic and Municipal, Commercial and industrial, and, Construction and Demolition) and treatment (n_Z) (composting, recycling or landfill) sectors, (thus, $n_{w,}n_z \geq 3$), and n_F final demand sectors. Other satellite accounts have been kept out of this model for ease of display in the tables below.

In table 5, one can observe the WIO table setup for a single region (with the various waste types and treatments), as well as the S matrix and a squared table. All these steps are then expanded into a 9 region model. The shaded grey areas of the MRWIO represent each state/regions own WIO table, while the dotted areas represent cross regional flows.

Data sources

- *The blue book : Australian waste industry, 2007/08 industry and market report*. 2008, North Sydney, NSW: WCS Market Intelligence.
- *Inside waste industry report 2011-12*. 2011, Waste Management & Environment Media Pty Ltd: Gladesville, N.S.W.
- *National Waste Report 2010*, W. Environment Protection and Heritage Council and the Department of Environment, Heritage and the Arts, , Editor. 2010.
- *Annual Survey of Victorian Recycling Industries 2003-2004*. 2005, EcoRecycle Victoria: Melbourne.
- *The state of waste and recycling in Queensland 2007 Technical Report*. 2008, Environmental Protection Agency QLD.
- *PACIA 2011 National Plastics Recycling Survey July 2010 to June 2011 survey period*. 2011, The Plastics and Chemicals Industries Association, Sustainable Resource Use Pty Ltd,.
- (2010). *Recycling activity in Western Australia 2007-08 & 2008-09,* Department of Environment and Conservation, Western Australia, Hyder Consulting Pty Ltd.
- NA (2007). *South Australia's Waste Strategy 2005-2010* Benefit Cost Assessment Volume 2: Technical Report, ZeroWaste SA.
- (2009). *The Tasmanian Waste and Resource Management Strategy,* Environment Division Depar tment of Environment, Parks , Heritage and the Arts.

Table 3 Single region layout with 3 waste types and 3 treatments (square and non square matrix)

Non square matrix						
	Sector 1 …	Composting	Recycling	Landfill	Final Demand	Total
Sector 1 … Sector n	$x_{i,i}$				$x_{i,F}$	x_I
MSW						
C&I						
C&D						

Square matrix

	Sector 1 …	Composting	Recycling	Landfill	Final Demand	Total
Sector 1 … Sector n	$x_{i,i}$				$x_{i,F}$	x_I
Composting						
Recycling						
Landfill						

Table 4 Allocation matrix S for Table 5

	Composting	Recycling	Landfill
MSW			
C&I			
C&D			

Table 5 Full MR WIO table

		NSW		VIC		QLD		WA		SA		TAS		NT		ACT		ROW	
		IO	Waste	IO	Waste	IO	Waste	IO	Waste	IO	Waste	IO	Waste	IO	Waste	IO	Waste	IO	Waste
NSW	IO																		
	Waste																		
VIC	IO																		
	Waste																		
QLD	IO																		
	Waste																		
WA	IO																		
	Waste																		
SA	IO																		
	Waste																		
TAS	IO																		
	Waste																		
NT	IO																		
	Waste																		
ACT	IO																		
	Waste																		
ROW	IO																		
	Waste																		

Assumptions and changes from the Japanese model:

As the largest and most published upon WIO model, the Japanese WIO tables are a good practical application of the WIO methodology. Thus below we outline how an Australian WIO is both similar and different to the Japanese WIO, noting the assumptions and changes needed to make the Australian WIO as relevant to Australia as possible.

The S-matrix composition of this model differs from the Japanese WIO. This is due to the collection of waste data in Australia differing from Japan, because of the lack of incineration as a legal form of waste disposal in Australia. This paper seeks to classify only solid waste that is extracted via LGAs or corporations (as recorded by the ABS). It will not examine or attempt to capture waste water at the present time, nor illegal dumping or non-commercial waste treatment. In the Japanese condensed WIO, the S allocation matrix has the following waste categories: garbage; waste paper and textile; waste plastics; metal scraps; waste glass and ceramics; plant and animal waste; ash, dust, and slag, sludge; waste oil, acid, and alkali; construction debris; bulky waste; discarded automobiles; shredder dust. These are then treated by separation and shredding, incineration, and landfill (Nakamura and Kondo 2002). For ease of understanding the waste flows, at this stage the Australian WIO will have three categories: Domestic and Municipal, Commercial and Industrial, and, Construction and Demolition, with three treatment processes: composting, recycling or landfill (as previously mentioned Incineration is illegal). These categories can be disaggregated further in later research as the aggregated categories above are little use for life cycle or material flow analysis.

Technological considerations between states (regions): All of Australia's states are very similar in terms of the waste disposal technology and treatment methods available and in use on a large scale. However, each state's own environmental legislation (i.e. landfill levies, container deposit legislation, etc) and waste education campaigns have led to differences among states in terms of landfill use and recycling levels. For example, South Australia has become an exemplar case globally due to its proactive waste policy (2010; Reynolds 2011). Other technological factors can also be assumed (for now) to be common across the regions, with common external links also present (Cooper 1998). The product mix of each of region is assumed to be identical to that of the nation.

As in the case of Japan (Kagawa, Inamura et al. 2004), Australia also relies on the transport of waste to central processing areas (such as Material Recover Facilities (MRF) or landfills). However, due to the geographic size of each region (state) there is far less transport or movement of waste between regions until after sorting (recycling) has occurred. See the *National Waste Report 2010* for further details.

Finally, illegal dumping of waste is another blind spot in the Japanese model that will be carried through to an Australian model as there is little formal capture of the scale of this waste, though there are at present programs in many states to catalogue the scale of illegal dumping.

Conclusion

This paper has provided an overview of the modelling approaches and the issues surrounding the implementation of a Waste Input-Output (WIO) and Multi Regional Input-Output (MRIO) model to Australia. Giving a brief review of the history and theoretical construction techniques of WIO, this paper has outlined some of the challenges in creating a contemporary integrated MRWIO for Australia. It is understood that the combined MRIO and WIO model's data requirements are enormous and complex drawing upon many data sources, many of which will have to be estimated due to their lack of existence or ease of availability. Yet this should not put off the potential user, the rewards for such a comprehensive mapping of waste within an economy are great.

References

(2004). 8698.0 Waste Management Services, Australian Bureau of Statistics.

(2005). Annual Survey of Victorian Recycling Industries 2003-2004. Melbourne, EcoRecycle Victoria.

(2008). The blue book : Australian waste industry, 2007/08 industry and market report. North Sydney, NSW, WCS Market Intelligence.

(2010). National Waste Report 2010. W. Environment Protection and Heritage Council and the Department of Environment, Heritage and the Arts, .

(2010). Solid Waste in the World's Cities -WATER AND SANITATION IN THE WORLD'S CITIES 2010. London, United Nations Human Settlements Programme (UN-HABITAT).

(2011). Inside waste industry report 2011-12. Gladesville, N.S.W., Waste Management & Environment Media Pty Ltd.

(2011). PACIA 2011 National Plastics Recycling Survey July 2010 to June 2011 survey period, The Plastics and Chemicals Industries Association, Sustainable Resource Use Pty Ltd,.

Adams, P., J. Dixon, et al. (2010). MMRF: Monash Multi-Regional Forecasting Model: A Dynamic Multi-Regional Model of the Australian Economy. Working Paper Number G-223. Clayton, Victoria, The Centre of Policy Studies and the IMPACT Project.

Australian Bureau of Statistics (2010). 4602.0.55.002 ENVIRONMENTAL ISSUES: WASTE MANAGEMENT AND TRANSPORT USE. Canberra.

Australian Bureau of Statistics (2010). 4613.0 Australia's Environment Issues and Trends Special issue: Climate Change. Canberra.

Chenery, H. B. (1953). Regional Analysis. The Structure and Growth of the Italian Economy. H. B. Chenery, P. G. Clark and V. C. Pinna. Rome, US Mutual Security Agency**:** 97-129.

Cooper, R. J. (1998). "On The Assimilation of Regional Sample Information into Regional Input-Output Models Reluing on National Input-Output Data." Australasian Journal of Regional Studies **4**(1).

Dixon, P. B. and M. W. Peter (1996). "Export-Led Growth fo a Regional Economy: A CGE Analysis of a South Australian Export Project." Australasian Journal of Regional Studies **2**(1).

Duchin, F. (1990). "The conversion of biological materials and wastes to useful products." Structural Change and Economic Dynamics **1**(2): 243-261.

Gallego, B. and M. Lenzen (2009). Estimating generalized regional input-output systems: a case study of Australia. The Dynamics Of Regions And Networks In Industrial Ecosystems. Cheltenham, Northampton, MA, Edward Elgar Publishing.

Hartwick, J. M. (1971). "NOTES ON THE ISARD AND CHENERY-MOSES INTERREGIONAL INPUT-OUTPUT MODELS." Journal of Regional Science **11**(1): 73.

Isard, W. (1951). "Interregional and Regional Input-Output Analysis: A Model of a Space-Economy." The Review of Economics and Statistics **33**(4): 318-328

Isard, W., D. F. Bramhall, et al. (1960). Methods of Regional Analysis: An Introduction to Regional Science. New York, The Technology Press of MIT and John Wiley and Sons.

Jensen, R., Mandeville, et al. (1979). Regional Economic Planning: Generation of Regional Input-Output Analysus. London, Crook Helm.

Kagawa, S. (2012). Frontiers of environmental input-output analysis. Abingdon, Oxon ;New York, NY, Routledge.

Kagawa, S., H. Inamura, et al. (2004). "A Simple Multi-Regional Input Output Account for Waste Analysis." Economic Systems Research **16**(1): 1 - 20.

Kagawa, S., S. Nakamura, et al. (2007). "Measuring spatial repercussion effects of regional waste management." Resources, Conservation and Recycling **51**(1): 141-174.

Kondo, Y., S. Kagawa, et al. (2005). Inter-regional Waste Input-Output Linear Programming Model and Its Application to the Japanese Regions. Environmentally Conscious Design and Inverse Manufacturing, 2005. Eco Design 2005. Fourth International Symposium on.

Kondo, Y. K., Takase (2007). Waste Input-Output Analysis of Sustainable Consumption. Advances in life cycle engineering for sustainable manufacturing businesses: proceedings of the 14th CIRP Conference on Life Cycle Engineering. Y. U. Shozo Takata. Tokyo, Japan, Waseda University**:** 413-417.

Lenzen, M. (2009). "Understanding virtual water flows: A multiregion input-output case study of Victoria." Water Resour. Res. **45**(9): W09416.

Leontief, W. (1970). "Environmental Repercussions and the Economic Structure: An Input-Output Approach." The Review of Economics and Statistics **52**(3): 262-271.

Lin, C. (2009). "Hybrid input-output analysis of wastewater treatment and environmental impacts: A case study for the Tokyo Metropolis." Ecological Economics **68**(7): 2096-2105.

Mason, L., T. Boyle, et al. (2011). National Food Waste Assessment: Final Report. E. The Department Of Sustainability, Water, Population and Communities (DSEWPC). Sydney, Institute For Sustainable Futures (UTS), .

Miller, R. E. and P. D. Blair (2009). Input-output analysis: foundations and extensions, Cambridge University Press.

Moses, L. N. (1955). "The Stability of Interregional Trading Patterns and Input-Output Analysis,." American Economic Review **45**: 803-832.

Nakamura, S. (1999). Input-output analysis of waste cycles. Environmentally Conscious Design and Inverse Manufacturing, 1999. Proceedings. EcoDesign '99: First International Symposium On.

Nakamura, S. and Y. Kondo (2002). "Input-Output Analysis of Waste Management." Journal of Industrial Ecology **6**(1): 39-63.

Nakamura, S. and Y. Kondo (2002). "Recycling, landfill consumption, and CO2 emission: analysis by waste input–output model." Journal of Material Cycles and Waste Management **4**(1): 2-11.

Nakamura, S. and Y. Kondo (2002). Waste Input-Output Modle: concepts, data, and application. KEO discussion paper. No. G-153: Inter-disciplinary studies for sustainable development in Asian countries, Keio University.

Nakamura, S. and Y. Kondo (2008). Waste Input-Output Analysis, LCA and LCC. Handbook on Input-Output Economics in Industrial Ecology. S. Suh. New York, Springer: 561-572.

Nakamura, S. and Y. Kondo (2009). Waste Input-Output Analysis: Concepts and Application to Industrial Ecology. New York, Springer.

Nakamura, S. and E. Yamasue (2010). "Hybrid LCA of a Design for Disassembly Technology: Active Disassembling Fasteners of Hydrogen Storage Alloys for Home Appliances." Environmental Science & Technology **44**(12): 4402-4408.

Peter, M. W., M. Horridge, et al. (1996). The Theoretical Structure of MONASH-MRF. Working Paper Number OP-85. Clayton, Victoria, The Centre of Policy Studies and the IMPACT Project.

Reynolds, C. J. (2011). Climate Change on the Menu? A Retrospective Look at the Development of South Australian Municipal Food Waste Policy. Third International Conference on Climate Change: Impacts and Responses. Rio De Janeiro, Brazil

Reynolds, C. J., J. Boland, et al. (2011). An introduction to the Waste Input Output Model: a methodology to evaluate sustainable behaviour around (food) waste. Creating sustainable communities in a changing world. P. E. Roetman and C. B. Daniels. Adelaide, Crawford House Publishing.

Trendle, B. (1999). "Implementing a multiregional input-output model: The case of Queensland." Economic Analysis and Policy **29** (Special): 17-26.

Tsukui, M. (2007). Analysis of structure of waste emission in Tokyo by interregional waste input-output table. 11th International Waste Management and Landfill Symposium Sardinia.

Tsukui, M. (2007). " LCA of garbage disposal for household use by interregional waste inputoutput analysis." Journal of Life Cycle Assessment Japan **13**(4): 212-220.

Tsukui, M., T. Ichikawa, et al. (2011). A Regional WIO Analysis of the Effect of Non-residents' Consumption: A Comparison between Tokyo and Kyoto. 19th International Input-Output Conference. Alexandria, USA.

Tsukui, M. and K. Nakamura (2010). The impact and effects of modal shift of waste transportation by IR-WIO (interregional waste input-output) analysis. 18th International Input-Output Conference. Sydeny.

Wang, J. (2011). High Speed Rail and Regional Economic Development in Australia: A Multi-regional Input-Output Approach. 19th International Input-Output Conference. . Alexandria, USA.

West, G. and A. Gamage (2001). "Macro Effects of Tourism in Victoria, Australia: A Nonlinear Input-Output Approach." Journal of Travel Research **40**(1): 101-109.

West, G., J. Wilkinson, et al. (1979). Generation of regional input-output tables for the state and regions of South Australia (GRIT 2) : report to the Treasury Department, the Department of Urban and Regional Affairs and the Department of Trade and Industry / by G.R. West, J.T. Wilkinson and R.C. Jensen. St. Lucia, Qld. :, University of Queensland, Dept. of Economics.

West, G. R. (1990). "Regional Trade Estimation: A Hybrid Approach." International Regional Science Review **13**(1-2): 103-118.

Wiedmann, T., A. Geschke, et al. (2012). Input-Output Scenario Analysis - Using constrained optimisation to integrate dynamic model outputs. 20th International Input-Output Conference of the International Input-Output Association (IIOA). Bratislava, Slovakia.

Wiedmann, T., H. C. Wilting, et al. (2011). "Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis." Ecological Economics **70**(11): 1937-1945.