Estimation of International Demand Behaviour for Use with Input–Output Based Data

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ABSTRACT The making of projections often requires an economy-wide perspective, and the estimation of consumer demands at the international level. In this paper, an implicit, directly additive demand system (AIDADS) is estimated using cross-country data on consumer expenditures from two different sources: the International Comparison Programme (ICP), and the Global Trade Analysis Project (GTAP). The two data sets are found to produce results that are quite consistent despite their differing origins, and the fact that the former is based on consumer goods that embody wholesale/retail margins, while margin demands are treated separately in GTAP. Given the similarity of the results, the estimation based on GTAP data is favoured for economy-wide projection purposes because it can be readily matched to input–output based production and trade data. An additional benefit of the GTAP-based estimates is that they provide direct evidence concerning how aggregate margin expenditures vary with per capita income.

KEYWORDS: Demand system estimation; input–output data; wholesale retail margins

1. Introduction

Projections of future economic activity regarding issues such as future energy demand, environmental emissions, and sectoral employment, often require taking an economy-wide approach to modelling. Such an approach, in turn, requires specification of a complete system of consumer demands, and linking these estimates to input–output production activities (e.g. Bardazzi & Barnabani, 2001). This latter task can be particularly daunting, given the pronounced disparity between consumer activities described by expenditure data, and production activities described by input–output data. Once these links are forged, however, the impact of future income growth on specific industries and commodities can be estimated (Lawson, 1997). Linking consumer behaviour to input–output based data is also useful for understanding the process of economic development, and
testing certain theories of international trade (e.g. Lluch et al., 1977; Hunter & Markusen, 1988; Davis et al., 1997).

When such studies are international in nature, then a global demand system must be estimated, and data on per capita expenditures for multiple countries must be obtained. The traditional source of such data is the International Comparison Programme (ICP), initiated at the University of Pennsylvania in the 1960s, and currently coordinated by the World Bank (Kravis et al., 1982). ICP data have been used in numerous international demand studies. Some of their features, however, hinder the linking of ICP-based demand estimates to international production data, including the widely used OECD Structural Analysis (STAN) data, and Global Trade Analysis Project (GTAP) data (Dimaranan & McDougall, 2002; OECD, 2002).

Some of the compatibility problems are inherent in any attempt to reconcile consumer expenditures with producer activities. For example, consumer expenditures are evaluated at purchaser prices, while production data are evaluated at producer prices. The latter exclude the cost of transforming producer output into a final, retail commodity. A related issue is the tendency for consumer data to be aggregated according to similarity in end use, while input–output data are aggregated more nearly according to production processes (including usage of certain factors, especially labour). For example, the ICP ‘Medical Care’ category includes expenditure on ‘Services of Nurses’ as well as ‘Therapeutic appliances and equipment’. The former is a narrowly defined service category that is intensive in labour, while the latter is a physical good that is intensive in capital. While OECD STAN and GTAP also include a medical-related category, this includes other unrelated activities, and omits still others included in the ICP definition.

In principle, these inconsistencies can be handled through construction of a ‘bridging’ or ‘transition’ matrix (e.g. Scarf & Shoven, 1984; Ballard et al., 1985). In the case of margin expenditures, a portion of consumer expenditures is mapped to the transportation and wholesale/retail trade sectors, i.e. those services that bring a product from factory to store. Such transition matrices are available for many countries, such as Australia (Lenzen, 2001), Japan (Davis et al., 1997), Denmark (Wier et al., 2001), and the USA (Lawson, 1997). However, these matrices are often not in a form useful for international comparisons. Furthermore, such matrices do not exist for many countries, particularly those at early stages of economic development, and establishing such transition matrices is a costly and time-consuming process (Piergiovanni & Pisani, 1998). A single, representative matrix for all countries of the world could be used as an alternative to country-specific transition matrices. This is not promising, however, as it obscures the vast differences in technology and economic structure that prevail across countries.

Another ICP compatibility issue lies in the definition of ‘actual total consumption of households’. Unlike input–output based data, the ICP definition includes ‘goods produced by households for their own consumption, or received as remuneration in kind’ (United Nations, 1992). In other words, home production of food, for example, is included in the ICP consumption data, as well as other non-market consumption activity. Another dissimilarity with input–output based data is ICP’s use of PPP methodology in calculating per capita expenditures. Both of these methods are perfectly legitimate, and consistent with the objectives of the ICP. However, they add additional layers in the differences between ICP and input–output data, and greatly reduce the possibility of a satisfactory reconciliation.

In light of these drawbacks, the purpose of this paper is to propose and test an
alternative to the ICP dataset for estimating international demand behaviour, and linking the estimates to global input–output production data. The paper’s approach begins with the observation that, as with the ICP, some input–output based data also have information on per capita consumer expenditures for a large number of countries and commodities. In particular, the GTAP 5.0 dataset contains information on per capita household expenditures for 57 categories of goods and services, and 66 regions. This provides a basis for estimation of international demand behaviour.

A natural concern about this approach is that some GTAP sectors involve raw industrial commodities not directly consumed by households. For example, a sector such as ‘ferrous metals’ is hardly a final product over which consumers have preferences. The GTAP database, however, recognizes that this commodity serves almost exclusively as an intermediate input, and does not enter into final demand. Moreover, to estimate a demand system, commodities are normally aggregated to be representative of the consumption choices faced by households. For example, categories such as ‘electronics’ and ‘motor vehicles’ can be aggregated quite naturally into a ‘manufactured goods/durables’ category.

Another concern is that, in an ideal sense, one would like to explain consumer behaviour at the prices consumers actually face. In contrast, GTAP expenditures are evaluated at producer prices. The margins that distinguish consumer expenditures from producer valuations are broken out in a distinct category. To convert the producer categories into ‘final’ products, a margins matrix is needed that distributes margin expenditures across producer categories. Yet much of the necessary information for such a matrix is lacking, particularly for countries at earlier stages of development. While this is a potential drawback, this must be weighed against the bias-inducing, compatibility problems that would be associated with trying to link ICP-based demands to input–output data.

To evaluate the potential of the GTAP dataset, a global demand system (AIDADS) is estimated using 1996 ICP per capita consumer expenditure data, then re-estimated using a comparable aggregation of the 1997 GTAP data. A series of comparisons shows that the GTAP-based results are qualitatively quite similar to ICP-based results for those goods where reasonably close comparisons can be made. For example, the shapes of fitted budget shares are replicated almost precisely for grains and livestock products, even though the latter is a non-monotonic function of per capita income. This is quite unexpected given the very different genesis of the data, and our prior expectations that only ICP-based demand estimates will be comparable to earlier international demand studies based on various datasets and functional forms.

It is an appealing result, however, and a boon to researchers needing to reconcile estimates of consumer behaviour, with input–output based data. The results of this exercise also contribute to our knowledge of international demand behaviour in general. For example, we present mean income elasticities of demand for ten aggregated producer goods, as well as new information concerning how aggregate wholesale/retail trade margins vary across per capita income levels. The extent of this variation in trade margins serves to underscore further the difficulties inherent in building comparable margins matrices for countries at substantially different levels of economic development.

The remainder of the paper is organized as follows. Section 2 provides an overview of the demand system (AIDADS) that is estimated. Section 3 describes the ICP and GTAP data used in this analysis, including how they are aggregated.
Section 4 presents the demand system estimation results, and Section 5 summarizes and concludes.

2. The AIDADS Demand System

A primary reason to link international demand behaviour with input–output data is to estimate the impact of projected income growth on specific industries and commodities. There is much to build upon in this respect, as the relationship between demand and per capita income has long been studied. In one of the earliest analyses, Engel (1857) uses data on 153 Belgian families to make the following well-known generalization. The proportion of total expenditure devoted to food declines as income rises. This hypothesis, now known as ‘Engel’s Law,’ has been verified in many subsequent studies, and suggests that consumer preferences are non-homothetic (i.e. income elasticities are not always unitary). 4

As a result, in thinking about how to characterize global demands, it is clear that the underlying utility function must be non-homothetic, so that patterns of consumer spending vary with income. In addition, the demand system should allow for more than just ‘quasi-homotheticity’, which severely limits demand response across the income spectrum (Deaton & Muellbauer, 1980, p. 145). At the same time, the demands should be well-behaved across the tremendous variation in incomes that are inherent to a global study. International per capita incomes can vary by a factor of several hundred, and in such a setting, the fitted budget shares of many demand systems can stray outside the [0,1] interval (price variation is much more moderate, with maximum variation in the neighbourhood of two or three). The demand system should also have a parsimonious parameterization, and be able to incorporate the economic restrictions of adding up, homogeneity, and symmetry.

Taken together, these requirements rule out a number of demand models, such as the Cobb–Douglas, Homothetic Constant Elasticity of Substitution, and Linear Expenditure System (LES). 5 Relatively more flexible models, such as the Almost Ideal Demand System (AIDS) and Working Preference Independence models, are also ruled out. Their fitted budget shares stray outside the unit interval under substantial variations in expenditure (Rimmer & Powell, 1996, p. 1614), and the international cross-section datasets include countries that span the world income spectrum. 6

One of the few demand systems to possess all the desirable properties is AIDADS (An Implicitly Directly Additive Demand System). Developed by Rimmer & Powell (1996), AIDADS is a generalization of the LES that allows for non-linear income consumption paths, while maintaining a parsimonious parameterization of preferences. AIDADS has the additional advantage of being an effectively globally regular demand system. In an international, cross-section comparison with four other demand systems (QUAIDS, QES, AIDS, and LES), AIDADS performs exceptionally well in out-of-sample forecasts, particularly in situations where there are widely varying income levels (Cranfield et al., 2003). 7 A disadvantage of AIDADS for some purposes is that it imposes implicit direct additivity, thereby limiting the range of substitution that is possible across goods. Instead of devoting more parameters to substitution responses, AIDADS captures a rich array of Engel effects by adding \( N - 1 \) income response parameters (where \( N \) is the total number of goods), beyond the number in the LES. Thus, the total number of parameters to be estimated is \( 3N + 1 \).
Before developing the AIDADS demand system in detail, two important assumptions are introduced. Both are necessary for estimating demands at a global level. One is that there is a single, representative private consumer in each country, and this ‘per capita household’ constitutes a useful unit of observation for the purposes of the study. Of course, this approach ignores heterogeneity within a country, and within towns and individual families. Yet given the data available to us, this assumption is essential to make progress in this field of research.

A related, perhaps even stronger, assumption is that preferences are internationally identical over aggregate goods and services. This might be unreasonable if one were working with 40 different food categories, for example. However, estimation of a consistent demand system requires working with aggregate commodities (unless, as discussed below, multiple-levels of nesting are introduced). In such a setting, the identical preference assumption is not unreasonable. Indeed, this approach has been used repeatedly over time, in studies such as Lluch et al. (1977), Theil et al. (1989), Rimmer & Powell (1996), and Cranfield et al. (2000, 2003). Several authors test the hypothesis that per capita national demands are consistent with a common set of preferences. For example, Clements & Chen (1996) find that when goods are narrowly defined, diversity in cross-country consumption patterns is evident. But the same authors find that similarity in cross-country consumption patterns predominates at the level of aggregation considered in this study: ‘Taken as a whole, the results reveal a surprising degree of similarity in international consumption patterns and support the idea that tastes are constant, at least with respect to broad commodity groups’ (Clements & Chen, 1996, p. 747).

The development of AIDADS begins with Hanoch’s (1975) formalization of implicit direct additivity. This is defined with the utility function:

$$U_n(x_n, u) = \frac{\sum_{i=1}^{N} x_{ni} u_n}{1 + e^{r_n}}$$

for any $n$ and $c$. The parameters $\gamma_n, \beta_n, \text{ and } \gamma_n$ are to be estimated in a regression involving uncompensated demands. The $\gamma_n$ parameter reflects the subsistence level of good $n$ that everyone must consume. $A$ is an ‘intercept’ parameter associated with country $c$’s utility ($u_c$). To obtain uncompensated demands, the first-order conditions for utility maximization are solved subject to a linear budget constraint: $\Sigma_{i=1}^{N} p_i x_{ni} = M^c$, where $p_i$ is the price of good $n$ in country $c$, and $M^c$ is total per capita consumer expenditure in country $c$. In budget share form, the demand functions are:

$$w_n = \frac{\sum_{i=1}^{N} x_{ni} u_n}{M^c} + \left( \frac{\gamma_n + \beta_n e^{r_n}}{1 + e^{r_n}} \right) \left( \frac{M^c - p' \gamma}{M^c} \right)$$

where $w_n$ is the share of good $n$ in $c$’s expenditure; $p$ and $\gamma$ are vectors of goods prices and subsistence levels, respectively, while other variables are as previously defined. The term $p' \gamma$ represents the minimally sustainable per-capita expenditure in any country. In turn, $[M^c - p' \gamma]$ is discretionary income. The following para-
metric restrictions are used to ensure well-behaved demands: \( z_n > 0 \) and \( \beta_n < 1 \) for all \( n \), and \( \Sigma_n x_n = \Sigma_n \beta_n = 1 \). Of similar importance, the regularity conditions of consumer theory are satisfied in the price-income space for which discretionary income is strictly positive. Note that in the special case that \( z_n = \beta_n \) for all goods \( n \), only the constant \( \beta_n \) is left to determine the (now constant) marginal budget share, and AIDADS collapses to LES.

In estimating AIDADS, an issue of primary concern is the level of commodity disaggregation. In principle, a detailed level of disaggregation is desirable, since it offers a rich and realistic characterization of demand behaviour. There are two limitations, however, that prevent AIDADS from being estimated with more than about 10 commodities. The first of these constraints is computational in nature. In order to have a demand system that is globally regular, and capable of capturing the wide range of behaviour observed in an international cross-section, a highly non-linear system is required. Due to this non-linearity, the Cranfield et al. (2000) estimation procedure—while greatly improving upon the original approach of Rimmer and Powell—generally fails to converge for systems larger than 10 commodities.

The second limitation is theoretical, and relates to the imposition of implicit additivity. This restriction is routine in international cross-section studies, since it has the important benefit of reducing the number of parameters to be estimated. The downside is that it restricts the potential for differential patterns of substitution and complementarity among goods. While this is appropriate for the level of aggregation undertaken in this study, it is not well suited to more disaggregate levels. An alternative approach might be to estimate a multi-level demand system, with a top level that restricts substitution relationships, and a lower level that permits a wider range of substitution effects (Seale et al., 2003). This is a natural way to get at the problem of disaggregation, once one has identified the commodities that one wishes to disaggregate. However, these authors are also led to use a demand system that is not globally regular. In short, no one approach offers all of the desirable traits, and our choice of demand system and aggregation reflects the particular context and purpose of this paper.

3. Data Sources and Aggregation

This section provides some background on the International Comparison Programme (ICP) and Global Trade Analysis Project (GTAP) datasets, and how they are used in this paper.

3.1. The ICP Database

The general objective of the ICP is to develop internationally consistent price and quantity comparisons across countries for the components of GDP. Although these international comparisons could be made with respect to the structure of production (i.e. GDP could be decomposed by industrial sectors), the ICP makes international comparisons via expenditure category breakdowns: household consumption (C), capital formation (I), government consumption (G), and net exports (United Nations, 1992).

Another key ICP feature is the use of the Purchasing Power Parity (PPP) concept. A PPP rate is a type of exchange rate that compares the cost of a common basket of goods in two countries. In particular, a PPP rate indicates the amount of
Local Currency Units (LCUs) needed to purchase a bundle of goods that is identical in quality and quantity to what can be bought with one unit of a base country's currency. Advocates of the PPP approach point to its advantages over the alternative of conventional exchange rates for making international price and expenditure comparisons. Another key characteristic of the ICP data is that they encompass many developing nations, in addition to the usual OECD countries (United Nations, 1992). The 1996 ICP data obtained for this study have complete information for 114 countries, the most ever made available under this programme.

Features such as these make the ICP data well-suited to the study of international demand behaviour. Indeed, they represent the current 'state of the art' regarding our understanding of international expenditure patterns. They have the most credible current information regarding how prices vary across countries, and the largest number of observations for the purpose of cross-country demand system estimation. On the other hand, as noted previously, the ICP data are quite difficult to link to input–output production data across the numerous countries encompassed.

### 3.2. The GTAP Database

GTAP data combine detailed bilateral trade, transport and protection data characterizing economic linkages among regions, with individual country input–output databases that account for intersectoral linkages within regions (Dimaranan & McDougall, 2002). For the purpose of estimating an international demand system, the GTAP data allow for disaggregation of each country's total private household consumption into 57 commodities. Therefore, in conjunction with population data (obtained from the World Bank), per capita household expenditures can be calculated at a fairly disaggregated level. One can also calculate 'comparative price levels' using GTAP data that are rough approximations to those calculated using the ICP methodology. By way of GTAP's tariff information, a commodity's price in a particular country can be distinguished from the average world price for that commodity. This is calculated by dividing a nation's expenditure on a commodity valued at domestic market prices, by its expenditure valued at c.i.f. prices. Whether or not one feels comfortable with this notion of comparative price levels, the issue of prices may not be of critical importance for estimating a global demand system. This is because international incomes vary by a factor of several hundred, while prices tend to vary by a factor of one or two times at most (in either the ICP or GTAP data). In this setting, the over-riding challenge is to adequately characterize demand behaviour as it relates to per capita income. Accordingly, the likelihood that ICP comparative price levels are more credible than those of GTAP does not confer a significant advantage to the ICP data, for the purposes of making projections based on future income growth.

### 3.3. Aggregation Schemes

GTAP version 5.0 data contain information specific to 52 countries, all of which are used to estimate AIDADS. The ICP data, on the other hand, enable AIDADS to be estimated with 114 national observations (refer to Seale et al., 2003, for a complete list). The greater country coverage of the ICP data reflects differences in the history, objectives, and organizational structure of the respective data sets.

With regard to the commodities used to estimate the demand system, both data...
sets were aggregated up to 10 categories, so that \( N = 10 \), and \( 3N + 1 = 31 \) parameters need to be estimated (Appendix Tables A.1 and A.2). This number was chosen based on historical practice for the ICP data set, and also represents what may be the practical limit of AIDADS (see discussion in Section 2). The ICP aggregation is very similar to that used in other ICP applications, such as Hunter & Markusen (1988), and Seale et al. (2003). To the greatest extent possible, the GTAP data follow a similar aggregation. However, this match is not perfect, primarily due to the fact that, in GTAP, wholesale/retail trade margins are maintained as a distinct category. Therefore, the reader must be mindful that in the following analysis, ICP and GTAP commodities are different, even when they are similarly named.

4. Demand System Estimation and Results

A brief description of the AIDADS estimation approach is offered here, before moving to discussion of the results. The procedure of Cranfield et al. (2000) is followed, who work with a six-good aggregation of the older, 1985 version of the ICP data. Estimation of AIDADS is formulated as a mathematical programming problem in the General Algebraic Modelling System (GAMS) software. Letting goods be indexed by \( n \) and \( i \), with \( c \) indexing observations corresponding to the per capita household of individual countries, a concentrated log-likelihood function is developed:

\[
0.5 \ln |DWD| (3)
\]

where \( w_{ni} = C^{-1} \sum_{i=1}^{c} e_{ci} \) is the \((n, i)\)th element of the matrix \( W \), and \( e_{ci} \) is the error term for the \( n \)th equation in the \( c \)th observation (see Greene, 1993, p. 496). This is minimized according to a constraint set involving non-linear equality and linear inequality constraints. Starting values for the non-linear estimation are chosen to be consistent with an LES demand system, since it is easily estimated, and represents a special case of AIDADS. Upper and lower bounds on all choice variables are included to reduce the size of the feasible set. Cranfield et al. (2000) carry out 100 bootstrap replications, and find the maximum likelihood estimators to have very little bias, as well as a high degree of efficiency. For more information on the estimation procedure, the reader may consult Cranfield et al. (2000).

AIDADS parameter estimates are presented in Table 1. This table also provides expenditure elasticities evaluated at the means of the data \( (\hat{\xi}) \), and gives simple correlations between the actual and fitted shares \( (\hat{\rho}) \). The correlation coefficients range from 0.282 to 0.839 in the case of the ICP-based demand system, and from 0.378 to 0.852 in the case of the GTAP-based demand system. While they give an indication of goodness-of-fit, they do not capture the important non-linearities that dominate. To get a feel for how well AIDADS does across this diverse set of countries, consider Figure 1, which plots the GTAP-based, fitted budget shares (at mean prices) with the observed budget shares for grains and other crops. Even without taking into account price variation, the fit looks quite good.

The results for both sets of data are consistent with one’s intuition regarding how the composition of consumption is likely to differ across income levels (Table 1). Begin by observing that the estimated ICP subsistence budget shares \( (\hat{\xi}_{ni}) \) for ‘Meat, dairy, fish’, ‘Home furnishings and appliances’, and ‘Transport and communication’ are zero (these represent three of four active bounds associated with the ICP-based estimation). In contrast, for ‘Grains, other crops’ the subsistence share is 0.690. This implies that consumption of the former three categories
Table 1. AIDADS estimated parameters and other summary statistics

<table>
<thead>
<tr>
<th></th>
<th>$\hat{e}_n$</th>
<th>$\hat{b}_n$</th>
<th>$\hat{\gamma}_n$</th>
<th>$\hat{\delta}_n$</th>
<th>$\hat{\rho}_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICP-based estimates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grains, other crops</td>
<td>0.218</td>
<td>0.000</td>
<td>0.690</td>
<td>0.286</td>
<td>0.839</td>
</tr>
<tr>
<td>Meat, dairy, fish</td>
<td>0.205</td>
<td>0.012</td>
<td>0.000</td>
<td>0.415</td>
<td>0.644</td>
</tr>
<tr>
<td>Processed food, beverages, tobacco</td>
<td>0.176</td>
<td>0.028</td>
<td>0.022</td>
<td>0.557</td>
<td>0.622</td>
</tr>
<tr>
<td>Apparel, footwear</td>
<td>0.089</td>
<td>0.044</td>
<td>0.077</td>
<td>0.810</td>
<td>0.296</td>
</tr>
<tr>
<td>Rent and housing utilities</td>
<td>0.083</td>
<td>0.207</td>
<td>0.052</td>
<td>1.200</td>
<td>0.552</td>
</tr>
<tr>
<td>Home furnishings and appliances</td>
<td>0.060</td>
<td>0.069</td>
<td>0.000</td>
<td>1.044</td>
<td>0.282</td>
</tr>
<tr>
<td>Medical products and services</td>
<td>0.016</td>
<td>0.132</td>
<td>0.081</td>
<td>1.322</td>
<td>0.731</td>
</tr>
<tr>
<td>Transport and communication</td>
<td>0.076</td>
<td>0.144</td>
<td>0.000</td>
<td>1.155</td>
<td>0.547</td>
</tr>
<tr>
<td>Recreation and education</td>
<td>0.055</td>
<td>0.177</td>
<td>0.024</td>
<td>1.239</td>
<td>0.633</td>
</tr>
<tr>
<td>Other goods and services</td>
<td>0.020</td>
<td>0.186</td>
<td>0.042</td>
<td>1.336</td>
<td>0.703</td>
</tr>
<tr>
<td>GTAP-based estimates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grains, other crops</td>
<td>0.084</td>
<td>0.000</td>
<td>0.298</td>
<td>0.403</td>
<td>0.852</td>
</tr>
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<td>Meat, dairy, fish</td>
<td>0.122</td>
<td>0.026</td>
<td>0.000</td>
<td>0.649</td>
<td>0.452</td>
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<tr>
<td>Processed food, beverages, tobacco</td>
<td>0.138</td>
<td>0.032</td>
<td>0.142</td>
<td>0.645</td>
<td>0.632</td>
</tr>
<tr>
<td>Textiles, apparel, footwear</td>
<td>0.068</td>
<td>0.030</td>
<td>0.030</td>
<td>0.784</td>
<td>0.379</td>
</tr>
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<td>Utilities, other housing services</td>
<td>0.035</td>
<td>0.047</td>
<td>0.000</td>
<td>1.092</td>
<td>0.618</td>
</tr>
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<td>Wholesale/retail trade</td>
<td>0.132</td>
<td>0.238</td>
<td>0.078</td>
<td>1.164</td>
<td>0.497</td>
</tr>
<tr>
<td>Manufactures, electronics</td>
<td>0.169</td>
<td>0.099</td>
<td>0.002</td>
<td>0.867</td>
<td>0.378</td>
</tr>
<tr>
<td>Transport, communication</td>
<td>0.115</td>
<td>0.097</td>
<td>0.000</td>
<td>0.964</td>
<td>0.524</td>
</tr>
<tr>
<td>Financial and business services</td>
<td>0.030</td>
<td>0.118</td>
<td>0.014</td>
<td>1.337</td>
<td>0.449</td>
</tr>
<tr>
<td>Housing, education, health, govt.</td>
<td>0.108</td>
<td>0.313</td>
<td>0.086</td>
<td>1.275</td>
<td>0.542</td>
</tr>
</tbody>
</table>

Notes: $\hat{e}_n$ are expenditure elasticities evaluated at the means of the data. $\hat{\rho}_n$ are correlation coefficients between the actual and fitted budget shares. Other estimated parameters correspond to parameters in the AIDADS share equation. The utility ‘intercept’ parameter, $\hat{\alpha}$, is 1.603 in the ICP-based results, and 1.977 in the GTAP-based results. Note that the ten GTAP-based goods do not correspond directly to the ten ICP-based goods, for the reasons discussed in Section 1.

is not necessary for survival at the lowest levels of income, while staple grains are essential. Likewise, the lower half of Table 1 indicates that estimating AIDADS with GTAP data results in subsistence budget shares for ‘Meat, dairy, fish’, ‘Utilities, other housing services’, and ‘Transport, communication’ that are also zero (these represent three of the four active bounds associated with the GTAP-based estimation). Similar to the ICP-based estimates, staple foods tend to have large subsistence budget shares, at 0.298 and 0.142 for ‘Grains, other crops’ and ‘Processed food, beverages, tobacco’, respectively. Thus, as expected, both data sets imply that staple grains are necessary for survival at the lowest levels of income, whereas meat, dairy, fish, transport, communications, and some housing expenditures are not.

Table 1 also displays results for $\hat{\gamma}_n$ and $\hat{\delta}_n$. These parameters represent the estimated bounds on AIDADS marginal budget shares. These estimates appear to be quite sensible for all commodities, in both the ICP and GTAP estimations. Consider, for example, the values corresponding to the ICP ‘Grains, other crops’ category. Its $\hat{\gamma}_n$ estimate indicates that at low income levels, this category accounts for as much as 21.8 cents of each additional dollar of expenditure. However, the $\hat{\delta}_n$ estimate of zero suggests that, at higher income levels, ‘Grains, other crops’ is no longer part of any increases in expenditure (this is the remaining active bound in the ICP-based estimation). Likewise, the $\hat{\delta}_n$ value corresponding to ‘Grains, other crops’ for the GTAP data is zero (this is also the remaining active bound in the GTAP-based estimation).
Figure 1. GTAP-based fitted and actual budget shares for ‘Grains, other crops’.

However, if the value of $\hat{a}_n$ for ‘Grains, other crops’ is compared between the sets of results, it is noticeably higher for the ICP-based estimates. There are several reasons for this. First, the ICP data include many more countries at very low income levels, and it is in these countries that staple grains dominate the budget. Second, $\hat{a}_n$ is higher in the ICP-based estimation because the data incorporate expenditure on transportation and wholesale/retail margins. Whereas ‘Grains, other crops’ is a final consumer good in the ICP data, it is a farm-gate producer good in the GTAP data. Therefore, the AIDADS share is expected to be higher. Third, the ICP defines ‘actual total consumption’ to include non-market activities, including food produced at home. This is excluded from the GTAP dataset (as with most input-output based data), and also contributes to a higher $\hat{a}_n$ ICP estimate for ‘Grains, other crops’.

It is also interesting to note that $\hat{a}_n$ does not equal $\hat{b}_n$ for any category of expenditure, in either estimation (Table 1). This suggests that there is a great richness of behaviour that is missed if a demand system of lower rank is estimated. It also clearly rules out the LES demand system, which implicitly restricts $\hat{a}_n$ to equal $\hat{b}_n$, thereby assuming constant marginal budget shares.

Table 1 also reports expenditure elasticities evaluated at the means of the data ($\hat{\epsilon}_n$). Again, the ICP- and GTAP-based results have reasonably similar results, given their underlying differences. For example, the commodity having the lowest expenditure elasticity in each case is ‘Grains, other crops’ (it is 0.286 for ICP, 0.403 for GTAP). In contrast, expenditure categories concerning housing, health, and education services tend to have expenditure elasticities well above 1.00. For
Figure 2. ICP-based fitted AIDADS budget shares (Goods 1–5).

Note: For a given commodity, there is one fitted budget share per country. These fitted shares have been calculated at the mean international price for a commodity, and therefore differ solely due to per capita income.

example, the ICP ‘Rent and housing utilities’ and ‘Medical products and services’ categories have expenditure elasticities of 1.200 and 1.322, respectively. Likewise, the GTAP category ‘Housing, education, health, public services’ has an expenditure elasticity of 1.275. Overall, both sets of expenditure elasticities appear realistic.

Figures 2 and 3 plot the ICP-based fitted budget shares evaluated at mean prices, against the log of per capita household expenditure (the results have been split into two figures for clarity). First of all, note that in contrast to what would happen with some of the most popular demand systems (e.g. AIDS or Working’s model), the fitted budget shares never stray outside the unit interval, even at extreme income levels. The fitted shares have three basic shapes: monotonically increasing, monotonically decreasing, and a non-monotonic pattern in which a good’s share of the budget rises at low income levels, then falls at higher income levels. The most dramatic change over the observed income range occurs in the ‘Grains, other crops’ category in Figure 2, which goes from being the most important part of consumption at low income levels (43%), to the least important at high income levels (2%). In contrast to the mostly food- and apparel-related expenditure categories of Figure 2, those in Figure 3 concern services and other apparent ‘luxuries’. Thus, the budget shares in Figure 3 monotonically increase with income. Note that in the case of ‘Other goods and services’ there is an interesting S-shaped curve. Clearly, AIDADS is a very flexible functional form when it comes to Engel responses.
Figures 4 and 5 plot the fitted budget shares when AIDADS is estimated with the GTAP data. In many respects the results are quite similar to those when ICP data are used, although one must refrain from making direct comparisons since there are no equivalent categories (even in those cases where a name is identical), and since ICP uses the PPP methodology to compute expenditure levels. Although there is a great deal of information in Figures 4 and 5, a particularly interesting point to focus on relates to the ‘Wholesale/retail trade’ category of Figure 5. To the authors’ knowledge, this is the first explicit evidence as to how aggregate margins vary across the per capita income spectrum. Recall that in the ICP data, aggregate wholesale/retail margins are incorporated within each category of expenditure, and it is impossible to determine their role in the changing patterns of demand exhibited in Figures 2 and 3. The fact that this category is broken out in the GTAP data makes these results unique and potentially quite valuable. Figure 5 reveals that—like nearly every other category of expenditure—the proportion of the budget allocated to ‘Wholesale/retail trade’ varies substantially over the income spectrum. It is estimated to be only 12% of the budget in the poorest countries, but takes up more than 20% of the budget in the richest countries.

This variation in the share of spending allocated to wholesale/retail trade reflects a marked change of behaviour associated with the way that products are marketed and distributed at different stages of a country’s development. For example, consider that a shopper in a developing country might purchase food from a kerbside vendor, while a shopper in a wealthier country, in contrast, is likely to visit a vast, climate-controlled supermarket with computerized inventory and checkout facilities. Figure 5 also makes clear that demand for education, health,
Estimation of International Demand Behaviour

Figure 4. GTAP-based fitted AIDADS budget shares (Goods 1–5).

Note: A given country’s per capita expenditure varies across the two data sets, because the ICP uses the PPP methodology. Therefore, it is not overly meaningful to focus on a particular expenditure level when comparing Figures 2 and 3, with Figures 4 and 5.

and financial services also rises markedly as countries undergo economic development and structural change. In particular, there are notable increases in demand for ‘Housing, education, health, government’ and ‘Financial and business services’. Again, this is very similar to the behaviour exhibited in the ICP-based results of Figure 3. (Those results may not be as striking, but in part this reflects the greater range of values on the vertical scale.)

Another interesting result from the GTAP estimation is that the share of spending devoted to ‘Manufactures, electronics’ has a non-monotonic shape (Figure 5). The share of spending on this category peaks at roughly the income level of Thailand, then falls as wealth increases. This humpback shape is also found in the GTAP ‘Meat, dairy, fish’ category of Figure 4. In particular, this category’s share of the budget is only 7% in the poorest countries, then rises across the income spectrum, peaking at 10% at roughly the income level of Indonesia. It then falls in importance until it takes up only 6% of the budget at the highest expenditure level.

It is revealing to compare this result with the ICP ‘Meat, dairy, fish’ category in Figure 2, which—quite impressively—also shares the same non-monotonic shape. There the ‘Meat, dairy, fish’ percentages at low, medium, and high levels of expenditure are 11%, 15%, and 2%, respectively (Figure 2). The fact that this humpback shape is picked up in both demand systems speaks well of the perfor-
Figure 5. GTAP-based fitted AIDADS budget shares (Goods 6–10).

formance of each one. Indeed, it is remarkable given the very different provenance of the ICP and GTAP data.

Figure 6 contrasts key expenditure categories of the two estimations in a more direct fashion. As with Figures 2–5, Figure 6 plots the fitted AIDADS budget shares evaluated at mean prices, against the log of per capita household expenditure. This graph has been limited to two aggregate consumption categories that are more nearly comparable than was feasible in the previous figures. In particular, the fitted budget shares of one commodity have been added to another commodity to overcome some of the differences in classification.

The first aggregate commodity to be compared is an aggregate of ‘Grains, other crops’ and ‘Processed food, beverages, tobacco’. Figure 6 indicates that ‘Grains, other crops; Processed food, beverages, tobacco’ has an exceptionally high share of the budget in the poorest countries (54% and 42% for ICP and GTAP, respectively), and a very low share of the budget at the highest income levels (6% and 8%). In each case the decline in this category’s share of the budget is nearly linear in the log of per capita expenditure. The other aggregate commodity that is compared relates to housing, health, education and other expenditures (Figure 6). The ICP-based estimates suggest that this aggregate is about 15% of the budget in poor country households, but nearly half of the budget in the rich country households. The GTAP-based estimates give rise to corresponding values of about 14% and 36% (Figure 6). For both of these commodity aggregates, the GTAP fitted shares tend to be lower across the income spectrum, which reflects the fact that margins have a separate category in GTAP, whereas they are embodied by each category of the ICP data. Differences between the ICP and GTAP results
Estimation of International Demand Behaviour

Figure 6. Aggregations of ICP-based and GTAP-based fitted budget shares.

Also reflect the remaining differences in category definitions, the ICP’s inclusion of many more countries at low income levels, and incorporation of non-market activities into ICP expenditures.

It is thus apparent that, for many applications, one would not get qualitatively different results by using GTAP data in place of ICP data, or vice versa. The two sets of results are remarkably similar considering the myriad differences in definitions, different treatment of margins, different sample of countries, and the fact that the raw data are collected from separate sources with distinct methodologies. In this regard, the data sets strongly ‘corroborate’ one other. Furthermore, these findings support the hypothesis that the GTAP data are useful for relating estimates of national demand behaviour to input–output based data. Since GTAP data are organized according to ISIC definitions, estimation results can be readily linked to data sets such as OECD STAN, and—easier yet—GTAP production and trade data.

5. Summary and Conclusions

A variety of applications in economic research call for estimation of consumer demands at the international level, and for these to be linked to production and trade data based on input–output accounts. One such application is to estimate the impact of future income growth on future resource needs, sectoral outputs, environmental emissions, and employment. While the International Comparison Programme (ICP) is a traditional data source for global demand system estimation, ICP-based demand estimates are very difficult to reconcile with input–output based
data, in part because the data necessary for producer-to-consumer transition matrices are unavailable for many countries. In addition, due to their unique purpose and design, ICP data have other, more fundamental incompatibilities with input–output based data. For example, the ICP definition of 'total household consumption' includes non-market, self-produced consumption, which is excluded from input–output data. In addition, per capita expenditures are calculated with the PPP method, which also differs from input–output accounting.

To circumvent such problems, this study examines the feasibility of estimating a global demand system with data from the Global Trade Analysis Project (GTAP). These data combine individual country input–output databases accounting for intersectoral linkages within regions, with detailed bilateral trade, transport and protection data characterizing economic linkages among regions. Since the data also have information on international per capita expenditures and an approximation of regional price differences, they can also be used to estimate a global demand system.

To evaluate the potential of GTAP data, an AIDADS demand system is estimated with an international cross-section of 1996 ICP data, and then with the 1997 GTAP data. The two sets of results not only provide a great deal of new information about international demand patterns, they suggest that GTAP data are truly a viable alternative for this type of estimation work. The GTAP-based estimations give rise to the same shapes in the fitted budget shares that are produced by ICP data, even in those cases where the fitted shares have an unusual non-monotonic shape.

Both estimations make clear that international demand behaviour has a close relationship with per capita income, since fitted budget shares (and hence expenditure elasticities) exhibit a great deal of variation across the income spectrum. For example, the GTAP-based fitted budget shares for total food, beverage, and tobacco consumption decline from more than half the budget in the poorest countries, to less than one-tenth of spending in the richest countries, which is a strong confirmation of Engel's Law. Demand for services such as education and health, on the other hand, exhibits just the opposite behaviour—their share of expenditure increases rapidly as incomes rise.

The GTAP-based estimation also provides valuable new information regarding the close, positive relationship between aggregate wholesale/retail trade margins and per capita income. Given the similar, high-quality results produced by both data sets, the estimation based on GTAP data is favoured because it can be readily and accurately mapped to input–output based data, thereby improving the effectiveness of subsequent modelling exercises. Although ICP comparative price levels may be more credible than those of GTAP, this advantage is of somewhat less importance when making projections based on future income growth.

One limitation of the study is that only ten aggregate commodities are considered in the applications. While this is more than in many related studies (e.g. Cranfield et al., 2000, 2003), a finer level of commodity aggregation may be useful for some applications. In the demand formulation of this study, this possibility is hindered by computational constraints. AIDADS demands are highly non-linear in order to parsimoniously capture the wide variation in behaviour exhibited in international cross-section data, while maintaining global regularity and other desirable features. Development of a demand system that shares these properties, but allows for finer aggregations and richer substitution effects among goods, is an important area for future research.
Notes

2. As discussed below, some of the latter are composites; GTAP 5.0 has original information for 52 countries, and it is this subset of countries that is used in the econometric estimation below.
3. For interested readers, country-specific income elasticities can be provided by the authors upon request.
4. Classic studies in this area include Stigler (1954); Prais & Houthakker (1955); Lluch et al. (1977); Deaton & Muellbauer (1980); and Theil & Clements (1987).
5. Another drawback of the LES concerns the evolution of its income elasticities. They are highly counterintuitive, since for necessity they always increase with income, while for luxury goods they always decrease with income.
6. The AIDS demand system and variants of the Working model also have the disadvantage that they possess only local curvature properties, if they satisfy concavity at all.
7. This is because AIDADS is a rank 3 demand system, according to Lewbel’s (1991) definition. Rank 1 demands are independent of income, and therefore the most restrictive. Rank 2 demand systems are also fairly restrictive, but do not force the Engel curve through the origin. Rank 3 demand systems are the least restrictive, allowing for non-linear Engel responses.
8. It may seem unusual to see utility in this function. In principle, one could obtain uncompensated demands (and budget shares) that depend solely on prices and expenditure by substituting out utility, but this cannot be done analytically. The estimation process, documented in Cranfield et al. (2000), involves solving for utility numerically, and making the necessary substitution. The implied level of utility (upon which consumption shares depend) is then computed from the implicit function, for each vector of prices and total expenditure. Note that this implies that in plots of predicted budget shares on income (presented in later sections), utility varies across the income spectrum.
9. The 1996 ICP data were obtained from Mr Yonas Biru of the World Bank, by way of Dr Anita Regmi of the US Department of Agriculture, Economic Research Service. They cannot be disaggregated beyond a 26 commodity level, because of World Bank difficulties in obtaining the appropriate disaggregated data from certain regions of the world. While several versions of 1990s ICP data exist in which commodities are highly disaggregated, and have been used by some researchers (e.g. Eaton & Kortum, 2002), only a small number of regions are represented, and these individual data sets are not compatible with each other (World Bank, 2002).
10. First of all, PPPs do not fluctuate over time to the same degree that conventional exchange rates do. PPP rates are also less likely to overstate poverty in developing countries, since PPPs allow for the fact that non-traded services are often much cheaper there. Additionally, the ICP produces PPP rates that are specific to the individual components of a highly refined decomposition of GDP. A conventional exchange rate, in contrast, provides but a single conversion factor for all goods and services (see also United Nations, 1992). A drawback of the PPP methodology is that it reduces the compatibility of ICP data with other types of datasets, including those based on input–output data.
11. In the GTAP ‘Baseview’ data-viewing software application, divide VIMS (imports valued at domestic market prices, summed over all sources) by VIWS (imports valued c.i.f., summed over all sources).
12. Indeed, in estimating AIDADS with, and then without, any price variation, very few qualitative or quantitative differences in the Engel responses are found (these results are available from the authors).
13. There are 66 regions in the GTAP data, but 14 are regional composites and are deleted since they do not contain original information. Countries and regions are listed in Dimaranan & McDougall (2002).
14. To facilitate comparison of the estimation results, the possibility of deleting the countries in the ICP and GTAP data that are not common to both data sets was considered. However, the number of countries in common is only 44. Deleting all other countries would result in a loss of many degrees of freedom, and so this is not carried out. Furthermore, a given country’s per capita expenditure is not the same between the two data sets, because ICP uses the PPP methodology. In terms of demonstrating that the two data sets yield qualitatively similar results, differences such as these should only work against the paper’s findings.
15. The authors thank John Cranfield for graciously providing the GAMS-based estimation code.
16. As before, the ICP per capita expenditure of a given country will not equal the GTAP per capita expenditure for that country, due to ICP’s use of the PPP methodology, and a different definition of actual total consumption.

17. Note that the two sets of results compare favourably to the results of Cranfield et al. (2000, 2003), although a direct comparison is not overly meaningful, since those studies are based upon 1985 ICP data, have six expenditure categories, and are based on a different set of countries.

**Table A.1. ICP commodity aggregation**

<table>
<thead>
<tr>
<th>Present study 10 commodities</th>
<th>Original 26 commodities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grains, other crops</td>
<td>Bread and cereals; Fruit, vegetables and potatoes</td>
</tr>
<tr>
<td>Meat, dairy, fish</td>
<td>Meat; Fish; Milk, cheese and eggs</td>
</tr>
<tr>
<td>Processed food, bev., tobacco</td>
<td>Oils and fats; Other food; Non-alco. beverages; Alco. Bever.; Tobacco</td>
</tr>
<tr>
<td>Apparel, footwear</td>
<td>Clothing, including repairs; Footwear, including repairs</td>
</tr>
<tr>
<td>Rent and housing utilities</td>
<td>Gross rent and water charges, including maintenance; Fuel and power</td>
</tr>
<tr>
<td>Home furnishings and appliances</td>
<td>Furniture and floor coverings, including repairs; Other household goods and services; Household appliances and repairs</td>
</tr>
<tr>
<td>Medical products and services</td>
<td>Medical care, including both services and goods</td>
</tr>
<tr>
<td>Transport and communication</td>
<td>Trans. equip. &amp; repairs; Operation of trans. Equip.; Transport services; Communication</td>
</tr>
<tr>
<td>Recreation and education</td>
<td>Recreation and cultural goods and services; Education services</td>
</tr>
<tr>
<td>Other goods and services</td>
<td>Restaurants, cafes and hotels; Other goods and services, nec</td>
</tr>
</tbody>
</table>

*Note: For additional description of these sectors, please refer to United Nations (1992).*

**Table A.2. GTAP commodity aggregation**

<table>
<thead>
<tr>
<th>Present study 10 commodities</th>
<th>Original 57 commodities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grains, other crops</td>
<td>Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Crops nec; Processed rice</td>
</tr>
<tr>
<td>Meat, dairy, fish</td>
<td>Livestock; Animal products; Raw milk; Fishing; Bovine cattle, sheep and goat, horse meat products; Meat products nec; Dairy products</td>
</tr>
<tr>
<td>Processed food, beverages, tobacco</td>
<td>Oils and fats; Sugar; Food products nec; Beverages and tobacco products</td>
</tr>
<tr>
<td>Textiles, apparel, footwear</td>
<td>Fibers; Wool, silk-worm cocoons; Textiles; Wearing apparel; Leather products</td>
</tr>
<tr>
<td>Utilities, other housing services</td>
<td>Coal; Gas; Electricity; Gas manuf. &amp; distrib.; Water; Construction; Insurance</td>
</tr>
<tr>
<td>Wholesale/retail trade</td>
<td>Trade</td>
</tr>
<tr>
<td>Manufactures, electronics</td>
<td>Forestry; Minerals; Wood products; Publishing; Chemical, rubber, plastic products; Mineral products; Ferrous metals; Metals nec; Metal products; Motor vehicles and parts; Electronics; Mach. and equip. nec; Manuf. Nec</td>
</tr>
<tr>
<td>Transport, communication</td>
<td>Oil; Oil &amp; coal products; Trans. equip. nec; Transport nec; Water trans; Air transport; Communication</td>
</tr>
<tr>
<td>Financial and business services</td>
<td>Financial services nec; Business services nec</td>
</tr>
<tr>
<td>Housing, education, health, government</td>
<td>Recreational and other services; Education, health, public administration and defence; Dwellings</td>
</tr>
</tbody>
</table>

*Note: For additional description of these sectors, please refer to Dimaranan & McDougall (2002).*
References


Hancock, G. (1975) Production and demand models with direct or indirect implicit additivity, Econometrica, 43, pp. 395–419.


