Linking CGE Country Models: An Example Using the OECD's WALRAS Model

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1. Introduction

These notes describe the implementation, modification and extension by staff of the Industries Assistance Commission (IAC) of an international applied general equilibrium (AGE) model, WALRAS, developed by the Secretariat to Organisation for Economic Co-operation and Development (OECD).

The model arose from an invitation by Working Party No. 1 of the Economic Policy Committee of the OECD, in the northern spring of 1987, to the Secretariat to use AGE models to analyse the economy-wide consequences of agricultural policies in OECD countries. In response to this invitation, a team in the Secretariat was given the task of developing an AGE model focusing on agricultural trade in OECD countries. The leader of the team is John Martin, and the other members are Jean-Marc Burniaux, Francois Delorme and Ian Lienert.

The WALRAS model, which this team is currently developing, has the following general features. It distinguishes six regions and,within each region, thirteen commodities, each produced by a single product industry. These commodities are called production commodities, to distinguish them from the consumption commodities, of which more will be said later. The model distinguishes between an imported and a domestically produced variety of each commodity. There are three factors of production, labour, capital and land, none of these factors being industry-specific.

A list of the regions represented in the OECD's WALRAS data base is given in Table 1, and a list of the commodities in the data base in Table 2.

Distortions in real economies are represented in the data base by import duties, commodity taxes (though these have been set at zero in the current version of the data base), production taxes and subsidies and income tax. In the latest material provided to us from the OECD, the model consisted of six unconnected single region models, but the OECD has been working to link the models. The model is solved by the OECD in the levels, rather than in percentage changes.

Since April 1988, a team under the direction of John Zeitsch has been working to set up the WALRAS model at the Commission. The members of the team are Robert McDougall and Craig Sugden. The tasks are, firstly to replicate the OECD version of WALRAS as accurately as possible, and then to link the single region models and make any other changes or extensions thought desirable.

The Secretariat has assisted Commission staff by freely providing information on the equation system and the construction of the data base. The data base itself, which was built with the assistance of OECD member countries, cannot be made available without those countries' permission. So far the Secretariat has been allowed to provide us with data for all but one of the regions in the model, on condition that we keep the data confidential, and do not use the model for policy discussion.

We have implemented the unlinked WALRAS model, following closely the equation system developed by the OECD (as written down in their technical manual), and using part of the data base which they have created. At present the IAC's data base includes data for Australia and New Zealand only. We have then introduced some changes into the equation system, and extended the revised model into a linked model of Australia and New Zealand. The additional trade data needed for the linked model has been provided by the New Zealand Department of Agriculture and by staff of the Commission. We have implemented the model using GEMPACK. Unlike the OECD, therefore, we solve the model in percentage change form.

The remainder of these notes is organised as follows. Section 2 describes the unlinked version of the model, as developed by the OECD. Section 3 describes the modified unlinked model implemented by the Commission. Section 4 describes the linked model.

2. The Unlinked Version of WALRAS, as Implemented by the OECD

Rather than rehearse the features common to most AGE models, this section takes them mostly for granted, and concentrates on those respects in which WALRAS differs from ORANI.

The production functions underlying the demand equations for primary factors and intermediate usage in WALRAS are almost identical in form to those in ORANI. The only difference is that, instead of aggregating labour, capital and land in a CRESH sub-production function, WALRAS first aggregates labour and capital in a CES function, and then aggregates the labour capital bundle and land in another CES function.

Investment demand is, as in ORANI, fixed in its commodity composition. Since capital is not industry specific, there is just one category of investment demand, rather than a separate category for each industry as in ORANI.

The consumer demand system in WALRAS is an extended linear expenditure system, in which saving is treated as a consumer commodity. The commodity classification used in this system is not the thirteen commodity classification used in the rest of the model, but a classification of consumption into ten commodities (plus saving) which resembles more closely the type of classification used in econometric study of consumer demand. The mapping from the thirteen production commodities to the ten consumption commodities is not many-one but many-many. A transition matrix is used to calculate the consumption demands for production commodities from the demands for consumption commodities (actually two transition matrices, for reasons that will become apparent when the application of the Armington asumption to consumer demand is described below). In effect each consumption commodity is assumed to be composed of production commodities in fixed proportions.

A list of the commodities distinguished in the consumer demand system is given in Table 3.

The consumer demand and saving equations in WALRAS satisfy a budget constraint defined in terms of aggregate disposable income. Aggregate disposable income is defined as the difference between aggregate household income and income tax. Aggregate household income is the sum of factor income (net of depreciation) and transfer payments by government. Depreciation is proportional to the rental price of capital, and to the size of the capital stock.

The export demand equations in WALRAS are similar to those in ORANI. The only difference is that, whereas the ORANI equations contain export demand shift terms, the WALRAS equations contain the same world price variables as appear in the import price equations. In WALRAS therefore, unlike ORANI, the shift in the export demand schedule for each commodity must be equal to the percentage change in its CIF import price.

Government is treated in WALRAS not only as a demander of goods and services but also, implicitly, as a producer. The productive activities of general government and of public enterprises are subsumed within the governmnent sector, which accordingly demands not only goods but also primary factors. Government demands are derived from a CES production function which combines labour, capital and a composite commodity. The composite commodity is composed in fixed proportions of the thirteen production commodities.

Unlike ORANI, WALRAS recognizes change in stocks as a demand category (positive or negative). The commodity composition of aggregate change in stocks is assumed to be constant.

WALRAS does not distinguish a separate demand category of margins usage, as ORANI does. Purchasers' prices differ from basic prices only by including commodity taxes or subsidies. Commodity tax variables are defined for each production commodity and for each category of demand. Tax rate variables are defined separately for domestically produced and imported varieties of each commodity in intermediate usage and consumption, but not for other demand categories.

The WALRAS model adopts the 'Armington assumption' that domestically produced goods and imported goods are imperfect substitutes. Substitution between goods from different sources is allowed in intermediate usage and consumption, subject to CES sub-production or sub-utility functions; but no such substitution is allowed in investment, government usage or change in stocks.

In consumption, substitution between goods from different sources is assumed to occur at the consumption commodity level rather than at the production commodity level. Once income has been allocated between consumption commodities in accordance with an ELES, it is allocated between a domestically produced and an imported variety of each consumption commodity. The domestically produced variety of each consumption commodity is composed in fixed proportions of domestically produced production commodities. The imported consumption commodities are likewise composed in fixed proportions of imported production commodities.

The closures available in WALRAS are generally similar to those available in ORANI with the NAGA extension but without the Horridge long run. That is, a government budget deficit constraint can be imposed, and private consumption will reflect changes in direct tax rates, but no account is taken of capital flows or changes in foreign ownership levels.

Short run closures are not available in WALRAS, since the capital stock is not industry specific, but commands the same rental price in all industries. This is consistent with the long run orientation of the policy questions which the model was designed by the OECD to answer. But although the model is designed for long run simulations, the closures which the model is designed to allow all involve fixed aggregate capital stocks.

Since all factors of production are in fixed supply, income taxation imposes no loss of allocative efficiency in WALRAS.

Having defined a variable representing the purchase price of capital (as noted in the next section), we could readily add a rate of return variable, and run the model with the aggregate capital stock endogenous and the rate of return exogenous. The model would then be liable to the same accusation as was laid against long run ORANI simulations before the development of the Horridge closure, that they assumed that a country could accumulate capital without either foregoing consumption or accumulating debt.

The OECD's approach to model closure differs in some details from that commonly adopted by Commission staff under the guidance of the IMPACT Project. Some nominal variables (aggregate government spending, transfer payments, and the balance of trade or the budget deficit) are commonly set exogenously to zero. With such closures the model is not homogeneous with respect to changes in the nominal exchange rate. It is then possible to impose a balance of trade constraint and allow that constraint to help determine the nominal exchange rate.

Another feature of the OECD closures is that aggregate investment is determined by imposing a condition that NDP calculated from the expenditure side must be equal to NDP calculated from the disposition side.

3. Changes Made by Commission Staff in Implementing the Unlinked Version of WALRAS

The major difference between the original WALRAS model land the IAC's version is that the original model is non-linear, whereas the version implemented by the IAC is linearised.

Several minor changes were made to the model by Commission staff. A variable representing the creation cost of capital was defined. The equation for capital depreciation was theb changed so that depreciation was proportional to the creation cost of capital rather than the user cost. Several scalar variables were added to the model for descriptive purposes or to extend the set of possible closures. Indexing parameters were introduced into some equations, also to extend the variety of assumptions which could be adopted in model solutions (for example, a parameter was introduced allowing government spending to be indexed to private consumption spending). The condition imposing equality between NDP from the expenditure side and NDP from the disposition side was removed from the equation system.

At this stage we had implemented a model designed to allow us to replicate the OECD's results reasonably closely, but which also had slightly more flexibility than required for that purpose alone. This version of the model is documented in Attachment 1.

Before proceeding to implement a linked version, we implemented a further version of the unlinked model. The only differences between this version and the earlier versions were in the consumer demand system.

The first change made to the consumer demand system was to contract the system from ELES to LES, together with a consumption function. This was done because we wished to be able to impose equality between the marginal and the average propensity to consume. This equality seemed consistent with the stylised facts of consumer behaviour over the medium run. We found that to impose this condition on the ELES we had to set the Frisch parameter equal to unity. This we were unwilling to do, since the consumer demand literature also suggested that the Frisch parameter was significantly differently from unity. Setting it at unity would have led to stronger substitution effects between broadly defined consumer commodities in the model than in econometrically estimated demand systems.

The other change to the form of the system was to the level at which substitution occurred between domestically produced and imported varieties of each commodity. In the earlier version of the model, various domestic production commodities were combined to form a domestically produced variety of each consumption commodity, and imported production commodities were combined to form imported version of the consumption commodities. Substitution was then allowed between the domestically produced and the imported variety of each consumption commodity.

We believed that this formulation of import substitution was liable to generate implausible implicit elasticities of consumer demand for imported production commodities. For consider an imported production commodity which represents only a small part of each consumption commodity. The extent to which this commodity is substituted for the corresponding domestically produced production commodity would not depend, to any considerable extent, on its own price relative to the price of corresponding domestically produced production commodity. For changes in its own price would have no considerable effect on the price of the consumption commodities in which it was incorporated. But changes in the relative price of other imported production commodities, which represented a part of the value of imported consumption commodities, could lead to substitution of the first imported production commodity for its domestically produced equivalent, even if their relative prices had remained unchanged.

In short, the earlier formulation could generate plausible import demand elasticities for consumption commodities, but was liable to generate implausible import demand elasticities for production commodities. But since the variables representing world prices, tariffs and consumption taxes are defined over production commodities rather than consumption commodities, it seemed important that the import demand elasticities for production commodities should be plausible.

The simplest remedy would have been to eliminate the consumption commodity classification, and redefine the LES over production commodities. But this would have been a radical change in the model, and one unlikely to be palatable to the original developers of the model. They had been aware of the effects described above, but still preferred not to define the consumer demand system directly in terms of the production commodity classification. They believed that a consumer demand system defined over production commodities would be seriously misspecified.

We therefore adopted a remedy which, though more complicated, preserved the consumption commodity classification. The LES was defined over consumption commodities, exactly as before.But consumption commodities were not then differentiated into domestically produced and imported varieties. Instead each consumption commodity was defined as a composite in fixed proportions of production commodities. Thus the two transition matrices (one for domestically produced varieties and one for imported varieties) of the earlier formulation were replaced by a single matrix.

Demand for each production commodity was then allocated between the domestically produced and the imported variety subject to CES sub-utility functions. A separate sub-utility function was defined for each consumption commodity in which the production commodity was incorporated. Total consumer demand for the imported variety of each production commodity was then calculated by summing over consumption commodities; and likewise for total consumer demand for the domestically produced variety.

The effect of this reformulation was to make the elasticity of demand for imports of each production commodity with respect to its own import price more negative, and to make the elasticities of demand with respect to the import prices of other production commodities less negative.

4. Development of a Linked Version of WALRAS

We have produced an equation system in which the single region models in WALRAS are linked together through trade in a very simple way.

The single region models incorporated in the linked model incorporate the modified formulation of the consumer demand system described in the last section.

The world economy is represented as the union of the regions for which single region models have been developed, and a residual 'rest of the world' region, which has no internal structure, but acts as a source of imports into and a sink of exports from the modelled regions.

For each pair of regions A and B in the model, and for each commodity, the volume of imports into B from A is identified with the volume of exports from A to B. The CIF price of imports into B from A is equal (in common currency units) to the FOB price of exports from A into B, plus a margin for international freight.

The price of international freight services is a weighted average of the price of the commodity 'other private services' in each region. This commodity includes transport services. No category of margins usage of freight services is recognized in the model, so that total demand for 'other private services' is not dependent (as it should be) on the volume of international trade.

Imports of each commodity into each region are differentiated into varieties by source. Within each category of demand in which substitution between domestically produced and imported goods is allowed (the thirteen intermediate usage categories, one for each industry, and the ten consumer demand categories, one for each consumption commodity), substitution is also allowed between varieties imported from different sources. The source differentiated varieties of each imported commodity are combined in a CES sub-production of sub-utility function to form a composite imported variety. As in the unlinked version of the model, the composite imported variety is then combined with the domestically produced variety in another CES function.

For the demand categories in which no substitution between domestically produced and imported goods is allowed (investment, government demand and change in stocks), we have allowed no substitution between goods imported from different sources.

Bilateral rates of exchange have not been defined in the model. Instead we have defined each region's exchange rate relative to some common anonymous exchange rate. Like the unlinked single country models, the linked model cannot determine nominal exchange rates, unless some price or nominal variable in each region is made exogenous. So it is likely that in most applications of the model, nominal exchange rates will be set exogenously. Even if a price or nominal variable in each region is made exogenous, it is not possible to endogenize all nominal exchange rates simultaneously. It is however possible to endogenize all exchange rates but one, say the US exchange rate. All other exchange rates in the model can then be interpreted as rates relative to the US dollar.

FOB prices of exports by the rest of the world to explicitly modelled regions are likely to be exogenous in most applications of the model. FOB price variables for exports from the rest of the world have not been differentiated by the destination of the exports, so export prices from the rest of the world to different regions cannot vary independently.

Imports of each commodity by the rest of the world from each source are determined in a two stage process. In the first stage, imports of a composite imported variety are determined by the price of the composite imported variety relative to the price of the variety produced in the rest of the world (proxied by the price of exports from the rest of the world). In the second stage, imports from each source are determined subject to a CES function.

This linked version of the model is documented in Attachment 2.

As stated above, the additional trade data required to implement the international linking was supplied by the New

Zealand Department of Agriculture and by staff of the Commission. It was also necessary to set some new parameters, namely the elasticities of substitution between commodities imported from different sources. We set these parameters arbitrarily by assuming that in each category of demand the elasticity of substitution between commodities imported from different sources was twice as great as the elasticity of substitution between domestically produced commodities and imports.

5. An Application of the Linked Model

5.1. Introduction

To explore the properties of the linked model we have used it to simulate the effects of opening trans-Tasman shipping routes to ships crewed by sailors from countries other than Australia and New Zealand.

The trans-Tasman trade is said to be reserved for vessels manned by crews from Australia or New Zealand, not by government regulation, but by work bans imposed by maritime industry unions. In the present simulations, we estimate the effects of removing those bans. We use estimates made by the Business Council of Australia of the freight savings which would result from that removal (see Business Council of Australia, 'The Slow Boat to Reform,' Business Council Bulletin, August 1988. These estimates are presented in Table 4. The freight savings are represented in the linked model by shocks to a shift term (added specially for the simulation) in the equation relating CIF to FOB import prices.

We make the extreme assumption that, upon removal of the ban on outside crews, the entire trade will be lost to non-Australasian ship operators. We represent this loss of the trade by contractions in demand for exports of the WALRAS commodity 'other private services' from Australia and New Zealand. We assume that initially Australia and New Zealand supply half each of the market for trans-Tasman freight.

To supply a standard of comparison for the estimates derived using the linked model, we also present estimates derived using the revised version of the unlinked model. This also allows the single country properties of WALRAS to be considered before examining the properties of the international linking.

In the simulations with the unlinked model we represent the freight savings by shocks to export demand shift terms (again, added specially for the simulation) and CIF import prices. The shocks are calculated by averaging the freight savings over the total value of each country's exports and imports of each commodity. This procedure assumes in effect that the export demand and import supply elasticities applied by the model to Australia's and New Zealand's total international trade are applicable also to their trade with each other alone.

In the simulation with the unlinked model the incidence of the freight savings is determined largely by the elasticities of export demand and import supply. Import supply into each country is assumed to be perfectly elastic. If export demand was also assumed to be perfectly elastic, then simulation with the Australian module of the unlinked model of would show the entire freight savings accruing to Australia. Simulation with the New Zealand module would show the entire savings accruing to New Zealand. The unlinked model would in effect double count the freight savings.

In fact the model does not assume that export demand elasticities are infinite. But it does assume infinite elasticities of import supply. These infinite import supply elasticities are, in the present experiment, inconsistent with the finite elasticities of demand by Australia and New Zealand for each other's exports. There is therefore still an element of double counting of freight savings in the simulation conducted with the unlinked model.

When we pass from the unlinked to the linked model results we can see how the linked model divides the freight savings between the two countries.

5.2. Model Closure

Similar closures are used for the two simulations. The only difference is that, in the simulation with the linked model, the prices of imports into Australia from New Zealand, and vice versa, are endogenous.

In both simulations aggregate real fixed investment is fixed in both countries. Inventory investment in each commodity is indexed to total output of the commodity (for domestically produced commodities) or total imports of the commodity (for imported commodities). Real aggregate government spending and real transfer payments by government are fixed (the nominal values are deflated by a price index for government spending and the consumer price index respectively). All tax rates are fixed, and no constraint is applied to the government budget deficit or the balance of trade.

This is not quite our preferred closure. We should have preferred to apply a budget deficit constraint and let the income tax rate vary endogenously. This would have eliminated government as a source of unmotivated change in national saving in the simulations. We were prevented from applying such a closure by undiagnosed errors in the government revenue equations.

6. Directions for Further Work

The immediate task is of course to get the linked model working just as it is meant to. After that the highest priority should probably be to revise the data base. The objects of this revision are to balance the data base (at present NDP from the expenditure side, as calculated from the data base, differs by about 20 per cent from NDP from the disposition side, both in Australia and New Zealand), and to incorporate better estimates of distortionary instruments, especially import duties and other border interventions.

Another obvious step is to incorporate data provided by the OECD for regions other than Australia and New Zealand. They have given us data for Canada, the European Economic Community, and Japan, but not as yet for the United States of America.

A useful change to the equation system would be to extend the variable list in the model, in order to increase the variety of shocks which can be applied to the model. Obvious variables to add are export demand shift terms (distinct from import prices), technology variables and taste variables.

The treatment of demand for imports into the rest of the world could be modified so that the model would in effect perform some Cronin-type calculation of elasticities.

An extension incorporating capital flows and international asset ownership, along the lines of the Horidge closure, would allow capital stocks to be endogenised.

TABLE 1 : REGIONS REPRESENTED IN THE OECD VERSION OF WALRAS

Australia[a]
Canada
European Economic Community
Japan
United States of America
New Zealand[a]

a These regions are represented in the IAC version of WALRAS.

TABLE 2 : PRODUCTION COMMODITIES IN WALRAS

Livestock and livestock products
Other agricultural products
Other primary products
Meat products
Dairy products
Other food products
Beverages
Chemicals
Petroleum and coal products
Other manufactures
Construction
Wholesale and retail trade
Other private services

TABLE 3 : CONSUMPTION COMMODITIES IN WALRAS

Food and non-alcoholic beverages
Alcoholic beverages
Tobacco
Clothing and footwear
Gross rents, fuel and power
Household equipment and operation
Medical care
Transport and communication
Education and recreation
Miscellaneous goods and services

TABLE 4 : ESTIMATES OF FREIGHT SAVINGS IN TRANS-TASMAN TRADE RESULTING FROM OPENING THE TRADE TO NON-AUSTRALASIAN SHIP OPERATORS

	Freight savings as a percentage of initial freight cost[a]	Initial freight cost as a percentage of FOB value[b]	Freight savings as a percentage of FOB value
Livestock and livestock products	20	30	6
Other agricultural products	20	30	6
Other primary products	50	50	25
Meat products	20	15	3
Dairy products	20	15	3
Other food products	20	15	3
Beverages	20	15	3
Chemicals	20	20	4
Petroleum and coal products	~~20~~ 50	70	~~14~~ 35
Other manufacturing industries	~~50~~ 20	10	~~5~~ 2
Other private services	20	5	1

SOURCES: a Business Council of Australia, 'The Slow Road to Reform', Business Council Bulletin, August 1988.

b Australia, Bureau of Transport Economics, and New Zealand, Ministry of Finance, Review of Trans Tasman Shipping, AGPS, Canberra, 1987.

TABLE 5 : ESTIMATED MACROECONOMIC EFFECTS OF OPENING TRANS-TASMAN TRADE TO NON-AUSTRALASIAN SHIP OPERATORS

	Australia		New Zealand	
Variable	Unlinked	Linked	Unlinked	Linked
Real consumption	0.49	-0.04	0.75	0.28
Real exports	0.48	0.81	0.51	-0.69
Real imports	2.28	-0.15	1.62	0.38
Consumer price index	1.97	-0.40	1.07	-0.64
Export price index	-1.69	-0.36	-2.37	-0.44
Import price index	-0.06	-0.08	-1.34	-1.14
Primary factor price index	2.41	-0.43	1.89	-0.33
Balance of trade[a]	-0.53	0.11	-0.63	-0.05

a Change in ratio of balance of trade to NDP, times 100.

TABLE 6 : ESTIMATED EFFECTS ON OUTPUT OF OPENING TRANS-TASMAN TRADE TO NON-AUSTRALASIAN SHIP OPERATORS
(Percentage changes)

	Australia		New Zealand	
Commodity	Unlinked	Linked	Unlinked	Linked
Livestock and livestock products	-5.55	-0.22	-3.41	0.64
Other agricultural products	-2.96	0.34	-4.90	1.60
Other primary products	-0.98	0.39	-0.83	-0.04
Meat products	-2.47	0.33	-3.27	0.73
Dairy products	-1.37	0.14	-3.36	0.80
Other food products	-2.04	0.22	-1.40	1.01
Beverages	-0.70	-0.04	1.35	-0.64
Chemicals	-2.53	0.78	-2.31	0.85
Petroleum and coal products	-2.10	2.54	-1.37	-0.93
Other manufacturing industries	-1.75	0.32	-1.74	0.79
Construction	0.07	-0.01	-0.23	-0.01
Wholesale and retail trade	-0.21	0.01	-0.40	0.33
Other private services	1.41	-0.21	3.10	-0.99

FIGURE 1: DEMAND SYSTEM FOR DIRECT INPUTS INTO PRODUCTION IN THE OECD VERSION OF WALRAS

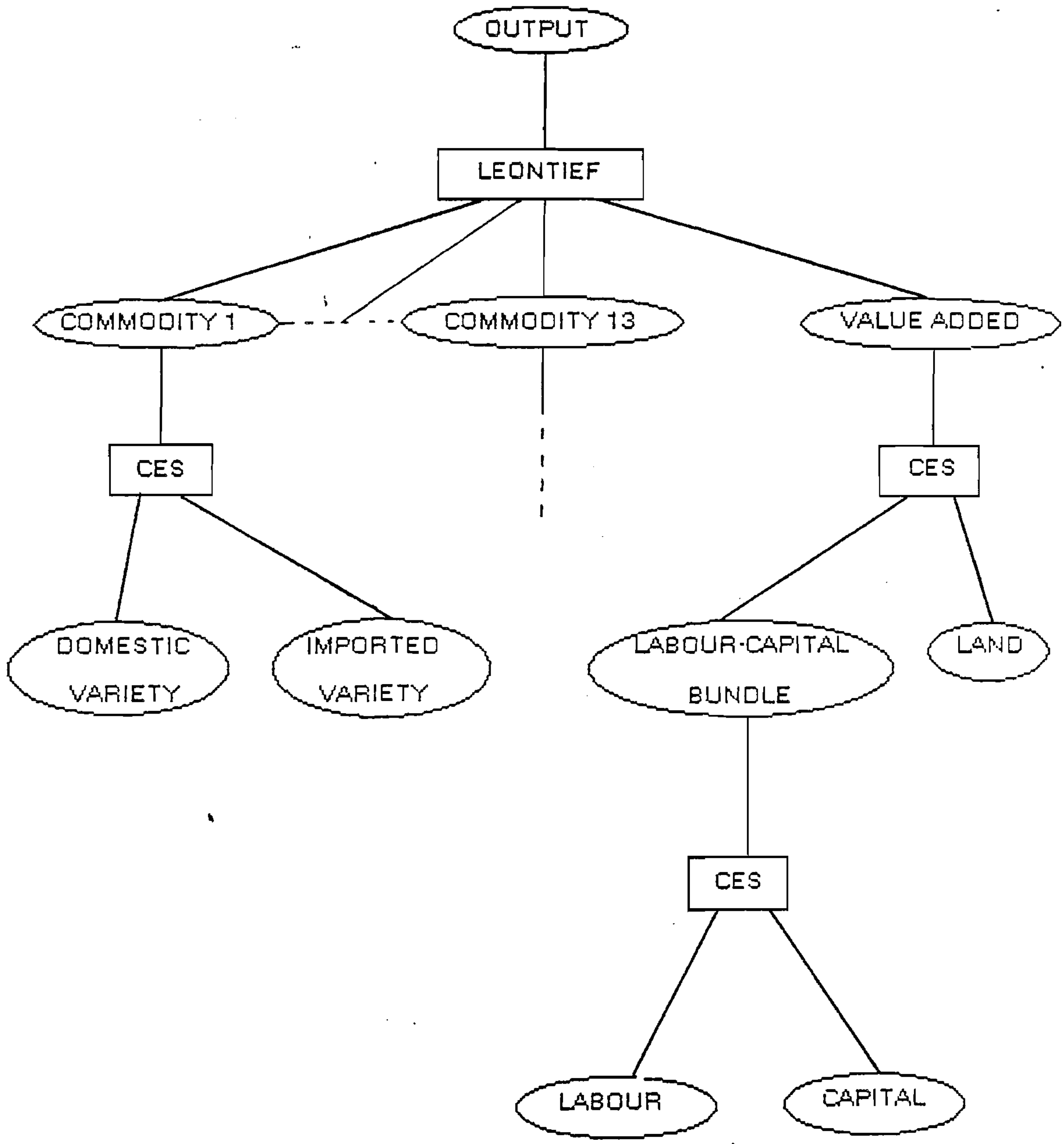


FIGURE 2: THE EXTENDED DEMAND SYSTEM IN THE OECD VERSION OF WALRAS

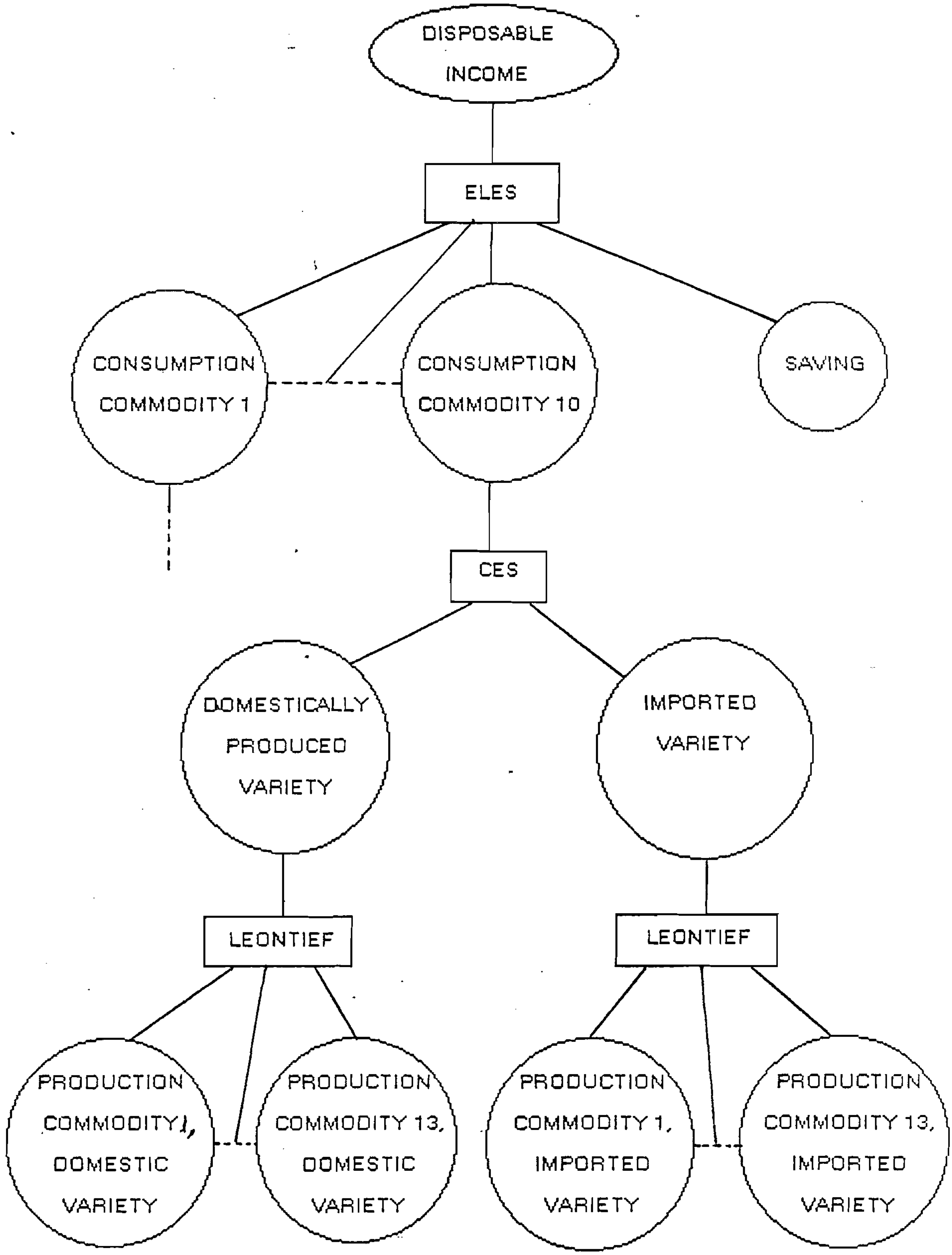
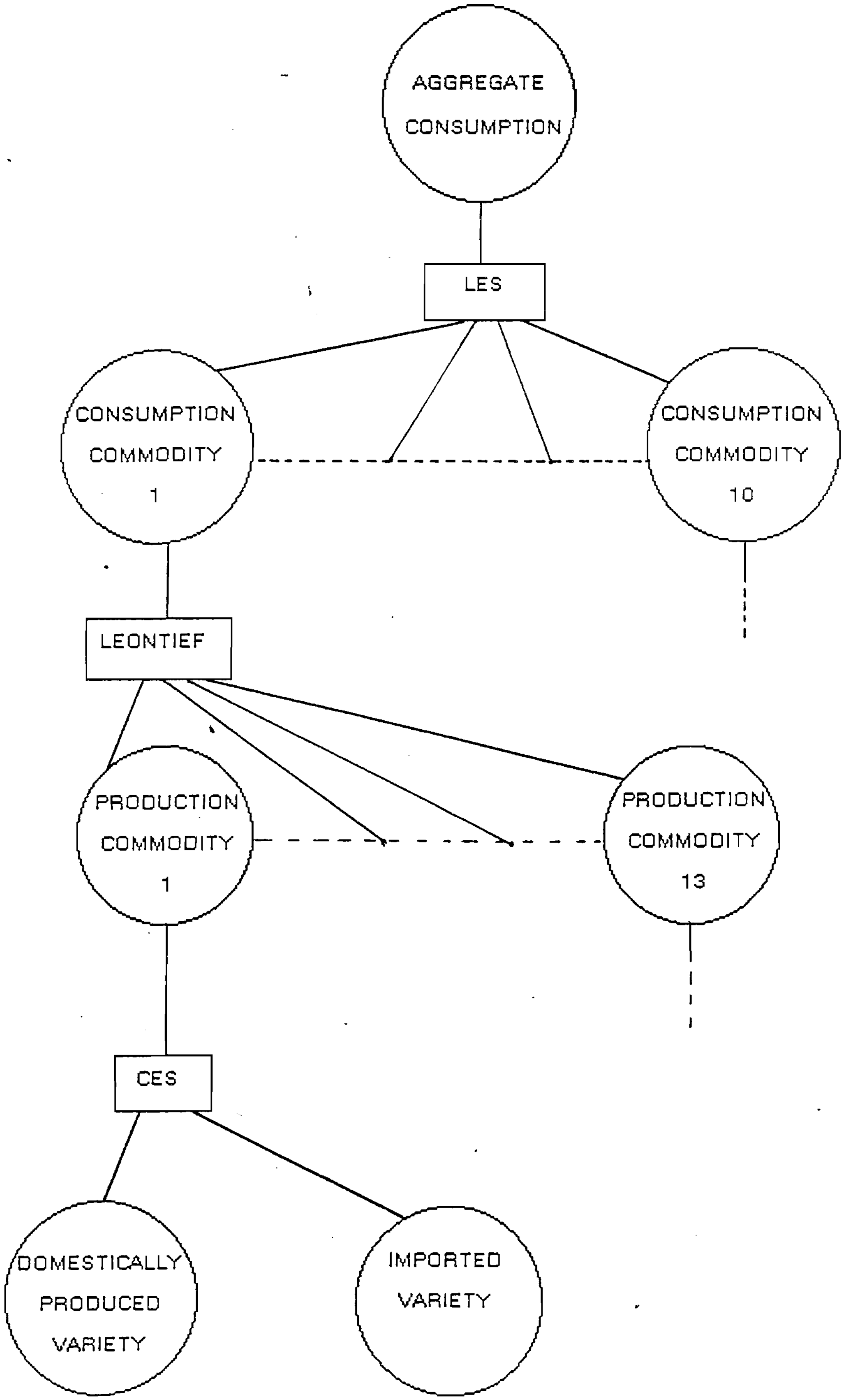


FIGURE 3: THE CONSUMER DEMAND SYSTEM IN THE IAC VERSION OF WALRAS



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No.

1 McDougall, R. *Linking CGE Country Models: An Example Using the OECD's WALRAS Model*

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3 McDougall, R. and Sugden, C. *Implementation of the WALRAS Model of the Australian Economy*

4 Zeitsch, J., McDougall, R., Jomini, P., Welsh, A., Hambley, J., Brown, S. and Kelly, J. *SALTER: A General Equilibrium of the World Economy*

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[a] SALTER working papers document work in progress on the development of the SALTER model of the world economy. They are made available to allow scrutiny of the work undertaken but should not be quoted without the permission of the author(s).