On the role of demand systems in CGE[1] simulations of trade reforms

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Very Preliminary Version – not to be quoted

Abstract. Computable General Equilibrium (CGE) models are often used to simulate the effects of political reforms. In these models the way demand reacts to price and income changes is of crucial importance when one wants to evaluate the evolution of demand in the baseline or simulate the effects of political reforms. Yet, functional forms used to model households' demand in CGE models do not necessarily exhibit enough flexibility to fully account for income and price changes on the structure of demand. Our objective in this study is to empirically compare the results generated by a CGE using different demand functions, to see if the additional complexity associated to the flexibility of demand really modifies the results and has an impact on policy recommendations. We implement four demand systems in the Mirage model: a Linear Expenditure-Constant Elasticity of Substitution (LES-CES) function, a Cobb-Douglas function, a Constant Elasticity of Substitution (CES) function, and a Normalized Quadratic Expenditure System (NQES) demand system. We conduct simulations of trade reform with a particular focus. We then compare the economic effects of the reform simulated with the different demand functions. From these first results, the LES-CES thus appears to be a good compromise between flexibility and simplicity. It actually requires less parameters and simplifies the model solving compared to the NQES to get similar results.

JEL Classification. F11, F13, F14, F17

Keywords. Computable General Equilibrium Models ; Trade Policy Reforms ; Demand System

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1. Introduction

Context. Computable General Equilibrium (CGE) models are often used to simulate the effects of political reforms, notably in agricultural sectors. Those effects are usually expressed in terms of deviation from a baseline or *statu quo* scenario. The evolution of agricultural markets in this baseline is of particular importance.Yet, the current world economic situation will undoubtedly evolve dramatically in the forthcoming years, even if economic policies remain unchanged. This is particularly true for some developing countries like China or India, where incomes are expected to keep growing for several years. Since the level of food consumption is a crucial parameter when one gets interested in the effects of agricultural policy or trade reforms, the way the growth of income can impact the level, but also the structure, of households' demand for agricultural commodities has to be taken into account seriously. Furthermore, even if policy reforms impacting agricultural sectors do not have much impact on national income levels (agriculture generally represents a small part of Gross Domestic Product –GDP-), they can have huge impacts on agricultural prices. So, in the same way as the impact of income growth on households’ demand has to be taken into account as accurately as possible in the baselines used in CGE models, the way this demand react to price changes is of crucial importance when one wants to simulate the effect of political reforms in agricultural sectors.

Functional forms used to model households’ demand in CGE models do not necessarily exhibit enough flexibility to fully represent the effects of income and price changes on the structure of this demand. Actually, there are some trade-offs between the flexibility of income and price responses of the systems on one side, and their regularity and ease of calibration on the other side. Our objective in this study is to empirically compare the results generated by a CGE using different demand functions, and to see if the additional complexity associated to the flexibility of demand really allows to improve the quality of the results and has an impact on the policy recommendations that can be derived from the CGE simulations.

Review of literature. There is a huge literature concerning demand systems and how they realistically represent private households’ behavior. This literature also considers how these demand systems may be implemented in applied economic models.

Several functional forms have been tested in applied economic modelling literature. The most common forms, Cobb-Douglas and Constant Elasticity of Substitution (CES), are homothetic. Two simple extensions, the Linear Expenditure System (LES) and the Linear Expenditure System- Constant Elasticity of Substitution (LES-CES), of these functional forms can present local non-homothetic behaviour by adding minimal consumption. They share with their "*parents*" their limited price flexibility, but can be calibrated on any positive income elasticities. The CES framework can be extended to give complete price flexibility through a nesting of CES functions with latent goods as proposed by Perroni and Rutherford (1995) with the NNCES (Nonseparable N-stage Constant-Elasticity-of-Substitution). The introduction of hidden goods allows a local non-homothetic behaviour (Perroni, 1992; Gohin, 2005). Most advanced economic models (*e.g.* Hertel *et al.*, 2003; Yu et al., 2003) have implemented the 'An Implicit Direct Additive Demand System' (AIDADS) demand system (Rimmer and Powell, 1996) which has non linear Engel curves thus allows to represent a broad range of demand-income / relationship. In practice, the AIDADS is just an extension of the LES that embeds more income response flexibility. It has the same limitations than the LES regarding price elasticities. The interest of AIDADS, namely its flexible income response, comes at the price of an increased data requirement, especially regarding the Engel curves. Local income elasticities are available for a wide number of products and countries, but the complete path of the budget shares across the income spectrum, that is to say the Engel curve, is usually unknown. It is the product of the estimation of a complete demand system. This point implies that the use of an AIDADS would require an econometric estimation for each chosen aggregation, which is not really convenient. Other flexible functional forms (the Translog, the Generalised Leontief...) lack global regularity properties which limits their reliability in simulation-based studies (Perroni and Rutherford, 1998).

<u>Methodology</u>. We start from the Mirage model, where households' demand is currently represented by a LES-CES function, and alternatively implement the Cobb-Douglas, the CES, and Normalized Quadratic Expenditure System (NQES) demand systems.

The Cobb Douglas demand system is easy to implement and calibrate. However, this simplicity has a cost. First, the Cobb-Douglas demand system is homothetic, there is no flexibility regarding the reaction of demand to income change. Second, its own price elasticities are unitary, which is likely to be much too high for agricultural products which demand is known to be relatively inelastic to prices.

The CES demand function is commonly used in CGE. It is less restrictive than the Cobb-Douglas, since since its substitution and own price elasticities are non-unitary and its cross price elasticities are different from zero, but still presents some rigidities regarding the impacts of income on demand since it is homothetic.

The LES-CES is an extension of the CES. It introduces a parameter representing the minimal, consumption quantities for each good, which makes this demand system quasi homothetic: budget shares vary with income. The LES-CES thus constitutes an improvement compared to the Cobb-Douglas or the CES. Nevertheless, these preferences are ``only'' quasi homothetic: the marginal budget shares are constant. Furthermore, the demand converges to a CES as income increases, so average budget shares converge monotonically to unity. Another issue with this demand system is that income elasticities are systematically positive, as a consequence inferior commodities are ruled out, which can be problematic since food products can become inferior goods as income increases. Finally, the LES-CES is less easy to calibrate than a Cobb Douglas, or even a CES demand function because additional parameters, namely minimal consumption shares, have to be determined.

Finally, the NQES demand system is a flexible functional form. However this higher flexibility comes with a vengeance: it requires more information and is more difficult to calibrate, which limits the number of countries and products on which it can be applied. But contrary to other flexible demand system like the AIDS, the NQES is globally regular under some assumptions

To calibrate the different demand systems, we use own price, cross price and income elasticities collected from different sources in the literature. These elasticities are aggregated to fit the aggregation level of Mirage. To do so, we rely on a CES aggregation and follow the methodology defined by Carpentier and Guyomard (2001).

Data are aggregated to 3 regions: the European Union, the United States and the Rest of the World in order to reduce the dimension of the model and ease the simulations. This is particularly important regarding the NQES demand system which makes simulation difficult to run.

First results. Our final goal is to design a baseline of the world economy and to conduct simulations of trade reform. As already mentioned, the world economy (in particular Asian countries) is expected to face huge income growth in the next decades. We then compare the baselines and the economic effects of the reform simulated with different demand functions implemented.

We first simulate a baseline scenario to represent the evolution of markets from 2005 to 2020 under some assumptions regarding the projected evolutions of population and GDP during this period.

Our first results show that the projections of food consumption simulated with the CES function are close to those obtained with the Cobb Douglas function. This is due to the fact that the elasticity of substitution calibrated for the CES is closed to 1. The projections obtained with the LES-CES and NQES are different but rather close one from each other. From these first results, the LES-CES thus appears to be a good compromise between flexibility and modeling facility. It actually requires less parameters and simplifies the model solving compared to the NQES to get similar results. However, these are just preliminary results on aggregated data. In the next steps of this research project we will use more disaggregated data. We also studied the impact of the same trade reform under different demand systems. We show that changing the demand system modifies only marginally

Main conclusions. This paper has important conclusions. First it illustrates how households'incomes will augment in some countries like China and India in the next future, and how this will impact the structure of final consumption worldwide. Second we show that CGE models may fail to represent these trends. We show in particular that in a CGE baseline this is the income effect which matters while in the scenarios these are the substitution effects which are important. Since various demand systems widely differ in terms of income and substitution effects the choice of a demand system is a key decision for a modeler. A LES-CES demand system may be a right compromise between too much simplicity and excessive requirements in terms of calibration procedure and behavioral parameters to be estimated.

Section 2 summarizes economic implications of various demand systems. Section 3 exposes our strategy of implementation of four demand systems in MIRAGE. Section 4 illustrates what the implications of these different choices are in terms of the baseline while section 5 presents the same point with two trade policy scenarios. Section 6 concludes.

2. Demand systems

In this section we first review the theoretical properties of demand systems that one would expect to accurately model the evolution of the level and structure of agricultural commodities demand; we then move to the characteristics of four demand systems (Cobb-Douglas/CES/LES-CES/NQES) which we compare in our modeling exercises based on MIRAGE while other functional forms actually used in demand projections by CGE are exposed in Appendix.

2.1. Theoretical ground and expected properties of demand systems

When it comes to demand systems aiming at projecting world food consumption in the context of expected large income increases in some regions, some features can be expected in addition to those ensuring the global regularity of the system (homogeneity, monotonicity, symmetry and curvature).

First, as already advocated, an increase of households' income not only leads to an increase of their global consumption, but also leads to a decrease of the share of expenditure devoted to food consumption (also called « Engel coefficient »). This property, formalized by the « Engel's Law », implies that income elasticities of food products are inferior to one.

Second, among food expenditures, it is expected that the share of raw products decreases and the share of processed products increases as income increases. This is formalized by the « Bennet's Law ». Thus, an increase of income not only modifies the level of consumption, but also its structure and this can influence the evolution of markets at world level in several ways. First of all, if facing a new demand for a product they don't produce domestically, some countries can increase their imports, which leads to an increase in international trade flows and in transportation needs. Those countries can also react to new demands for processed food by increasing their production and/or transformation capacities, and this can have an impact on the distribution of production factors, and on their remuneration. Finally, the effects on international markets can be very important when a densely populated country like China is concerned.

A demand system used to project food consumption should thus take into account the impact of income on the level as well as on the structure of the demand for agricultural commodities. These different effects are captured by the income elasticity of demand which measures the responsiveness of households' demand to changes in income. If income elasticities are equal to one, households' preferences are said to be homothetic: the demand increases or decreases in the same proportion as income. This corresponds to a utility function homogenous of degree 1.[3] Homothetic preferences are often assumed because of their simplicity. However, they are also not realistic, in particular since they imply constant budget shares when income increases.

[3] For any positive value of t, if the basket of goods (x_1, x_2) is preferred to the basket of goods (y_1, y_2), then the basket (tx_1, tx_2) is also preferred to (ty_1, ty_2)

Non homothetic preferences for food products are thus necessary for the Engel's law to be satisfied: income elasticities inferior to one represent goods for which the demand increases less than proportionally to income. The budget shares of these goods thus decrease as income increases. Moving to non-unitary income elasticities also allows a distinction between normal, or necessary, goods which have an income elasticity comprised between zero and one, and inferior goods which have a negative income elasticity. The demand for the later decreases as income increases. Yet, a necessary good for the poor can become an inferior good for the rich. It thus seems important to represent, not only the evolution of budget shares, but also the evolution of marginal budget shares, with income. Since there is strong evidence that the marginal budget share of food falls with increasing income (Rimmer and Powell, 1994; Cranfield *et al*., 1998; Powell *et al*., 2002) this issue is particularly important when dealing with developing countries expected to face huge income increases in the future.

These different properties of demand functions, related to the evolution of budget shares with income, can be graphically summarized by Engel curves. Indeed, Engel curves represent the relation between households' expenditure on one good and income and can be used to compute income elasticities, compare households' welfare or determine some properties of demand function such as their rank.[4] On that last point, Lewbel (1991) proposed a classification of demand systems and related it to the shape of Engel curves. The classification of Lewbel (1991) is as follows: rank 1 demand systems correspond to homothetic preferences, they have constant elasticities independent of income and are represented by a linear Engel curve crossing origin; rank 2 demand systems are quasi homothetic, they are linear or log linear in expenditure, their Engel curves are linear but do not necessarily cross the origin; finally, rank 3 demand systems are non homothetic and have nonlinear Engel curves. Lewbel (1991) concludes that, for average incomes rank 2 functions are sufficient to represent demands (budget shares are linear function of income), but for very low or very high incomes, rank 3 functions are necessary to model demands.

[4] As stated by Barnett and Serletis (2009) a demand system is of rank R if there exist R goods such that the Engel curve of any good is equal to the weighting average of the Engel curves of these R goods. The rank of a demand system can also be defined as the number of independent price indexes needed to specify the indirect utility function corresponding to the system

2.2. Properties of some demand systems used to project food demand

Our objective here is not to give an exhaustive review of all demand systems used in food demand projections, but to describe different types of demand function relevant to the projection of food demand. We thus discuss the properties of two rank 1 demand systems, the Cobb-Douglas and the CES functions, a rank 2 demand system, the LES-CES function, and a rank 3 demand system, the NQES function. We present these four demand systems in the body of the text since these are the four systems alternatively tested with the MIRAGE model in sections 4 and 5. In the Appendix we present the economic properties of other demand systems.

2.2.1. The simplest form of a rank one demand system: Cobb-Douglas

We start with the simplest functional form derived from utility maximization and consistent with economic theory: the Cobb Douglas demand function, which was proposed in 1928 by Richard Cobb and Paul Douglas.

This function is such that:

$$q_i = \alpha_i \frac{R}{p_i}$$

With q_i and p_i corresponding respectively to the demand quantity and price of good i, and R to income.

As mentioned above, the main advantage of this demand system is its simplicity: own price, substitution and income elasticities are all equal to 1 in absolute value, and cross price elasticities are null. Concerning its use in CGE models a big advantage of this functional form is its ease of calibration. Indeed, as all elasticities are fixed to 0, 1 or -1, they don't need to be estimated; and, since the α_i parameters are equal to initial budget shares, they can be easily calibrated. Furthermore, the Cobb Douglas demand system globally satisfies the theoretical regularity conditions by construction.

However, this simplicity has a cost and the Cobb Douglas demand system presents several drawbacks. It relies on extremely strong assumptions. First, it is typically a homothetic rank 1 demand system: as income elasticities are fixed to one, there is no Engel flexibility here. Second, since many agricultural products are staple, their demand is inelastic, or relatively inelastic, to prices: unitary price elasticities are thus likely to be much too high, in absolute value, for these products. Third, cross price elasticities are zero and no substitution effect is authorized.

Yet, even if until now we have essentially focused our discussion on income elasticities, one must keep in mind that price elasticities are of crucial importance in simulations dealing with the effects of agricultural policies. Indeed, as mentioned by Hertel (1999) for instance, overstating the consumers' ability to respond to a price change in simulation models used to assess the effects of such policies can lead to misleading results.

So, despite its simplicity which makes it easy to implement in simulation models, the Cobb Douglas demand function appears to have too restrictive theoretical properties to be used in food demand projections and/or simulations of agricultural policy reforms.

2.2.2. A more elaborate form of a rank one demand system: the CES

The Constant Elasticity of Substitution (CES), originally proposed by Arrow *et al.* (1961) is still commonly used in CGE models to represent the differentiation of goods by country of origin (Armington assumption), and so the imperfect transmission of world to domestic prices. It is derived from the following utility maximization program with the same notations:

$$U = \sum_{i=1}^{n} \left(\alpha_i q_i^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

s.t. $\sum_{i=1}^{n} p_i q_i \leq R$.

α_i is a share parameter, σ is the (constant) elasticity of subtitution between two commodities. When σ approaches infinity, commodities are perfect substitutes. When σ approaches zero, commodities are perfect complements. It gives birth to demand functions :

$$q_i = \frac{\alpha_i^{\sigma} R}{p_i^{\sigma} \sum_{j=1}^{n} \alpha_j^{\sigma} p_j^{1-\sigma}}$$

$\sum_{j=1}^{n} \alpha_j{}^{\sigma} p_j{}^{1-\sigma}$ is a consistent price index. It can be shown that income-elasticity is always equal to one, while the elasticity of substitution concerning any pair of commodities is σ. Moreover we have :

$$\varepsilon_i = \frac{\partial q_i}{\partial p_i}\frac{p_i}{q_i} = -\sigma + \frac{\alpha_i{}^{\sigma}(\sigma - 1)}{p_i{}^{\sigma-1}\sum_{j=1}^{n}\alpha_j{}^{\sigma}p_j{}^{1-\sigma}}$$

$$\varepsilon_{ij} = \frac{\partial q_i}{\partial p_j}\frac{p_j}{q_i} = (\sigma - 1)\frac{p_j q_j}{R}, \qquad \forall i \neq j$$

The CES functional form is a progress as compared to the Cobb-Douglas form since own price and substitution elasticities are different from 1 in absolute value, and cross price elasticities are different from 0. However the income elasticity of demand is unitary and it requires estimated elasticities of substitution and a calibration of the share parameters.

2.2.3. A rank 2 demand system: the LES-CES function

We now move to a rank 2 functional form, which is the one currently implemented in the MIRAGE model: the Linear Expenditure - Constant Elasticity of Substitution (LES-CES) demand system.

This demand function is an extension of the CES function: the LES-CES form is closed to the CES one with, as in the Linear Expenditure System (LES), an additional parameter corresponding to the minimal, or subsistence, consumption quantities for each good:

$$q_i = qmin_i + \frac{\alpha_i \sum_j p_j\left(q_j - qmin_j\right)}{p_i{}^{\sigma}\sum_j \alpha_j p_j{}^{\sigma-1}}$$

$qmin_i$ denotes the minimal consumption of good i, and σ the elasticity of substitution, common to all pair of goods.

Like the CES, the LES-CES presents the advantage of being less restrictive than a Cobb Douglas demand system. Notably the substitution and own price elasticities are non unitary and cross price elasticities are different from zero. It also globally satisfies the theoretical regularity conditions. However, whereas the CES is a rank 1 demand system, the introduction of the minimal consumption parameter in this demand system makes it, as the LES, a rank 2 demand system with quasi homothetic preferences.

The LES-CES constitutes an improvement compared to rank one demand systems, since it relies on preferences that are not homothetic. Nevertheless, these preferences are "only" quasi homothetic: the marginal budget shares are constant (even if they don't cross origin, Engel curves are still straight lines). Furthermore, the demand converges to a CES as income increases, so average budget shares converge monotonically to unity. The Engel's law is thus not fully satisfied here and, as mentioned by Yu *et al*. (2004), the LES- CES presents troublesome Engel properties.

Another issue with this demand system is that income elasticities are systematically positive, as a consequence inferior commodities are ruled out (Parks, 1969), which can be problematic since, as mentioned previously, normal food products can become inferior goods as income increases. Finally, the LES-CES demand function is less easy to calibrate than a Cobb Douglas, or even a CES, because additional parameters, namely minimal consumption shares, have to be determined.

By moving away from the assumption of homothetic preferences, the LES- CES demand system thus possesses some interesting properties for the projection of food demand. It however still doesn't include a complete Engel's flexibility and its calibration in CGE models can be more complex than it is for rank 1 demand systems.

2.2.4. NQES: a rank three demand system

The Normalized Quadratic Expenditure System (NQES) originally proposed by Diewert and Wales (1988) is a rank 3 demand system. This demand system derives from the Normalized Quadractic Expenditure function[5]:

$$e(p,u) = \sum_j a_j p_j + \left(\sum_j b_j p_j - \frac{1}{2} \frac{\sum_j \sum_k \beta_{jk} p_j p_k}{\sum_j \alpha_j p_j} \right) u$$

[5] An expenditure function results from a consumer's optimization program and expresses its minimal expenditure to attain a certain utility, given existing consumption prices.

With u the consumer's utility, p_j the price of good j and a_j, b_j, β_{jk}, α_j model parameters.

Normalization conditions are imposed such that: $\sum_j a_j p*_j = 0$, $\sum_j b_j p*_j = 1$ and $\sum_k \beta_{ij} p_j * = 0$, with $p*_j$ a reference price. We can note here that $e(p*, u) = u$, namely the consumer's utility is measured by the size of the budget set provided that prices remained fixed at p*.

The Hicksian demand function derived the Quadratic Expenditure function is such that:

$$q_i{}^H(p,u) = a_i + \left(b_i + \frac{\sum_j \beta_{ij} p_j}{(\sum_j \alpha_j p_j)} + \frac{\alpha_i \sum_j \sum_k \beta_{jk} p_j p_k}{2(\sum_j \alpha_j p_j)^2} \right) u.$$

The NQES exhibit non linear Engel curves which makes it a rank 3 demand system. However, it lacks global regularity properties in the sense that curvature and monotonicity condition may not be satisfied. As shown by Ryan and Wales (1998), the curvature condition can be imposed by forcing it at a reference point appropriately chosen. This curvature restriction leads to a quasi homothetic (semi-flexible) version of the NQES which globally satisfies concavity conditions and is flexible at the second order (full income flexibility and partial price flexibility are maintained - Ryan and Wales, 1999 -). Furthermore, the number of parameters in the model is reduced which can ease its calibration. The violation of the monotonicity condition seems more problematic since it can lead to negative consumption quantities (McKitrick, 1998), especially for high substitution elasticities (Perroni and Rutherford, 1998). However, this apparent drawback can be overcome in a CGE framework by relying on the theory of household behavior under rationing (Neary and Roberts, 1980). Basically, null consumptions are associated to a virtual price, determined by the model and higher than the prevailing market price; positive consumption are function of the prevailing market price and determined by the demand function. This "regime switching" approach has also been used by Gohin and Laborde (2006). All these considerations make the quasi homothetic version of the NQES an attractive demand system.

2.3. Main demand systems adopted to evaluate future food demands

What are the main demand systems adopted in models (either Partial Equilibrium or General Equilibrium) used to evaluate future evolution of food demand?

The IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) Model developed by researchers at the International Food Policy Research Institute (IFPRI) is a partial equilibrium agriculture model that emphasizes policy simulations. Based on IFPRI's IMPACT model framework, Nelson *et al.* (2010) take into account spatial extension and incorporate a hydrology model and a Decision Support System for Agrotechnology Transfer (DSSAT) crop model suite that estimates crops yields under varied management systems and climate change scenarios to project world food production from 2010 to 2050. The modeling methodology reconciles the limited spatial resolution of macro-level economic models that operate through equilibrium-driven relationships at a national level with detailed models of biophysical processes at high spatial resolution. In this model, demand is determined at the national level by consumer responses to changes in national income and prices according to an isoelastic function of prices, incomes and population. World prices are adjusted to ensure that net trade of a commodity equals to zero.

In the GTAP (Global Trade Analysis Project) model private households demands are derived from a Constant Difference of Elasticities (CDE) functional form. It was first proposed by Hanoch (1975). These are nonhomothetic preferences which can be easily calibrated on available income and own-price elasticities of demand.

In LINKAGE, the World Bank's model designed by Dominique Van der Mensbrugghe, the demand system is the extended linear expenditure system (ELES). It is based on a Stone-Geary LES demand system but also includes a demand for future goods (through savings).

In Mirage the demand system is a LES-CES form. So this is a rank 2 demand system where share parameters and minimal consumption have to be calibrated in order to generate income and own-price elasticities equal to availables estimates.

3. Yu *et al.* (2004) project world food demand in 2020 by introducing the AIDADS demand systems (see Appendix 2 for a detailed description of this demand system) into the GTAP model. They also compare it with several alternative demand systems (*i.e.* LES, HCD and CDE) that are currently widely used in CGE models. They find that the AIDADS can represent a substantial improvement inmodeling income effects, particularly for the rapidly growing developing countries. These results must however be qualified by the fact that the AIDADS is not second order flexible in its treatment of price effects (Gohin, 2005) and its price responsiveness is particularly constrained (Preckel et al., 2005). Moreover it has a large number of parameters which can prevent it from being used in many practical applications (de Boer, 2009).Implementation

In a first subsection we detail the calibration strategy of the four demand systems alternatively implemented in MIRAGE. Then in a second subsection we explain the procedure followed to select income and price elasticities used in the modeling exercise.

3.1. Calibration strategy

In MIRAGE there are 4 equations defining households' final consumption:

(i) The consumption of good i in region r, equal to the individual Hicksian demand for good i in region r times the total population in region r

$$C_{irt} = POP_{rt}\, q^{H}{}_{irt}(p_{1rt}, \dots, p_{nrt}, U_{rt})$$

(ii) The price of utility

$$P_{rt} = e(p_{1rt}, \dots, p_{nrt}, U + 1) - e(p_{1rt}, \dots, p_{nrt}, U)$$

(iii) The utility level

$$U_{rt} = V(p_{1rt}, \dots, p_{nrt}, R_{rt})$$

Table 1 indicates the different equations implemented in MIRAGE corresponding to the four demand systems studied here.

3.2. Elasticities

We need more elasticities to calibrate the new demand functions, in particular cross price elasticities. A database of elasticities has been developed.

Own price, cross price and income elasticities have been collected from the literature, with a special focus on Asian countries. 10,234 elasticities have been collected from 84 economic papers. These elasticities have been estimated using data from different sources, different demand systems and different econometric/statistic methods.

Once these elasticities have been collected we conduct a standardization of these data: the sectors which can have very different labeling in the initial data have been into converted FAO product codes. We also use ISO3 codes for the countries. If several values are available for the same type of elasticity, the same FAO product and the same region, we calculated and adopted an average elasticity.

Price elasticities can be either Hicksian or Marshalian, depending on the study from which they are collected. Both can be useful to calibrate demand systems. When the income elasticity is also available, we convert Marshalian into Hicksian elasticities using the Slutsky equation:

$$\varepsilon^{H}{}_{ij} = \varepsilon_{ij} + w_j \eta_i$$

Table 1. The modeling equations of the four demand systems

	LES-CES	Cobb-Douglas	CES	NQES
Consumption of good i in region r	$POP_{rt}\left(qmin_{ir}+\alpha_{ir}U_{rt}\left(\frac{P_{rt}}{p_{irt}}\right)^{\sigma_r}\right)$	$POP_{rt}\left(\frac{\alpha_{ir}P_{rt}U_{rt}}{p_{irt}}\right)$	$POP_{rt}\,U_r\alpha_{ir}\left(\frac{P_{rt}}{p_{irt}}\right.$	$POP_{rt}\left(a_{ir}+U_{rt}\left(b_{ir}+\frac{\alpha_{ir}(\sum_j b_{jr}p_{jrt}-P_{rt})+\sum_j\beta_{ijr}p_{jrt}}{\sum_j\alpha_{jr}p_{jrt}}\right)\right)$
Price of utility	$\left(\sum_i \alpha_{ir}{p_{irt}}^{1-\sigma_r}\right)^{\frac{1}{1-\sigma_r}}$	$\prod_i\left(\frac{p_{irt}}{\alpha_{ir}}\right)^{\alpha_{ir}}$	$\left(\sum \alpha_{ir}{p_{ir}}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$	$\sum_i b_{ir}p_{irt}+\frac{1}{2}\frac{\sum_i\sum_j\beta_{ijr}p_{jrt}p_{irt}}{\sum_i\alpha_{ir}p_{irt}}$
Utility level	$\frac{(R_{rt}-\sum p_{irt}qmin_{ir})}{P_{rt}}$	$\frac{R_{rt}}{POP_{rt}P_{rt}}$	$\frac{R_r}{P_r}$	$\frac{R_{rt}}{POP_{rt}}-\sum_j a_{jr}p_{jrt}$

With ε_{ij} the Marshalian price elasticity, $\varepsilon^{H}{}_{ij}$ the Hicksian price elasticity, η_i the income elasticity, w_j the share of income devoted to the expenditure of product j computed from FAO data, subscript i and j denoting sectors/products.

When both Marshalian and Hicksian elasticities were available for the same product in the same region, we kept the Hicksian elasticity as is. Overall, 7,541 Marshalian elasticities are converted to Hicksian elasticities.[6]

We then needed to aggregate the FAO products to GTAP products because this is the nomenclature used in the Mirage model. To aggregate FAO elasticities into GTAP elasticities, we follow Carpentier and Guyomard (2001). Namely, we have:

$$\eta_i = \eta_{G(i)}\eta_G \Leftrightarrow \eta_G = \frac{\eta_i}{\eta_{G(i)}}$$

$$\varepsilon_{ij}^{H} = \varepsilon_{G(i)H(j)}^{H} + w_{H(j)}\varepsilon_{GH}^{H}\eta_{G(i)}\eta_{H(j)} \Leftrightarrow \varepsilon_{GH}^{H} = \frac{\varepsilon_{ij}^{H} - \varepsilon_{G(i)H(j)}^{H}}{w_{H(j)}\eta_{G(i)}\eta_{H(j)}}$$

$$\varepsilon_{ij} = \varepsilon_{G(i)H(j)} + w_{H(j)}\left(\frac{\delta_{G=H}}{\eta_{H(j)}} + \varepsilon_{GH}\right)\eta_{G(i)}\eta_{H(j)} + w_{H(j)}w_H\eta_{G(i)}\eta_G\left(\eta_{H(j)} - 1\right)$$

$$\Leftrightarrow \varepsilon_{GH} = \frac{\varepsilon_{ij} - \varepsilon_{G(i)H(j)} - w_{H(j)}w_H\eta_{G(i)}\eta_G\left(\eta_{H(j)} - 1\right)}{\eta_{G(i)}\eta_{H(j)}w_{H(j)}} - \frac{\delta_{G=H}}{\eta_{H(j)}}$$

With the following notations: considering FAO goods i and j belonging respectively to GTAP aggregates G and H, η_i is the unconditional income elasticity of good i, η_G is the income elasticity of aggregate G, $\eta_{G(i)}$ is the conditional income elasticity of good i, ε_{ij}^{H} is the unconditional Hicksian elasticity, ε_{GH}^{H} is the Hicksian elasticity of aggregates, $\varepsilon_{G(i)H(j)}^{H}$ is the conditional Hicksian elasticity (null for $G \neq H$), ε_{ij} is unconditional Marshalian elasticity, ε_{GH} is the Marshalian elasticity of aggregates, $\varepsilon_{G(i)H(j)}$ is the conditional Marshalian elasticity (null for $G \neq H$), $w_{G(i)}$ is the budget share of i in G and w_G the budget share of G.

[6] Converting Hicksian into Marshalian elasticities is not possible since corresponding income elasticities are not available..

Using a CES aggregation, we thus have:

$$\eta_G = \eta_i, \forall i \in G$$

$$\varepsilon_{GG} = \frac{\varepsilon_{ij} + \sigma_G \delta_{i=j} - (\sigma_G - 1) w_{G(i)}}{w_{G(j)}} - 1, \forall i, j \ \in G$$

$$\varepsilon_{GH} = \frac{\varepsilon_{ij}}{w_{H(j)}}, \forall i \in G, j \in H$$

$$\varepsilon_{GG}^{H} = \frac{\varepsilon_{ij}^{H}}{w_{G(j)}} - \sigma_G, \forall i, j \in G$$

$$\varepsilon_{GH}^{H} = \frac{\varepsilon_{ij}^{H}}{w_{H(j)}}, \forall i \in G, j \in H$$

With σ_G the elasticity of substitution between goods in aggregate G.[7]

Since our elasticities have been collected from different economic papers, the equalities presented above do not necessarily prevail for all the goods belonging to the same aggregates. Moreover, some goods have a really small share in their aggregate, leading to extremely large aggregate elasticities. To tackle this issue, we chose to apply these aggregation formulae using the good having the largest budget share in the aggregate.

The elasticities of the goods for which FAO data do not exist or are missing (tobacco, alcohol, non food products) have been directly averaged into GTAP codes.

Finally for the elasticities which are missing, we use the average elasticity for the same region of the world and same level of GDP per capita, if available. If this average is not available, we use the average elasticity for the same level of GDP per capita, if available. If this average is not available, we use the average elasticity for the same region of the world, if available. Finally, if this average is not available, we use the average elasticity for the world.

[7] Since the CES demand function is homothetic, those formulae are the same as in Edgerton (1997). See Carpentier and Guyomard for more details.

We turn now to the modeling exercise with, first the presentation of how these demand systems affect the baseline, second how they affect the simulation.

4. Baseline results

What do we expect from this exercise? First we expect that in each country consumption increases with income with a modification of demand structure. In particular it is expected that the share of expenditure allocated to food decreases in order to respect the Engels law. Amongst the food items it is expected that the share of raw items decreases more while those of transformed items may increase (Bennet's Law). It is noteworthy that the literature points out that marginal budget shares and Engel elasticities may vary substantially with income per head (Rimmer and Powell, 1993; Cranfield *et al*., 1998; Coye *et al*. 1998).

Second, with substantial modifications in income and consumption structure, international trade may be used by countries to fill the gaps between local demand and supply of goods. It may lead to significant production variations and factor demands.

In particular in the baseline, income effect should be prominent: policy reform is absent (no removal of taxes) such that substitution effects should be minimal while economic growth, through capital and land accumulation, augmentation of active population and increase in total factor productivity should lead to substantial income augmentation on the entire period.

In this section we study how different demand systems impact the baseline. Let us remind that in the baseline there is not policy reform, but the world economy is growing thanks to factor accumulation and technical progress.

Table 2 presents the evolution of the share of agrifood products in households' consumption in the three zones from 2004 to 2020 under the four demand systems studied in this paper. Since the Cobb-Douglas (CD) and the CES are both rank 1 demand system, income-elasticity is unitary and this share remains constant all along the period: they are represented in the same line in Table 2.

From Table 2 it is clear that the share of agrifood products in households's consumption is less in the US, then in the EU (EU27 for EU with 27 countries), then in the Rest of the World (Row). This is consistent with a hierarky of GDP per capita.

Table 2. Share of agrifood products in households' consumption – 2004-2020

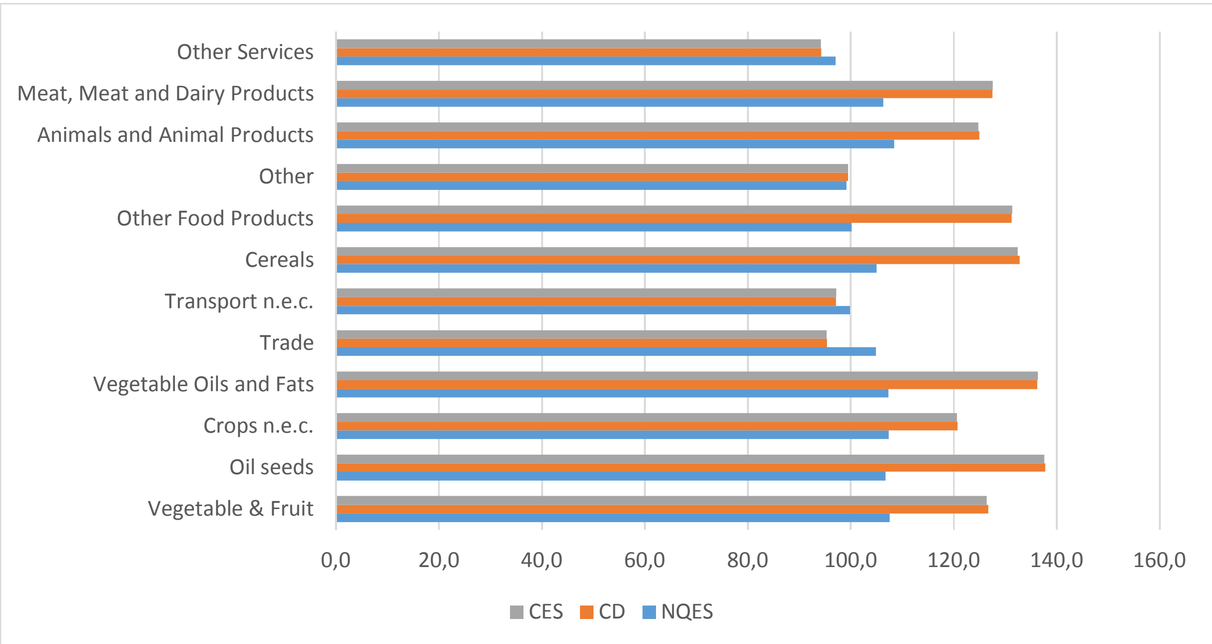
US	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
NQES	3.8%	3.7%	3.7%	3.6%	3.6%	3.6%	3.6%	3.5%	3.4%	3.4%	3.3%	3.2%	3.2%	3.1%	3.1%	3.1%	3.0%
LES CES	3.8%	3.7%	3.7%	3.6%	3.5%	3.6%	3.6%	3.5%	3.4%	3.3%	3.2%	3.2%	3.1%	3.1%	3.0%	2.9%	2.9%
CD/CES	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.9%
EU27	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
NQES	6.6%	6.5%	6.5%	6.4%	6.3%	6.2%	6.2%	6.1%	6.1%	6.0%	5.9%	5.9%	5.8%	5.7%	5.7%	5.6%	5.6%
LES CES	6.6%	6.5%	6.5%	6.3%	6.2%	6.2%	6.1%	6.0%	5.9%	5.8%	5.7%	5.7%	5.6%	5.5%	5.4%	5.3%	5.3%
CD/CES	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%	6.6%
RoW	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
NQES	11.6%	11.4%	11.2%	11.0%	10.8%	10.7%	10.5%	10.4%	10.2%	10.0%	9.9%	9.7%	9.6%	9.5%	9.4%	9.2%	9.1%
LES CES	11.6%	11.4%	11.2%	10.9%	10.7%	10.5%	10.4%	10.2%	10.0%	9.9%	9.7%	9.5%	9.4%	9.2%	9.1%	8.9%	8.8%
CD / CES	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%

Source : MIRAGE and authors'calculation

Under the LES-CES and the NQES, the Engel curves, which relates income to share of agrifood in total final consumption, are decreasing: all agrifood consumptions have income elasticity less than one. With the NQES the share of agrifood products in total final consumption decreases less than with the LES-CES. For example in the Rest of the World region (ROW) the share of agrifood products in total final consumption decreases from 11.6% in 2004 to 8.8% under the LES-CES while it decreases to only 9.1% with the NQES (of course it remains at 11.6% with both the Cobb-Douglass and the CES).

Figure 1 presents the world consumption by sector in volume in 2020. Each variable corresponding to one of the three demand systems Cobb-Douglas /CES/NQES is divided by the corresponding value for the LES-CES demand system, and multiplied by 100. It allows to compare these three demand systems to the one traditionnally implemented in the MIRAGE model.

Figure 1. World consumption by sector in volume for three demand systems in percentage of the LES-CES form - 2015



Source: MIRAGE and authors'calculation

On average the NQES demand system gives estimation of world consumption in volume in 2020 relatively close to the value given by the LES-CES demand system. The CES and Cobb-Douglas demand systems give similar estimations. At the same time both estimations are far from the one given by the LES-CES demand system.

If we believe that the NQES provides accurate estimates of world demand by sector in 2020, then the Cobb-Douglass or the CES functional forms overestimates world demand for 'Vegetable and Fruit', 'Meat, Meat and Dairy Products' and 'Animals and Animals Products by about 25%, 'Cereals' and 'Other Food Products' by about 30%, 'Oilseeds' and 'Vegetable Oils and Fats' by 35%. In the same idea the LES-CES system does a relatively good job by underestimating the sector world demand for these agricultural commodities by only 5 to 8%.

Table 3 presents the rate of variation of the value added in volume by sector and country between 2004 and 2020. It clearly illustrates how the evolution of value added at sector and country level may be quite different as estimated by MIRAGE depending on the included demand system. For example if we consider the case of US and of the sector 'Vegetable Oils and Fats' under the Cobb-Douglas demand system the rate of variation of value added is +217% while under the LES-CES demand system this rate is +179%.

Table 3. Value Added in Volume by Sector and Country – 2020/2004

	LES CES			CD			CES			NQES		
	RoW	US	e27	RoW	US	e27	RoW	US	e27	RoW	US	e27
Vegetable & Fruit	172.5	135.8	117.1	204.5	164.2	142.5	204.2	164.1	142.3	180.3	139.7	124.1
Oil seeds	177.4	145.6	120.2	210.8	173.1	136.9	210.8	173.2	136.9	183.1	150.2	123.2
Crops n.e.c.	184.7	150.3	128.8	204.5	161.5	140.7	204.4	161.5	140.6	190.4	151.8	132.0
Vegetable Oils and Fats	179.3	133.1	119.5	217.5	156.4	140.8	217.6	156.7	140.8	185.8	134.9	123.7
Trade	221.8	153.1	150.7	214.9	151.3	146.7	214.9	151.1	146.6	223.3	162.6	155.2
Transport n.e.c.	216.5	153.9	148.7	214.6	154.0	148.6	214.6	154.2	148.6	215.4	154.4	149.7
Cereals	174.9	149.4	125.6	209.3	178.0	142.7	209.2	178.0	142.7	178.4	151.1	129.3
Other Food Products	177.1	131.1	125.9	215.0	158.0	147.7	215.1	158.5	147.7	176.7	131.9	128.8
Other	218.1	153.3	141.4	217.2	153.0	141.6	217.2	153.1	141.6	217.7	152.4	140.6
Animals and Animal Products	181.7	130.9	126.3	212.2	155.8	145.3	212.1	155.9	145.3	190.7	132.4	131.2
Meat, Meat and Dairy Products	181.7	128.1	124.1	218.2	153.8	147.4	218.3	154.0	147.3	190.2	129.6	131.1
Other Services	220.0	146.2	156.6	212.9	144.8	153.7	212.9	144.5	153.9	218.3	141.2	156.8

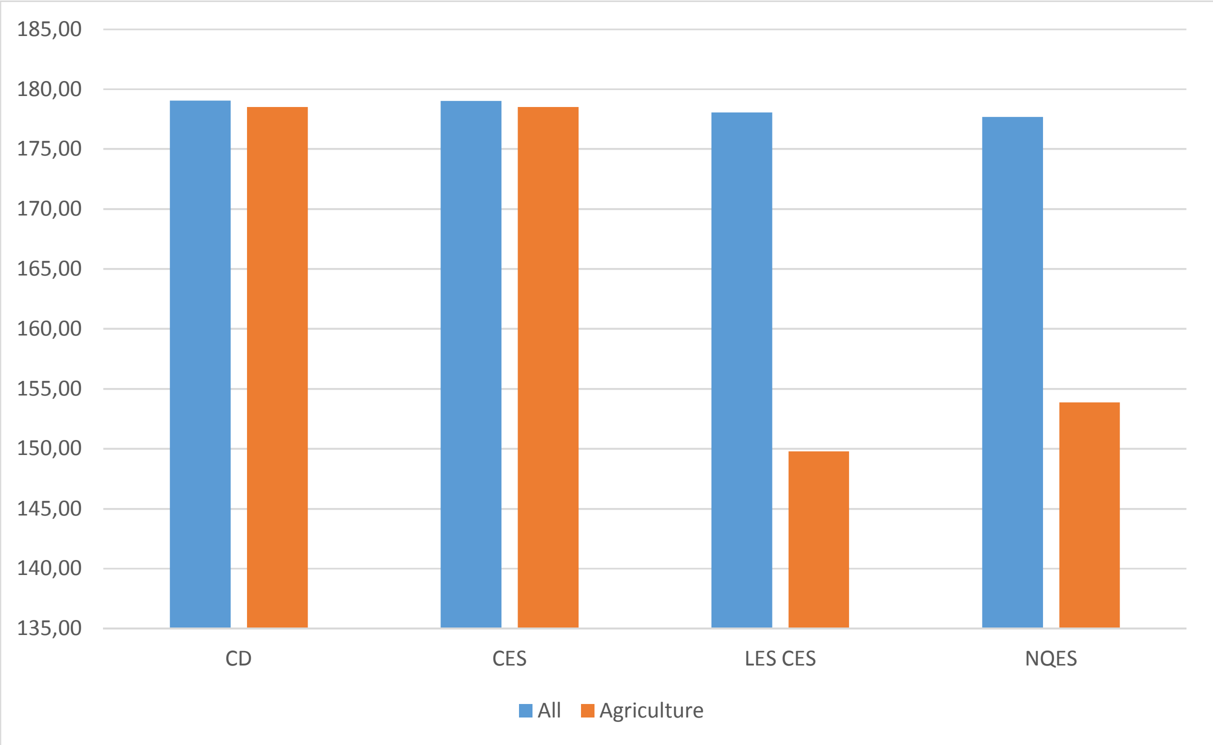
Source : MIRAGE and authors'calculation

Globally we notice again that evaluations based on the CES demand system are very close to the ones obtained with the Cobb-Douglas system[8]. : both overestimate the augmentation of production and value added from now until 2020 since they keep budget shares constant and do not take into account the decrease of these budget shares spent on agrifood commodties with rising incomes. The evaluations obtained with the LES-CES demand system on one side and the NQES system on the other side differ significantly from the evaluations obtained through the CES or the Cobb-Douglas systems. However it is clear from Table 3 that differences between LES-CES and NQES evaluations are larger than differences between CES and Cobb-Douglas evaluations.

Finally we look at the evolution of trade in volume on the entire period. This is done on Figure 2. Whatever the demand system is, the volume of trade is estimated to increase by about 75 to 80% between 2004 and 2020: this correspond to a 3.7% of average annual rate of growth during these sixteen years. There are not much differences between the four evaluations conducted under the different demand systems since the world GDP is increased by as much in each evaluation and there is no trade policy reform such that prices of foreign goods relative to local goods are unaffected. Large differences would come from a substitution effect that does not prevail here.

Figure 2. World Trade (constant US$ 2004) - All sectors vs. Agricultural sectors– 2020/2004

[8] This result is not only due to the fact that both demand systems have the same (unitary) income elasticities: they are also very closed because the calibrated substitution elasticities of the CES function are closed to one



Source : MIRAGE and authors'calculation

But considering world trade of only agricultural commodities the broad picture is sustantially modified: if the decrease in worldwide budget shares for agrifood items is accounted for, as it is with the LES-CES and the NQES, there is less pressure on the world agricultural system and world trade is increased by 50 to 55% between 2004 and 2020, corresponding to an annual average rate of growth of 2.5 to 2.7% (instead of 3.7%).

As a conclusion of this section baselines are significantly impacted by the choice of a demand system. In particular different demand systems lead to different evolutions of national demand and different evolution of local supply reacting to these changes of demand. Evaluation of the evolution of world trade in agricultural commodities is also substantially affected.

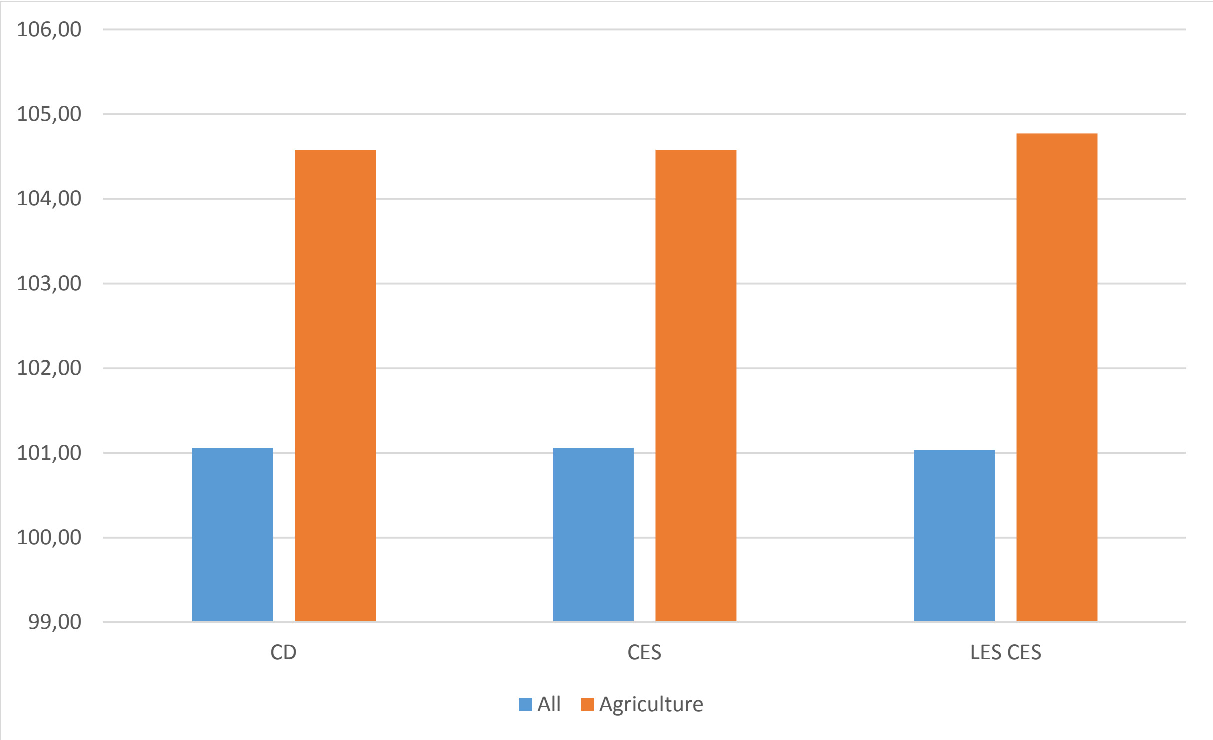
5. Scenario results

In this section we implement a trade policy scenario which consists in the reduction in tariffs by 50%. We examine if different demand systems implemented in MIRAGE (today concerning this simulation of trade reform we just studied three demand systems: the Cobb-Douglas, the CES and the LES-CES). First we give the results of this scenario on trade, then we give the results on consumption and production.

2.4. The impact on trade.

The trade reform consists in a decrease of import duties (by half) at the border. So it is a trade-creating reform. Globally the trade creation is only 1.0%/1.1% in 2020 in volume according to the various demand systems implemented (see Figure 2). Since average border protection on all products is low (around 4 %) the size of the trade creation is also low. Since border protection is larger in agriculture, trade creation is bigger in this sector: between 4.6-4.8% in 2020 as compared to a baseline (without reform) according to the three demand systems.

Figure 3. Impact of trade reform on world trade – Volume - 100*Scenario/Baseline – 2020 – Three demand systems

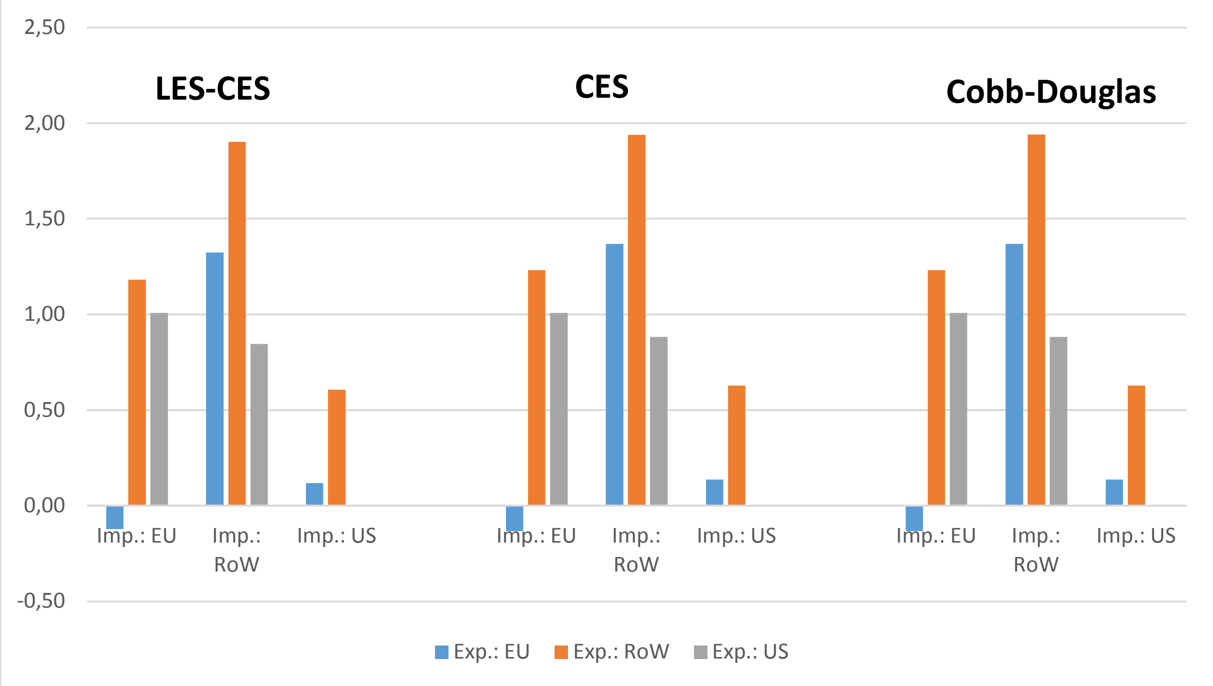


Source : MIRAGE and authors'calculation

The main point is that the implementation of different demand systems affects only marginally the impact of this trade reform on world trade.

Figure 4 presents the impact of this reform on bilateral trade, in terms of rate of growth in the scenario as compared to the baseline, in volume, in 2020.

Figure 4. Impact of trade reform on bilateral trade – Rate of Growth Scenario/Baseline – 2020 - % – Three demand systems



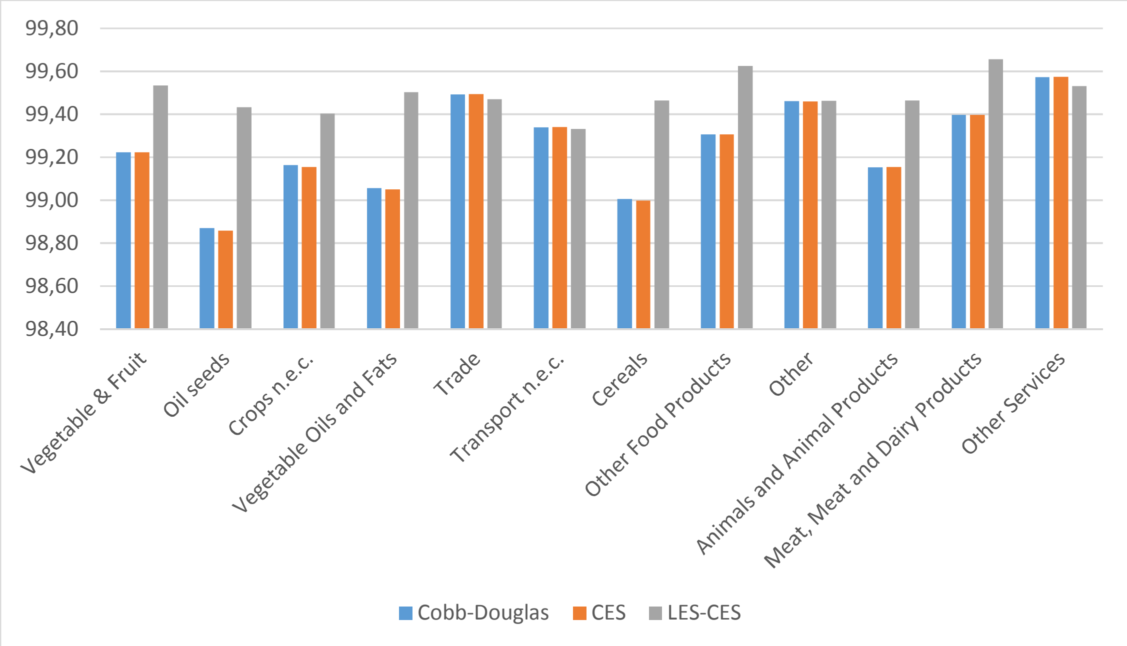
Source : MIRAGE and authors'calculation

Since intra-EU trade is free the decrease of border import duties increases EU exports to other regions and EU imports from other regions at the detrimental of intra-EU trade. Trade between EU and US increases only marginally since border protection is low between both countries. Again the implementation of different demand systems modifies only marginally the evaluation of the impact of trade reform.

2.5. The impact on consumption and production

We turn now to the impact of trade reform on consumption. Figure 5 points out the impact on world consumption in volume by sector in 2020. The trade reform has clearly a negative impact on real incomes in all regions: world consumption in volume is decreased in each sector in 2020. The important point is that again the implementation of different demand systems does not change the evaluation of this reform.

Figure 5. Impact of trade reform on world consumption in volume by sector – 100*Scenario/Baseline - 2020 – Three demand systems



Source : MIRAGE and authors'calculation

We now present the impact of this half reduction of import duties at the border on production in volume and in 2020. In order to see more precisely the impact of different demand systems we present more disaggregated results, at the level of sector and country. This is done on Table 4.

Even if there are more differences, the results are quite similar whether the demand system is a Cobb-Douglas (CD), a CES or a LES-CES. The largest increase in sector production is cereals in the US (+3.4-3.7%).

Table 4. Impact of trade reform on World Production in volume – Rate of Growth Scenario / Baseline - % - Three Demand Systems

	Cobb Douglas			CES			LES-CES		
	RoW	US	e27	RoW	US	e27	RoW	US	e27
Vegetable & Fruit	-0.11	0.36	0.18	-0.11	0.35	0.18	0.15	0.57	0.32
Oil seeds	0.81	1.23	0.56	0.80	1.22	0.55	1.09	1.46	0.62
Crops n.e.c.	0.38	0.74	0.34	0.37	0.73	0.33	0.54	0.84	0.38
Vegetable Oils and Fats	1.29	0.79	0.65	1.28	0.78	0.65	1.61	0.92	0.75
Trade	-0.62	-0.08	-0.18	-0.62	-0.08	-0.18	-0.64	-0.09	-0.19
Transport n.e.c.	-0.44	-0.03	0.01	-0.44	-0.03	0.01	-0.44	-0.03	0.00
Cereals	0.36	3.46	0.63	0.35	3.45	0.63	0.66	3.66	0.67
Other Food Products	0.00	0.43	0.30	0.00	0.43	0.30	0.31	0.55	0.38
Other	-0.25	-0.03	0.00	-0.25	-0.03	0.00	-0.24	-0.03	0.00
Animals and Animal Products	-0.21	0.31	0.35	-0.21	0.31	0.35	0.03	0.45	0.42
Meat, Meat and Dairy Products	0.14	0.40	0.40	0.14	0.40	0.40	0.43	0.53	0.49
Other Services	-0.50	-0.06	-0.17	-0.50	-0.06	-0.18	-0.53	-0.06	-0.18

Source : MIRAGE and authors'calculation

6. Conclusion

This paper addresses an important topic in the CGE literature: how to model private household demand in the long run ; and how it affects the baseline and the policy recommendations drawn from modeling different scenarios.

The role of various functional forms of consumer's demand system used in CGE modeling is assessed. The Mirage model is then used to evaluate the performance of four functional forms, viz., Linear Expenditure-Constant Elasticity of Substitution (LES-CES), the Cobb-Douglas, Constant Elasticity of Substitution (CES) and Normalized Quadratic Expenditure System (NQES). Income and price elasticities are taken from existing literature to calibrate the parameters of the alternative functions used. Projections under the alternative functional form specifications are then compared to evaluate their performance.

In the theoretical part we demonstrate that it is important to adopt a rank 2 or a rank 3 demand system to account for the major changes in income and consequently on consumption structure that should prevail during the next decade. In the empirical part we show that the choice of a demand system is a key question concerning the baseline, *i.e.* the modeling exercise of the evolution of the world economy without policy reform where income effects are prominent and substitution effects are less important. We also show that on one side the Cobb-Douglass and the CES functions, on the other side the NQES and the LES-CES give similar results but that there is a substantial difference between both groups of demand systems. Finally the change of a demand system changes only marginally the evaluation of trade reform since this gives a leading role to substitution effects while income effects become less important. We conclude that the LES-CES may look like a right compromise between rank 1 demand systems which are much too simple to account for substantial modifications of income and consumption structure in the world economy and rank 3 demand systems which are data-demanding and difficult to calibrate.

More research is needed in particular a modeling exercise with a more disaggregated geographical breakdown and a clear need to implement this work on GTAP8. This will be done in the short term.

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8. Appendix. Other functional forms

8.1. A flexible functional forms: the Almost Ideal Demand System (AIDS)

Flexible functional forms have become popular since the last three decades, and are frequently used today in applied econometric studies. These demand functions are different from the other demand systems presented in this paper since they are not directly derived from a specific utility function but are built so as to minimize the specification biases in the representation of demand systems of which the form is unknown. They are in fact second order approximations of a general utility function. Among these functions, the Generalized Leontief (Diewert, 1971), the Rotterdam (Theil, 1965; Barten, 1967), the Translog (Christensen et al., 1975) and the Almost Ideal Demand System (AIDS) (Deaton and Muellbauer, 1980) are the most often cited in the literature. We have chosen here to focus on the AIDS because there have already been some attempts to introduce it in CGE frameworks (see Robinson et al. (1993) for instance, or Savard (2010) more recently).

The AIDS is such as:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln \frac{R}{P}$$

With w_i the budget share of good i, and γ_{ij} and β_i model parameters. In the original version of AIDS, the price index is such as: $\ln \mathrm{P} = \alpha_0 + \sum_k \alpha_k \ln p_k + 0.5 \sum_j \sum_k \gamma_{jk} \ln p_k \ln p_j$. However the linearized version of the AIDS (LA/AIDS) is more often used is more often used. In this linear version, the original nonlinear price index is replaced by the Stone Geary linear one: $\ln \mathrm{P} = \sum_j w_j \ln p_j$. It is worse underlying here that one must be very careful when using one or the other version of the system that the elasticities possibly taken from the literature to calibrate the model have been estimated with the same version, since, as pointed out by Green and Alston (1990), using LA/AIDS elasticities with an AIDS can really be misleading.

The AIDS has the advantage of not imposing homothetic preferences. It also overcomes the issue, found in the LES-CES for instance, of constant marginal budget shares. Indeed, the marginal expenditure shares and Slutsky terms are assumed to be functions of budget shares.

This characteristic also differentiates the AIDS from other flexible forms like the Rotterdam model.

However, this higher flexibility comes with a higher number of parameters that have to be calibrated: with $0.5n(n+3)-2$ parameters for n goods, instead of *n* in the Cobb Douglas or $2n+1$ in the LES-CES, the AIDS is thus requires more information and is more difficult and to calibrate, and this limits the number of countries and products (Kuiper and van Tongeren, 2006) on which it can applied. Another drawback of this demand system is that it does not constraint the budget share to the theoretically admissible range (0; 1). Indeed, expenditure shares may stray outside this permissible range for large changes in total expenditure, and this is particularly likely to occur for staple food demands when income growth is large. The AIDS model is likely to perform poorly in price and income elasticities as income changes, and particularly the income elasticity tends to be smaller as income increases (Abler, 2010; Meyer et al., 2011). This risk of violation of global regularity conditions is common to all flexible functional forms: the Translog demand system, for instance, is prone to loss of concavity away from the benchmark point (Yu et al., 2004). Some extensions of flexible functional forms can guarantee in fact regularity (the MAIDS proposed by Cooper and McLaren (1992), for instance, allows changes in consumer behaviors with income levels and different minimal consumptions for different utility level) but this requires additional parameters which make the system still more complicated to estimate.

This description brings out a trade-off existing between the global regularity of demand systems (like the Cobb Douglas or the LES-CES) and their flexibility (like the AIDS or other flexible functional form like the Translog). This point was besides mentioned by (Guilkey, 1983).

8.2. AIDADS: a rank three demand system

In this last subsection we focus on a rank three demand system proposed by Rimmer and Powell (1992): An Implicit Direct Additive Demand System (AIDADS). This system relies on the concept of implicitly additive utility function introduced by Hanoch (1975) and is such as:

$$q_i = \frac{\phi_i\left(R - \sum_j p_j q_j\right)}{p_i} + \gamma_i$$

With γ_i the minimal consumption and $\phi_i = \frac{\alpha_i + \beta_i e^u}{1+e^u}$, u being the utility level, and α_i and β_i parameters which give its flexibility to the AIDADS: the LES can, for instance, be seen as a particular case of AIDADS where $\alpha_i = \beta_i$. The advantages of the AIDADS are that, first, it constraints the udget share to the theoretically admissible range [0;1] and its global regularity is guaranteed when at least subsistence level is affordable by the consumers, in fact it remains regular even under a very large change in income (Powell et al., 2002), which is an advantage, compare to AIDS notably; then its third order Engel curves allow a representation of a broad range of demand/income relationship, typically this system does not constraint the demand's response to an income change to be constant, and marginal budget shares may vary with the level of real income; furthermore, with the AIDADS own price elasticities can exceed 1 in absolute value without requiring the corresponding subsistence parameter to be negative (contrary to the LES-CES), inferior goods are thus allowed (Hanoch, 1975) here; finally, this system has less parameters than flexible functional forms.

The AIDADS thus seems to present a lot of advantages. Yu *et al.* (2004) compare it with several alternative demand systems (*i.e.* the LES, the Homothetic Cobb-Douglas –HCD- and the Constant Difference of Elasticities –CDE-) that are currently widely used in CGE models, and conclude that the AIDADS outperforms several other models in projecting long-run world food deman. The Maximum Likelihood Estimation method was adopted 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 econometrically estimated AIDADS demand system is updated from the year of estimation (1985) to the benchmark year for the CGE model (1995) by shocking per capita expenditure to their corresponding 1995 levels, according to the observed growth in regional per capita incomes over this period, while assuming relative prices remain unchanged. However, they are thus essentially focused on income effects. Yet, price effects are also crucial in projections or policy simulation. Gohin (2005) mentions that the AIDADS is in fact not second order flexible in its treatment of price effects because of the assumption of implicitly additive preferences on which it based, and Preckel et al. (2005) that its price responsiveness is particularly constrained. Moreover, as for the LES (and the LES-CES) that the income elasticities eventually converge to one as income increases (Abler, 2010). Then, the fact that the AIDADS has less parameter that flexible functional forms are in fact ambiguous. Indeed, on the one hand, the reduction in the number of parameters is achieved through some restrictions on substitution elasticities which are reduced to n for n goods; on the other hand, with 3n - 1 parameters, the AIDADS still has (n-1) more parameters than the LES which can prevent it from being used in many practical applications (see de Boer (2009)).