WALRAS – A MULTI-SECTOR, MULTI-COUNTRY APPLIED GENERAL EQUILIBRIUM MODEL FOR QUANTIFYING THE ECONOMY-WIDE EFFECTS OF AGRICULTURAL POLICIES

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INTRODUCTION

The OECD Economics and Statistics Department has developed a set of applied general equilibrium models for six OECD countries/regions with the explicit objective of quantifying the economy-wide effects of agricultural policies in OECD countries. The project is called the World Agricultural LibeRAlisation Study, hereafter referred to as the WALRAS model. The purpose of this paper is to provide a guide to the specification of the model; this is essential to understanding the results cited in the papers by Martin *et al.* and van der Mensbrugghe *et al.* in this volume. At the same time, an attempt has been made to keep the paper as non-technical as possible – a complete listing of all the model equations and parameters is available from the authors on request.

The mode of analysis is comparative statics and aims at providing long-run results. The usual limitations of such models also apply to WALRAS: the model takes no account of inflation, financial sectors and assets or liabilities.

The structure of the paper is as follows. It begins with an overview of the main blocks in the country/region sub-models together with a description of how world trade flows are modelled in an internationally consistent way. The second section attempts to explain the main economic mechanisms at work in the model using a graphical presentation. The final section discusses the construction of the benchmark data sets used to calibrate the model and the choice of numerical values for the key exogenous parameters in the calibration process.

I. OVERVIEW OF THE MODEL

The present version of WALRAS includes six sub-models for the major OECD agricultural trading countries/regions – Australia, Canada, EC, Japan, New Zealand and the United States. These individual models are linked together and with a residual aggregate for the rest of the world (ROW) via a bilateral world trade sub-model. Each country/regional model can be subdivided into five blocks of equations. These are described briefly in turn.

A. Production

Table 1 lists the thirteen sectors of the production sub-model. Given that the main objective is to quantify the economy-wide effects of agricultural policies rather than their effects on the agricultural sector itself, the sectoral disaggregation of the model was chosen deliberately to highlight the main links between farm activities, food-processing industries and the rest of the economy. Agriculture in WALRAS groups two farm sectors – livestock and other agriculture (mainly grains) – which use land as a specific fixed factor, and is considered separately from the three major food-processing industries – meat, dairy and other food products. The other eight sectors comprise other primary industries, various manufacturing and service industries.

For each sector, a production function describes the technology available to the industry. Given the levels of sectoral demand, producers minimise costs by using optimal quantities of primary factors and intermediate goods (domestic and imported) as a function of their relative after-tax prices. Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply conditions in all markets. Since each sector supplies inputs to other sectors, output prices – which are the cost of inputs for other sectors – and the choice of the optimal combination of inputs are determined simultaneously for all sectors.

Some simplifying assumptions are used in the specification of the sectoral production functions. All non-agricultural sectors are assumed to operate under constant returns to scale, which permits the determination of output prices independently of the level of activity'. The primary factors of production are assumed to be in fixed supply to the total economy, fully employed and partially mobile between sectors. Labour and capital are allocated to each industry according to demand and supply, and are paid a price that equates demand with supply.

Land is assumed to be a mobile factor of production between the two agricultural sectors only; it is not modelled as a factor of production in the non-agricultural sectors. This treatment of land implies that the two agricultural sectors are characterised by decreasing returns to capital and labour. The results of some sensitivity analysis with the Japanese model in which land is used as an input in the non-agricultural sectors, are described in the paper by van der Mensbrugghe *et* al. in this volume.

Another element of simplification is the assumption of fixed intermediate inputs per unit of gross output in all sectors. There are, however, two important elements of flexibility in the choices available to producers:

i) The optimal combination of capital and labour – and land in the two agricultural sectors – is variable and depends on the relative prices of these inputs, assuming substitutability between them;

Table 1. The structure of industries and demand in the WALRAS model

The thirteen industries	The seventeen demand components[a]
1. Livestock and livestock products	1. Bread and cereals
2. Other agricultural industries	2. Meat
3. Other primary industries[b]	3. Milk, cheese and eggs
4. Meat products	4. Other food and non-alcoholic beverages
5. Dairy products	5. Alcoholic beverages
6. Other food products	6. Tobacco
7. Beverages	7. Clothing and footwear
8. Chemicals	8. Gross rents, fuel and power
9. Petroleum and coal products	9. Household equipment and operation
10. Other manufacturing industries	10. Medical care
11. Construction	11. Transport and communication
12. Wholesale and retail trade	12. Education and recreation
13. Other private services	13. Other consumer goods and services
	14. Gross private fixed investment
	15. Change in stocks
	16. Government expenditure[c]
	17. Exports of goods and services[d]

a) The first thirteen items are components of private consumption.
b) Forestry, fishing, mining and quarrying.
c) Includes government investment.
d) Includes re-exports.

ii) For each intermediate input, producers are allowed to buy domestic or imported commodities, depending on relative prices and given the level of product differentiation.

Moreover, the model incorporates the assumption that labour and capital are less than perfectly mobile between the two farm sectors and the rest of the economy. At the same time, labour and capital are assumed to be perfectly mobile within the farm and non-farm sectors. This implies that the returns to labour and capital are not equal in all sectors. The reasons for introducing partial factor mobility are three-fold:

i) Historical evidence from OECD countries of persistent discrepancies between farm and non-farm returns to factors:
ii) Econometric evidence in favour of this hypothesis*: and
iii) The presumption that ageing of the farm labour force would contribute to lower labour mobility over the term of this analysis.

B. Consumption

A single representative consumer is assumed to choose between thirteen consumer goods (see Table 1). These consumer goods are different from the outputs of the thirteen sectors of production, and correspond more closely to the standard groups of products which consumers demand. A matrix of fixed coefficients – a so-called "transition matrix" – is used to convert goods and services in the production-sector classification into consumer goods and services. Using this matrix, producer prices are translated directly into prices for consumer goods, and the demands for consumer goods can be immediately transformed into demands for producer goods.

It is well known that demand for certain goods – and in particular for food – increases less than it does for other goods as income rises. For this reason, the model of consumer behaviour incorporates different income elasticities of demand for different goods and services.

Consumers are assumed to have the option of importing the commodities they want to buy. Their optimising decisions are thus separated in two stages: first, given their disposable income and the prices of consumer goods, they decide how much they want to save and how much they want to spend on each type of good or service; and second, they decide, for each of these, what proportions to buy domestically or to import, as a function of relative prices.

Consumers obtain their income from the returns to supplying primary factors of production and from government transfers. In countries where agricultural production quotas are operative, quota rents add to farm household income. After paying income taxes, consumers spend a proportion of their disposable income on the purchase of goods and services; the remainder is saved. Saving is assumed to take the form of purchases of investment goods; financial intermediation is not incorporated in the model.

C. The role *of* the government

The government collects taxes on incomes, intermediate inputs, outputs, and consumer expenditures, as well as on imports. It also subsidises exports of agriculture and food. All of these taxes and subsidies influence the decisions of economic agents, by changing prices and/or by reducing incomes. Tax revenues collected by the government are a function of the level of economic activity and are therefore calculated endogenously. In addition, household income taxes can be adjusted to compensate for the variations in government net budget positions due to changes in agricultural protection.

Government expenditure is not constrained to be constant at its benchmark level nor equal to revenues. Once the total level of spending is decided, the government allocates it to transfers, which are exogenous in the model, or to the purchase of goods, services, capital and labour. Non-transfer expenditures are functions of relative prices, obtained from an assumption of optimising behaviour by the government.

D. Foreign trade

The world trade sub-model is based on a set of bilateral trade matrices which describe how price and quantity changes in national economies affect world markets, with imports originating in different countries/regions being treated as imperfect substitutes. The use of such a specification – commonly referred to as the Armington specification[3] – represents a major departure from the typical Hecksher-Ohlin framework. One drawback, however, with the use of the Armington specification in AGE models is that it often leads to strong terms-of-trade effects following changes in trade policies. In such a framework, welfare losses due to the imposition of tariffs may be compensated for by terms-of-trade gains.

Imports have already been mentioned above in the context of producer and consumer behaviour. Given composite import prices, calculated as the weighted average of export prices set by the other countries/regions plus tariffs, the decisions to import by producers and consumers are part of their optimising behaviour.

In most AGE models imports and domestic goods are treated as imperfect substitutes, while it is assumed that exports and domestically-sold goods are perfect substitutes. This specification of export supply, however, overstates both the links between export and domestic prices and the responsiveness of exports to demand shifts on world markets. Following the approach developed by Dervis et al. **(1982)** and de Melo and Robinson **(1985, 1988)**, the external closure of WALRAS involves a symmetric assumption of product differentiation for imports and for exports. In each industry, producers are assumed to choose the optimal output-mix between exports and domestic supplies in response to the market-clearing price ratio between domestic and export markets.

This specification of export supply – the so-called "Constant-Elasticity-of-Transformation" (CET) approach – is often justified on aggregation grounds, i.e. many of the broad sectors used in models such as WALRAS group together industries with widely differing export shares. The wider the product coverage of a given sector, the likelier it is that exported goods will be different from domestically-sold ones. Hence, it seems justified to assume a lower value of the transformation elasticity for large aggregates, which group together a wide variety of different industries, than for sectors with a more homogeneous coverage. In practice, finite transformation elasticities have only been introduced in the two farm sectors and in three large non-farm sectors in WALRAS – other manufacturing industries, wholesale and retail trade and other private services (see Annex I).

Trade flows depend on both country supplies and foreign export demands, with the latter being determined by export prices from one country relative to its competitors' prices. Since goods are nationally differentiated, each country is assumed to face a downward-sloping demand curve for both its agricultural and industrial exports. Due to the relatively more homogeneous nature of many agricultural products as compared with manufactures, they could be treated as perfect substitutes. However, at the levels of aggregation used in WALRAS, there are considerable inter-country differences between broad categories such as "livestock" or "meat products". The capacity to take account of imperfect substitutability, therefore, seems desirable.

As a result, export prices for any commodity may differ from world prices as well as from prices paid on the domestic market, and a country may both export and import goods in a given sector. In this way the model captures the phenomenon of intra-industry trade. This represents a significant departure from the "small-country assumption" of traditional trade theory in which countries can export any amount of a given commodity at a given price and nothing at a higher price.

Countries can, in principle, run current-account surpluses or deficits in the model. The counterpart of these imbalances is a net outflow or inflow, respectively, of capital, which is subtracted from or added to the domestic flow of saving[4]. To satisfy the world current-account constraint, the counterpart of this net flow in turn has to be reallocated between the other countries/regions. At this stage of development of the model, however, this is done exogenously and no account is taken of net income flows associated with changes in stocks of foreign assets or liabilities.

The model includes a measure of the "real exchange rate", which is defined as the weighted average of domestic factor prices relative to the average world price. Changes in this relative price play a key equilibrating role in the model.

E. Investment and saving: closing the model

To complete the model, an investment equation is specified. Since there are no financial assets in the model, net saving is allocated entirely to investment goods, and thus the specification of investment is greatly simplified. Savings come from three main sources:

i) Private saving, as determined by consumer behaviour;
ii) Public saving, which correspond to the net budget position; and
iii) Foreign saving, arising from a current-account deficit.

It is important to note that all income generated by economic activity is assumed to be distributed to consumers. Therefore, corporate saving is treated as part of household saving and is dealt with in the consumer sub-model. Overall consistency requires making total domestic investment identical to net national saving plus net capital inflows. One possible closure rule would be to allow government and foreign saving to be determined endogenously. A government budget deficit, or a capital outflow as a counterpart of a current account surplus, represent applications of saving, which reduce the amount available for domestic investment.

The closure rule in the WALRAS model can be varied for different simulations. In the standard WALRAS closure, it is assumed that the initial government deficit and base-year foreign trade imbalance do not change. Given a change in agricultural policy, the government's deficit could be expected to change. In the model, the marginal income tax rate is adjusted to restore the initial government deficit/surplus position. This approximates revenue-neutrality which is considered the appropriate closure to apply to the government sector for long-term simulations. Similarly, it would be unreasonable in the long-run to have a changing foreign balance. In the model, adjustment via real factor prices is the mechanism which restores the initial balance-of-payments position. In the case of exogenous government and foreign trade imbalances, investment is almost entirely savings driven. If these constraints were to be relaxed, changes in the fiscal and external imbalances would be expected to have crucial effects on the aggregate savings-investment picture.

F. The specification of production and demand functions

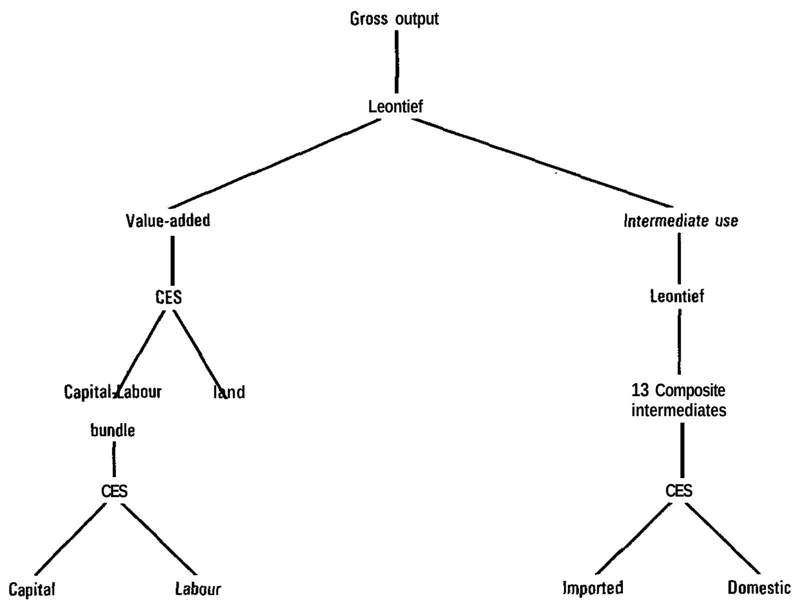
In WALRAS – as in many AGE models – various final and intermediate demand components are typically represented by tree-structured nested functions. This usually involves several levels of constant-elasticity-of-substitution (CES) functions being nested under a production or utility function which is assumed to be non-negative, continuous and homogeneous of degree zero in all prices: i.e. doubling all prices (and income) does not change the quantities supplied and demanded.

The overall production structure of the model is depicted in Figure A. Weak separability is assumed to characterise the relationship between intermediate demand and value added. For intermediate inputs, a Leontief (fixed-coefficient) specification has been adopted. Using the assumption that output prices are initially normalised on one, total intermediate output of each industry can be obtained from the benchmark data set in value terms.

Value-added is modelled via two-level CES functions; in the inner nest, capital and labour are aggregated to form a capital-labour bundle which is combined with land in the outer nest. There is assumed to be no scope for substitution possibilities between intermediate inputs since these are specified by a fixed-coefficient (Leontief system). However, substitution is possible between domestic and foreign intermediate inputs.

FIGURE A

THE PRODUCTION STRUCTURE OF THE WALRAS MODEL



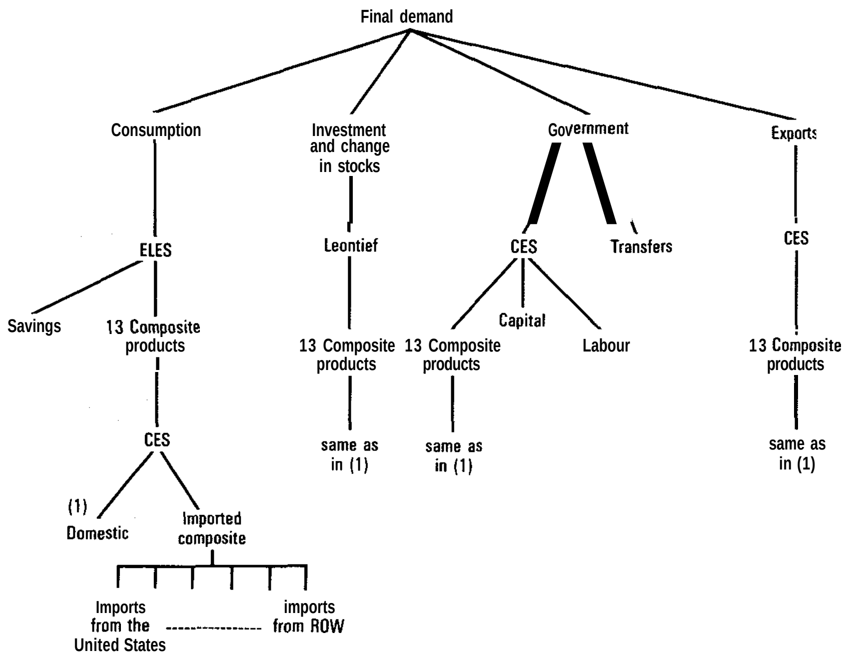
The specification of consumption is illustrated in Figure B. This is represented by the Extended Linear Expenditure System (ELES) which permits a relatively flexible specification in which the non-unit income elasticity property of the LES approach is extended to incorporate saving and combined with nested CES-demand functions. The other components of final demand – investment, government expenditures and stock changes – are specified by using a similar mix of Leontief and CES functions (see Figure B).

Exports by each country are determined by supply and demand mechanisms. The former is linked to the producer response to the price ratio between domestic and world prices: this ratio, via the CET function, determines the allocation of total supply between domestically-sold and exported goods. Export demand depends on import demands originating in the other countries; these are allocated among countries of origin in response to relative prices via a set of bilateral CES world demand functions.

The specification for the Rest of the World (ROW) aggregate is restricted to a set of simple import demand functions which express imports by ROW as a

FIGURE B

THE FINAL DEMAND STRUCTURE OF THE WALRAS MODEL



function of the ratio between world import prices and ROW factor prices. Imports from ROW are derived from the world sub-model. Two aggregate factors are identified for the agricultural and non-agricultural sectors, respectively, in ROW, with the price of the latter taken as the numéraire of the model. The domestic demand for agricultural commodities in ROW is exogenous and output in agriculture varies only with changes in the net trade positions. Supply of the agricultural factor in ROW is allowed to adjust to the differential in its return between the agricultural and non-agricultural sectors.

G. The solution algorithm

In order to solve the model, a tâtonnement procedure based on the Gauss-Seidel algorithm was chosen for its practical advantages in solving large non-linear models. The solution method proceeds in the following order:

i) Each country/region sub-model is solved and excess demands for primary factors are calculated;

ii) The world trade sub-model is solved for bilateral trade flows and derives total export demands for each country/region; and

iii) Factor prices are adjusted in each country/region in order to eliminate excess demand of factors.

Then, a new iteration is initiated on the basis of the adjusted factor prices.

At the beginning of each iteration, the model first uses the adjusted factor prices in each country/region to solve for the producer prices, given the technical coefficients used in each production sector. Using the transition matrix, producer prices are then converted to consumer good prices. Primary factor prices also determine the income of consumers, under the assumption that all factors are fully employed. Once both consumer incomes and consumer prices are determined, it is possible to calculate the demands for consumer goods, the most important component of final demand.

Government spending is fixed exogenously and is allocated to various goods and services as a function of factor and producer prices. Stock changes are also exogenous. Export demands are given by the world trade sub-model. For reasons of simultaneity, the level of investment is calculated by taking for some components of the government budget their corresponding value at the previous iteration as a "proxy" for the current one.

When all components of final demand are known, the production sub-model is used to determine total output required to meet demand, and subsequently imports, labour, capital and land demands. Government revenue from all types of taxation can then be computed.

With all import demands by each country/region being known, the world trade sub-model can be solved for exports. When the, model approaches the equilibrium solution, factor price adjustments between each iteration, as well as the bias from using previous iteration values, become smaller. At equilibrium, factor markets in all countries/regions are simultaneously cleared; total values of world imports and exports are strictly balanced and the current accounts of all countries/regions sum to zero.

II. A GRAPHICAL TREATMENT OF THE MAIN ECONOMIC MECHANISMS IN WALRAS

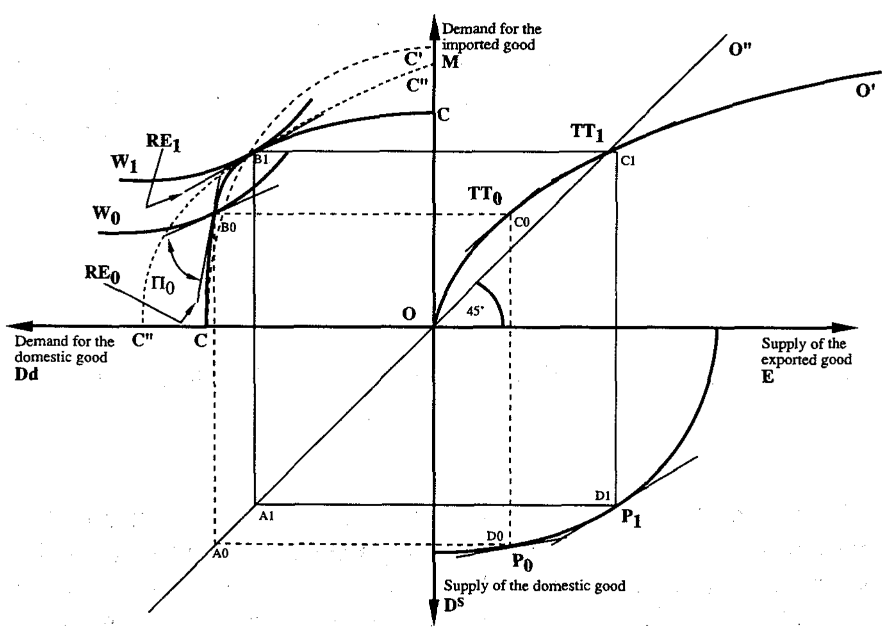
This section aims to provide the reader with an overall understanding of the main mechanisms at work in WALRAS using a series of graphs. It first highlights the role of two key relative prices in the model – the real exchange rate and the terms of trade – by referring to a one-sector model which is simple enough to be solved graphically but still contains the main features of the full model. The analysis is then extended to a two-sector framework – agriculture and non-agriculture – and discusses the various sources of real income changes with reference to typical agricultural net-exporting or -importing countries.

A. Real exchange rate and the terms of trade

The following discussion of a one-sector model draws inspiration from a four-quadrant diagram (Figure C) developed by de Melo and Robinson (1988). For convenience, all prices are normalised at unity and the current account is set to zero. The upper right quadrant describes the current account constraint as a relation between imported (M) and exported (E) goods. The standard closure in WALRAS implies that the current-account balance is the counterpart of a capital flow with the rest of the world. In the case of this illustrative model it is assumed to be zero, whereas it is non-zero and set to the benchmark values in the full specification. If world prices remain constant – the small-country case when the foreign net offer curve is infinitely elastic – the current-account constraint is represented by a 45-degree line. However, in WALRAS exporters are assumed to

FIGURE C

EFFECTS OF REMOVING AN IMPORT TARIFF



face a downward-sloping demand curve as goods coming from different countries are not viewed as perfect substitutes. Given constant world import prices, they have to lower export prices if they want to export more. In this case, the current-account constraint takes the form of a monotonic and convex curve (OO'), the slope of which gives the terms-of-trade at each level of exports.

The lower right quadrant shows the producer transformation frontier between the quantity of production that is exported (E) and the quantity which is sold domestically (Ds). It shows how producers allocate a fixed factor endowment between production for domestic and world markets, subject to relative prices, in order to maximise their profits. Due to the assumption that exported and domestically-sold commodities are imperfect substitutes, the transformation frontier is concave. In the lower left quadrant, the 45-degree line indicates the equilibrium condition between demand (Dd) and supply (Ds) of the domestic good.

The upper left quadrant deals with the consumer optimisation problem in terms of possibility frontiers (CC) and indifference curves (W). The possibility frontier (CC) describes all combinations of imported and domestic goods that can be purchased given the resource endowment and its allocation between domestically-absorbed and exported goods. This curve is drawn as the locus of points which satisfies both domestic and foreign equilibrium conditions, given the shape of the transformation function in the lower right quadrant. If the terms of trade were to remain unchanged whatever the level of net export supply (i.e. the current account constraint in the upper right quadrant is a 45-degree line), the consumer possibility frontier would be the symmetrical image of the producer possibility frontier in the lower right quadrant (see the dotted frontier CC'). With the rest of the world net demand being less than infinitely elastic, the shape of the consumer possibility frontier is given as a combination of the producer transformation function and of terms-of-trade effects. The more producers export, the more they have to lower their relative export prices; this outcome, in turn, implies that, as consumers, their purchasing power in terms of the imported good declines.

Each point on the curve CC describes an equilibrium solution represented by a rectangle – (A_0, B_0, C_0, D_0), for instance. An optimal equilibrium, however, is defined by the tangency between the consumer indifference curve – as represented by the equivalent income contour (W) and the consumer possibility frontier (CC). The slope at the point of tangency indicates the price of the domestic good relative to the world import price, which is chosen as the numbaire of this reduced model. This price ratio is usually referred to as the "real exchange rate"; variations in this relative price allow the model to move towards a new equilibrium solution in response to an exogenous shock.

The initial level of protection is represented by a tariff which makes the relative price of the imported good higher on the domestic than on the world market. This price wedge (π_0) yields a sub-optimal equilibrium (A_0, B_0, C_0, D_0) and the initial real exchange rate is defined by the slope of the line RE_0. When the wedge T_0 is removed, a new equilibrium is reached at (A_1, B_1, C_1, D_1), which implies that:

i) Consumer demand is shifted towards the imported good (from B_0 to B_1) and the equilibrium real exchange rate depreciates – as shown by the shift in the price line from RE_0 to RE_1. Consumer utility increases as the new equilibrium is on a higher equivalent income contour (represented by the move from W_0 to W_1);

ii) Export volumes have to increase more than import volumes to compensate for the corresponding terms-of-trade depreciation (represented by the decline in the slope of the price line between C_0 and C_1);

iii) The export price has to increase relative to the price of the domestic good (the change in the slope of the P line in the SE quadrant) in order to induce a supply shift towards exports.

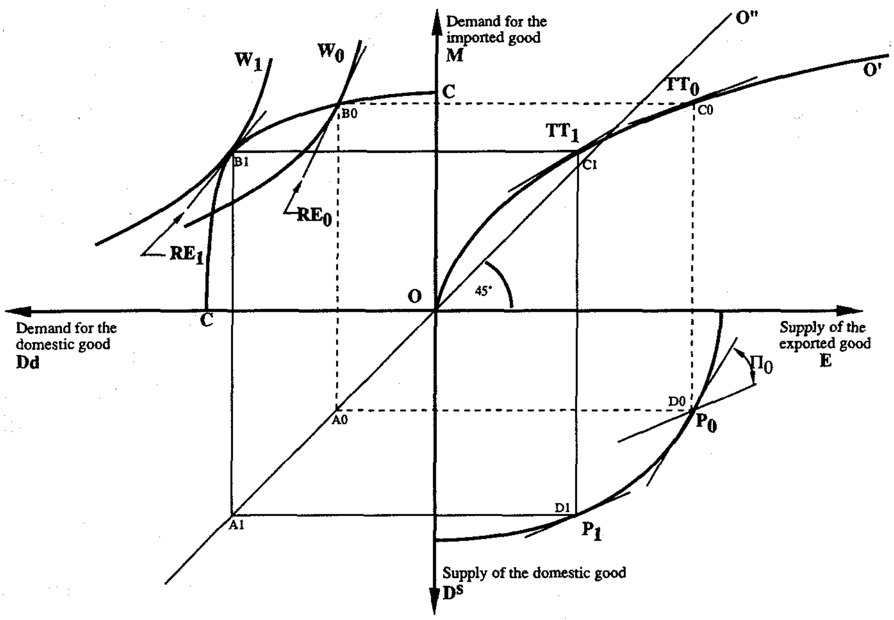
All three relative price changes are correlated, with their respective magnitudes depending on the elasticity levels. If the foreign net supply is assumed to be perfectly elastic and no differentiation is introduced between domestic and exported goods, producer and consumer possibility frontiers become straight parallel lines. All domestic prices remain strictly equal to the given world price, and the equilibrium depends on consumer preferences only. With reference to this limiting case, we can highlight two important features of the specification used in WALRAS:

i) The higher the demand elasticities on the world market, represented by the curvature of the OO' line in the upper right quadrant, the lower the magnitude of changes in both the real exchange rate and the terms of trade. To illustrate this point, the curve CC' has been drawn on the assumption that the demand in the rest of the world is perfectly elastic. In such a case, it is a mirror-image of the producer transformation frontier in the SE quadrant relative to the 45-degree line (A_0OO''). The real exchange rate depreciation is shown to be lower than with the base specification while the terms of trade remain constant;

ii) Assuming imperfect transformation between domestic and exported goods, however, increases the magnitude of the real exchange-rate depreciation (by comparison with the perfect transformation case, for which the corresponding consumption possibility frontier is C''C'' in the upper left quadrant). Also, by making the country's net supply to the rest of the world less elastic, it reduces the magnitude of the required terms-of-trade changes. Therefore, both high trade substitution elasticities and imperfect transformation on the supply side act together to moderate the terms-of-trade effects and, to a lesser extent, the real exchange rate sensitivity to exogenous shocks.

FIGURE D

EFFECTS OF REMOVING AN EXPORT SUBSIDY



Consider now the case of an export subsidy (Figure D). The initial situation then relates to a price wedge on the export side (π_0 in the lower right quadrant) which distorts the output mix towards exports for which producers are paid a higher price than on the domestic market. The corresponding equilibrium is defined by the rectangle (A_0, B_0, C_0, D_0); as in the case of a tariff, it is a sub-optimal one as the slope of the price line RE_0 is not tangential to the consumer possibility frontier. In that case, the export subsidy in the lower right quadrant is equivalent to an import subsidy represented by a price wedge in the upper left quadrant. When the export subsidy is removed, producers choose to reallocate their supply in favour of the domestically-absorbed good and an optimal equilibrium is reached at (A_1, B_1, C_1, D_1) with the following repercussions:

i) The terms of trade improve (from TT_0 to TT_1) and the real exchange rate depreciates (from RE_0 to RE_1);

ii) The current account position is restored by the terms-of-trade gain and by a cut in imports;

iii) Consumer welfare increases (from W_0 to W_1).

The single-sector approach shows how changes in the real exchange rate and the terms of trade are interdependent and their magnitudes are a function of some key elasticities. Assuming economies to have only one agricultural sector, protection is seen to have different outcomes whether the country is a net importer or exporter of this agricultural commodity. Agricultural support in a food-exporting country, where it mainly takes the form of export subsidies, is at the price of undercutting its terms of trade. Liberalising agriculture in such a country implies trade volumes will be reduced and world export prices of agricultural goods will increase. On the other hand, import tariffs in a food-importing country act as export taxes; when they are removed, both exports and imports will increase at the price of a terms-of-trade depreciation. In both cases, however, supporting agriculture implies the real exchange rate is over-valued. Although it takes no account of the non-agricultural sector, this approach stresses an important mechanism in understanding the world market reaction: liberalising agriculture in a net-importing country will tend to increase trade volumes while the opposite will be true in the case of a net exporter.

B. Sources of real income gains from agricultural liberalisation

The analysis must now be extended to a two-sector model (agriculture and non-agriculture). Figure E presents the case of a net agricultural exporter. Producers maximise their profits under the constraint of a convex transformation frontier (PP) while consumer utility is represented by a set of equivalent-income contours such as DD. In the initial situation, the domestic relative price for the agricultural good exceeds the relative world price PW_0, as a result of border interventions represented by a price wedge π_0. Production takes place at S_0 and consumption at D_0. This implies that, as drawn, the food-exporting country has to import the non-agricultural good under protection. When this distortion is removed, the domestic price ratio falls to the level of the world one which, in the first instance, is assumed to be unaffected and a new equilibrium is reached at S^* and D^*. Factors are reallocated along with changing marginal returns and the supply of the non-agricultural commodity increases at the expense of the agricultural one – represented by the move along the production possibility frontier from S_0 to S^*. The consumer welfare gain from agricultural trade liberalisation is indicated by the fact that D^* lies on a higher indifference curve than D_0.

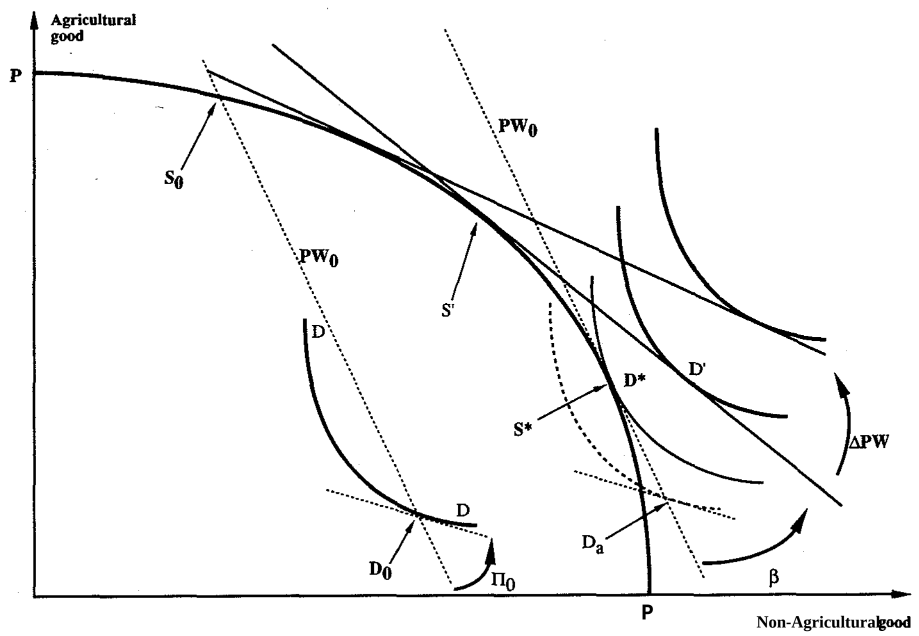
The move from the initial tariff-distorted equilibrium to the free-trade position can be decomposed into two steps, relating to resource and consumption re-allocations. The former gain (represented by the shift from D_0 to D_a) relates to an income effect as resources are shifted into producing domestically the commodity which is the most expensive on the world market and importing the cheapest one; this additional real income is spent according to the consumer preferences. In this case, it is mainly used to purchase additional non-agricultural goods. The latter effect – represented by the shift from D_a to D^* – is directly related to cheaper agricultural commodities and will depend on the degree of consumer sensitivity to agricultural prices.

This traditional exposition assumes that domestic and foreign goods are perfect substitutes *so* that relative domestic prices align exactly to the world price when protection is removed. Such an assumption is not made in WALRAS: products are assumed to be differentiated in respect to their origins as well as their destinations. This is the most suitable assumption for a multi-good model with broad commodity aggregates. But it confers on both domestic and export suppliers some market power which depends upon the magnitude of the substitution elasticities.

Therefore, with product differentiation, the "law of one price" on world markets no longer holds. When all distortions are removed, the production possibility frontier (PP) and the indifference curve (DD) in Figure E must be tangential to the price line at which goods are traded. This, however, is no longer unique: it differs from one country to another. The world price line PW_0 further refers to the average of relative prices applied by the other countries, which, *so* far, is assumed to be constant.

FIGURE E

REMOVING AGRICULTURAL SUPPORT IN A FOOD-EXPORTING COUNTRY



Countries which undergo an agricultural reform exert their market power on the world export markets in such a way that their terms of trade remain different from the average world price line PW_0. For instance, removing output and export subsidies forces agricultural producers to sell at a price which exceeds that of competing imports and exports. Given that their product is not a perfect substitute for the foreign product, they are granted some residual market share even if their price exceeds the corresponding world price average. This also applies to the elimination of an import tariff.

Furthermore, the one-sector model developed in the previous sub-section has underlined the need for a real exchange-rate depreciation to give non-agricultural exports a boost in order to keep the current account balanced. Where agricultural protection is removed, country-specific terms of trade at equilibrium imply that agricultural exports are traded at a real price which is higher than the world average. This residual deviation, which still persists after complete liberalisation, is represented by the price wedge ß in Figure E and stands for the market power which results from national product differentiation.

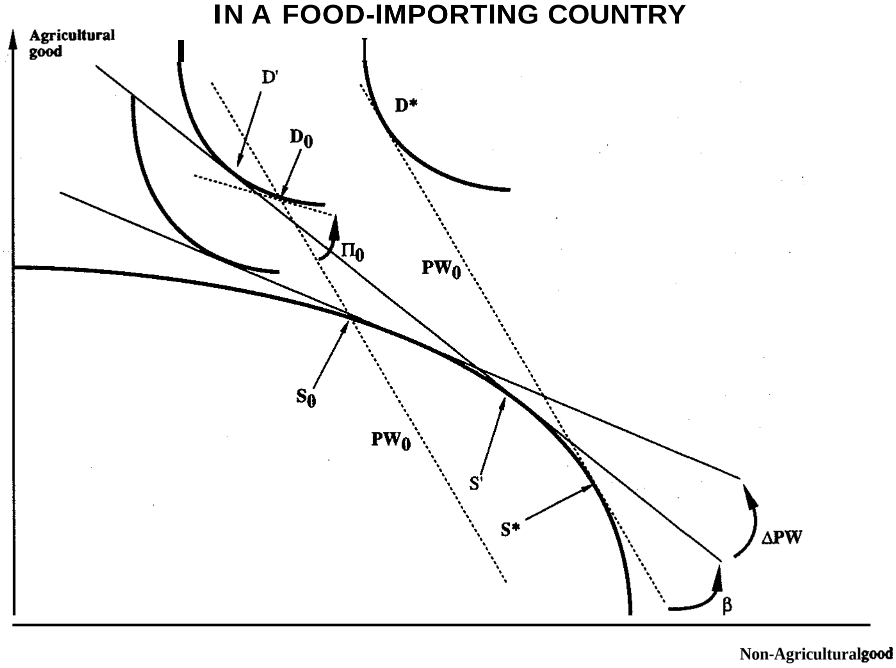
In the case of an agricultural net-exporting country, this residual price wedge reduces the resource transfer compared with that in the perfect substitution case (the new equilibrium is at S' instead of S*) and leads to higher consumer welfare via a positive terms-of-trade effect (D' instead of D*).

Figure F considers the case of a net-agricultural importer, such as the EC and Japan, where an initial import tariff raises the agricultural real price on the domestic market above its corresponding world level by a wedge represented by π_0. When this tariff barrier is eliminated, the equilibrium is expected to move from S_0D_0 towards the optimal solution S*D* but the adverse terms-of-trade effect from product differentiation (ß) may be large enough to wipe out the expected welfare gains. Figure F depicts the case where, despite a gain in purchasing power for the agricultural good, there is no increase in consumer real income as shown by D' being on the same equivalent-income contour as D_0.

The above discussion highlights that the usual welfare gains arising from resource and consumption reallocations are modified – and may even turn into losses – due to terms-of-trade effects yielded by the assumption of origin differentiation. This is a well-known property of the Armington specification in AGE models (see Brown, 1987). Therefore, the model results depend on the assumption about the degree of product differentiation. They may be grossly misleading if the substitution elasticities are set too low relative to the presumption that the flexibility on world markets should be significantly higher in the long run. The one-sector analysis reported earlier suggested that an agricultural net-exporting country, like New Zealand or Australia, should record a terms-of-trade improvement after liberalising agriculture; this, as well as the corresponding welfare gain, will be reduced as the trade substitution elasticity levels are increased. For the other net food-importing countries, however, the demand effect prevails. Higher levels of

FIGURE F

REMOVING AGRICULTURAL SUPPORT IN A FOOD-IMPORTING COUNTRY



substitution in demand between domestic and imported goods mean higher welfare gains as this leads to more consumption and factor reallocation. Moreover, as foreign demand is logically more flexible too, the welfare losses induced by both real exchange-rate and terms-of-trade depreciations are smaller. These mechanisms are illustrated in the section of the paper on sensitivity analysis by van der Mensbrugghe ***et** al.* which deals with import and export elasticities.

C. World trade linkages

Agricultural trade liberalisation has two main effects on world trade flows in WALRAS. First, countries which apply high import barriers, like the EC and Japan, will increase their demand for agricultural imports from other countries after these barriers have been removed. This ***demand effect*** serves to increase the world volume of agricultural trade, thereby increasing agricultural production and factor prices in food-exporting countries in the OECD and the rest of the world. Countries which directly subsidise their agricultural exports (like the EC) or compensate their farmers for selling at below marginal costs with direct payments (like the United States and Canada) will now be forced to increase their offer prices on agricultural exports. This, in turn, will drive a further reallocation of the world supply towards non- or less-subsidising countries. The magnitude of this supply effect depends on whether products can be substituted for each other on world markets and on the ability of potential agricultural exporters to provide what was previously supplied by OECD countries. This supply effect entails an increase of the real prices for agricultural commodities on world markets.

With reference to Figures E and F, the average world market price change can be viewed as a counter-clockwise move of the world price line (APW), the effect of which is to increase welfare in an agricultural net-exporting country and to lower it in a net-importing country. A higher degree of trade reallocation can be achieved when trade substitution elasticities are raised; this reallocation leads to a lower increase of world agricultural relative prices and lower real income transfers. Whether net food-importing countries have an interest in liberalising agriculture crucially depends on whether gains from domestic reallocation are large enough to compensate for the losses induced by adverse terms-of-trade effects.

D. Effect of factor mobility

Allowance is made in WALRAS for partial factor mobility between farm and non-farm sectors. Although this could be expected to reduce the efficiency gains from liberalising agriculture compared with the case where factors are fully mobile, the final outcome depends once again on the relative magnitudes of reallocation and terms-of-trade effects. Figure G, like Figure F, evokes the case of an agricultural net-importing country in which reallocation gains are offset by an adverse terms-of-trade effect ß. Assuming factors are fully mobile, the post-liberalisation solution (S'D') is welfare-inferior compared with the first-best outcome of an agricultural liberalisation where domestic and foreign products are not differentiated (S*D*).

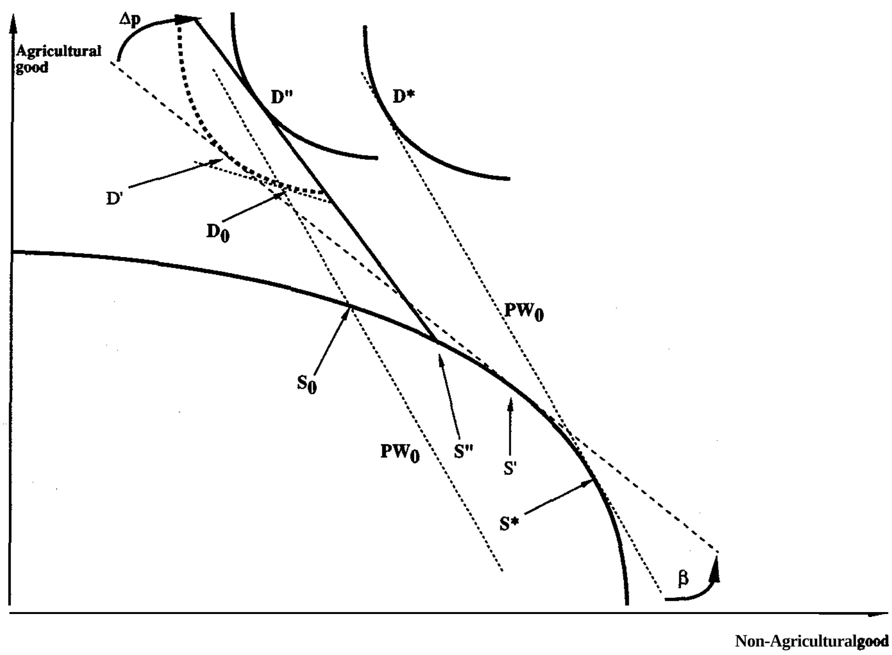
With restricted factor mobility, the product-mix lies at a point on the frontier such as S'' in Figure G instead of S'. If relative prices were to remain unchanged, this alone would imply a lower real income gain than the perfect mobility situation denoted by **(S'D')**. However, labour and capital have a lower propensity to leave agriculture than under perfect mobility. This results in a larger fall of the relative agricultural price. The reasons for this are twofold:

i) Farm costs decrease more than with perfect mobility as capital and labour are more specific to the farm sector; and

ii) Agricultural output contracts less (S_0S'' instead of S_0S') inducing a smaller trade deficit and a lower depreciation of the real exchange rate. Both changes result in a fall in the real agricultural price (Δp) which

FIGURE G

EFFECTS OF RESTRICTED FACTOR MOBILITY



outweighs the negative terms-of-trade effect from national origin differentiation ß. Although welfare-inferior to D*, the outcome with partial factor mobility (D'') implies real income gains higher than under the perfect mobility assumption (D').

This concludes the discussion of the main mechanisms at work in the WALRAS model. The base scenario is run under the assumption that, in a long-run view, substitution elasticities between agricultural goods from various origins are likely to be high while consumer sensitivity to prices of the various food items is presumed to be low at an aggregate level. From the above discussion, this creates a presumption that factor reallocation effects will dominate over terms-of-trade effects when agricultural protection is removed. The factor reallocation takes place at the world level to the benefit of agriculture in New Zealand, Australia and the Rest of the World while it favours non-agricultural industries and services in Canada, the EC, Japan and the United States. The latter effect is further enhanced by the low consumer reaction with regard to food prices, which guarantees that income effects will outweigh substitution effects in reallocating the purchasing-power gain resulting from agricultural liberalisation.

III. MICRO-CONSISTENT DATA SETS AND CALIBRATION

A. The benchmark data sets

As with all AGE models, constructing the benchmark data set of the WALRAS model involved a major investment in data collection and adjustment to ensure consistency and to match the data to the model's sectoral disaggregation. The reader should refer to Burniaux ***et al.*** (1988) for a more detailed description of data collection and adjustment. Input-Output (I-O) tables provided the essential source, supplemented by data from other sources, including OECD ***National Accounts*** and ***Foreign Trade Statistics.*** Additional information was required to split value added into the returns to each primary factor of production distinguished in the model.

The "benchmark" year in the WALRAS model is 1980 or 1981, depending on the country or region. This choice was governed by the availability of the latest I-O tables for all countries in question. The basic I-O tables were supplied by national statistical agencies together with the corresponding transition matrices linking producer and consumer classifications, the latter being consistent with the National Account categories.

In Burniaux ***et al.*** (1988), private consumer demands were assumed to be allocated between ten aggregate commodities, one of which was "food and non-alcoholic beverages". However, it was judged that this category was too aggregated to properly represent consumer responses to the large sectoral distortions in prices. In particular, it was felt necessary to produce more plausible implicit elasticities of consumer demand for imported food goods. It was, therefore, decided to split food into four distinct goods:

- *i)* Bread and cereals;
- *ii)* Meats;
- *iii)* Milk, cheese and eggs; and
- *iv)* Other foods and non-alcoholic beverages.

This disaggregation was undertaken using data on private consumption expenditures for 1980 collected as part of the joint OECD/EUROSTAT work on Purchasing Power Parities.

The bilateral world trade matrices which underpin the world linkage sub-model were constructed from three sources:

i) The WALRAS country I-O tables;
ii) The **UN** ***Handbook of International Trade and Development Statistics;*** and
iii) OECD ***Statistics of Foreign Trade*** (Series **C**).

The figures from the latter two sources were adjusted, using an iterative bilateral adjustment process, to make the world trade matrices consistent with the micro data sets used for the country models.

B. Selection of key exogenous parameters

Calibrating the model consists of adjusting certain parameters to make it fit the data for the benchmark year, given its specification ***and*** exogenous values for certain key parameters. These latter parameters play a crucial role in determining the simulation results.

For WALRAS, the following parameters are exogenous:

- Elasticities of substitution between labour and capital;
- Elasticities of substitution between land and the labour-capital bundle in the two farm sectors;
- Supply elasticities of labour and capital in agriculture relative to their return differentials between farm and non-farm sectors;
- Elasticities of transformation between domestic output and exports;
- Price elasticities of imports for intermediate use and for final demand;
- Price elasticities for export demand;
- Income elasticities for consumer-good demand;
- Marginal tax rates on household incomes;
- Elasticities of substitution between types of government expenditure;
- Supply elasticity for agriculture in ROW.

The typical procedure in AGE modelling is to search the relevant econometric literature for plausible values for such exogenous parameters. The results of such a literature search for the WALRAS model are described in Burniaux ***et al.*** **(1988)**, Section **V.** The picture is rather mixed. For some parameters, such as the elasticities of substitution between labour and capital or the income elasticities for consumer goods, it was judged that the econometric evidence provided a good guide to the "true" values. For others, notably for the foreign trade elasticities which play a crucial role in the model, the estimates typically found in the econometric literature were judged to be much less satisfactory. Econometric estimates of price elasticities for import and export demands for agricultural and food products were generally lower than for manufactured products, a finding which is contrary to ***a priori*** expectations, given the relative homogeneity of agricultural goods, even at the level of aggregation used in WALRAS. In addition, it is extremely difficult to find commodity-specific estimates of price elasticities for import and export demands that match the thirteen WALRAS sectors.

Discussion with national experts of the initial simulation results with the single-country models revealed a fairly general consensus that the price elasticities of import and export demand used to calibrate the model in Burniaux et al. (1988) were too low for a long-run analysis. There was also consensus that elasticities for agricultural and food products should be higher than for non-agricultural goods. Faced with this, it was decided to raise the baseline set of foreign trade elasticities significantly.

At the same time, one key feature of the previous approach was retained: identical values for all substitution elasticities in production and foreign trade, and the transformation elasticities of export supply are used for all countries/regions. This is not very realistic, but our survey of the econometric literature did not provide much useful guidance on country-specific values. The values of the foreign trade elasticities used in the baseline simulations in this paper are presented in Table 2 together with the values of other key parameters.

For most sectors, the baseline price elasticities for export demands are set at either –10 or –20 and substitution elasticities between imported and domestic

Table 2. Parameters values used for baseline simulations

All countries

Sector	ubstitution elasticities betweer		Price elasticities for export demand	CET elasticities of export supply
	labour and capital	land and the labour/capital bundle		
Livestock and livestock products	0.8	0.5	–20	8
Other agriculture	0.8	0.5	–20	8
Other primary industries	0.8	..	–1	..
Meat products	0.9	..	–20	..
Dairy products	0.9	..	–20	..
Other food products	0.9	..	–10	..
Beverages	0.9	..	–10	..
Chemicals	1.1	..	–10	..
Petroleum and coal products	0.9	..	–10	..
Other manufacturing	1.0	..	–10	17
Construction	1.0	..	–0.5	..
Wholesale and retail trade	1.0	..	–10	35
Other private services	1.0	..	–10	15
Elasticity of substitution between types of government expenditure (wage, non-wage and investment)			0.75	

Table 2 *(cont'd).* **Consumer import (Armington) elasticities**

	EC	Canada	Japan	New Zealand	United States	Australia
1. Grains and cereals	6.3	6.5	6.6	6.5	6.0	6.1
2. Meat	6.2	6.2	6.4	6.1	6.1	6.1
3. Milk, cheese and eggs	6.2	6.1	6.1	7.1	6.0	6.1
4. Other food	6.3	7.1	6.2	6.6	6.3	7.0
5. Alcoholic beverages	5.3	5.5	5.2	5.2	5.3	5.7
6. Tobacco	5.6	5.1	5.2	6.2	5.1	5.3
7. Clothing and footwear	5.4	5.8	5.2	5.7	5.5	6.5
8. Gross rents, fuel and power	1.0	1.0	1.0	1.0	1.0	1.0
9. Household equipment and operation	5.4	5.9	5.2	5.6	5.2	6.9
10. Medical care	0.2	0.2	0.0	0.2	0.0	0.2
11. Transport and communication	4.2	5.0	4.2	4.9	4.3	4.5
12. Education and recreation	0.2	0.3	0.2	0.2	0.2	0.2
13. Other consumer goods and services	4.1	4.2	4.1	5.0	4.2	4.3

Partial factor mobility elasticities[a]

	EC	Canada	Japan	New Zealand	United States	Australia
labour	3.00	2.66	1.06	0.42	2.66	0.42
Capital	2.20	2.76	1.02	2.16	2.76	2.16

a) Elasticities of labour and capital use in the agricultural and non-agricultural sectors with respect to relative factor returns in the two sectors. These estimates are taken from the IIASA model . See Parikh *et al.* (1986), Table 3.3; for the purposes of *Walras,* the IIASA elasticities are doubled. The elasticities for New Zealand and the United States are assumed to be the same as those reported by IIASA for Australia and Canada.

goods range from –5 to –7. The larger values are assigned to most agricultural and food products on the grounds that such commodities are closer substitutes than most other manufactured goods or services.

Elasticities of this magnitude appear large when compared to time-series estimates for broad aggregates, such as total exports or manufactured exports – where values of –1 to –2 appear to be the norm. Several observations are, however, relevant for such comparisons. First, the elasticity values needed for an AGE model such as WALRAS are *long-run* ones. Such elasticities should be relatively high otherwise all countries would have strong incentives to restrict their exports via optimal export taxes – incentives that are clearly not perceived in reality. Second, there are sound theoretical and econometric reasons why estimates of disaggregate elasticities should be significantly higher than aggregate estimates. Finally, export demand elasticities of similar orders of magnitude are used in other AGE models. One such example is ORANI, the large multi-sector model of the Australian economy[5].

In any event, the critical issue is not the magnitude of the foreign trade elasticities ***per se,*** it is the sensitivity of WALRAS results to the particular choice of parameter values used in the calibration process. The results of extensive sensitivity analysis with some of these key parameters are reported in the paper by van der Mensbrugghe ***et*** *al.* in this volume.

Estimates are needed on the size of the transformation elasticities between domestic output and exports. But there are no econometric studies which provide such estimates. In the absence of any evidence, arbitrary values were assigned to these elasticities for the five sectors in which the CET specification was implemented (see Annex I).

Use of the CET specification mitigates the response of exports to changes in relative prices on the world market. Combining export demand and supply equations, one can derive a partial reduced-form elasticity which expresses the export volume change in response to a change in the export subsidy rate (see Annex II). For the sectors in which the CET specification is implemented, these elasticities are typically well below the values of the price elasticities for export demand on world markets.

The choice of the labour and capital supply elasticities in agriculture was guided by those in the IIASA model – see Fischer ***et al.*** (1988), page 129. In using these elasticities in WALRAS, account was taken of the fact that they referred to time periods when farmers expected some degree of agricultural

Table 3. Income elasticities in the WALRAS model

	Australia	Canada	EC	Japan	New Zealand	United States
Income elasticity *of* ***demand*** *for:*						
Grains and cereals	0.1	0.0	0.1	0.0	0.0	0.0
Meat	0.3	0.5	0.4	0.7	0.2	0.4
Milk, cheese and eggs	0.2	0.2	0.3	0.7	0.2	0.2
Other food	0.5	0.3	0.5	0.6	0.6	0.3
Alcoholic beverages	0.4	0.5	0.5	0.5	1.1	0.3
Tobacco	0.4	0.5	0.5	0.5	1.1	0.3
Clothing and footwear	0.6	0.6	0.6	0.5	0.7	0.6
Gross rents, fuel and power	1.4	1.1	1.2	1.3	1.3	1.2
Household equipment and operation	1.5	1.4	1.5	1.3	0.9	1.4
Medical use	1.7	0.6	0.6	1.2	1.4	1.1
Transport and communication	1.5	1.3	1.5	1.1	1.2	1.0
Education and recreation	0.8	1.0	1.2	1.1	1.3	1.0
Other consumer goods and services	1.2	1.2	1.4	1.2	1.3	1.4

Source: See Burniaux *et al.* (1988), Table 3.

protection to continue indefinitely into the future. As such, they probably underestimate the response of capital and labour mobility when all agricultural protection is removed. In order to make some adjustment for this, the IIASA elasticities were doubled in the baseline simulations.

One can derive analytically a reduced-form elasticity for the total farm supply response to price changes in each OECD country/region as a function of *i)* the labour and capital supply elasticities in agriculture; and *ii)* the level of substitution between the fixed factor – land – and the labour/capital bundle. In Annex III, values for these elasticities are calculated and compared with ***"ex-post"*** calculated elasticities from a baseline simulation. Both sets of values suggest that the long-run supply elasticity in agriculture for the OECD is around two. Accordingly, the supply response in the ROW aggregate has been set at the same level in the baseline simulations, although the sensitivity of the results to this parameter is analysed in the paper by van der Mensbrugghe *et* al. in this volume.

Income elasticities are country-specific (Table 3); they are derived from various studies which have been reported in Table 3, page **29** of Burniaux ***et*** al. (**1988).** This has been supplemented by an additional literature search needed to document the required elasticities of the four disaggregated food categories introduced in the latest version of the model[6].

NOTES

1. The assumptions of constant-returns-to-scale technology and perfect competition have, however, been relaxed in the single-country model for Canada – referred to as the WALRAS-SE model – in order to explore what differences this could make to the results. This work is described in the paper by Delorme and van der Mensbrugghe in this volume.
2. Econometric evidence in support of imperfect mobility of capital and labour between rural and urban sectors is reported in Fischer et *al.* (1988), p. 129.
3. Armington (1969) was the first to examine the specification of import demand equations when domestic goods and imports are treated as imperfect substitutes.
4. Net factor income from abroad is treated as exogenous in the model.
5. See Powell (1985) for a defence of the use of large export demand elasticities in ORANI. Pagan and Shannon (1987) review the Australian debate on the sensitivity of ORANI results to the size of the export demand elasticities. They also point out that the results are equally, if not more, sensitive to variations in the export supply elasticities.
6. See Dixon et *al.* (1982), FAO (1986), Hassan and Johnson (1976), Remier and Kulshreshtha (1974), Tryfos and Tryphonopoulos (1973), Hassan and Lu (1974), INSEE (1983). BAE (1985).

Annex I

THE CET SPECIFICATION

When the CET specification is introduced, the response of sectoral output to external shocks can be decomposed into two terms relating to ***expansion*** and ***transformation*** effects. The former deals with the overall supply elasticity of the sector in question and the latter with the shift in the output-mix within the sector. Output supply with the CET specification can be represented, in percentage change form, by the following four equations:

- Domestically-absorbed supply (x_d) is a function of total output (x), the price on the domestic market (p_d) and the producer price (p), given a transformation elasticity. τ :

$$x_d = x + \tau\ (p_d - p) \qquad [1]$$

- Export supply has a symmetric specification with p_e being the export market price:

$$x_e = x + \tau\ (p_e - p) \qquad [2]$$

- The producer price (p) is a weighted average of domestic and export prices:

$$p = (1 - sh_e)\ p_d + sh_e\ p_e \qquad [3]$$

  where sh_e = share of exports in total output.

- The sector supply response to producer price changes (p) depends on the supply elasticity η :

$$x = \eta\ p \qquad [4]$$

The net effect on domestically-absorbed production x_d of an exogenous increase in the price p_e is given by:

$$sh_e\ p_e\ (\eta - \tau) \qquad [5]$$

The positive and negative terms of [5], respectively, define the above-mentioned expansion and transformation effects. For the CET specification to have the same properties as the corresponding disaggregated model, the expansion effect must be outweighed by the transformation effect – this requires the transformation elasticity (τ) to exceed the supply elasticity (η) in each sector. In a long-term model, such as WALRAS, which does not incorporate any inter-country/region factor mobility, sectoral supply elasticities depend on: ***a)*** the share of the sector's value added in total value-added; and *b)* the degree of factor specificity in each sector.

On the basis of these considerations, sectoral supply elasticities in WALRAS are found to be significantly lower than infinity in the two farm sectors and in the three large non-farm sectors: other manufacturing industries, wholesale and retail trade and other private services.

Annex II

REDUCED-FORM EXPORT ELASTICITIES

Combining export demand and supply functions allows us to derive a positive elasticity which relates the percentage change in export volumes by country *r* (E_r) to a percentage change in its export subsidy rate (τ_r) :

$$E_r / \tau_r = [1/\{\varepsilon_r \cdot (1 - \alpha_r)\} + 1/\{\sigma \cdot (1 - \xi_r)\}]^{-1}$$

The export response to a change in the subsidy rate depends on *i)* the level of the price elasticity for export demand on world markets (σ), given the world market share of country *r* (ξ_r); and *ii)* on the level of the transformation elasticity between domestic and exported output in country *r* (ε_r), given the export share in total output (α_r). Values for these reduced-form elasticities, calculated on the basis of the base-case values of world substitution elasticities σ and transformation elasticities ε_r, are listed in Table A1.

Table A1. Reduced-form export elasticities

	Australia	Canada	EC	Japan	New Zealand	United States
1. livestock and livestock products	4.4	5.3	5.5	5.7	5.1	5.6
2. Other agricultural industries	4.1	3.9	5.4	5.7	5.2	4.2
3. Other primary industries	3.0	2.9	3.0	3.0	3.0	2.9
4. Meat products	18.1	19.3	13.0	19.9	18.4	16.8
5. Dairy products	19.1	19.4	8.5	19.9	17.6	18.6
6. Other food products	9.7	9.6	8.3	9.8	10.0	8.3
7. Beverages	9.8	9.5	6.4	9.9	10.0	9.7
8. Chemicals	10.0	9.8	6.9	9.2	10.0	9.2
9. Petroleum and coal products	9.9	9.9	8.7	9.9	10.0	9.2
10. Other manufacturing industries	6.0	5.0	5.1	5.5	5.9	5.5
11. Construction	0.5	0.5	0.3	0.5	0.5	0.5
12. Wholesale and retail trade	7.6	7.6	5.4	7.1	7.6	5.9
13. Other private services	5.8	5.8	5.0	5.6	5.8	5.4

Annex III

AGRICULTURAL SUPPLY ELASTICITIES IN WALRAS

We assume a simplified model for agriculture, with one fixed factor and one factor in variable supply according to its price differential between agricultural and non-agricultural uses. The production function implies that intermediate inputs and primary factors are used in fixed proportions whereas some substitution is allowed for between fixed and variable factor uses. Infinite supply of intermediate inputs is assumed. The reduced form of this simplified model yields the following analytical expression for the price elasticity of agricultural supply E^{sa}:

$$E^{sa} = [(\xi_{va} / \mu \, \xi_v) + (\xi_{va} \, \xi_f / \varepsilon \, \xi_v)]^{-1}$$

where ξ_{va} is the value-added share in total production;

ξ_v is the variable factor share in agricultural value-added;

ξ_f is the fixed factor share in agricultural value-added;

ε is the substitution elasticity between fixed and variable factors; and

μ is the price elasticity of the variable factor supply in agriculture.

Table A2 provides a comparison between these analytically-deduced elasticities and those which are calculated "ex post" for the aggregate agricultural sector from the baseline simulation.

Table A2. Supply elasticities in the agricultural sector in WALRAS

	Analytical elasticities	"Ex-post" elasticities
Canada	1.5	2.8
EC	2.2	2.5
Australia	0.7	1.0
Japan	1.4	2.0
New Zealand	1.1	0.5
United States	1.4	1.4
Average	1.7	2.0

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