Projecting World Food Demand Using Alternative Demand Systems

By

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Abstract

Computable General Equilibrium (CGE) models are increasingly being used to project world food markets in order to support forward-looking policy analysis. Such projections hinge critically on the underlying functional form for representing consumer demand. Simple functional forms can lead to unrealistic projections by failing to capture changes in income elasticities of demand. We adopt as our benchmark the recently introduced AIDADS demand system and compare it with several alternative demand systems currently in widespread use in CGE models. This comparison is conducted in the context of projections for disaggregated global food demand using a global CGE model. We find that AIDADS represents a substantial improvement, particularly for the rapidly growing developing countries. For these economies, the most widely used demand systems tend to over-predict future food demands, and hence overestimate future production and import requirements for agricultural products.

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1. Introduction

Projecting future food demands is important for many reasons. First, and foremost, such projections are necessary for assessing the world's ability to feed itself (Islam 1995 and Anderson *et al.* 1997). Less obvious, but also important are the interactions between global demands and the cost of trade barriers. In their evaluation of the Uruguay Round, Bach *et al.* (2000) show that the potential gains from global trade liberalization can be significantly altered by their interaction with economic growth – particularly when quotas are involved. Frandsen *et al.* (1998) further underscore this point in their analysis of the costs of EU enlargement and its interactions with the EU's quantitative restrictions on subsidized exports.

However, food is not a simple, aggregate commodity and the composition of world food demand has been changing dramatically over the last two decades, much of this itself fueled by income growth. At lower levels of per capita income, consumers have been shifting consumption patterns away from grains towards livestock and meat products, and at higher income levels consumers have sought greater product variety and reduced food preparation requirements. As a consequence, there has been a major shift in the pattern of world food trade. During the period 1980 to 1995, although aggregate food trade grew at a modest annual rate of 5.3 percent, the relative changes at the disaggregate levels were quite varied. For four broadly defined food categories—bulk, livestock, horticulture, and other processed food, the annual growth rates in trade were 2.1, 6.9, 6.6, and 8.3 percent, respectively (Coyle *et al.* 1998). These changes are predicted to continue, and even accelerate in some cases (Delgado *et al.* 1999). Capturing such changes in projections of the global economy can be very important for any researcher seeking to analyze policies relating to trade, production or consumption of agricultural products, as well as for those interested in the potential environmental impacts of agricultural activity (Rae and Strutt 2001).

To what extent can an empirical model of consumer demand predict future changes in food consumption? The answer depends in part on the functional form employed. Of particular importance is the Engel flexibility of the underlying demand system. Are marginal budget shares permitted to vary with income level? Can goods that are initially luxuries become necessities as income grows? The concept of demand system rank, offered by Lewbel (1991), provides some guidelines to these questions. According to this concept, only rank three demand systems give sufficiently flexible, non-linear Engel responses while rank one and two systems are more or less restricted in this regard. Unfortunately, virtually all general equilibrium and partial equilibrium models used for predicting world food demand incorporate relatively simple functional forms, with limited Engel flexibility, such as the Linear Expenditure System (LES), the Constant Difference of Elasticities (CDE) demand system, and the Homothetic Cobb-Douglas system (HCD). Examples include the RUNS and GREEN models (LES: Burniaux and van der Mensbrugghe, 1991; Burniaux *at el.*, 1988), the GTAP model (CDE: Hertel, 1997), and the GTAP in GAMS model (HCD: Rutherford, 2001). Many partial equilibrium models use a simple log-log specification in which income elasticities are held constant. Examples here include: the International Food Policy Research Institute's global model of food products (Agcaoili and Rosegrant 1995), the World Bank's econometric model of global grain market (Mitchell *et al.* 1997), and the FAO's world agricultural model (Alexandratos 1995). The demand systems in

these studies are all severely limited in their ability to capture changes in consumer demand across the global spectrum.

In contrast, a recently developed, rank three demand system, AIDADS (An Implicitly Direct Additive Demand System) by Rimmer and Powell (1996) has proved well-suited for this task. Cranfield *et al.* (2002) compared AIDADS with several other functional forms and their out-of-sample forecasts show that the AIDADS system outperforms all the other functional forms in predicting aggregate food demand across a wide range of developing and developed countries. In this paper, we adopt the AIDADS model as a "best practice" benchmark, and compare it to the simple functional forms currently used in CGE modeling. As will be seen, there are non-trivial costs involved in incorporating AIDADS into a global general equilibrium model, and these must be weighed against the potential benefits. We investigate this tradeoff between complexity and flexibility by constructing a carefully designed set of experiments, focusing on long run projections of global demand, and the implied rates of growth in production and import requirements. This leads us to a set of conclusions regarding the costs and benefits of using alternative functional forms to represent consumer demand in global CGE models.

The remainder of the paper is structured as follows. Section 2 begins with a general discussion of properties of demand systems and then briefly reviews demand systems in the context of projections over a long period of time, during which per capita incomes of many countries change dramatically. The AIDADS system is formally introduced and contrasted with the LES, HCD and the CDE systems. Section 3 develops the methodology for comparing AIDADS with the three alternative systems used in projecting global food demands. This involves estimation of ADAIDS, followed by calibration of the other demand systems. These are then incorporated into a global CGE model, where they are used for a series of simulation experiments. Section 4 focuses on the different predictions of future food demand, production and trade requirements as income grows. Throughout this analysis, the estimated AIDADS demand system is adopted as the best practice benchmark, against which the others are compared. Conclusions are offered in the final section.

2. Functional Form Choice and Long Run Projection of Food Demand

2.1 Regularity of demand systems

Demand systems consistent with economic theory should satisfy the usual theoretical restrictions, including: adding-up, symmetry, homogeneity, and negativity. These regularity requirements are related to the properties of the expenditure function. An expenditure function is considered regular if its value is non-negative, its first derivatives with respect to prices (compensated demands) are non-negative, and if the matrix of second partial derivatives with respect to prices is negative semi-definite (implied by the concavity property). The non-negativity requirement, coupled with the adding-up property, requires that the budget share of the good should lie in the [0,1] interval. In long run projections, with considerable changes in income/expenditure, this requirement is crucial in ensuring the demand system behaves in accordance with economic theory.

The LES, HCD, CDE, Almost Ideal Demand System (AIDS), the Translog system, and the Rotterdam model are the most popular demand systems in recent applied work. Unfortunately, global regularity requirements are not typically satisfied by some of these systems. For example, budget shares of the AIDS system (Deaton and Muellbauer 1980) can fall outside the [0,1] interval. This is particularly likely to occur for staple food demands when

income growth is large. The Translog demand system by Christensen, Jorgenson, and Lau (1975) also suffers from the fact that fitted budget shares may become negative, and the imposition of global curvature restrictions is quite limiting in this case.

2.2 Engel properties of demand systems

While regularity requirements ensure that a system is consistent with economic theory, Engel's law, which is supported by numerous empirical studies, requires a demand system to generate declining budget shares for food as income rises. This implies an income elasticity of demand less than one. Econometric studies of income elasticities for countries at different stages of development often show that demand for food in low-income countries is relatively more elastic than in wealthy countries. This suggests that when economic growth in poor countries raises consumer expenditure, the demand for food should become less elastic. The extent of Engel flexibility required for projections work is even greater when dealing with disaggregated food demand. For example, high-value, ready-to-eat food has a relatively high budget share in rich countries, while staple foods have a high budget share in low-income countries. Chaudri and Timmer (1986) confirm that staple food's share in the total food budget declines as income rises.

Most of the systems mentioned above fall into the category of either rank one or two and thus do not possess sufficient flexibility to capture these effects across the development spectrum. Even though some demand systems may be able to produce very sensible estimates around a certain data point, extrapolation of these systems based on large *per capita* income shocks often leads to unrealistic Engel responses at the new income level. The HCD and log-log specifications clearly give no Engel flexibility as income elasticities are constant. The Rotterdam demand system (Barten 1964, and Theil 1965) displays constancy in the marginal budget shares, which further implies very little Engel flexibility. As we will show below, the LES and CDE functions also display troublesome Engel properties.

2.3 The AIDADS system

These limitations on regularity and Engel properties led Rimmer and Powell (1996) to develop a new, rank three demand system based on implicitly directly additive preferences, which they nicknamed AIDADS. In the authors' words (p. 1614), AIDADS is "globally regular throughout that part of the price-expenditure space in which the consumer is at least affluent enough to meet subsistence requirements and which allows the MBS's (Marginal Budget Shares) to vary as a function of total real expenditures." According to Rimmer and Powell (p. 14, 1992), this system has better regularity properties than AIDS or other versions of Working's model and it is "more flexible in its treatment of Engel effects than the LES or Rotterdam models."

Cranfield *et al.* (2002) compared the performance of LES and AIDS with several rank three systems (AIDADS, Quadratic AIDS—QUAIDS and the Quadratic Expenditure System—QES) in predicting food demands based on estimation with cross section data spanning a range of 64 countries with very different income levels. They showed that the full rank QES, AIDADS and QUAIDS do indeed out-perform the LES and AIDS using both in-sample and out-sample criteria. A further comparison between the rank three systems does not show which system is preferred. However, the results suggest that AIDADS would be a more suitable demand system in projecting food demand when the projection covers a long period of time and involves a wide range of countries. Thus, we choose AIDADS as the best practice benchmark for our projections of global food demand.

AIDADS starts from an implicitly directly additive utility function (Rimmer and Powell 1996):

$$\sum_{i=1}^{n} U_i(q_i, u) = 1 \quad (i = 1,2,\ldots,n) \tag{1}$$

where $\{q_1, q_2, \ldots, q_n\}$ is the consumption bundle, u is the utility level, and U_i is a twice-differentiable monotonic function and is strictly quasi-concave in q_i and has the following form:

$$U_i = \frac{[a_i + b_i G(u)]}{[1 + G(u)]} \ln\left(\frac{q_i - g_i}{A G(u)}\right) \tag{2}$$

where G(u) is a positive, monotonic twice-differentiable function, g_i is the subsistence level of consumption, a_i, b_i and A are parameters. The following restrictions are imposed:

$$0 \le a_i, b_i \le 1; \quad \sum_{i=1}^{n} a_i = 1; \quad \sum_{i=1}^{n} b_i = 1. \tag{3}$$

Choosing $G(u) = e^u$ and denoting M as expenditure, the usual utility maximization yields the system of demands:

$$q_i = \frac{f_i (M - g' \cdot P)}{P_i} + g_i \quad \text{for } i = 1,2,..,n \tag{4}$$

where

$$f_i = \frac{a_i + b_i e^u}{1 + e^u} \quad \text{for } i = 1,2,...,n \text{ and } g'P = \sum_{i=1}^{n} P_i g_i \tag{5}$$

The AIDADS Engel elasticities are:

$$h_i = y_i / w_i \tag{6}$$

where Y_i is the marginal budget share and w_i is the average budget share. They are defined as:

$$y_i = f_i - (b_i - a_i)\Xi \quad \forall i \quad \text{where} \quad \Xi = \left[\sum_{i=1}^{n} (b_i - a_i) \ln(q_i - g_i) - \frac{(1 + e^u)^2}{e^u}\right]^{-1} \tag{7}$$

$$w_i = f_i + \left(\frac{P_i g_i - f_i P'g}{M}\right) \quad \forall i \tag{8}$$

AIDADS satisfies the regularity conditions over the price-expenditure space where consumers have strictly positive discretionary expenditure (above the subsistent level, i.e., $M - P'g > 0$).

McLaren, Powell and Rimmer (1998) showed that the AIDADS expenditure function is non-negative, continuous, homogenous of degree one in prices, non-decreasing in prices if $q_i > \gamma_i \geq 0$ for all i, and concave in prices. And the expenditure function is non-decreasing in utility if and only if

$$\Xi = \left[\sum_{i=1}^{n} (b_i - a_i) \ln(q_i - g_i) - \frac{(1+e^u)^2}{e^u} \right]^{-1} < 0 \qquad (9)$$

The marginal budget shares contain f_i, which behaves logistically and falls within the interval $[a_i, b_i]$. The average budget shares (w_i) are also non-linear in expenditure. Thus, the Engel elasticities will in general vary non-linearly with respect to income/expenditure changes. Although as real income grows indefinitely all Engel elasticities will converge to unity, it should be noted that these asymptotes are not approached monotonically. This is a very important point that distinguishes AIDADS from the widely used LES. As we can see from below, as income grows, the income elasticities for necessities such as grains fall over the range of observed incomes.

2.4 The commonly used demand systems: HCD, LES and CDE

The simplest functional form used in CGE models is the Homothetic Cobb-Douglas function (HCD), which exhibits constant average budget shares. This type of preference clearly cannot describe the dynamic phenomena of changing consumption and trade patterns in the world food market and is in contradiction with Engel's law. However, this system is still used in CGE models due to the simplicity of its calibration and hence it is included in our comparison to establish a "worst case" but nonetheless relevant benchmark.

The Linear Expenditure System (LES), which is more general than HCD and can be viewed as a special case of AIDADS[1], satisfies the theoretical restrictions of adding-up, homogeneity and symmetry. However, the marginal budget shares are constant over all income levels (i.e. the fraction of an extra dollar spent on food is independent of per capita income). The LES further implies that as income increases without bound, average budget shares converge to marginal budget shares and consequently, income elasticities converge monotonically to unity. Assuming food is initially a necessity, this implies that the income elasticity for food will rise as incomes increases. Thus the LES clearly contradicts Engel's Law.[2]

The Constant Difference of Elasticity function (CDE) was proposed by Hanoch (1975) and has been widely used in CGE models since the work of Hertel *et al.* (1991). This system has been shown to be robust and globally regular. However, this system also has some drawbacks. In particular, while the marginal budget shares are non-constant in the CDE system, it will be shown below that the CDE structure prevents luxury goods from becoming necessities as income grows. This means that, if meat is a luxury at very low-income levels, it will remain a luxury

[1] AIDADS becomes LES when parameter α_i are equal to β_i, for all i. If all the subsistence parameters γ_i are zero, LES becomes CD. So both CD and LES are special cases of AIDADS.

[2] This point was probably first made by Theil (p. 512, 1983).

even as their per capita incomes grow many times over. This is clearly an undesirable feature. Another troublesome fact about the CDE is that the adjustment of the marginal budget shares as households become wealthier, while typically in the right direction, is modest, relative to the available econometric evidence.

3. Methodology for Comparing Alternative Demand Systems

While one could choose among demand systems for use in a CGE model based on purely theoretical considerations, most researchers find themselves weighing the benefits of incorporating more complex functional forms into their analysis against the relatively higher costs of implementation. Therefore, it is important to work through a specific application in order to shed additional light upon the benefits and costs associated with these alternative demand systems. This section outlines our methodology for comparing the LES, HCD and CDE functions to the econometrically estimated, AIDADS benchmark.

We begin with estimation of the AIDADS system for disaggregated food products. Second, the LES and CDE systems are calibrated to the AIDADS estimates so that all three systems start with the same income elasticities of demand. (Note that this is not possible for the HCD functional form for which these elasticities are always unitary.) We then systematically explore how these income elasticities evolve for countries with different income levels as the global economy grows. The third step involves individually building these different demand systems into a global CGE model. For this purpose, we have chosen the GTAP model (Hertel 1997), which is widely used to make projections of global trade in food and non-food products. Finally, a long run demand-side growth experiment is carried out on all four "versions" of the CGE model and the results are compared to investigate the empirical significance of the differences in model performance. In so doing, we hope to establish the potential benefits, as well as the costs, of incorporating this type of rank three demand system into a CGE model.

3.1 Estimation of AIDADS

Estimation of international demand systems is an important problem, which has received a great deal of attention. Readers interested in the issues that arise and how they might be addressed are referred to Clements and Selvanathan (1994); Theil, Chung, and Seale (1989); Theil (1996) and the references contained therein. In this paper we follow earlier work by using data from the International Comparison Project data set, in this case for 1985 (UN 1992). This data set is based on national household consumption surveys and is evaluated in 1985 "international dollars". We adopt the Maximum Likelihood Estimation method developed by Cranfield *et al.* (2000) to estimate the AIDADS system. This is formulated as a constrained optimization program in which the objective function is minimized with respect to the unknown parameters of AIDADS, fitted budget shares, residuals and the utility levels. The latter are needed due to the implicit nature of the ADAIDS function. While Cranfield *et al.* (2000) only worked with a single, aggregate food product, our study extends the estimation to disaggregated food products, which include grains (GRA), livestock and meat products (LIV), horticulture and vegetable products (HOR), fish (FIS), and other food (OFD). Also included in our study are textiles and wearing apparel (TEX), resource intensive goods (RES), manufacturing (MAN), and services (SEV).

Estimation of AIDADS, using international, cross-section data, is based on the assumption that preferences are common across all countries. This produces a demand system for the world in 1985. Each country's demand structure differs due to its prices and per capita income level. To make computation manageable in the subsequent simulations of the global model, the version 4 GTAP database (McDougall, Elbehri and Truong, 1998) is aggregated into 13 regions[3] for this study. One advantage of having an econometrically estimated demand system is that it can be updated from the year of estimation (1985) to the benchmark year for the CGE model (1995). This update is done by shocking per capita expenditure to their corresponding 1995 levels according to the observed growth in regional per capita incomes over this period (relative prices are assumed to remain unchanged).

3.2 Calibration of LES and CDE to AIDADS estimates

Instead of estimating the LES and CDE systems, we choose to calibrate them to the estimated AIDADS elasticities. This provides us with a common basis for comparison since the LES and CDE systems start at the same income elasticities in 1985 as AIDADS. It is also consistent with the way in which CGE models are constructed, since the demand system is typically calibrated to externally estimated elasticities. Note that we calibrate these competing demand systems to the income elasticities in the year of estimation – since this is the norm for CGE analysis. Thus there are really two sources of approximation error. The first is the error associated with having out-of-date elasticities in the benchmark equilibrium, and the second is the error introduced when per capita incomes grow as part of the model simulation – in this case, long run growth projections to the year 2020.

The Linear Expenditure System (LES) is calibrated for each region in the CGE model to ensure that the 1985 AIDADS elasticities can be reproduced. The calibration problem is formulated as the following optimization program:

$$\underset{b,g}{\text{Min}} \sum_{i=1}^{n} \left[\left(b_i / w_i - \bar{h}_i \right) / \bar{h}_i \right]^2 \tag{10}$$

Subject to:

$$p_i q_i = p_i g_i + b_i \left(M - \sum_{j=1}^{n} p_j g_j \right) \quad \forall i = 1,..,n-1 \tag{11}$$

$$\sum_{i=1}^{n} p_i (q_i - g_i) = -M / V \tag{12}$$

[3]The thirteen aggregated regions are: Australia amd New Zealand (AUS), Japan (JPN), Newly Industrialized Regions (NIC), ASEAN (AS6), China (CHN), Canada (CAN), USA, Mexico (MEX), MERCOSUR (MER), Western Europe (WEU), Economies in Transition (EIT), Mid East and North Africa (MEA) and the rest of the world (ROW). This regional aggregation is provided in Table 1. The demands for each of the 13 aggregated regions in this study are represented by those of a typical country in the ICP data set.

$$\sum_{i=1}^{n} b_i = 1, \quad b_i \geq 0, \quad \text{and } 0 \leq g_i \leq q_i \tag{13}$$

where $\bar{\eta}_i$ are the targeted income elasticities from the AIDADS systems, β_i and γ_i are the LES substitution and subsistence parameters, respectively. p_i, q_i, w_i, M and ς are the observed prices, quantities, budget shares, expenditures, and the Frisch parameter[4], respectively. The objective is to minimize the sum of the squares of the percentage deviations of the calibrated income elasticities from the targeted ones. The first constraints (eq. 11) are the (*n*-1) independent LES demand equations, which are derived from the utility maximization problem. Due to the adding-up property, one of the demand equations is dropped. The second constraint (eq. 12) is the Frisch equation, where the Frisch parameter is expressed as minus the ratio of total expenditure over supernumerary expenditure and its value is drawn from the AIDADS estimation. This equation is added into the program because the Frisch parameter helps to determine the subsistence budget shares, hence the subsistence parameters of the LES system. The last constraints (eq. 13) are the regularity requirements imposed on parameters β_i and γ_i. The optimization problem posed by (10)-(13) is solved 13 times to generate LES systems for each of the 13 regions in the study.[5] These calibrated systems are then updated to 1995 using real, per capita income growth rates and assuming constant prices – as was done with AIDADS[6].

The calibration of the CDE functional form involves choosing the parameters so that the pre-specified income and own price elasticities can be replicated. Similar to the calibration of the LES systems, the regional CDE systems are first calibrated to income elasticities predicted by AIDADS in 1985. The routine (eqs. 14-20) to calibrate the CDE, developed by Liu *et al.* (1998), is used here with some modifications. The formulation employed is as follows:

$$\underset{a_i g_i}{\text{Min}} \quad (T_1 \mathrm{P}_g + T_2 \mathrm{P}_a) - \mathrm{E}_g - \mathrm{E}_a \tag{14}$$

Subject to:

$$\mathrm{P}_g = \sum_{i=1}^{n} [(h_i - \bar{h}_i)/\bar{h}_i]^2 \tag{15}$$

$$\mathrm{P}_a = \sum_{i=1}^{n} [(e_{ii} - \bar{e}_{ii})/\bar{e}_{ii}]^2 \tag{16}$$

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[4] The Frisch parameter is minus the reciprocal of the marginal utility of income, or the money flexibility. See Frisch (1959).

[5] Uniqueness of the solution to this calibration problem is established in an appendix that is available upon request from the authors.

[6] In order to fit the GTAP data point at 1995, budget shares for the LES and CDE systems had to be once again adjusted to fit the same data point as for the AIDADS system in that year. We preserve the 1995 income elasticities predicted by these functional forms in the previous step. This process is also formulated as a constrained optimization program, similar to (10)-(13).

$$E_g = -\sum_{i=1}^{n} g_i \ln g_i \tag{17}$$

$$E_a = -\sum_{i}^{n} \left[(a_i \ln(a_i) + (1-a_i)\ln(1-a_i) \right] \tag{18}$$

$$h_i = \left[\sum_{k}^{n} w_k g_k a_k + g_i (1-a_i) \right] / \sum_{k}^{n} w_k g_k + \left(a_i - \sum_{k}^{n} w_k a_k \right) \tag{19}$$

$$e_{ii} = -(1-w_i)a_i - w_i g_i + w_i \left(a_i g_i - \sum_{k}^{n} w_k a_k g_k \right) \tag{20}$$

The objective of the program is to minimize the sum of four weighted terms. The first term is the sum of squares of percentage deviations of the calibrated income elasticities from the targeted ones. The second term is the sum of squares of percentage deviations of the calibrated own price elasticities from the targeted ones.[7] The third term is the entropy of the expansion parameters, which treats these parameters symmetrically and thus encourages equalization of the values of these parameters, insofar as that is consistent with the observed data. The fourth term is the sum of the entropies of the individual substitution parameters, which will again encourage equalization of the values of these parameters, but will also result in values strictly between zero and one as is required for regularity. The α_i and γ_i are CDE parameters that are calibrated using this problem. The symbols $w_i, h_i, \bar{h}_i, e_{ii}, \bar{e}_{ii}$ are, for good i, the budget share, the calibrated income elasticity, the targeted income elasticity, the calibrated uncompensated own price elasticity, and the uncompensated own price elasticity target, respectively. T_1 and T_2 are arbitrary scale parameters related to the penalty components in the objective function. In order to get a closer fit of the income elasticity targets, the penalty to the deviation from the AIDADS income elasticity targets is assigned a bigger weight than that to the deviation from the price elasticity targets.

The first term in the objective for the CDE calibration problem (14) has the same interpretation as the objective of the LES calibration problem. The other terms in the objective of the CDE calibration problem serve to further pin down the parameters and allow the demand system to also target the own price elasticities. The constraints (15)-(18) define each of the individual terms in the objective, and (19)-(20) define the targeted elasticities as functions of the data and parameters to be calibrated. Thus, the equivalents of (15)-(20) are directly embedded in the objective for the LES calibration problem. The regularity conditions for the LES calibration

[7] Note in this program, both income elasticities and own price elasticities are exp licitly targeted, which is different from the calibration of the LES system. In the calibration of the LES, the price elasticities are implicitly targeted by imposing a constraint that defines the Frisch parameter.

problem are given in (13), and the regularity conditions in the CDE calibration problem are handled implicitly handled through the formulation of the fourth objective term.[8]

This program is solved individually for each of the 13 regions in the model. These calibrated CDE systems are updated to 1995 and adjusted to the GTAP data point in a similar procedure to the one used in the LES case.

3.3 Integration of the four systems into a CGE model

With calibrated parameters for these demand systems, the structure of the GTAP model can be modified to reflect each of these functional forms. Aggregate final demand in each region of the GTAP model is governed by a per capita aggregate utility function specified over private demand, government demand and savings (see Chapter 2 in Hertel 1997). We do not alter this specification – which is Cobb Douglas in form and aims to hold each of these macro-economic aggregates fixed as a share of net national income. The four different functional forms are applied at the next level – to represent private household demands for individual products and services. In the standard GTAP model, private demand is specified as a CDE function whose parameters are calibrated to price and income elasticities adopted from the literature. These individual demands (e.g., the demand for staple grains) are further divided into domestic and imported products and services through the commonly used "Armington" specification (Armington 1969).

Integration of the AIDADS, LES and CD representations of consumer demand into the GTAP model requires replacement of the usual CDE representation with the alternative functional forms. Details of the modification are documented in Yu (2000) and Yu *et al.* (2000).[9] These modifications result in four different GTAP models, which fit the same benchmark data point at 1995 and have otherwise identical structure.

3.4 The projections scenario

The projections scenario used to compare these different functional forms is designed to allow direct comparison of their Engel flexibility (or inflexibility). Thus we project the global economy forward 25 years, to the year 2020. Normally such a projection would involve both price and income effects – which would greatly complicate our comparison – since the implied price elasticities of demand from these four demand systems differ – even at the point of calibration. Therefore, we have chosen to conduct a more limited experiment. In this case, we formulate a purely "demand-side" growth scenario in which endowments are allowed to adjust freely to match the changes in demand induced by population and real income growth. Therefore, relative prices remain unchanged in this experiment – permitting us to focus our attention on the

[8] We could also add an additional constraint designed to compute the intercept terms in the CDE function. However, this information is already embodied in the observed budget shares and our CGE implementation of the CDE follows Hertel, Horridge and Pearson (1992) in using the share-based implementation of the CDE.

[9] This modification is quite straightforward, with the exception of the fact that the AIDADS demand system has been estimated at consumer prices. Therefore, we must introduce margins activities to bridge the difference between the producer prices, for which GTAP is normally solved, and these margin-inclusive, consumer prices. In order to retain comparability, the CDE, CD and LES demand systems are also implemented at consumer prices.

differences in predicted output and trade "requirements" under the four different functional forms.

According to the projected income and population growth data from 1995 to 2020, as reported in Table 1 (see Walmsley and McDougall, 2000), the regions with the highest population growth are Mid-East and North Africa (MAN) and the Rest of the World (ROW). Since only population and aggregate income are increased, higher population growth means relatively less per capita real income growth. In the developing world, China, Newly Industrialized Countries (NIC) and ASEAN (AS6) show the highest rates of projected per capita income growth, whereas ROW and MAN show reasonably high aggregate growth, but low per capita income growth due to very high rates of population growth.

4. Does It Matter? Projecting World Food Market under Alternative Systems

4.1 Comparison of the income elasticities

A useful starting point for our analysis involves simply comparing the predicted income elasticities of demand across the four models, over time. We begin with an examination of the predicted elasticities from the AIDADS model that we will use as the standard against which to compare the performance of the other functional forms. Table 2 reports AIDADS elasticities in 1985, 1995 and 2020. These estimates are quite consistent with other studies in which AIDADS has been estimated using international cross-section data (Rimmer and Powell, 1996; Cranfield *et al.* 2000, 2002), i.e., elasticities for food products are generally under unity, indicating that food is a necessity, while elasticities for industrial goods are generally above unity, suggesting these are luxuries.

One interesting thing about the present study is the additional disaggregation of food products in the AIDADS system. Here, our results also show significant differences in income elasticities across products and regions. The estimated income elasticity for grains in ASEAN in 1985 is 0.53, decreasing to 0.22 in 1995, and finally dropping to 0.04 in 2020. This shows the Engel flexibility of the AIDADS model. ROW (the rest of the world), which represents the poorest economies, is projected to also see a decline in income elasticity of demand for grains from 0.76 in 1985 to 0.47 in 2020. At the other end of the income spectrum, however, we see that in the US, demands for food are relatively stable, and the income elasticity for grains remains under 0.1 over the entire period. Compared to the demand for grains, the elasticity for meats is relatively more elastic and remains in the 0.7 – 0.8 range for most of the regions (except for CHN and ROW where it is over 1 in 1985 but drops to the 0.7-0.8 range in 2020). Overall, we can see that, within the low-income regions such as CHN and ROW, income elasticities for all food products drop from 1985 to 2020, indicating that income growth in these countries causes significant changes in the marginal response of consumers to additional income growth. For the wealthy regions, however, the demand for food products remains quite stable.

Recall that the other three demand systems in our study are all calibrated to the same, *estimated* elasticities in 1985. They are then updated to 1995 based on observed per capita income growth over that period, so a comparison of the different starting values in the 1995 benchmark year is a relevant place to begin our analysis. We also compare them at the end of the projections period – in the year 2020 to obtain an initial understanding of the likely differences in output and trade requirements over this period across models. For this purpose, Table 3 reports

these differences from the benchmark. (The HCD differences are trivial since all of the income elasticities are unitary.)

Compared to the AIDADS system in 2020, the calibrated LES system generates income elasticities that converge to the HCD ones (unitary income elasticities) despite the initial calibration to AIDADS in 1985. While both of these demand systems must converge asymptotically to unitary income elasticities, the LES converges monotonically and much more quickly than AIDADS. The difference between the LES and the AIDADS is most significant for the countries with high income growth (such as China). In fact, for China and most of the other developing regions, the 1995 income elasticities for food from LES are much higher than those from AIDADS, and the differences generally become even greater in the year 2020. For example, the income elasticity of demand for grains in China drops from 0.74 in 1995 to 0.22 in 2020 according to the AIDADS, whereas the LES system predicts an increase from 0.92 to 0.98 during this period, causing a dramatic overstatement in this key elasticity by the year 2020. On the other hand, for the USA and other developed economies, the LES system generally predicts insignificant increases in income elasticities for food products, due to the smaller income growth and already high-income levels. This is comparable to the AIDADS system which also predicts little movement in these elasticities. As a result, the LES elasticities are not very much different from AIDADS in 2020 for the rich economies.

The CDE system implies small drops in income elasticities during 1985-2020 for all the food products across all the regions. This could be problematic where income growth is significant, but not so where income is high and/or income growth is low. Unlike the LES system, the CDE does not always predict higher food income elasticities than does AIDADS. In fact, for the NIC and MER regions, CDE income elasticities are actually lower than the AIDADS ones for some food products. For the developed economies, we observe that CDE income elasticities for food products are slightly lower than those from AIDADS, due to the fact that AIDADS elasticities are relatively stable in these regions while those from the CDE continue to decrease.

The most serious problem with the CDE stems from the observation that it precludes the possibility of goods switching from luxuries to necessities as income rises. To see why this is the case, rearrange the expression for the income elasticity of demand in (19) using the following standard normalization rule for the expansion parameters: $\sum_k^n w_k g_k = 1$:

$$h_i = \left[\sum_k^n w_k a_k (g_k - 1) + (g_i - 1)(1 - a_i) + 1 \right] \tag{21}$$

In the case where the income elasticity of demand is initially greater than one, the sum of the first two terms on the right hand side of (21) must be positive. For this good to become a necessity as income increases, this combined effect of these two terms must eventually become negative, thereby causing the income elasticity of demand to fall below one. However, we know that, in order to satisfy the conditions for global regularity, the CDE substitution parameters must

satisfy the following: $1-\alpha_i > 0$.[10] Furthermore, for the good in question to initially be a luxury, the CDE expansion parameter must exceed the share-weighted average, so that $\gamma_i > 1$. This means that the second term in (21) is positive. It is also invariant to income. Thus the only way this good can become a necessity is for the negative elements of the summation comprising the first term to become more dominant as income increases. However, with $\alpha_k > 0$, this can only arise if the budget share, w_k, associated with the necessities [for which $(\gamma_k - 1) < 0$] rises. But we know by their very definition that the budget share for necessities will fall with increasing income. So this cannot happen. Therefore, if we start out in a situation where good *i* is a luxury, it will remain a luxury as income increases (holding prices constant).

This property of the CDE is particularly problematic for livestock products where income elasticities are typically above one for countries at very low-income levels, thereafter falling below one as these countries reach middle-income status. The fact that the AIDADS elasticities for food decline for low income countries with high income growth implies that there is a significant gap between CDE and AIDADS income elasticities for these countries and this gap becomes bigger in 2020. For example, in China, demands for livestock, horticulture and fish remain elastic (1.34 for livestock, 1.16 for horticulture and 1.23 for fish) in 2020 according to the CDE, whereas the demands have actually become inelastic by 2020, based on the predictions of our estimated AIDADS model. To summarize the differences between the calibrated LES and CDE systems, and the AIDADS system, the root mean square percentage error (RMSPE[11]) index is computed (the bottom panel of Table 3) using AIDADS as the benchmark. According to this index, we offer several general observations. First, the deviation from the AIDADS income elasticities under the LES and CDE systems increases from 1995 to 2020 for most regions. Second, the deviation is generally bigger in the developing regions than the developed ones, indicating potentially bigger differences in food demand projections for developing countries. Third, the LES performs more poorly than the CDE for most developing regions, due to its rapid convergence on the HCD. The CDE does not differentiate itself from the LES for developed regions where income growth is rather slow.

4.2 Projection results using the AIDADS model

We now turn to the simulation of impacts from projected population and income growth on production and trade over the period: 1995-2020. As noted above, this involves shocking the GTAP model with the projected growth rates for these variables, as reported in Table 1. Percentage changes in consumer demand, output and import requirements, relative to their levels in 1995, are presented in Table 4. Bear in mind that these simulations abstract from the supply-side by freeing up endowments to keep commodity prices unchanged over the projection period.

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[10] It is also possible to have global regularity of the CDE if $1-\alpha_i < 0$ for all commodities i. However, in practical calibration exercises using estimated demand elasticities, we find that this case does not arise.

[11] This error measure ζ is defined as $\zeta = \left(\sum_i [(\eta_i - \eta_i^a)/\eta_i^a]^2 \right)^{1/2}$ where η_i are the calibrated income elasticities for the LES and CDE systems, and η_i^a are the income elasticities for the AIDADS system.

For China, per capita consumption of grain and associated products is projected to double over this period (the first column in Table 4). This is a relatively modest change in light of the fact that per capita income is rising more than four-fold. (From Table 2 we can see that the income elasticity of demand for staple grains products falls to 0.2 by 2020.) As we move down the column for China, we see larger increases for the other food products – particularly for livestock and meat products where per capita consumption is projected to increase by 223 per cent.

Due to the presence of intermediate input requirements and population growth, output typically must increase more than consumption. This is evidenced in the second panel of Table 4 where production of grains increases by 273%. Grains production requirements (recall that we have relaxed any supply-side constraints in these simulations) must increase by more than consumption since some grains are used as an input into grains production (seed), as well as into other products such as livestock – the demand for which is rising more strongly. Since China imports some of the grains used for intermediate and final consumption, and since all supply side constraints are relaxed in this projections exercise, import requirements increase – at a similar rate to that observed for output.[12]

In contrast to food products, China's rate of increase in domestic consumption of manufactured goods far outstrips her increase in domestic production (509% vs. 284%). This is because China is a very significant net exporter of manufactured goods. But import demand in China's most important market (USA) is growing much more slowly – just 88% over this 25-year period. A similar phenomenon – although less pronounced – is observed for textiles and natural resources. In the case of services, the consumption category with the highest income elasticity of demand in 2020 (1.37 in 2020), the rate of consumption increase exceeds that of production since much of the services output is tied to the provision of wholesale/retail and transport margins for the merchandise goods. And demands for the latter are growing more slowly. The combination of all of these factors means that the differences in output expansion across sectors (213% - 349%) are much less than the differences in consumption (106% - 574%).

The entries in the column for USA provide a striking contrast to those for China. Consumer demands for grains and fish are virtually flat, with other per capita demands increasing at a rate between 39% (horticultural products) and 61-62% (resources, manufactures and services). However, the USA is an important exporter of grains, and so this product group shows one of the highest rates of increase in USA output requirements (92%) – slightly exceeding that for livestock products. In general, the USA has a very dense input-output matrix, and the high level of intermediate input demands tends to spread the output increases quite evenly across sectors.

4.3 Comparing projection results under alternative functional forms

To see the differences in projection results by the four demand systems, percentage differences of the predictions in consumer demand, output and import requirements by the HCD, LES and CDE models from the AIDADS predictions for four representative regions (China,

[12] There are two reasons why the rates of increase in import requirements and output requirements differ. Firstly, the intensity of use of import and domestic goods differs across industries and intermediate uses. Secondly, where exports play a large role in driving output changes, we expect the two to diverge as well.

Newly Industrialized, West Europe and USA) are presented in Table 5. The complete results for all regions are provided in the appendix tables A1 - A3.

It is interesting to start with the HCD functional form. Since it assumes homotheticity, this is trivial case, and a good vehicle to see how poorly a naïve model might do. Table 5 shows that the HCD model over-predicts consumption in all food products and textile products and under-predicts manufacturing, resources and services for all the four regions. This is especially true for grains where the income elasticities are far below unity for all four regions. For example, HCD over-predicts grain demands in China and NIC by 97 and 173 percent, respectively. Even for West Europe and USA, the HCD model over-predicts grain demands by 77 and 53 percent. For livestock products, the difference is less serious as the HCD model over-predicts by less than 25 percent. This is because in year 2020, livestock demands in all these regions remain relatively elastic and the difference between income elasticities of AIDADS and HCD is relatively small.

The LES model produces projections similar to the HCD model for developing countries (CHN and NIC), i.e., it over-predicts demand in food products and textiles and under-predicts demand in non-food products. This is due to the tendency of LES elasticities to converge to unity, whereas the AIDADS income elasticity for food goes down during the same period. On the other hand, for developed regions (WEU and USA), the LES model predicts similar results to the AIDADS model for all the products (except horticultural goods).

The deviations in predictions of the CDE model from AIDADS are not as clear-cut as for the LES. Although demands of nonfood products in CHN and NIC are under-predicted and demands for nonfood products in WEU and USA are close to those predicted by AIDADS, it is hard to draw a clear line as to where the CDE over-predicts and/or under-predicts demands for food products. In fact, the CDE model over-predicts demand for food in China but under-predicts demand for some food products in NIC. Dramatic income growth, coupled with low base period income in China, causes universal declines in food income elasticities under AIDADS, whereas the CDE model predicts very little adjustment in these elasticities. Therefore, it is not surprising that the CDE over-predicts food demands in China. It should be noted that since the CDE income elasticities for luxury goods remain above unity (e.g. livestock), it actually produces worse predictions than the HCD model for livestock demand in China. Specifically, the HCD system only over-predicts demand for livestock by 25 percent, whereas the CDE over-predicts demand for the same product by over 100 percent.[13] For the case of low–value food (e.g. grains) in NIC, where AIDADS income elasticities decrease and CDE income elasticities adjust slowly, the CDE model over-predicts demands, whereas for the case of high-value food (e.g. horticulture and livestock), where AIDADS income elasticities remain relative elastic and CDE income elasticities fall, the CDE model slightly under-predicts demand.

While the differences in projections of food demand by these systems are significant, especially for developing countries, the differences in output and import requirements are smaller, due to intermediate input and trade linkages. Take China as an example. Using AIDADS

[13] This poor performance of the CDE in projecting demand growth for China can be greatly improved upon by anticipating the switch from luxury to necessity and calibrating the model to an income elasticity of demand below one. This is the approach taken by Nin et al. (2002) who use outside estimates of the future income elasticity of demand for livestock products in China to obtain a mean value over their projections period. They subsequently calibrated the CDE-based GTAP model to this value – which happened to fall below one.

projections as the base, output requirements of grains are over-projected by only about 29-44% by the HCD, LES and CDE systems, in contrast to the 37-97% over-prediction in grains demand by these systems. These differences are even smaller for the projections of import requirements (in the range of 24-35%). For the USA, the biggest difference in the projection of output and import requirements by the HCD model comes from fish, around 20% of over-prediction, while the LES and CDE models predict almost the same results.

Table 6 summarizes the differences in projections of demand, output and import requirements using Root Mean Square Percentage Errors (RMSPE) along both the regional (upper panel) and commodity (lower panel) dimensions, using the AIDADS projections as a base. First we look at this index for demand. From the regional dimension, the HCD model performs the worst for all the regions except China (where the CDE model performs the worst). The LES and CDE models each produce a larger RMSPE for some of the regions. From the commodity dimension, HCD performs the worst for all food products except livestock, for which the CDE model performs the worst (due to the problem in China again), and resources. Compared to the LES system, CDE performs better in grains and other food products.

Moving down the rows in Table 6, we can see that the RMPSE measure for production or import requirements is universally smaller than its counterpart for demand. For example, these measures for demand in China are 1.535, 1.644 and 2.488 for the CD, LES and CDE models, respectively, while for production requirements these measures are 0.825, 0.916 and 1.439. The RMPSE values for import requirements are even smaller. The bottom portion of Table 6 (commodity dimension) also shows smaller deviations from the AIDADS best practice benchmark in the projection of output and import requirements using simpler functional forms. Again, the relative performance of the CDE and LES systems are not substantially different in terms of their projections of output and import requirements.

5. Conclusions

Computable General Equilibrium models are increasingly being used to support projections of world food markets in order to support forward-looking policy analysis. Such projections of world food demand hinge critically on the underlying functional form used. Simple functional forms can lead to unrealistic projections by failing to capture changes in income elasticities of demand as consumers become wealthier. This paper compares several demand systems in the projection of disaggregated food demand across a wide range of countries with different income levels using a global general equilibrium model.

We adopt as our benchmark the recently introduced AIDADS demand system which has been shown to outperform competitors in its ability to predict *per capita* food demands across the global income spectrum. Against this baseline, we compare the performance of alternative functional forms currently in widespread use in CGE modeling. We find that the AIDADS functional form represents a substantial improvement, particularly in the case of rapidly growing developing countries. For these countries, the widely employed Homothetic Cobb Douglas (HCD), Linear Expendable System (LES) and Constant Different of Elasticities (CDE) demand system tend to over-predict future food demands, and hence overestimate future export and import requirements. This could be grossly misleading for those seeking to evaluate the consequences of economic growth in developing countries for world food markets.

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Table 1. Regional aggregation in GTAP, and GDP and population growth rates during 1995-2020

Abbreviation	Name and Description	GDP	Population	GDP per year	Population per year	Per capita GDP per year
CHN	China	523.3	53.7	7.6	1.7	5.8
NIC	Newly Industrialized Countries (Korea, Taiwan and Hong Kong)	243.8	19.5	5.1	0.7	4.3
AS6	Six ASEAN countries (Singapore, Malaysia, Indonesia, Thailand, the Philippines, and Vietnam)	210.2	32.6	4.6	1.1	3.5
MEX	Mexico	208.8	23.3	4.6	0.8	3.7
ROW	Rest of World	184.1	68.6	4.3	2.1	2.1
MER	MERCOSUR (Argentina, Brazil, and Uruguay)	165.9	26.9	4	1	3.0
EIT	Transition Economies: Central and East Europe and Former Soviet Union	159.7	20	3.9	0.7	3.1
MEA	Middle East and North Africa	155.9	92.9	3.8	2.7	1.1
AUS	Australia and New Zealand	124.9	23.6	3.3	0.9	2.4
USA	United States of America	94.8	22.6	2.7	0.8	1.9
CAN	Canada	93.7	22.7	2.7	0.8	1.8
WEU	Western Europe (European Union and EFTA)	87.3	1.8	2.5	0.1	2.5
JPN	Japan	54	3.9	1.7	0.2	1.6

Source: Authors' aggregation based on GTAP 4 database (McDougall, Elbehri and Truong, 1998). GDP and population growth data are drawn from Walmsley and McDougall (2000). All numbers in the table are percentage growth rates.

Table 2. Income elasticities from AIDADS system for the years 1985, 1995 and 2020

	China			N. Industrialized			ASEAN			Mexico			Rest of World			MERCOSUR			Econ. in Transition		
Grain	0.81	0.74	0.22	0.31	0.06	0.05	0.53	0.22	0.04	0.06	0.06	0.03	0.76	0.72	0.47	0.12	0.09	0.03	0.26	0.22	0.02
Livstock	1.46	1.02	0.69	0.72	0.73	0.86	0.80	0.71	0.84	0.73	0.73	0.83	1.07	1.00	0.79	0.70	0.71	0.82	0.70	0.70	0.87
Horti&Veg	1.33	0.94	0.46	0.52	0.44	0.63	0.66	0.47	0.60	0.45	0.44	0.57	0.99	0.91	0.64	0.43	0.43	0.57	0.47	0.46	0.64
Fish	1.43	0.93	0.23	0.34	0.05	0.01	0.56	0.22	0.00	0.04	0.05	0.00	0.99	0.90	0.53	0.12	0.08	0.00	0.27	0.22	0.02
Oth food	0.96	0.86	0.61	0.65	0.66	0.81	0.71	0.62	0.79	0.66	0.66	0.77	0.88	0.85	0.71	0.63	0.64	0.77	0.62	0.62	0.82
Textile	0.94	0.91	0.84	0.87	0.89	0.95	0.89	0.86	0.94	0.88	0.88	0.93	0.92	0.91	0.87	0.87	0.88	0.94	0.85	0.85	0.95
Resources	0.72	0.97	1.17	1.17	1.11	1.05	1.11	1.14	1.05	1.12	1.12	1.06	0.94	0.99	1.14	1.14	1.13	1.06	1.21	1.20	1.05
Manufa.	1.20	1.25	1.28	1.28	1.17	1.07	1.30	1.24	1.07	1.16	1.16	1.08	1.24	1.26	1.29	1.21	1.19	1.09	1.26	1.25	1.07
Services	0.86	1.24	1.37	1.34	1.21	1.10	1.35	1.30	1.09	1.20	1.21	1.10	1.19	1.26	1.39	1.26	1.23	1.11	1.34	1.33	1.10
	M.East & N Afr.			Aus & NZ			USA			Canada			W Europe			Japan					
Grain	0.40	0.37	0.21	0.08	0.07	0.07	0.06	0.07	0.10	0.06	0.06	0.07	0.09	0.07	0.06	0.06	0.04	0.13			
Livstock	0.75	0.74	0.76	0.79	0.83	0.87	0.84	0.87	0.91	0.81	0.84	0.88	0.78	0.80	0.86	0.76	0.80	0.88			
Horti&Veg	0.57	0.55	0.49	0.52	0.58	0.65	0.60	0.66	0.74	0.55	0.60	0.68	0.51	0.54	0.65	0.47	0.53	0.68			
Fish	0.42	0.39	0.21	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.07	0.05	0.02	0.04	0.02	0.09			
Oth food	0.69	0.68	0.69	0.73	0.78	0.82	0.79	0.83	0.88	0.76	0.79	0.84	0.72	0.75	0.83	0.69	0.74	0.84			
Textile	0.87	0.87	0.95	0.92	0.93	0.95	0.94	0.95	0.97	0.93	0.94	0.96	0.91	0.93	0.95	0.90	0.92	0.96			
Resources	1.16	1.16	1.20	1.09	1.07	1.05	1.06	1.05	1.03	1.08	1.06	1.04	1.09	1.07	1.04	1.10	1.08	1.04			
Manufa.	1.27	1.26	1.33	1.12	1.09	1.06	1.08	1.06	1.03	1.10	1.08	1.05	1.13	1.10	1.05	1.14	1.11	1.06			
Services	1.32	1.32	1.38	1.14	1.10	1.05	1.09	1.07	1.03	1.12	1.09	1.04	1.15	1.12	1.04	1.17	1.13	1.07			

Note: The three columns (from left to right) under each region contain the income elasticities for the years 1985,1995 and 2020, respectively.
Source: Authors' calculation.

Table 3. Differences* between the LES and CDE income elasticities, and those predicted by AIDADS for the years 1995 and 2020 (see Table 1 for region descriptions)

		CHN	NIC	AS6	MEX	ROW	MER	EIT	MEA	AUS	USA	CAN	WEU	JPN
LES95	Grain	18	44	45	-1	8	5	11	10	2	-1	-1	0	4
	Livstock	13	12	16	0	6	2	4	3	-3	-5	-5	-6	1
	Horti&Veg	18	26	29	0	9	3	12	10	-10	-25	-16	-24	2
	Fish	22	46	47	0	20	6	33	70	-4	-2	-2	-5	4
	Oth food	13	14	20	0	5	2	3	5	-1	-4	-3	-4	1
	Textile	6	5	7	0	3	1	5	-3	-3	-3	-5	-4	1
	Resources	-11	-4	-12	0	-2	-1	16	5	-5	-3	-4	-5	0
	Manufa.	-18	-6	-13	0	-6	-1	-3	-10	-1	-1	-1	0	0
	Services	-30	-13	-16	0	-14	-1	-11	-10	2	2	3	4	-1
LES20	Grain	76	68	79	8	28	22	45	27	7	-1	0	6	2
	Livstock	34	7	16	1	17	3	11	9	-1	-4	-4	-3	1
	Horti&Veg	57	20	38	2	25	8	28	22	-7	-23	-15	-22	1
	Fish	80	74	83	10	37	25	67	79	-2	-3	-3	-1	2
	Oth food	39	9	20	1	17	4	12	12	0	-2	-2	-2	0
	Textile	16	2	6	0	8	1	6	0	-2	-2	-3	-2	0
	Resources	-20	-1	-7	0	-11	-1	3	-2	-3	-2	-3	-3	0
	Manufa.	-26	-2	-7	0	-18	-1	-5	-15	-1	0	0	0	0
	Services	-38	-4	-9	0	-31	-1	-10	-17	1	1	2	2	0
CDE95	Grain	3	12	15	0	1	2	2	1	-1	-2	-1	0	0
	Livstock	48	-13	-6	1	5	-3	-1	0	-6	-4	-4	-4	-6
	Horti&Veg	34	-5	4	0	4	-2	0	0	-7	-7	-6	-5	-7
	Fish	44	16	18	0	4	3	2	1	0	-1	0	1	1
	Oth food	9	-14	-7	1	3	-3	-1	0	-6	-5	-4	-5	-6
	Textile	-3	-15	-12	1	-1	-2	-1	-1	-4	-2	-2	-3	-3
	Resources	-33	-7	-17	-8	-10	0	-1	-1	-2	0	-5	0	1
	Manufa.	-8	-1	-4	-12	-4	1	0	1	-4	1	-6	-4	2
	Services	-39	5	7	5	-3	1	1	1	4	1	4	4	1
CDE20	Grain	50	14	33	-2	13	8	18	11	-2	-5	-4	1	-5
	Livstock	65	-29	-14	-17	17	-15	-8	1	-13	-9	-10	-12	-12
	Horti&Veg	70	-28	-1	-23	19	-15	-2	5	-20	-16	-17	-18	-18
	Fish	100	21	39	1	24	11	18	12	1	-2	-2	4	-3
	Oth food	28	-31	-17	-20	10	-16	-9	1	-15	-10	-12	-14	-14
	Textile	0	-24	-18	-11	0	-10	-8	-2	-8	-5	-5	-7	-8
	Resources	-56	-9	-17	-3	-21	-1	-3	-4	-1	1	-3	1	0
	Manufa.	-21	-1	-3	-9	-10	2	2	-1	-2	1	-5	-2	3
	Services	-58	7	8	9	-15	4	6	-1	5	2	5	5	3
RMPSE#	LES95	0.53	12.37	3.05	0.13	0.31	1	1.57	1.83	1	1.01	0.96	1.06	2.55
	LES20	5.13	106.24	78.18	15.98	0.89	83.2	13.64	3.03	1.21	0.96	0.92	1.22	0.4
	CDE95	0.90	4.09	1.09	0.15	0.14	0.47	0.14	0.05	0.22	0.60	0.32	0.20	0.80
	CDE20	5.25	30.32	36.21	2.24	0.59	35.55	4.32	0.58	0.74	0.82	0.79	2.56	0.78

* These differences are calculated by subtracting AIDADS elasticities from the corresponding calibrated LES/CDE ones. For presentation purposes, these numbers are multiplied by 100.

Root mean square percentage errors using the AIDADS income elasticities as the reference points.

Table 4. Percentage changes in private demand, import and output requirements in 2020, relative to the base data, from the AIDADS model

	China	Newly Industrialized	ASEAN	Mexico	Rest World	MERCOSUR	Transition Economies	M East & N Africa	AUS & NZL	USA	Canada	W Europe	Japan
per capita consumer consumption													
Grain	106	5	9	4	41	3	10	10	4	4	3	4	3
Livestock	223	135	86	108	63	76	75	25	67	51	48	67	39
Horti&Veg	165	79	48	63	55	43	41	16	47	39	34	44	26
Fish	133	2	8	1	51	2	10	10	2	1	1	2	1
Oth food	179	122	74	97	53	68	64	22	63	49	46	62	36
Textile	239	167	112	132	60	96	97	31	76	56	54	77	45
Resources	368	211	157	169	73	124	146	42	87	61	61	90	52
Mnfcs	509	222	172	176	96	131	160	49	89	62	62	91	53
Services	574	239	182	183	103	137	182	51	88	61	61	90	54
total output													
Grain	273	91	115	113	138	102	80	119	108	92	101	64	33
Livestock	349	165	160	161	162	130	111	136	112	89	87	76	50
Horti&Veg	328	128	135	123	148	100	87	121	97	77	81	59	42
Fish	276	65	97	66	140	93	76	115	81	63	75	52	40
Oth food	327	167	136	144	151	121	102	132	104	86	82	73	45
Textile	213	178	132	160	145	151	123	127	131	95	93	89	63
Resources	321	190	160	155	150	153	139	127	117	95	94	89	67
Mnfcs	284	158	135	133	144	146	125	125	108	93	92	86	77
Services	337	200	162	188	160	151	140	127	115	92	90	86	63
total import													
Grain	276	146	123	134	143	113	88	120	99	66	69	59	49
Livestock	355	177	164	158	163	133	113	128	110	88	86	74	54
Horti&Veg	335	139	140	138	154	105	95	125	96	76	71	60	49
Fish	284	84	85	129	153	99	93	123	72	62	87	62	40
Oth food	336	170	144	145	154	124	104	133	103	85	82	72	47
Textile	308	200	152	173	157	150	132	135	119	92	90	82	54
Resources	314	188	172	149	159	150	136	129	116	95	93	88	73
Mnfcs	286	162	144	135	153	127	130	103	99	88	89	80	70
Services	438	216	205	170	180	159	143	136	118	94	92	86	63

Source: Simulation results.

Table 5. Percentage deviations in projections on private demand, output and import requirements from base for selected regions (base = projection from the AIDADS model)

		China			Newly Industrialized			W Europe			USA		
		HCD	LES	CDE	HCD	LES	CDE	HCD	LES	CDE	HCD	LES	CDE
Demand	Grain	97	84	37	173	84	16	77	2	0	53	-1	-2
	Livestock	25	39	125	22	11	-20	10	-3	-5	5	-2	-3
	Horti&Veg	53	66	107	61	29	-16	27	-13	-7	15	-11	-5
	Fish	74	93	163	182	91	23	81	-2	2	57	-1	-1
	Oth food	45	44	29	30	13	-22	13	-2	-6	7	-1	-4
	Textile	20	18	-2	8	4	-19	4	-2	-3	2	-1	-2
	Resources	-13	-22	-49	-7	-3	-8	-3	-2	0	-2	-1	0
	Mnfcs	-33	-30	-21	-11	-4	-1	-4	0	-2	-2	0	1
	Services	-40	-43	-54	-15	-8	7	-3	2	3	-2	1	1
Output	Grain	44	40	29	72	35	-1	19	1	-2	11	2	-1
	Livestock	18	27	81	21	10	-16	8	-2	-4	4	-1	-2
	Horti&Veg	33	37	54	47	22	-14	19	-7	-5	12	-6	-4
	Fish	50	61	102	99	49	5	24	0	0	21	0	-1
	Oth food	28	27	20	22	10	-13	10	-1	-4	6	-1	-3
	Textile	3	1	-8	4	1	-9	3	-1	-3	2	-1	-2
	Resources	-7	-9	-14	-3	-2	-2	-1	-1	0	-1	-1	0
	Mnfcs	-9	-9	-11	-3	-2	-1	-1	0	-1	-1	0	0
	Services	-9	-9	-13	-5	-3	2	-1	0	0	0	0	0
Imports	Grain	35	33	24	28	13	-9	20	0	-2	19	0	-1
	Livestock	17	25	77	12	5	-13	8	-2	-4	4	-1	-2
	Horti&Veg	34	39	57	37	17	-10	18	-7	-5	11	-7	-4
	Fish	47	57	97	79	39	6	16	-1	-2	20	-1	-1
	Oth food	26	25	22	22	10	-13	10	-1	-4	5	-1	-3
	Textile	4	2	-9	5	2	-13	3	-1	-3	2	-1	-2
	Resources	-7	-8	-12	-3	-2	-2	-1	-1	0	-1	0	0
	Mnfcs	-8	-8	-9	-4	-2	-1	-1	0	-1	-1	0	0
	Services	-14	-15	-20	-6	-3	2	-1	0	0	0	0	0

Source: Simulation results.

Table 6. Difference* from base between projection results by region and commodity using alternative functional forms (base=projection from AIDADS model)

Summary by region

		China	Newly Industrialized	ASEAN	Mexico	Rest World	MERCOSUR	Transition Economies	M East & N Africa	AUS & NZL	USA	Canada	W Europe	Japan
Demand	HCD	1.535	2.624	1.806	2.152	0.347	1.592	1.560	0.389	1.120	0.794	0.799	1.162	0.678
	LES	1.644	1.285	1.175	0.078	0.268	0.188	0.614	0.254	0.065	0.112	0.077	0.140	0.021
	CDE	2.488	0.489	0.453	0.198	0.161	0.140	0.148	0.029	0.127	0.075	0.082	0.113	0.075
Output	HCD	0.825	1.354	0.689	0.978	0.232	0.538	0.750	0.268	0.368	0.272	0.255	0.387	0.256
	LES	0.916	0.658	0.436	0.037	0.181	0.083	0.258	0.174	0.070	0.061	0.074	0.076	0.012
	CDE	1.439	0.269	0.150	0.110	0.096	0.072	0.045	0.020	0.080	0.055	0.048	0.079	0.051
Imports	HCD	0.764	0.951	0.750	0.535	0.193	0.482	0.610	0.217	0.371	0.303	0.229	0.338	0.173
	LES	0.868	0.463	0.491	0.019	0.164	0.060	0.192	0.102	0.024	0.073	0.052	0.078	0.008
	CDE	1.423	0.266	0.210	0.130	0.093	0.068	0.042	0.013	0.093	0.057	0.055	0.085	0.049

Summary by commodity

		Grain	Livestock	Horti&Veg	Fish	Oth food	Textile	Resources	Mnfcs	Services
Demand	HCD	3.351	0.592	1.424	3.417	0.847	0.29	0.25	0.472	0.581
	LES	1.431	0.452	0.86	1.628	0.512	0.2	0.247	0.321	0.471
	CDE	0.489	1.281	1.102	1.683	0.403	0.243	0.524	0.236	0.553
Output	HCD	0.793	0.375	0.773	1.295	0.572	0.166	0.104	0.116	0.171
	LES	0.397	0.278	0.475	0.835	0.31	0.067	0.092	0.086	0.159
	CDE	0.303	0.831	0.566	1.030	0.263	0.152	0.147	0.112	0.133
Imports	HCD	1.153	0.432	0.88	1.643	0.6	0.143	0.101	0.129	0.13
	LES	0.587	0.303	0.496	0.896	0.321	0.045	0.095	0.101	0.105
	CDE	0.266	0.783	0.594	0.988	0.285	0.189	0.130	0.098	0.206

*Note: The difference is defined as $\left(\sum_i ((x_i - \bar{x}_i)/\bar{x}_i)^2 \right)^{1/2}$, where x_i is the projection for country (commodity) i by the alternative system and $\bar{x}_i$ is the one by the AIDADS system

Appendix I. Additional Results

Appendix Tables A1 – A3 report, for all of the regions in our CGE model, the deviations from the base model (AIDADS) for private consumption, output and import requirements based on alternative demand specifications.

Appendix Table 1. Percentage Changes in Private Demand, Relative to the Simulation Results from the AIDADS Model

	China	Newly Industrialized	ASEAN	Mexico	Rest World	MERCOSUR	Transition Economies	M East & N Africa	AUS & NZL	USA	Canada	W Europe	Japan
							LES						
Grain	84	84	74	5	10	12	26	5	3	-1	0	2	1
Livestock	39	11	16	1	6	2	7	2	-1	-2	-2	-3	0
Horti&Veg	66	29	36	2	9	6	19	5	-5	-11	-7	-13	1
Fish	93	91	78	6	16	13	50	24	-2	-1	-1	-2	1
Oth food	44	13	20	1	6	3	8	3	0	-1	-1	-2	0
Textile	18	4	6	0	3	1	5	0	-1	-1	-2	-2	0
Resources	-22	-3	-8	0	-4	-1	6	0	-2	-1	-2	-2	0
Mnfcs	-30	-4	-8	0	-7	-1	-4	-4	0	0	0	0	0
Services	-43	-8	-10	0	-12	-1	-9	-4	1	1	1	2	0
							HCD						
Grain	97	173	114	141	19	103	97	21	74	53	53	77	44
Livestock	25	22	26	20	3	19	24	7	9	5	6	10	7
Horti&Veg	53	61	59	54	9	46	54	14	24	15	17	27	18
Fish	74	182	117	148	11	106	97	21	79	57	56	81	46
Oth food	45	30	35	27	10	25	32	9	12	7	8	13	9
Textile	20	8	11	8	5	7	10	1	3	2	2	4	2
Resources	-13	-7	-9	-7	-3	-7	-12	-6	-3	-2	-2	-3	-2
Mnfcs	-33	-11	-14	-9	-14	-9	-17	-11	-4	-2	-2	-4	-3
Services	-40	-15	-17	-11	-17	-12	-23	-12	-3	-2	-2	-3	-4
							CDE						
Grain	37	16	25	1	4	5	9	2	-1	-2	-1	0	-1
Livestock	125	-20	-7	-8	6	-6	-2	0	-6	-3	-3	-5	-3
Horti&Veg	107	-16	3	-9	6	-5	1	1	-8	-5	-5	-7	-5
Fish	163	23	30	2	8	6	10	2	1	-1	0	2	0
Oth food	29	-22	-8	-9	3	-7	-3	0	-6	-4	-4	-6	-4
Textile	-2	-19	-12	-5	0	-4	-3	0	-3	-2	-2	-3	-2
Resources	-49	-8	-14	-5	-8	-1	-2	-1	-1	0	-2	0	0
Mnfcs	-21	-1	-3	-9	-4	1	1	0	-2	1	-2	-2	1
Services	-54	7	6	7	-5	2	2	0	3	1	2	3	1

Source: Calculations from simulation results.

Appendix Table 2. Percentage Changes in Output Requirement, Relative to the Simulation Results from the AIDADS Model

	China	Newly Industrialized	ASEAN	Mexico	Rest World	MERCOSUR	Transition Economies	M East & N. Africa	AUS & NZL	USA	Canada	W Europe	Japan
						LES							
Grain	40	35	19	1	7	3	11	3	5	2	7	1	1
Livestock	27	10	6	1	5	2	6	2	1	-1	-1	-2	0
Horti&Veg	37	22	16	0	7	3	11	3	0	-6	-2	-7	0
Fish	61	49	33	3	13	6	18	16	4	0	1	0	1
Oth food	27	10	12	1	5	2	6	2	1	-1	-1	-1	0
Textile	1	1	2	0	2	0	3	0	0	-1	-1	-1	0
Resources	-9	-2	-3	0	-2	0	0	-1	-1	-1	0	-1	0
Mnfcs.	-9	-2	-2	0	-2	0	-1	-1	0	0	0	0	-1
Services	-9	-3	-3	0	-2	0	-1	0	0	0	0	0	0
						HCD							
Grain	44	72	31	36	14	25	39	13	15	11	17	19	18
Livestock	18	21	10	16	4	13	19	6	7	4	5	8	4
Horti&Veg	33	47	26	26	9	27	35	12	15	12	10	19	10
Fish	50	99	50	82	12	32	43	17	27	21	14	24	12
Oth food	28	22	20	23	9	17	25	8	11	6	7	10	8
Textile	3	4	5	7	4	3	7	2	3	2	2	3	2
Resources	-7	-3	-3	-2	-2	-3	-3	-2	-1	-1	-1	-1	-1
Mnfcs	-9	-3	-4	-3	-3	-4	-4	-3	-1	-1	-1	-1	-1
Services	-9	-5	-4	-5	-3	-3	-3	-1	-1	0	0	-1	-1
						CDE							
Grain	29	-1	4	-3	3	-1	2	1	-2	-1	3	-2	-1
Livestock	81	-16	-2	-5	5	-4	-2	0	-2	-2	-2	-4	-2
Horti&Veg	54	-14	1	-4	5	-3	0	0	-4	-4	-3	-5	-3
Fish	102	5	13	-2	6	1	2	2	-1	-1	-2	0	-2
Oth food	20	-13	-3	-6	3	-4	-2	0	-5	-3	-3	-4	-2
Textile	-8	-9	-6	-4	-1	-3	-3	-1	-4	-2	-2	-3	-2
Resources	-14	-2	-3	-1	-2	0	0	-1	-1	0	0	0	0
Mnfcs	-11	-1	-1	-2	-1	0	0	0	-1	0	0	-1	0
Services	-13	2	1	3	-1	1	0	0	1	0	0	0	0

Source: Calculations from simulation results.

Appendix Table 3. Percentage Changes in Import Requirement, Relative to the Simulation Results from the AIDADS Model

	China	Newly Industrialized	ASEAN	Mexico	Rest World	MERCOSUR	Transition Economies	M East & N Africa	AUS & NZL	USA	Canada	W Europe	Japan
						LES							
Grain	33	13	15	1	6	3	9	3	2	0	0	0	0
Livestock	25	5	7	1	5	1	6	1	0	-1	-1	-2	0
Horti&Veg	39	17	11	1	7	3	9	3	-2	-7	-5	-7	0
Fish	57	39	43	1	11	4	11	9	0	-1	0	-1	0
Oth food	25	10	12	1	5	2	6	2	0	-1	-1	-1	0
Textile	2	2	4	0	2	0	4	0	-1	-1	-1	-1	0
Resources	-8	-2	-4	0	-2	0	0	-1	-1	0	0	-1	0
Mnfcs.	-8	-2	-2	0	-2	0	-1	-1	0	0	0	0	0
Services	-15	-3	-4	0	-3	0	-1	-1	0	0	0	0	0
						HCD							
Grain	35	28	24	26	12	21	33	13	14	19	16	20	6
Livestock	17	12	11	14	3	10	19	5	7	4	4	8	4
Horti&Veg	34	37	18	24	8	26	29	11	13	11	13	18	7
Fish	47	79	64	29	8	29	28	10	29	20	5	16	12
Oth food	26	22	21	22	8	15	24	7	10	5	6	10	7
Textile	4	5	7	8	4	3	8	1	3	2	2	3	2
Resources	-7	-3	-5	-1	-2	-3	-3	-2	-1	-1	0	-1	-1
Mnfcs	-8	-4	-4	-2	-3	-3	-4	-3	-1	-1	-1	-1	-1
Services	-14	-6	-6	-2	-3	-3	-3	-1	0	0	0	-1	-1
						CDE							
Grain	24	-9	1	-5	3	-2	0	1	-4	-1	-1	-2	-2
Livestock	77	-13	-3	-5	4	-3	-2	0	-4	-2	-2	-4	-2
Horti&Veg	57	-10	1	-5	5	-3	-1	0	-5	-4	-4	-5	-2
Fish	97	6	18	-5	5	-1	1	1	-1	-1	-1	-2	-2
Oth food	22	-13	-4	-6	3	-4	-2	0	-5	-3	-3	-4	-2
Textile	-9	-13	-8	-4	0	-3	-3	-1	-3	-2	-1	-3	-2
Resources	-12	-2	-4	-2	-2	0	0	-1	-1	0	0	0	0
Mnfcs	-9	-1	-1	-2	-1	0	0	0	-1	0	-1	-1	0
Services	-20	2	2	1	-1	1	0	0	1	0	1	0	0

Source: Calculations from simulation results.