A Three Stage Reconciliation Method to Construct Time Series International Input-output Database

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Abstract

International trade statistics do not balance at the global level; giving rise to the humorous anecdote of Earth trading with Mars or the Moon. At the national level this can generally be ignored; the perspective being that the inconsistencies are in some other country's accounts. But when considering global accounts, and in particular in relation to analyses of global value chains and trade in value-added, these inconsistencies create significant problems. Analyses such as those related to trade in value-added require globally consistent input-output and supply-use tables. , This paper therefore develops a three stage optimization method to reconcile the official national accounts and detailed bilateral goods and services trade statistics, to produce a consistent global input-output database. At the first stage, the procedure reconciles total goods and services exports and imports recorded in each country's GDP by expenditure accounts with trade statistics at the product group level recorded in each country's supply and use tables. It results in a consistent time series of country and product group level total exports and imports, which satisfy the condition that world total exports plus a shipping (c.i.f.) margin equals world total imports. At the second stage, the procedure benchmark each country's supply and use tables with each country's GDP by expenditure account, using the global consistent exports supply and import demand estimates from the first stage as controls. At the final stage, the procedure allocates bilateral trade flows to producing/using industries and final users in each country based on international bilateral trade statistics broken down by end-use, resulting in a time series of bilateral trade statistics within a global supply-use table that records bilateral positions consistent with global control totals estimated in the first stage. Mirrored trade statistics are used as interval constraints in the final stage with a quality based reliability index for each bilateral trade flow by product group, to arrive at a final balanced global table that is consistent with the major components in each country's GDP by expenditure account.

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I. Introduction

There is increasing attention on global value chains and what has been described as trade in value-added to better understand the importance of trade to economic growth, jobs and material well-being in both academic and policy circles. A global value chain can be characterized as a chain that reveals how, and by how much, each industry involved in the production of a particular good or service contributes to the production of that good or service Within such a supply chain or production network, each producer purchases inputs and then adds value, which then becomes part of the cost (inputs) of the next stage of production. The sum of the value that is added at every stage in the chain equals the value of the final goods purchased at the end of the chain. Historically these chains were typically constrained within the economic borders of one country but in recent decades, driven by cheaper transport costs and lower tariffs, there has been an acceleration in chains that cross international borders (international fragmentation of production). This phenomenon has complicated analysis and policy making. Because goods and services can cross borders many times before they reach their final destination, the value of exports can overstate the importance of a given export to the exporting economy, as the export will embody value that has been added along the supply chain by industries in other countries.

Prior to this international fragmentation of production period, a single national input-output table could be used to give reasonably reliable estimates of how different industries within an economy participated in producing final goods, whether for domestic or export markets. But increased fragmentation has significantly changed the landscape. Imports of manufactured goods and services are increasingly being used as intermediate inputs in the production of goods and services within global value chains, and in addition the intermediate imports themselves increasingly embodied with value that was added in an upstream part of the value chain by the importing economy itself. The weaknesses in using a single country's input-output table to analyze and provide evidence on global value chains was recognized by a team of experts contracted by the U.S. National Research Council (NRC) [1] to study how much U.S. content was embodied in its imports and how much foreign content was embodied in its exports. They concluded (Leamer et al, 2006**)** that whilst it was possible to derive proxies of foreign contents in U.S. exports using solely a US input-output table, the results themselves, particularly those

[1] The committee was chaired by Professor Edward Leamer and consisted of members drawn from the council of National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

relating to the US content of imports, were highly dependent on the underlying assumptions. The most serious reservation the team has was the absence of harmonized supply and use (input output) tables that could be linked across countries.

Significant progress has been made since the NRC report however. The 1993 System of National Accounts for example recommended the development of supply-use tables, which has led to widespread use and development of these tables as a tool to balance GDP in most developed economies. Indeed, within the European Union it is a legal requirement to produce these tables, and the international statistics community has engaged in a number of initiatives to assist developing economies in this area.[2]

More recently the European Commission funded a consortium of eleven European research institutions and the OECD, to develop a time series of 'world' input-output tables, the World Input Output Database (or WIOD), covering 27 EU countries and 13 other major economies from 1995 to 2009. (Timmer et al.2012). In addition, the OECD has been actively involved in this area since the early 1990s, when it produced a set of harmonized input-output tables for 10 countries, expanding the coverage to over 20 in the early 2000s and to 58 economies today.

There has been widespread recognition within the official international statistics community that international fragmentation requires a new approach to how we measure trade, in particular the need to measure trade in value-added.[3] The needs and improvements in national statistics information systems led the OECD and WTO to launch a joint initiative on 15 March 2012: "Measuring trade in value-added" (www.oecd.org/trade/valueadded), which is designed to mainstream the production of trade in value added statistics and make them a permanent part of the statistical landscape. The first official release of this data is scheduled for 16 January 2013.

Underpinning this initiative is the creation of a global input-output table database (or tables that are as global in their coverage of countries as possible - the 58 countries in the OECD database for example reflect 95% of global GDP). But creating these tables is non-trivial and requires the leaping of a number of statistical hurdles. There are a numbers of attempts to compile global IO tables have been conducted in recent years (Kanemoto et al. (2012),

[2] ADB organized a project with participation of 17 developing countries (RETA 6483) in Asia Pacific to construct supply and use tables for each participating country.

[3] "International Trade Information Systems in 2020" Global Forum on Trade Statistics, Geneva, 2-4 February 2011, *Background note by UNSD, Eurostat and WTO*.

Wang(2011), Wang et al. (2012), Johnson and Noguera (2012) and the WIOD project), which has led to important improvements in the qualities of the estimated global IO tables. These include:

- Benchmark to official national accounts estimates of output and final consumption (as not all countries' supply-use tables are necessarily benchmarked to, nor revised in line with, their GDP by expenditure account).
- Assumptions used to allocate imports to users have moved away from the traditional crude "proportionality" assumption and now capture heterogeneities in imports from different sources based on the end use category that is available in trade statistic (UN Broad Economic Category classification);
- A recognition that shares rather than values per se are what matter in official bilateral trade statistics.

Besides these common features, each of these recent works has also provided additional useful experience in the construction of global IO tables, particularly in the context of balancing: an important point to note in this context concerns deficiencies in official trade statistics which show that global exports differ from global imports. A number of different approaches have thus far been adopted to estimate the balance tables. For example, Wang (2011) introduced estimates of initial data reliability to guide the balancing process, Lenzen et al. (2012) proposed a method to estimate the standard error for each cell in the global IO tables to assess their reliability and uncertainty using data of constraint violation and discrepancies between balanced IO table and unbalanced initial estimates.[4]

Another important improvement is the use of supply-use tables as the starting point to integrate trade statistics and derived the final symmetric world IO table, the approach adopted by WIOD. Intuitively this approach makes sense as it links trade statistics (which are product based) with the product statistics in the supply-use table in one hand, and value-added/employment data (that is industry-based) with industry statistics in the supply-use tables in the other hand. It also avoids errors inherent in the assumptions imposed when transferring SUTs to symmetric IO tables before the reconciliation process even start. However, as pointed by Streicher and Stehrer (2012) the current WIOD method has two major unsolved issues: first, its international

[4] See also Lenzen et al (2012).

transportation margins were assumed as being produced in the rest of the world by the "Panama assumption" and not linked back to the world economy. Second, exports to rest of the world were derived as residuals to balance world exports and imports, which resulted in negative exports from some countries in several products.[5] To overcome these problems, Streicher and Stehrer (2012) proposed a method to construct a trade matrix of cif/fob margins together with supply and use tables for the Rest of the World. This results in a consistent global SUT system with international transportation services balanced at the global level.

Building on the experiences of these recent works this paper develops a mathematical programming model to integrate individual country Supply-Use Tables (SUTs) with detailed bilateral trade statistics using a three-stage reconciliation procedure to produce a consistent annual global SUT database. The procedure solves the inconsistencies in trade statistics and data from different sources using a system of simultaneous equations that minimize a quadratic penalty function that only allow minimum deviation from both official SUTs and bilateral trade statistics.

The model deals with the data reconciliation problem at the global level first by reconciling official estimates of each country's total merchandise and service trade statistics reported in each country's national accounts with reported total exports to and imports from the world at product level in that country's SUTs. It results in a set of country and product level total exports and imports which satisfy the condition that world total exports (f.o.b) plus a shipping margin (c.i.f.) equals world total imports (cif). The use of international margin services is also balanced with its supply from margin producing industries at the global level simultaneously similar to Streicher and Stehrer (2012), but achieved in a unified modeling framework. At the second stage, the model reconciles each country's SUTs with the global consistent exports and imports data from the first stage. At the third and final stage, the model integrates individual country's SUTs with international bilateral trade statistics by distributing each country's total exports and imports in every commodity group to its trading partners based on bilateral trade shares computed from OECD bilateral trade in goods and services data, taking each country's

[5] See page 38 in Timmer et al. (2012) for details.

total exports to and imports from the world derived from the first stage as controls and adjusting their distribution among partner countries to produce a consistent annual global SUT[6].

The rest of the paper is organized as follows: Section II specifies the three stage procedure for National Accounts and official trade statistics reconciliation. Section III describes the major data sources used to implement and test the procedure. Section IV presents preliminary test results and provides some description on how the official statistics were adjusted. Section V concludes with a discussion on directions for future work.

II. The Three Stage Reconciliation Procedure

2.1 -Stage 1

In the first stage, the model reconciles global trade statistics. A key in this step is to estimate the reconciled value of total global exports and imports and each country's total imports and exports on goods and services that form part of this global total. The starting point is estimates of trade available in official national accounts statistics[7] of GDP by Expenditure. Prior to reconcile these national estimates, differences between total exports and imports in fob price are generally less than1-2% of global exports for most the years in the period covered (see detailed discussion in the data source section).

Using such data as controls, we adjust exports and imports in each country's SUTs provided in WIOD (by product) based on a reliability index of exporters and importers[8] to obtain a set of country by product exports and imports estimates which satisfies the condition that total global exports equals total global imports for each product. Purchases in the domestic territory by non-residents and direct purchases abroad by residents are treated as a special product in the balancing procedure. This global consistent trade data set is used as a control to rebalance each country's SUTs in Stage 2, before bilateral trade by product and end use are introduced to obtain the international SUTs in the final, third, stage.

The notations used to specify the first stage programming model are as follows:

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[6] One important spillover from the model is its ability to produce updated global SUT tables as and when (normal) revisions to GDP and trade statistics occur (i.e. excluding revisions related to conceptual changes in the accounting framework, such as the capitalization of R&D in the 2008 SNA).
[7] Sourced from OECD National Accounts database and UN National Accounts,
[8] We are grateful to Mark Gehlhar for providing such estimates from 1995 to 2007.

E_{ct}^{s} = Exports to the world of commodity group *c* by country *s* at year t, fob prices

M_{ct}^{r} = Imports from the world of commodity group *c* by country *r* at year t, cif prices

WE_{kt}^{s} = Total exports (K$\in${G=goods, S=services, T=total}) to the world by country s, fob price

WM_{kt}^{r} = Total imports (K$\in${G=goods, S=services, T=total}) from the world by country r, fob price

CIF_{ct}^{r} = Cost, Insurance and Freight for country r's total imports of commodity group c from the world at time t

$Eadj_{kt}^{s}$ = Purchase in the domestic territory by non-residents

$Madj_{kt}^{r}$ = direct purchases abroad by residents

RIX_{i}^{s} = reporter reliability index of commodity i by exporter s

RIM_{i}^{r} = reporter reliability index of commodity i by importer r[9].

To be consistent with the official statistics in an individual country's SUTs and National Accounts, the product level exports and imports are valued at fob and cif price respectively, but total exports and imports of goods and services are valued at fob prices. Product index *c* is defined over commodity set C $\in\{1, 2, \ldots, n\}$ and divided into three subsets: Goods CC, non-margin services CS and margin service CT; country indices *s* and *r* are defined over country set G $\in\{1, 2, \ldots, g\}$. Variables without zero are endogenous in the model, and variables with a zero are parameters, exogenous to the model. Using the above notation, the first stage programming model is specified as:

Objective function at each year t:

$$\text{Min } S=\frac{1}{2}\left\{\begin{aligned}&\sum_{s=1}^{g}\sum_{c=1}^{n}\frac{(E_{ct}^{s}-E0_{ct}^{s})^2}{(1-RIX_{ct}^{s})E0_{ct}^{s}}+\sum_{r=1}^{g}\sum_{c=1}^{n}\frac{(M_{ct}^{r}-M0_{ct}^{r})^2}{(1-RIM_{ct}^{r})M0_{ct}^{r}}+\sum_{c=1}^{n}\frac{(CIF_{ct}-CIF0_{ct})^2}{(1-RIM_{ct})CIF0_{ct}}\\&+\sum_{r=1}^{g}\sum_{k=s,g,t}\frac{(Eadj_{kt}^{r}-Eadj0_{kt}^{s})^2}{Eaj0_{kt}^{s}})+\sum_{r=1}^{g}\sum_{k=s,g,t}\frac{(Madj_{kt}^{r}-Madj0_{kt}^{r})^2}{Maj0_{kt}^{r}})\\&+100(\sum_{s=1}^{g}\sum_{k=s,g,t}\frac{(WE_{kt}^{s}-WE0_{kt}^{s})^2}{(1-RIX_{t}^{s})WE0_{kt}^{s}}+\sum_{r=1}^{g}\sum_{k=s,g,t}\frac{(WM_{kt}^{r}-WM0_{kt}^{r})^2}{(1-RIM_{t}^{r})WM0_{kt}^{r}})\end{aligned}\right. \quad (1)$$

[9] Definition of these reporter reliability indexes and their estimation will be discussed in detail later at section 3.

Constraints at each year t:

Country total exports

$$\sum_{c} E_{ct}^{s} + Eadj_{kt}^{s} = WE_{kt}^{s} \qquad \text{for all s and k} \qquad (2)$$

Country total imports

$$\sum_{c} (M_{ct}^{r} - CIF_{ct}^{r}) + Madj_{kt}^{r} = WM_{kt}^{r} \qquad \text{for all r and k} \qquad (3)$$

World market equilibrium at commodity group level for goods trade

$$\sum_{s=1}^{g} (E_{ct}^{r} + CIF_{ct}^{r}) = \sum_{r=1}^{g} M_{ct}^{r} \qquad c \in CC \text{ for goods trade only} \qquad (4)$$

World market equilibrium at commodity group level for non-margin services trade

$$\sum_{s=1}^{g} E_{ct}^{s} = \sum_{r=1}^{g} M_{ct}^{r} \qquad c \in CS \text{ for non-margin services trade only} \qquad (5)$$

International margin service supply and demand balance (6)

$$\sum_{r=1}^{g} \sum_{c \in CS} CIF_{ct}^{r} = \sum_{r=1}^{g} \sum_{c \in CT} (E_{ct}^{s} - M_{ct}^{r}) \quad c \in CT \text{ for margin services trade only} \qquad (7)$$

World market equilibrium for goods trade

$$\sum_{s=1}^{g} WE_{G,t}^{s} = \sum_{r=1}^{g} WM_{G,t}^{r} \qquad (8)$$

World market equilibrium for service trade (include margin trade)

$$\sum_{s=1}^{g} WE_{S,t}^{s} - \sum_{r=1}^{g} \sum_{c \in CT} CIF_{ct}^{r} = \sum_{r=1}^{g} WM_{S,t}^{r} \qquad (9)$$

Total world exports equals total world imports

$$\sum_{s=1}^{g} WE_{T,t}^{s} = \sum_{r=1}^{g} WM_{T,t}^{r} \qquad (10)$$

The model is used to reconcile official national account data on *goods* and *services* trade statistics ($WE0_{kt}^{s}$ and $WM0_{kt}^{r}$) with each country's reported total exports to and imports from the world at commodity group level ($E0_{ct}^{s}$ and $M0_{ct}^{r}$) recorded in each country's national SUTs. It results in a set of country and product level total exports and imports, along with the value of transport costs by country and commodity group, which satisfy the condition that world total exports plus a shipping cost equal world total imports for all products and services, including international transportation services.

2.2 Stage 2

To adjust each country's exports and imports in its SUTs[10] to the global consistent trade data set solved from stage 1, we also use a constrained quadratic programming model which minimizes the weighted sum of squares of deviations from the benchmark SUTs in value-added, intermediate inputs, and gross outputs, and in all final expenditure categories, over all industries, subject to the following five sets of constraints:

1. for each industry, total intermediate inputs purchased from all commodity groups and all sources (domestic and imported) as well as value-added generated by the industry sum up to the industry's total gross output;
2. for each product group, the amount sold to all industries as domestic intermediate inputs plus the amount sold to final users as domestic final goods and services plus the amount of domestic exports equal total product output produced by the industries;
3. for each product group, the imported intermediates used by all industries plus the amount of imported final goods used by all users plus the amount of goods re-exported minus a re-exports mark-up, equal total imports of that commodity group; which is fixed at the global consistent level of gross imports solved from stage 1;
4. the domestic exports plus re-exports equals each product groups' gross exports; which is also fixed at the global consistent level solved from stage 1;
5. the sum of each type of final domestic demand by product group plus net tax on products equals total final domestic demand for each category as recorded in each country's GDP by expenditure account.

Let us define *x, z, v, y* as country r's gross output, intermediate inputs, value-added, final domestic demands respectively, *mg, mgi, mgy, ntx, ntxi, ntxy* are the total, intermediate and final goods transportation margins and net taxes respectively, *wx, wz, wv, wy, wg, wt* are their corresponding reliability weights. We index products and industries by subscripts (c, i), value-

[10] And also to estimates SU tables between benchmark years when annual tables are not available.

added categories by subscript f, and final domestic demand categories by subscript k, respectively. The variables with “0” stand for the initial estimates of the variables. There are n+1 (adjusted for Non-resident purchases in domestic markets and residents' direct purchases abroad which are treated as a special product) product groups, m industries, l value-added categories (compensation for employees, indirect tax, operating surplus, and depreciation), and h domestic final demand categories(household consumption, government spending, gross fixed capital formation, and changes in inventory). All variables are evaluated at basic prices, except net taxes, which are evaluated at purchasers' prices.

Using the notations defined above, the second stage optimization model can be formally specified as follows:

Objective function at each year t for country r:

$$\begin{aligned}\mathrm{Min\,S} = \frac{1}{2}\Bigg\{ & \sum_{c=1}^{n}\sum_{i=1}^{m}\frac{(z_{cit}^{r}-z0_{cit}^{r})^{2}}{wz_{cit}^{r}} + \sum_{i=1}^{m}\sum_{c=1}^{n}\frac{(x_{ict}^{r}-x0_{ict}^{r})^{2}}{wx_{ict}^{r}} + \sum_{i=1}^{m}\sum_{f=1}^{l}\frac{(v_{ift}^{r}-v0_{ift}^{r})}{wv_{ift}^{r}} \\ & + \sum_{c=1}^{n}\sum_{k=1}^{h}\frac{(y_{ckt}^{r}-y0_{ckt}^{r})^{2}}{wy_{ckt}^{r}} + \sum_{c=1}^{n}\sum_{k=1}^{h}\frac{(mgy_{ckt}^{r}-mgy0_{ckt}^{r})^{2}}{wg_{ckt}^{r}} + \sum_{i=1}^{m}\sum_{c=1}^{n}\frac{(mgi_{cit}^{r}-mgi0_{cit}^{r})^{2}}{wg_{cit}^{r}} \\ & + \sum_{c=1}^{n}\sum_{k=1}^{h}\frac{(ntxy_{ckt}^{r}-ntxy0_{ckt}^{r})^{2}}{wt_{ckt}^{r}} + \sum_{i=1}^{m}\sum_{c=1}^{n}\frac{(ntxi_{cit}^{r}-ntxi0_{cit}^{r})^{2}}{wt_{cit}^{r}}\Bigg\}\end{aligned} \tag{11}$$

Constraints at each year t for country r:

balance condition for industrial gross output and input cost at basic prices:

$$\sum_{c=1}^{n}(z_{cit}^{r}+ntxi_{cit}^{r})+\sum_{f=1}^{l}v_{ift}^{r}=\sum_{c=1}^{n}x_{ict}^{r} \qquad \text{for all i} \tag{12}$$

balance condition for total product supply and use at basic prices:

$$\sum_{i=1}^{m}z_{ict}^{r}+\sum_{k=1}^{h}y_{ckt}^{r}+E_{ct}^{r}=\sum_{i=1}^{m}x_{ict}^{r}+M_{ct}^{r} \qquad \text{for all c} \tag{13}$$

Balance condition for margin service supply and use

$$\sum_{i=1}^{m}mgi_{ict}^{r}+\sum_{k=1}^{h}y_{ckt}^{r}=mg_{ct}^{r} \qquad \text{for all c} \tag{14}$$

$$\sum_{c=1}^{n}mgi_{ict}^{r}=0 \qquad \text{for all i} \tag{15}$$

$$\sum_{c=1}^{n}mgy_{ckt}^{r}=0 \qquad \text{for all k} \tag{16}$$

Balance condition for net taxes in use and supply tables :

$$\sum_{i=1}^{m} ntxi_{ict}^{r} + \sum_{k=1}^{h} ntxy_{ckt}^{r} = ntx_{ct}^{r} \qquad \text{for all c} \qquad (17)$$

Gross exports and aggregate expenditure components constraints:

$$de_{ct}^{r} + re_{ct}^{r} = E_{ct}^{r} \qquad \text{for all i} \qquad (18)$$

$$\sum_{c=1}^{n+1} (y_{ckt}^{r} + mgy_{ckt}^{r} + ntxy_{ckt}^{r}) = GDPE0_{kt}^{r} \qquad \text{for all k} \qquad (19)$$

GDP from the production side:

$$\sum_{i=1}^{m}\sum_{f=1}^{l} v_{ift}^{r} + \sum_{i=1}^{m} ntxi_{ict}^{r} = GDP_{t}^{r} \qquad (20)$$

GDP from the expenditure side

$$\sum_{k=1}^{n} GDPE_{kt}^{r} + \sum_{c=1}^{n+1} (E_{ct}^{r} - M_{ct}^{r})] = GDP_{t}^{r} \qquad (21)$$

Constraints 12 to 21 show that the supply and use tables are jointly used to ensure all the national accounting identities hold during the data reconciliation process. The adjustment made by the model to *initial* estimates in individual country's SUT does not necessarily change a country's GDP statistics nor any of the major aggregates of domestic expenditure components in the National Accounts, although countries total exports and imports, and so their balance of trade with the world may change due to the adjustment needed to reconcile global trade imports and exports. This seems counter intuitive because a country's balance of trade (BOT) s part of its GDP accounting identity, so a change in BOT should result in a change in GDP. However, as noted earlier, SUTs compiled by national statistical institutions are not always frequently revised in line with official GDP statistics, therefore GDP computed from national SUTs do not necessarily equa official GDP statistics. In addition, statistical discrepancies often exist in some countries' GDP by expenditure account. Therefore, when our model eliminates the small discrepancy between global exports and imports (1-2% global exports each year) in official trade statistics, depending on the weights used in the reconciliation process, the model returns balanced GDP (expenditure) estimates which typically do not differ from official GDP statistics. Typically the weighting process means that in cases where modifications occur, they are most likely to occur in those countries where there are statistical discrepancies between GDP computed and published in their SUTs and expenditure based

GDP estimates from the latest national accounts - in other words the procedure also removes these statistical discrepancies in national accounts (if they exist) together with discrepancies between global exports and imports [11].

2.3 Final Stage

A world supply and use table is a comprehensive account of annual transaction and payment flows within and between countries. We use the following notation to describe the elements of the world supply and use table (expressed in annual values):

x^{r}_{ict} = Gross output of product c from industry *i* in country *r*;

v^{r}_{it} = Direct value added by production of industry *i* in country *r*;

z^{sr}_{cit} = Product c produced by industry i in country *s* and used as an intermediate input by sector *i* in country *r*;

y^{sr}_{ckt} = Product c produced in country *s* for final use in final demand type 'k' in country *r;*

$cifi^{sr}_{ct,cit}$ = cif margin by margin service ct for intermediate goods c used in industry i in country r;

$cify^{sr}_{ct,ckt}$ = cif margin by margin service ct for final goods use in final expenditure category k in country r;

tfl^{sr}_{c} =bilateral trade flow of product c from country s to country r;

Thus the model used in the final stage of the reconciliation process can be defined as follows:

Objective function at each year t:

$$\mathrm{Min}\, S = \frac{1}{2}\left\{\sum_{s=1}^{g}\sum_{r=1}^{g}\sum_{c=1}^{n}\sum_{i=1}^{m}\frac{\left(z^{sr}_{cit}-z0^{sr}_{cit}\right)^{2}+\left(cifi^{sr}_{ct,cit}-cifi0^{sr}_{ct,cit}\right)^{2}}{wz^{sr}_{cit}} + \sum_{s=1}^{g}\sum_{r=1}^{g}\sum_{c=1}^{n+1}\sum_{k=1}^{h}\frac{\left(y^{sr}_{cit}-y0^{sr}_{cit}\right)^{2}+\left(cify^{sr}_{ct,cit}-cify0^{sr}_{ct,cit}\right)^{2}}{wy^{sr}_{cit}}\right\} \qquad (22)$$

Constraints at each year t:

Balance condition for industrial gross output and input cost at basic prices:

[11] In some ways one can draw analogies here with balancing procedures used in some countries, for example methods that take an average of GDP (I), (O) and (E) approaches, where a balance is forced by convention. Our approach also forces a balance but using an approach that weights initial estimates by their reliability.

$$\sum_{s=1}^{g}\sum_{c=1}^{n}(z_{cit}^{sr}+ntxi_{ict}^{r})+\sum_{s=1}^{g}\sum_{c=1}^{n}\sum_{c\in CT}cifi_{c,ccit}^{sr}+\sum_{f=1}^{l}v_{ift}^{r}=\sum_{c=1}^{n}x_{ict}^{r} \tag{23}$$

Balance condition for total product supply and use at basic' prices:

$$\sum_{i=1}^{m}\sum_{r=1}^{g}z_{ict}^{sr}+\sum_{k=1}^{h}\sum_{r=1}^{g}y_{ckt}^{sr}=\sum_{i=1}^{m}x_{ict}^{s} \tag{24}$$

Equation (23) defines the value of gross output from industry i country *r* as the sum of the values from all of its (domestic plus imported) intermediate and primary factor inputs. Equation (24) states that total gross output of product group *c* in country *s* is equal to the sum of its deliveries to intermediate and final users for all countries (including itself) in the world. This global SUT account has to be consistent with each individual country's SUT account and international trade statistics, which requires the following accounting identities also to be satisfied each year:

Constraint for intermediate use in the national use tables:

$$\sum_{s=1}^{g}z_{cit}^{sr}=z0_{cit}^{r} \tag{25}$$

Constraint for final demand in the national use tables:

$$\sum_{s=1}^{g}y_{ckt}^{sr}=y0_{ckt}^{r} \tag{26}$$

Constraints for bilateral trade flows at cif prices, to include international transportation service in a consistent way, the accounting equation for bilateral trade is split over goods and services:

$$\sum_{i=1}^{m}z_{cit}^{sr}+\sum_{i=1}^{m}\sum_{c\in CT}cifi_{c,cit}^{sr}+\sum_{k=1}^{h}y_{ckt}^{sr}+\sum_{i=1}^{m}\sum_{c\in CT}cify_{c,ckt}^{sr}=\mathrm{tfl}_{\mathrm{ct}}^{\mathrm{sr}} \quad \text{for c in CC} \tag{27b}$$

$$\sum_{i=1}^{m}z_{cit}^{sr}+\sum_{k=1}^{h}y_{ckt}^{sr}=\mathrm{tfl}_{\mathrm{ct}}^{\mathrm{sr}} \quad \text{for c in CS and CT} \tag{27b}$$

Range constraints for bilateral trade flows based on official mirror trade statistics:

$$MIN(\mathrm{tflx0}_{\mathrm{ct}}^{\mathrm{sr}},\mathrm{tflm0}_{\mathrm{ct}}^{\mathrm{sr}})\le \mathrm{tfl}_{\mathrm{ct}}^{\mathrm{sr}}\le MAX(\mathrm{tflx0}_{\mathrm{ct}}^{\mathrm{sr}},\mathrm{tflm0}_{\mathrm{ct}}^{\mathrm{sr}}) \tag{28}$$

Where $\mathrm{tflx0}_{\mathrm{ct}}^{\mathrm{sr}}$ and $\mathrm{tflm0}_{\mathrm{ct}}^{\mathrm{sr}}$ are reporting country s' reported exports to country r and partner country r's reported imports from country s.

Constraint for exports at fob prices in national use tables (solved from the first stage) is split over three product sets: Goods CC, non-margin services CS and margin service CT:

:

$$\sum_{r\neq s}^{g}\sum_{i=1}^{m} z_{cit}^{sr} + \sum_{r\neq s}^{g}\sum_{k=1}^{h} y_{ckt}^{sr} = E_{ct}^{s} \qquad \text{for c in CC} \tag{29a}$$

$$\sum_{r\neq s}^{g} tfl_{ct}^{sr} = E_{ct}^{s} \qquad \text{for c in CS} \tag{29b}$$

$$\sum_{r\neq s}^{g} tfl_{ct}^{sr} \sum_{i=1}^{m}\sum_{c\in CC} cifi_{ct,cit}^{sr} + \sum_{i=1}^{m}\sum_{c\in CC} cify_{ct,cckt}^{sr} = E_{ct}^{s} \text{ for c in CT} \tag{29c}$$

Constraint for imports at cif prices in national supply tables (solved from the first stage):

$$\sum_{s\neq r}^{g} tfl_{ct}^{sr} = M_{ct}^{r} \tag{30}$$

Equation (29) indicates that a country's total delivery of final goods and services to other countries for product group c must equal its gross exports at fob price, which include both domestic exports and re-exports (if applicable) as well as international transportation services from its margin producing industries. Equation (30) states each country's demand for imports of intermediate and final goods and services (plus its re-exports if applicable) equal the country's total gross imports from international markets at cif prices.

Constraint for country specific cif margins (solved from the first stage):

$$\sum_{c\in CT}\sum_{s\neq r}^{g}\left(\sum_{i=1}^{m} cifi_{ct,cit}^{sr} + \sum_{k=1}^{h} cify_{ct,ckt}^{sr}\right) = CIF_{ct}^{r} \tag{31}$$

Constraint for margin services product structure:

$$\sum_{c\in CC}\sum_{s\neq r}^{g}\left(\sum_{i=1}^{m} cifi_{c,ccit}^{sr} + \sum_{k=1}^{h} cify_{c,cckt}^{sr}\right) = \sum_{r=1}^{g}(E_{ct}^{s} - M_{ct}^{r}) \qquad c \in \text{CT} \tag{32}$$

GDP and aggregate domestic expenditure constraints:

$$\sum_{c=1}^{n+1}\left(\sum_{s=1}^{g}\left(\sum_{c\in CT} cify_{c,cckt}^{sr} + y_{ckt}^{sr}\right) + mgy_{ckt}^{r} + ntxy_{ckt}^{r}\right) = GDPE0_{kt}^{r} \tag{33}$$

GDP from the production side:

$$\sum_{i=1}^{m}\sum_{f=1}^{l}(v_{ift}^{r} + ntxi_{ict}^{r}) = GDP_{t}^{r} \tag{34}$$

GDP from the expenditure side

$$\sum_{k=1}^{n} GDPE_{kt}^{r} + \sum_{c=1}^{n+1}(E_{ct}^{r} - M_{ct}^{r})] = GDP_{t}^{r} \tag{35}$$

Equations (23) to (35) must hold for all $i \in$ M, $k \in$ H and $s, r \in$ G in each year.

The optimization problem in the last stage of our data reconciliation procedure is formulated to minimize a quadratic penalty function (equation 22) subject to constraints (23) through to (35).

There are several desirable theoretical properties of such a mathematical programming approach for data reconciliation. As discussed by Harrigan (1990), Canning and Wang (2004) and Wang, Gehlhar and Yao (2010), by imposing valid binding constraints, the optimization procedure will definitely improve, or at least not worsen, the initial statistics estimates. The weights (wz_{ij}^{sr} , wy_{ic}^{sr}) in the objective functions play a very important role in the data reconciliation process. By design they minimize the adjustment made to original data known to be of high quality, typically leaving these estimates largely unchanged, but allow changes (albeit typically small) to be made to data where reliability problems exist.

The advantages of such an optimization framework in data reconciliation are also significant from an empirical perspective. First, it provides considerable flexibility in achieving global coherence. It encapsulates a wide range of initial information that is used efficiently in the data reconciliation process. Additional constraints can also be easily imposed to allow, for example, upper and lower bonds to be placed on unknown elements (this is very common in mirror trade statistics), or inequality conditions to be added. It is also very flexible regarding to the required known information and accommodates and corrects for missing data in certain blocks of the SUTs, as long as the sum of the elements within the block is known. Such flexibility is important in terms of improving the information content of the final balanced estimates as shown by Robinson et al. (2001).

Second, the optimization approach permits alternative measures of the reliability of the initial data to be easily included in the reconciliation process, such that it is able to take account of improvements, say, in the statistical information system used in, and so reliability in the statistics of a given country. The idea of including data reliability weights in data reconciliation can be traced back to Stone (1942) when he explored procedures for compiling national income accounts. As noted before, these weights should reflect the relative reliability of the initial statistics. Using properly selected reliability weights, the optimal solution should yield estimates that deviate less from the initial estimates with higher degrees of reliability than for those with lower degrees of reliability.

The three-stage reconciliation procedure described above is solved with an optimization software package GAMS/CPLEX.[12] Optimal solutions from this procedure are equivalent to the estimates produced by generalized least square estimations (GLS).[13]

III Implementation and Numerical Testing of the Model

The key in implementing the three-stage recompilation procedure to produce a global balanced SUT database is to carefully link each variable in the model with the best available statistics. Official statistics are reported regularly by national or international statistical agencies. This section documents the data sources used to initialize and test the model and introduce the reliability weights used in the objective function at the first and final stages of the recompilation procedure.

3.1 Data Sources

Our objective is to conduct a preliminary feasibility test of the model by integrating the individual country Supply and Use tables, official national accounts and international trade statistics. Country SUTs are obtained from WIOD, which cover 27 EU member countries and other 13 major economies in the world from 1995 to 2009. We also estimate SUT for the rest of the world based on official national accounts statistics and OECD intermediate data sources used to compile the OECD's Inter-country Input-Output Database. The rest of the world is developed from the input-output/supply and trade in services of 15 countries[14] and trade in goods of all countries where UN COMTRADE data are available, with industries aggregated to the 35 sectors used in WIOD, based on ISIC Rev3. Therefore, the product and industry classification of our testing data sets are the same to WIOD.

We collected and compared various sources for goods and services trade data, including official National Accounts, sourced from the OECD and UNSD, UNCTAD, IMF's IFS and BOP database, WITS-COMTRADE database, and the OECD STAN database. The same data can

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[12] GAMS/CPLEX is a well established, versatile, high-performance optimization system powerful for solving large linear and quadratic programming models.

[13] Since the optimal solutions are equivalent to the GLS estimates, the term "optimal solution" and "estimates" are sometimes used interchangeably here.

[14] Chile, Iceland, Israel, Norway, Switzerland, Argentina, South Africa, Hong Kong, Malaysia, Philippines, Thailand, Viet Nam, Saudi Arabia, Brunei and Cambodia

often be obtained from several different sources, however, we found, there were often significant differences in values among different sources, typically relating to trade statistics.[15] Because of these differences, it is necessary to analyze the pros and the cons of each source to determine which is the most reliable sources for our reconciliation model. Ultimately, we chose the National Accounts as the best source for a country's total gross exports to and imports from the world. For bilateral trade positions we determined that the best source for establishing partner shares was the OECD's bilateral merchandise and services trade data (*Bilateral Trade by Industry and End-USE Category; Bilateral Trade in Services by Industry*).

3.1.1 Control totals for aggregate trade in each country

National Accounts data by design often capture estimates of trade that will not be reflected in underlying customs data, since the National Accounts include adjustments to correct for reporting errors, partner country coverage, and also for unobserved (e.g. informal) trade. But there are other reasons why differences across related sources may arise, for example relating to concepts, including valuation. Table 1 below for example shows that UNCTAD, IFS, and BOP world merchandise imports tend to be larger than the National Accounts data we used. This is also a result of: valuation differences (UNCTAD and IFS are both in c.i.f prices; WITS-COMTRADE data is also in c.i.f. prices) and definitional differences (IMF's BOP data is only for merchandise goods, while BOP2 includes merchandise goods plus goods for processing, repair of goods, goods procured in ports by carriers, and non-monetary gold).

Table 2 provides the same comparison for merchandise trade, but looking only at the four largest trading countries: China, Japan, Germany, and the United States. By focusing on these four major exporters and importers, we can provide a more accurate comparison between the various data sources. By examining these four countries, we can clearly see that the national accounts data is very close to that of other sources, especially in the case of merchandise exports. For merchandise exports, national accounts data are about 100 percent for all years for China, Germany, and the US. BOP data is typically lower but that is expected due to definitional differences with national accounts estimates (see above). Merchandise imports for most sources are clearly larger than the national accounts data, with the exception of the BOP2 database. The

[15] There are two major reasons for the difference. 1) valuation (trade valued on a f.o.b. (free on board) or c.i.f. (cost, insurance, and freight) basis) and 2) coverage (data missing for some countries, for some sectors, and for some years).

data from UNCTAD, WITS, and IFS are on average about 5 percent larger for China, 1 percent for Germany, 10 percent for Japan, and 2 percent for the US; these differences are a result of the c.i.f. margin. The data from BOP2 are about 100 percent of national accounts equivalents.

Table 1: Comparisons of World Goods and Service trade

(Various Sources as a Percent of National Accounts Data)

Year		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Source	Type	Exports														
UNCTAD	Goods	97	97	97	98	97	98	98	98	99	99	98	99	98	99	98
WITS		89	92	94	95	95	96	97	97	98	98	97	98	96	97	96
IFS		94	95	98	98	98	98	98	99	99	99	100	100	98	98	97
BOP		84	85	83	85	85	84	84	82	83	83	83	82	82	88	87
BOP2		90	91	91	110	109	107	108	109	110	110	103	108	108	109	107
UNCTAD	Services	101	101	101	101	101	101	101	100	100	100	100	102	104	105	106
BOP		85	84	85	88	88	88	88	87	87	87	87	88	91	90	92
		Imports														
UNCTAD	Goods	100	101	101	101	100	101	101	102	102	102	102	102	101	102	101
WITS		92	95	98	98	99	100	100	101	101	101	101	101	100	101	99
IFS		98	99	103	103	102	102	102	102	103	103	103	102	102	101	100
BOP		84	85	84	87	87	87	86	86	86	86	86	86	86	90	89
BOP2		90	91	91	109	109	109	108	109	110	109	110	110	110	111	110
UNCTAD	Services	101	99	99	99	99	99	100	98	98	98	98	99	101	103	104
BOP		85	83	82	85	86	85	86	84	83	83	82	82	84	85	86

Figure 1: Comparing Data Sources for Goods (g) and Services(s): World Imports + Exports (Various Sources as a Percent of National Accounts Data)

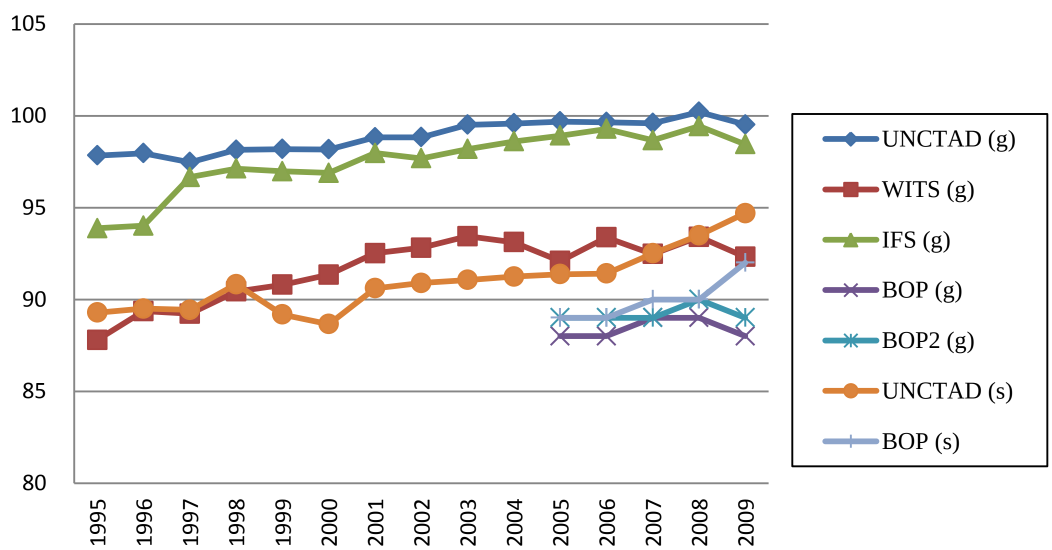

Table 2: Comparing Merchandise Trade Data for Selected Countries
(Various Sources as a percent of National Accounts data)

Reporter	Source	Exports								Imports							
		1995	1997	1999	2001	2003	2005	2007	2009	1995	1997	1999	2001	2003	2005	2007	2009
China	UNCTAD	102	100	100	100	100	100	100	100	107	104	104	105	105	105	106	105
	WITS	102	100	100	100	100	100	100	100	107	104	104	105	105	105	106	105
	IFS	102	100	100	100	100	100	100	100	107	104	104	105	105	105	106	105
	BOP	88	45	43	44	45	45	49	49	89	51	55	61	60	58	61	61
	BOP2	88	100	100	100	100	100	100	100	89	100	100	100	100	100	100	100
Japan	UNCTAD	104	103	104	105	105	105	106	107	113	110	110	111	111	109	109	110
	WITS	104	103	104	105	105	105	106	107	113	110	110	111	111	109	109	110
	IFS	104	103	104	105	105	105	104	106	113	110	111	111	111	109	108	110
	BOP	100	98	99	98	98	98	98	99	100	96	95	96	95	95	95	95
	BOP2	100	100	100	100	100	100	100	100	100	99	99	100	99	100	100	100
Germany	UNCTAD	100	100	100	100	100	99	99	98	101	102	100	101	100	99	99	98
	WITS	100	100	100	100	100	99	99	97	101	102	100	101	100	99	99	97
	IFS	100	100	100	100	100	99	98	97	101	102	100	101	100	99	99	98
	BOP	94	94	93	94	93	93	95	94	92	93	93	93	93	93	95	95
	BOP2	99	99	99	99	99	99	100	100	99	100	99	100	100	100	101	102
United States	UNCTAD	100	100	99	100	100	100	101	99	102	101	101	101	102	102	102	101
	WITS	100	100	99	100	100	100	101	99	102	101	101	101	102	102	102	100
	IFS	100	100	100	100	100	100	101	99	102	102	101	101	102	102	102	101
	BOP	97	97	97	97	98	97	97	96	98	98	98	98	98	98	98	98
	BOP2	98	98	98	98	99	98	98	98	98	98	98	98	98	98	99	98

Source: UN, UNCTAD, WITS-COMTRADE, OECD, IMF BOP, and IMF IFS databases

Similar patterns exist for services trade data. For example, world totals found in UNCTAD data on services trade are almost 100 percent of those of the national accounts based data (see Table 3). However, national accounts totals are between 9 and 18 percent larger than those found in the IMF's BOP database (Figure 1), reflecting the fact that some countries are absent from the BOP world totals. This difference in totals, however, does not exist in the individual country totals. For example, Table 3 shows that services trade data for most years, from most sources, including the BOP database, are 100 percent of the national accounts data for both services exports from, and imports to, China and Germany. They are about 30 and 17 percent larger for Japan's exports and imports, respectably. For the US, the services trade data are about 5 and 3 percent larger for US exports and imports, respectively. These differences underscore the difficulty in collecting and estimating accurate trade statistics in services and reinforce our position on using national accounts based data where statistics institutes make attempts to deal with inconsistencies or errors within the GDP accounting framework.

Table 3: Comparing Services Trade Data for Selected Countries
(Various Sources as a Percent of National Accounts Data)

Reporter	Source	Exports								Imports							
		1995	1997	1999	2001	2003	2005	2007	2009	1995	1997	1999	2001	2003	2005	2007	2009
China	UNCTAD	88	100	100	100	100	100	100	100	89	100	100	100	100	100	100	100
	BOP	88	100	100	100	100	100	100	98	89	100	100	100	100	100	100	100
	OECD	100	100	100	100	100	100	100	100*	100	100	100	100	100	100	100	100*
Japan	UNCTAD	124	128	130	131	130	131	137	138	111	116	117	117	118	117	120	123
	BOP	124	128	130	131	130	131	137	139	111	116	117	117	118	117	120	123
	OECD	124	128	130	131	122	126	134	131*	110	111	114	116	115	117	115	116*
Germany	UNCTAD	100	99	95	99	104	105	103	102	100	100	98	98	101	101	101	102
	BOP	100	99	95	100	104	105	106	109	100	100	101	101	101	101	101	102
	OECD	100	99	96	100	104	104	101	96*	101	102	102	101	101	99	99	101*
United States	UNCTAD	95	95	95	94	95	96	96	98	97	97	97	96	98	98	98	101
	BOP	95	95	95	94	95	96	98	98	97	97	97	96	98	98	97	99
	OECD	96	96	97	97	97	98	101	100*	97	97	97	96	98	99	99	99*

* Represent the year 2008.

3.1.2 Selection of control total for aggregate trade in the world

Another benefit of using national accounts data as a control is that it is fairly balanced. Looking at the share of imports over exports of world totals (see Table 4) allows us to compare the global trade balance of the different sources; in a perfectly balanced world this share would equal 100 percent when both exports and imports are valued in f.o.b. basis. The data show that on average imports account for 99 percent of exports (goods, services, and total). Imports from UNCTAD, IFS, and WITS are predictably larger, by about 2 percent. This difference reflects the fact that in these databases exports are valued on an f.o.b. basis and imports are valued on a c.i.f. basis.

Table 4: World Trade in Total (Share of Imports over Exports by Source)

	Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
National Accounts NA (total)		98	98	98	99	99	100	100	99	99	99	99	98	98	98	98
NA	Goods	98	98	97	98	99	99	100	99	99	99	99	99	98	99	99
UNCTAD		101	101	101	101	102	103	103	102	102	102	103	101	101	102	101
IFS		102	103	102	102	103	103	104	103	103	103	102	101	102	102	101
BOP		97	98	99	100	101	103	103	103	103	103	103	103	103	101	101
BOP2		97	98	98	97	99	101	100	99	99	99	100	100	100	101	100
WITS		101	102	102	101	103	103	103	102	102	103	103	102	103	103	102
NA	Services	100	100	100	100	100	100	100	100	100	98	98	96	96	96	97
UNCTAD		100	99	98	98	98	98	99	98	98	96	96	94	93	93	94
BOP		100	98	97	97	97	96	97	96	96	94	92	90	88	94	94

Source: UN, OECD, UNCTAD, WITS-COMTRADE, IMF BOP, and IMF IFS databases

3.1.3 Other data sources

Each country's exports to and imports from the world at WIOD product level are obtained directly from WIOD Use (for exports at fob) and Supply (for imports at cif) tables. Initial estimates of cif margins are also taken from WIOD.

We use the GDP by major expenditure components statistics as each country's macro control variables. The data are downloaded from *National Accounts Official Country data* of *UN statistics division*, and the OECD's National Accounts database, at current prices, in thousand USD. These provided the source for all countries except TWN, which was sourced from the Directorate-General of Budget, Accounting & Statistics (DGBAS) converted to US dollars.

Bilateral merchandise and services trade statistics are from OECD sources, but they are only used for source and destination shares after obtaining a globally consistent set of exports to and imports from the world at the WIOD product level for each country from our first stage optimization procedure. However, both exporter and importer reported data are used as the interval control in our final stage reconciliation when bilateral trade flows are estimated.

3.2 *Selection of reliability indexes in the objective function*

As pointed out by Wang et al (2010), one of the most desirable analytical and empirical properties of this class of data reconciliation models such as the one we specified by equations (1) – (35) is that it uses reliability weights in the objective function to control how much an initial estimate may be adjusted. From a statistical point of view, the best way to systematically assign reliability weights in the objective function is to obtain estimates of the variance-covariance matrix of the initial estimates, with the inverted variance-covariance matrix providing the reliability indicators. The larger the variance, the smaller the associated term $\frac{(z_{ci}^{sr} - z0_{ci}^{sr})^2}{wz_{ci}^{sr}}$ or $\frac{(y_{ck}^{sr} - y0_{ck}^{sr})^2}{wy_{ck}^{sr}}$ contributes to the objective function, and hence the lesser the penalty for the associated variables to move away from their initial value (only the relative, not the absolute size of the variance affects the solution). However, the lack of consistent historical data often makes the estimation of the variance-covariance matrix associated with the initial estimates very difficult to implement. For example, the common practice in SAM balancing exercises is to assign differing degrees of subjective reliabilities to the initial entries of the matrix, following the method proposed by Stone

(1984)[16]. Very few attempts to date have been made to statistically estimate data reliability such as error variance of the initial estimates from historical data, except Weale (1989), who developed a statistical method that uses time series information on accounting discrepancies to infer data reliability in a system of national accounts. Theoretically speaking, a similar statistical method can be applied to the historically reported discrepancies of bilateral trade data to derive those variances associated with international trade statistics. In practice, however, the historical data and knowledge of the changes in related country's trade statistics reporting systems are too demanding and make such a statistical method less attractive for large empirical applications. Therefore, here we use a practical alternative approach to estimate the reliability weights, which is constructed by reporter relative reliability indexes for both exporters and importers.

3.2.1 Reporter reliability indexes

Trade data reported by each country and its partners are often used in the international economic literature to check the quality of trade statistics. An approximate match of mirror statistics suggests that trade data reported via that route are reliable. However, such weights treat the reported trade statistics from both reporters equally and do not distinguish which reporter is more reliable. In the case where there is a (known) unreliable reporter in the pair, this approach may lead to changes being made to the data reported by the reliable reporter. This is undesirable. To correct this problem, a reporter's relative reliability index needs to be developed. Such an index should be able to deal with three critical issues.

The first issue is related to the difference of reporting countries in their ability to report bilateral commodity trade by end use categories. Variability in reporting quality across countries is highly relevant information for the problem we try to solve in our proposed statistics reconciliation approach. As discussed earlier, the adjustment process hinges heavily on the relative reliability of each of the reporting countries. An indicator of reporter reliability is a measure of how consistently a country reports its trade in each product relative to all its trading partners. However, judging reliability of a country's trade statistics based on a single bilateral flow alone is a poor reference, because a partner can misrepresent its trade thereby potentially discrediting a reliable reporter. Therefore, a good reporter reliability measure should take all reporting countries in the world into account in assessing a country's reporting reliability.

[16] Stone proposed to estimate the variance of x^0_{ij} as $var(x^0_{ij}) = (\theta_{ij}x^0_{ij})^2$, where θ_{ij} is a subjective determined reliability rating, expressing the percentage ratio of the standard error to the initial estimates of x^0_{ij}.

The second issue is what exactly should be captured by the reliability measure. The size of discrepancies could be incorporated into a measure of reliability. However, placing emphasis on the magnitude of discrepancies only may over-penalize the reliability of a legitimate reporter. A poor reporter that makes an error for a given trade flow usually makes a similar error with other partners. For example, a reporter that has mistaken the identity of one of its partners has implicitly made a mistake for others. It brings a systemic bias for that reporter. This type of problem should be detected and reflected in the reporter reliability measure without penalizing the reliable reporter.

The third issue is the capability of the measure to reflect both product and country-specific reliability information for each country as an exporter and as an importer. Countries typically have product specific strength and weaknesses. For example one exporting country may have an excellent reporting record on steel used as intermediate goods but at the same time is highly inconsistent in its reporting practice for organic chemical in final goods trade.

All three issues discussed above are effectively dealt with in the reliability index developed by Gehlhar (1996) where reporter reliability indices were used to make a discrete choice whether to disregard or accept reported trade flows. The index is calculated as the share of accurately reported transactions of a reporter’s total trade for a particular product using a threshold level. It assesses reporter reliability from a complete set of global reporting partners, captures the reporter’s ability to accurately report without interferences from gross discrepancies in reporting, and contains exporter and importer product specific reliability information. Specifically, the importer-product specific and exporter-product specific reliability indexes in the objective function (equations (1) and (22)) are defined as:

$$RIM_{ic}^{r} = \frac{MA_{ic}^{r}}{\sum_{s} M_{ic}^{sr}} \qquad where \qquad MA_{ic}^{r} = \sum_{s \in AL_{ic}^{sr} \leq 0.20} M_{ic}^{sr} \qquad AL_{ic}^{sr} = \frac{\left| M_{ic}^{rs} - E_{ic}^{sr} \right|}{M_{ic}^{rs}} \tag{36}$$

$$RIX_{ic}^{s} = \frac{XA_{ic}^{s}}{\sum_{r} E_{ic}^{sr}} \qquad where \qquad XA_{ic}^{s} = \sum_{s \in AL_{ic}^{sr} \leq 0.20} E_{ic}^{sr} \qquad AL_{ic}^{sr} = \frac{\left| M_{ic}^{rs} - E_{ic}^{sr} \right|}{M_{ic}^{rs}} \tag{37}$$

Under such defined reporter reliability indexes, the size of the discrepancies becomes immaterial because inaccurate transactions are treated the same regardless of the magnitude of the inaccuracy. The indexes have the flexibility of being implemented at the detailed 6-digit HS level and can be aggregated to any commodity group level. We computed such reporter reliability measures for each WIOD country and product. Major data are from UN COMTRADE with supplements from country sources.

3.2.2 Reliability weights used in objective function

After obtaining RIM and RIX for each WIOD product/country, there is an additional issue that needs to be solved before we can empirically compute the reliability weights in the objective function (equations (1) and (22)) of the data reconciliation model. There is only one unique number for each trade flow in each route in the resulted balanced global SUTs, which should be a combination of both reporter and partner reported trade statistics based on reporters' reliabilities. Therefore, we combine both reporter and partner's reliability indices and reported statistics for each trade routine at the WIOD product level to compute the final reporter reliability weights in the objective function. They are assigned by multiplying one minus each reporter's product weighted reliability index with their corresponding initial values. For example, the complete set of weights in equation (22) is defined as follows:

$$wz_{cit}^{sr} = (1 - RIM_{ct}^{r})\bar{z}m_{cit}^{sr} + (1 - RIX_{ct}^{s})\bar{z}x_{cit}^{sr} \tag{38}$$

$$wy_{ckt}^{sr} = (1 - RIM_{ct}^{r})\bar{y}m_{ckt}^{sr} + (1 - RIX_{ct}^{s})\bar{y}x_{ckt}^{sr} \tag{39}$$

Where $\bar{z}m_{cit}^{sr}$, $\bar{z}x_{cit}^{sr}$ and $\bar{y}m_{ckt}^{sr}$, $\bar{y}x_{ckt}^{sr}$ are the intermediate and final goods trade flows computed based on the share reported by importers and exporters respectively (shares multiple M_{ct}^{r} and E_{ct}^{s} ; the total world trade by products of each country in the balanced individual country SUTs). With such a weighting scheme, we achieve our goal of ensuring that the model has a higher probability of changing unreliable initial data compared reliable data.

IV. Adjustment made to official National Accounts and trade statistics by enforcing global consistence

Our model entails enforcing global consistency which takes place in the first stage. We first establish consistency between country-reported trade statistics in SUTs and official total trade statistics in goods and services. The model solves for the adjusted country total exports to and imports from the world for each WIOD product and these country/product totals are retained for the second and final stages as controls. The data reconciliation procedure produces a different set of estimates for both trade and SUT estimates than official statistics, and so it is desirable and important to know how much each set of estimates differs from the officially reported data. However, it is difficult to use a single measure to compare the original and adjusted data, since there are so many dimensions in the model solution sets. It is meaningful to use several measures to gain more insight on the model performance in different settings. Generally speaking, it is the proportionate deviation and not the absolute deviation that matters; therefore, we compute the "Mean Absolute Percentage Adjustment" with respect to the official data for different product and country aggregations. Consider the following aggregate index measure for country and product group total adjustment:

$$MAPA^r = \frac{100 \bullet \sum_{t=1}^{T} \sum_{c=1}^{n+1} |\overline{E}_{ct}^r - E0_{ct}^r|}{\sum_{t=1}^{T} \sum_{c=1}^{n+1} E0_{ct}^r} \tag{40}$$

$$MAPA^c = \frac{100 \bullet \sum_{t=1}^{T} \sum_{r=1}^{g} |\overline{E}_{ct}^r - E0_{ct}^r|}{\sum_{t=1}^{T} \sum_{r=1}^{g} E0_{ct}^r} \tag{41}$$

We first focus on results for country total adjustments to illustrate some key characteristics of the adjustment process. Each country's reliability as an exporter and importer is a key factor that governs the magnitude of adjustment on its total exports and imports (Figures 2). The magnitude of adjustment made by the model is relatively small, less than 2 percent for most countries except a few outliers reflecting the large inconsistencies between National Account total trade data and product level trade data recorded in WIOD national SUTs. We note also that there is a negative correlation between exporters and importers' reliability and adjustments magnitudes made to covered products (Figure 3), although the adjustments are more significant at product level[17]. As expected, both the country and sector patterns of the adjustments reflect their negative relationship with reporter's reliability, with the exception of a few outliers. This indicates that both country and product level adjustments are not only impacted by data reliability but also by the initial discrepancies between product level trade data

[17] The simple correlation coefficient between reporter reliability index with Mean absolute percentage of adjustment of trade is -0.46. Using RIX and RIM as regressor against MAPA by detailed product level adjustment data we get following liner relations: expadj = 0.268-0.287RIX and impadj = 0.216-0.224RIM. Both coefficient estimates are significant at %1 level.

reported in individual country's SUTs and country totals recorded in the National Accounts. We report each country's reliability indexes, the initial inconsistency between total trade reported in WIOD national SUTs and National Accounts data as well as the mean absolute percentage adjustments in Table 5.

Figure 2 Reporter Reliability and Mean Absolute Percentage Adjustment of total exports, 1995 -2009

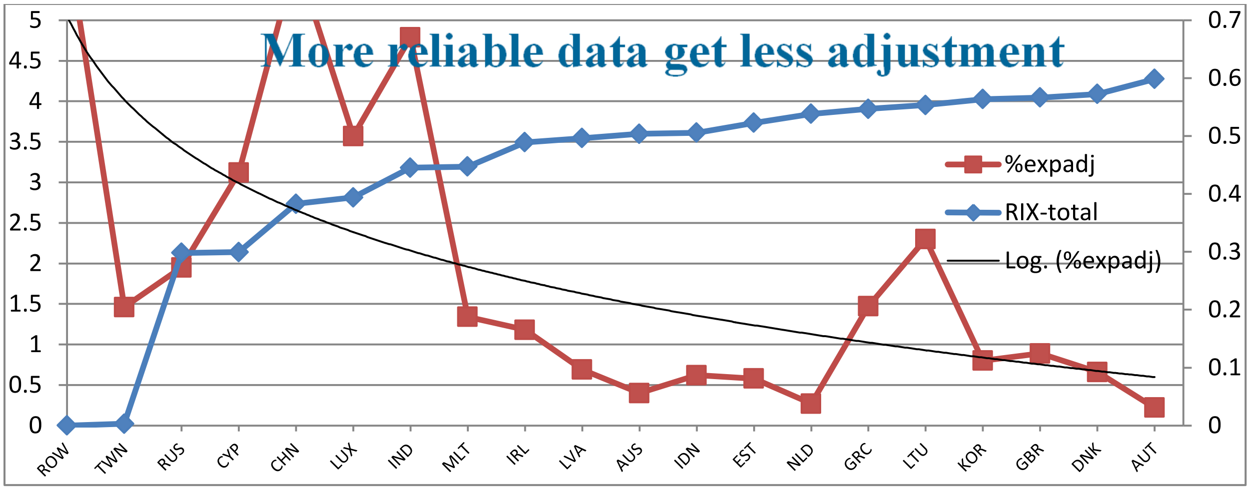

Figure 3 Reporter Reliability and Mean Absolute Percentage Adjustment of World Goods exports by WIOD product, 1995 -2009

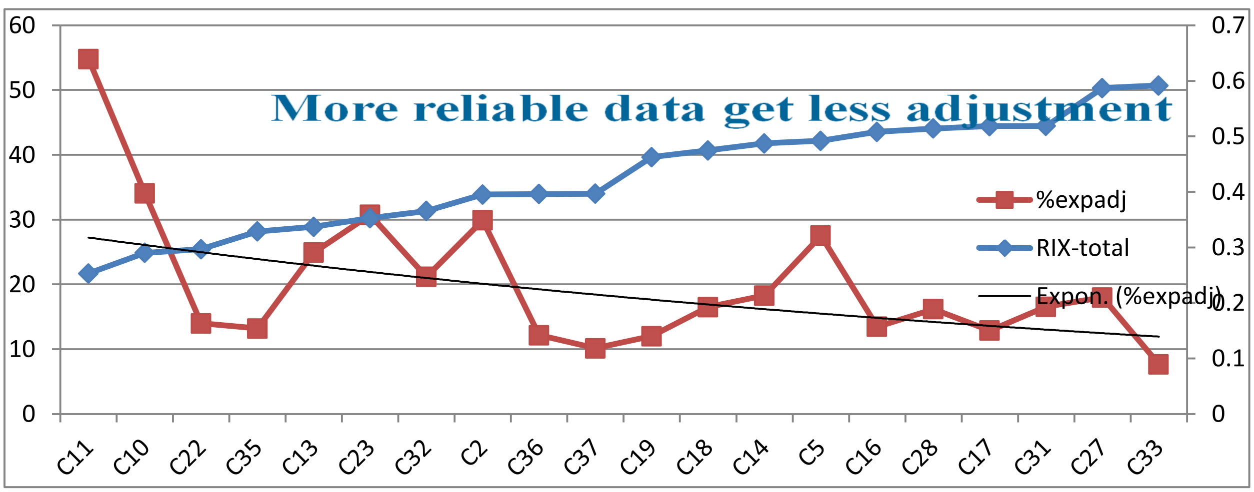

Table 5 Reporter reliability indexes, initial inconsistence, and Mean Absolute Percentage Adjustment of total exports and imports, 1995 -2009

countries	RIX	%xerr	%expadj	RIM	%merr	%impadj	Countries	RIX	%xerr	%expadj	RIM	%merr	%impadj
AUS	0.504	-0.1	0.4	0.637	0.0	0.9	ITA	0.763	0.7	0.5	0.693	0.7	1.1
AUT	0.598	0.1	0.2	0.665	0.1	1.1	JPN	0.667	-0.4	1.7	0.611	-0.2	1.0
BEL	0.347	0.7	0.7	0.460	0.6	1.2	KOR	0.564	0.0	0.8	0.613	0.0	0.8
BGR	0.623	4.8	4.8	0.439	4.6	5.7	LTU	0.554	3.1	2.3	0.562	2.6	3.7
BRA	0.627	-0.1	1.1	0.605	-0.1	2.7	LUX	0.394	1.1	3.6	0.530	1.0	2.0
CAN	0.862	-0.2	0.4	0.675	-0.2	1.2	LVA	0.496	0.0	0.7	0.600	0.0	2.4
CHN	0.383	14.5	5.8	0.375	12.9	8.8	MEX	0.836	0.0	0.6	0.484	0.0	0.6
CYP	0.300	0.2	3.1	0.494	0.1	2.1	MLT	0.447	-2.4	1.3	0.532	-2.4	1.7
CZE	0.720	7.7	4.0	0.632	7.2	4.7	NLD	0.538	0.6	0.3	0.517	0.6	1.5
DEU	0.739	-0.1	0.5	0.527	-0.2	1.0	POL	0.689	1.2	1.0	0.624	1.1	1.8
DNK	0.572	0.1	0.7	0.629	0.1	1.6	PRT	0.684	1.2	0.5	0.726	1.0	2.7
ESP	0.765	0.9	0.4	0.620	0.9	1.0	ROU	0.644	4.2	1.6	0.497	3.2	4.3
EST	0.523	0.2	0.6	0.440	0.3	1.6	RUS	0.298	0.0	2.0	0.473	0.0	2.3
FIN	0.636	1.0	0.5	0.548	1.1	2.0	SVK	0.694	0.0	0.4	0.492	-0.1	0.7
FRA	0.732	0.7	0.3	0.611	0.7	1.2	SVN	0.704	0.9	0.8	0.584	1.1	1.0
GBR	0.567	-1.3	0.9	0.613	-0.5	0.6	SWE	0.623	0.1	1.2	0.682	0.1	1.1
GRC	0.547	-1.1	1.5	0.564	-2.1	3.6	TUR	0.635	0.0	8.4	0.492	-0.2	6.4
HUN	0.639	1.4	1.3	0.584	1.3	1.6	TWN	0.003	-0.2	1.5	0.004	0.3	0.7
IDN	0.506	-0.4	0.6	0.455	0.8	1.3	USA	0.620	0.1	1.9	0.702	0.1	1.6
IND	0.445	0.1	4.8	0.361	-1.5	3.5	ROW	0.000	-64.1	36.1	0.000	-58.1	38.8
IRL	0.489	-0.1	1.2	0.478	0.0	0.7	WLD			9.2			9.4

The mean of absolute percentage adjustment for each country's National SUTs from WIOD is summarized in Table 6. The extent of adjustment not only depends on the difference between the global consistent trade data from the first stage of our model and the trade data in these national tables, but also depends on the quality of the individual countries SUT statistics and how far their aggregates differ from those recorded in the National Account (GDP by major expenditure components), which are used as macro controls. Generally speaking, the adjustments to sector level value-added and product level final demand related transactions are smaller than intermediate inputs and gross outputs related transactions with no exceptions. The underlying reasons for the large magnitude of adjustments to gross output at industry level need further investigation.[18] Computing the adjustment index similar to equations (40) and (41) by product groups and final demand categories, could help us to identify where the large adjustments come from, providing a means to identify and solve potential problems in the data. If the standard

[18] Ideally, the gross industry or commodity output should be fixed in the reconciliation process because such data collected by NSI are more reliable than data on intermediate inputs. However, if we fix the gross output recorded in WIOD SUTs, there will be no feasible solution for the model, so we have to relax this constraint. The issue is still under investigation.

error of national SUT statistics or some sort of reliability index could be developed similar to trade data, the resulting global SUT data could be improved.

Table 6 Mean Absolute Percentage Adjustment of National SUT Statistics

Country	z-int	x-output	y-final	v-VA	country	z-int	x-output	y-final	v-VA
AUS	47.9	49.6	0.3	2.6	ITA	30.4	33.8	0.2	0.5
AUT	40.4	39.5	0.3	0.6	JPN	45.7	36.8	0.8	2.2
BEL	37.1	36.7	0.2	0.3	KOR	37.5	52.5	1.4	1.4
BGR	35.7	45.4	0.3	4.5	LTU	39.8	40.4	0.4	0.7
BRA	33.9	29.0	0.4	0.5	LUX	47.6	62.7	1.2	0.8
CAN	39.6	33.9	0.7	0.8	LVA	46.5	42.4	0.3	0.5
CHN	37.2	78.3	1.0	1.4	MEX	48.7	28.8	0.5	1.0
CYP	59.3	32.1	6.3	5.0	MLT	30.6	35.2	0.4	0.8
CZE	35.2	49.6	0.2	4.0	NLD	37.3	37.4	0.3	0.2
DEU	36.3	34.6	0.3	0.4	POL	26.0	34.3	0.2	0.1
DNK	36.5	40.4	0.5	0.4	PRT	49.5	41.4	0.3	2.5
ESP	47.6	40.8	0.3	0.3	ROU	39.0	40.9	0.5	0.2
EST	39.3	52.7	0.4	0.6	RUS	37.5	34.1	0.7	1.0
FIN	38.8	38.9	0.4	0.4	SVK	34.0	42.1	0.2	0.2
FRA	33.3	31.0	0.2	0.3	SVN	42.4	44.8	0.3	0.4
GBR	29.7	26.6	0.2	1.2	SWE	35.1	34.7	0.4	0.2
GRC	37.7	30.2	1.1	0.9	TUR	38.2	34.0	1.0	0.8
HUN	31.8	36.6	0.3	0.9	TWN	39.5	36.7	0.6	1.6
IDN	43.8	31.4	1.1	2.8	USA	35.0	23.0	0.3	0.7
IND	39.5	39.5	0.4	2.4	ROW	120.7	233.4	64.3	178.1
IRL	49.6	50.4	0.5	0.9	WLD	41.0	42.5	3.4	9.8

Finally, we transform the global SUTs in basic prices produced from our data reconciliation model into industry by industry ICIO tables using "Model D" discussed in Eurostat (2008, Chapter 11) similar to WIOD.[19] The Mean absolute percentage difference between the adjusted ICIO tables and WIOD WIOTs is reported in table 7. Generally speaking, the differences in sector level gross outputs are very close between WIOD WIOT and the estimated ICIO table by our reconciliation procedure, followed by sector level value-added. The difference between domestic transactions is generally less than that of imported transactions, for both intermediate inputs and final demand. The largest difference show up on imported final demand.

[19] The justification of why "Model D" is chosen are clearly discussed in section 5 of Timmer et al. (2012).

Table 7 Mean Absolute Percentage difference between WIOD industry by industry WIOTs and the adjusted ICIO tables - 2005

ctr	Dom. Int	Imp. Int'	Dom Final	Imp Final	Gross Output	Value-added	ctr	Dom. Int	Imp. Int'	Dom Final	Imp Final	Gross Output	Value-added
AUS	62.0	77.1	51.6	317.0	1.0	26.1	ITA	52.2	68.2	47.1	88.9	1.2	23.8
AUT	52.7	63.1	36.7	125.0	1.7	20.0	JPN	56.1	72.1	45.7	103.9	1.4	20.3
BEL	42.7	68.4	34.8	138.2	4.2	19.1	KOR	53.4	77.8	58.5	144.5	2.2	24.1
BGR	52.7	73.9	49.9	243.0	1.8	25.8	LTU	101.7	85.7	52.2	282.5	4.0	27.2
BRA	55.8	68.0	45.0	137.8	1.5	26.8	LUX	88.6	92.7	43.0	355.5	4.8	74.2
CAN	63.8	43.7	48.2	81.9	1.9	13.9	LVA	76.8	85.2	65.6	370.4	3.8	29.2
CHN	41.3	74.3	57.4	91.7	1.8	37.5	MEX	59.7	55.8	31.4	99.6	1.4	9.3
CYP	97.6	102.7	51.1	410.6	8.4	26.3	MLT	76.7	95.9	64.0	500.1	4.9	31.6
CZE	53.8	56.3	55.4	103.4	1.4	29.7	NLD	51.8	65.3	37.0	145.4	6.0	28.5
DEU	51.3	66.8	43.5	99.7	1.3	17.2	POL	34.6	60.3	32.8	97.6	1.3	19.4
DNK	49.6	79.8	43.8	122.4	2.1	18.9	PRT	73.8	68.5	48.4	111.2	1.5	23.8
ESP	59.9	76.3	35.9	62.4	1.3	30.8	ROM	103.9	75.6	70.9	176.7	2.6	41.9
EST	48.3	74.6	69.5	299.2	3.8	15.1	RUS	59.9	75.7	54.3	698.9	1.3	26.9
FIN	51.9	67.9	36.3	182.6	1.3	20.9	SVK	49.0	56.0	40.8	128.1	1.2	25.3
FRA	64.0	62.7	49.3	93.2	1.7	14.7	SVN	60.3	60.9	41.6	132.6	1.3	20.6
GBR	82.2	76.9	61.3	149.2	2.0	34.6	SWE	48.4	72.2	42.6	130.8	1.4	16.3
GRC	76.1	93.7	40.5	311.5	2.2	24.6	TUR	75.4	71.8	51.4	70.8	2.1	39.0
HUN	55.4	63.3	43.3	132.8	1.4	21.8	TWN	57.7	64.8	48.9	206.8	2.2	37.8
IDN	81.3	72.5	59.0	248.7	2.6	40.2	USA	53.5	77.1	37.4	126.0	0.8	14.0
IND	54.6	82.2	33.1	123.0	1.3	19.5	ROW	98.9	69.9	68.7	132.3	48.6	41.9
IRL	88.3	86.7	53.4	131.7	1.2	21.4	WLD	59.9	70.3	46.7	122.2	6.8	23.2

V. Direction of future work and conclusion remark

This study developed a three-stage mathematical programming model to reconcile detailed bilateral goods and services trade statistics with individual country's Supply and Use tables to produce a balanced global SUT database. It also documents the major data sources for such data reconciliation excise and their pro and cons. Tests of the model using WIOD national SUTs and aggregate trade statistics from official National Accounts as well bilateral trade data from OECD, produced encouraging preliminary results and shows that the model is feasible and may have great potential in the estimation of an integrated world SUT account. Most importantly, our empirical excise to test the model using real world data has shown that impose global consistency and eliminate exports to the moon will make no significant changes on NSI's reported GDP and other major aggregate national account statistics in the balanced global SUT database. However, the model is still in its earlier stage of development, there are many important issues still to be addressed. We list a few of them in our conclusion remarks.

5.1 SUTs with statistical discrepancies or balanced SUTs?

Both sets of tables may be needed. A globally consistent SUT that keeps major discrepancies may be useful for statistical purposes when evaluating the accuracy of data recorded in the global SUTs; while a balanced global SUT is necessary for analytical purposes, especially for estimating a balanced Industry by Industry global IO table that provides the basis to compute trade in value-added estimates. So they are not substitutes but complements. A global SUT with statistical discrepancies could provide initial estimates for a balanced analytical world SUT, with the statistical discrepancy information in major accounting identities used to estimate standard errors for each cell in the balanced analytical global SUTs when combined with the adjustment information from the data reconciliation process as suggested by Lenzen et al. (2012). The model developed to produce balanced global SUTs in this paper also can be used to check the consistency of data from different sources that are needed to construct any global SUTs.

5.2 Re-exports and re-export mark up

Theoretically, re-exports can be integrated into the data reconciliation framework presented in this paper without any difficulties. However, we do not include re-exports statistics in our current data reconciliation exercise due to the lack of reliable total re-exports data at country and product level as controls. We are also not able to estimate exports mar-ups when reconciling individual country's SUTs. Further work is needed to identify data sources for re-exports and estimate the mark-up margins for major re-exporting countries in the world in order to treat them as the re-exporting country’s indirect service exports in our future efforts.

5.3 reliability weights for national SUT statistics

We did not estimate reliability weights for national supply and use statistics. Without a properly estimated reliability index, we have to adjust these SUT data proportionally during our reconciliation process. Obviously this will impact on the quality of the model solutions. Research efforts will be made to better estimate all initial data reliabilities.

5.4 Sector structure of international transportation

The use structure of international transportation services in our current reconciliation exercise is based on the supply structure estimated from our stage 1 model. Such information is available from detailed trade statistics by transportation modes. We plan to integrate such information into our reconciliation procedure in our future efforts.

5.5 Conclusions

Our data reconciliation exercise has demonstrated that it is feasible to arrive at a balanced global SUT system that preserves the key identities provided by official statistics, or remains very close to them. This is an important improvement on other attempts in this field, which often take simple conventions or include balancing items that allocate inconsistencies implicitly or explicitly to a residual, for example, Rest of the World adjustment, or by diverging from official statistics in an uninformed manner (i.e. without taking into account the relative reliability of the data produced by a given reporting country).

However, as noted above, much more can be done to improve the method. Central to this is the identification of sources that create better indicators of reliability throughout the system. Nevertheless, notwithstanding these areas of potential improvement, the model is already an improvement on current procedures and demonstrates that it is a tool to create tables in an efficient manner, for example it will be able to accommodate revisions in underlying data sources even though they may not (yet or never) be included in official SU tables. In addition the tool provides a means to create more timely estimates of SU tables than currently produced by official statistics institutes; thus providing a means to develop more timely estimates of trade in value-added.

The OECD ICIO tables and so the trade in value-added estimates produced in the OECD-WTO initiative currently take national IO tables linked with bilateral trade statistics as their starting point. In coming years, partly because of the increasing availability of national supply-use tables and partly because SU tables are generally more timely than IO tables, the OECD will begin to develop a global SU table that forms the basis of its ICIO tables.

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