Impact Project

Impact Research Centre, The University of Melbourne,
153 Barry Street, Carlton, Victoria 3053 Australia.

Telephone: (03) 344 7417 (*from overseas:* 61 3 344 7417)
Telex: AA 35185 UNIMEL Telegrams: UNIMELB, Parkville
Facsimile: (03) 344 5104 (*from overseas:* 61 3 344 5104)

MODELLING THE EFFECTS ON AUSTRALIA OF INTERVENTIONS IN WORLD AGRICULTURAL TRADE

by

MARK HORRIDGE
Industries Assistance Commission and
IMPACT Project Research Centre,
University of Melbourne

and

DAVID PEARCE
Industries Assistance Commission

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ABSTRACT

In this paper, we describe a general equilibrium model of the world economy, designed to simulate the effect of a liberalization of world food trade. Our model owes much to the Tyers (1985) partial equilibrium model which covered trade between 30 countries in 7 agricultural commodities. It also displays several important differences. First, ours is a general equilibrium model. We argue that the general equilibrium approach makes key assumptions explicit, and can be used to restrict uncertain parameter values. Second, we have adopted a comparative static framework, and have expressed our equations in percentage change form. Third, we have revised and updated most of the data used by Tyers. Last, our methodology allows us to include the ORANI model of the Australian economy as an integral part of the world model. This allows a detailed picture of the effects of world food trade liberalization on Australia. At the same time the ORANI results are completely consistent with those yielded by the world model.

MODELLING THE EFFECTS ON AUSTRALIA OF

INTERVENTIONS IN WORLD AGRICULTURAL TRADE[1]

by

Mark Horridge and David Pearce

1 INTRODUCTION

Since the inception of the General Agreement on Tariffs and Trade (GATT), restrictions on international trade in manufactured products have been steadily reduced. Agriculture, on the other hand, has not hitherto been so closely controlled by the GATT. It is still heavily protected in many regions -- particularly in the EEC and in Japan. As a result, other agricultural producers, including Australia, have faced low prices and weak demand for their exports. This has motivated the Cairns Group of nations and the USA to propose a liberalization of world agricultural trade. Even within the EEC, the growing fiscal burden of farm subsidies has aroused concern. Thus, agricultural trade has assumed particular importance in the current Uruguay round of GATT negotiations.

A number of studies have sought to quantify the effects of freer agricultural trade. Two examples from Australia are Tyers (1984,1985), and Breckling, Thorpe, and Stoeckel (1988). The methodologies employed are different. The Tyers model is partial-equilibrium, fully non-linear, and dynamic. It lends itself to investigating whether farm price support schemes actually stabilize farm prices. Breckling et al. present a comparative-static, general-equilibrium model which distinguishes intermediate demands and factor markets within each region. Although formulated as a non-linear system, it is solved via a linear approximation.

The model described in this paper has features in common with both of these. Like some versions of the Tyers model, it divides the world into 30 regions and recognizes 7 types of agricultural good. Like the Breckling et al. model it belongs to the growing class of comparative-static, general-equilibrium models which are solved in percentage change form.

Formally, our model resembles that of Trela, Whalley, and Wigle (1987). Like them, we do not model the technology of individual industries, or explicitly distinguish primary factor and intermediate inputs into production. However, we recognize that production technology and factor supply constraints impose limitations on potential output. Thus, for each region a production possibility frontier describes possible output mixes. The chosen mix maximizes the value of output at producer prices. Similarly, consumers, facing given prices, maximize utility subject to a budget constraint. However the Trela et al. model is smaller than ours -- it recognizes only 2 commodities and 9 regions.

A unique feature of our model is that one region -- Australia -- is treated in far greater detail than any other region. This is achieved by incorporating the ORANI model of the Australian economy (see Dixon et al., 1982) as an integral part of the world model. Hence, we focus on the Australian implications of overseas policy changes.

In the remainder of this paper we describe our model and its database. Results from the model are described in Horridge, Pearce and Walker (1988) and in Pearce (1988a).

2 A WORLD FOOD TRADE MODEL

Our model has its roots in efforts by Tillack (1987) and Lekawski _et_ _al_.(1987), all staff members of the Industries Assistance Commission (IAC), to develop an in-house version of the Tyers (1984,1985) dynamic, partial equilibrium model of world food trade, which distinguishes production and consumption of 7 food goods in 30 regions. The primary purpose of the IAC adaptation was to determine the effects on world prices of overseas liberalization of agricultural trade (see IAC,1988). These price changes could then form an exogenous input into the ORANI model of the Australian economy. Three principal changes were made to the Tyers model. First, the equations were linearized in percentage change form. Second, the own- and cross price elasticities which governed consumer demands in the Tyers model were replaced with elasticities derived from a CRESH demand system. Third, dynamic features of the Tyers model were replaced by a comparative static approach. For example, in the Tyers model domestic prices respond only gradually to changes in world prices. In the IAC version, the ratios of domestic to foreign prices were treated as exogenous policy instruments. Hence foreign price changes were fully transmitted into domestic price changes. Again, the Tyers model allowed inventories to smooth fluctuations in demand. The IAC model exogenized the rate of inventory accumulation.

The resulting partial equilibrium model contained 4 main blocks of equations:

(i) Equations relating consumer (or producer prices) of each food good in each region to the world price of that good and to consumer tax (or producer subsidy) levels in that region.

(ii) Equations relating consumption of each food good in each region to the consumer prices of foods in that region.

(iii) Equations relating production of each food good in each region to the producer prices of foods in that region.

(iv) Market clearing equations which ensured that world production and world usage of each good were equal.

Much of the data needed for the IAC model was contained in the database assembled by Tyers for his original model, covering the period 1980 to 1982. This included matrices (for each region) of own- and cross-price elasticities of demand and supply for each food good. Some of the database, such as the price distortions arising from agricultural policies and the consumption and production shares of each good in each region, was updated by the IAC. Broadly, 1986 data was used whenever possible -- see Skene (1988).

The model presented in this paper is a response to several perceived disadvantages of this initial IAC approach:

(a) Using the partial equilibrium approach, we cannot explicitly model movements of resources between agriculture as a whole and the rest of each region's economy. In general, the effect of current government interventions is to subsidize production of foods while taxing food consumption. Therefore, we should expect food trade liberalization to cause declines in food production in those regions where agriculture was initially most heavily subsidized. Production of other goods should increase. Also, the world price of foods should rise relative to the price of other goods. Thus production of foods in other regions (where agriculture was initially only lightly protected) should rise, and other production should decrease. Similarly, we should expect food consumption to increase in those regions where agriculture was initially most heavily taxed. Elsewhere, rising food prices should cause a move towards consumption of other goods. The global benefits of trade liberalization are strongly related to these consumption and production shifts.

(b) The partial equilibrium approach cannot allow for the effects of changes in regional income on each region's consumption levels. Nor does it lend itself to calculating the effects of trade policy changes on regional welfare.

(c) Although the model relied heavily on estimates of supply elasticities that were borrowed from Tyers, few constraints seem to have been imposed in estimating these elasticities. It was unclear how far the supply elasticities for each region were consistent either with each other or with plausible behaviour by those industries not covered by the model. On the other hand, the assumption of CRESH utility functions seemed to impose too many constraints on consumer behaviour. CRESH parameters were derived from the own-price demand elasticities supplied by Tyers: the cross-price elasticities that he estimated were not used.

(d) The difficulty of using two independent models -- first, a world model to determine the effect of liberalization on world prices, and, second, ORANI to determine the effect of these price changes on Australia -- is that each model independently calculates the effects of liberalization on Australia's exports and imports. The two results may be inconsistent: a problem of 'double endogeneity'.

We felt that a general equilibrium approach could overcome the first two of these problems. The third problem could be solved by imposing optimising behaviour on both producers and consumers -- which would itself be facilitated by the introduction of a general equilibrium approach. The fourth problem could be solved by incorporating ORANI within the world model, rather than using two independent models. On the other hand, we wished to retain an important advantage of linearised, comparative static models: their relative simplicity. Results from non-linear, multiperiod models, by contrast, are often difficult to explain. Such models can easily appear as 'black boxes'.

We describe below a model, which, whilst superficially similar to a linearized version of the Tyers model, is theoretically closer to some textbook models of international trade. Among the particular features of our model are:

(1) It distinguishes an 8th 'other' good, as well as the 7 foods, thus allowing for general equilibrium effects.

(2) A balance of trade constraint determines aggregate consumption in each region.

(3) Whilst in the Tyers model, production and consumption behaviour were described by unrestricted estimates of demand and supply elasticities, we impose the requirement that these own- and cross-price elasticities be consistent with underlying utility- and profit-maximising behaviour.

(4) ORANI is the sole determinant of Australian behaviour. Hence no 'double endogeneity' problem arises.

In more detail, the model equates demand and supply for 8 goods in 30 regions. These are listed in Table 2.1. No distinction is made within a commodity group for varietal differences so that each good produced and consumed is homogeneous world-wide. Hence each region interacts with the rest of the world only through its <u>net</u> import demands for each good. World prices adjust so that the worldwide sum of these net demands is zero for each good.

For each region, net imports of each good are given by the difference between local production of that good and local usage. For region 1, Australia, net imports are determined in this way by the ORANI model. For the remaining, 'foreign', regions, production and usage of each good are determined as follows.

We do not model individual industry technologies, nor do we explicitly distinguish primary or intermediate inputs into production. Instead we imagine that each foreign region has its own production

TABLE 2.1: GOODS AND REGIONS DISTINGUISHED BY THE MODEL

GOODS:

1	Rice	5	Dairy
2	Wheat	6	Ruminant Meat
3	Coarse Grains	7	Non-ruminant Meat
4	Sugar	8	Other Goods

REGIONS:

1	Australia	16	Bangladesh
2	New Zealand	17	India
3	Canada	18	Pakistan
4	USA	19	Argentina
5	EEC	20	Brazil
6	Spain and Portugal	21	Mexico
7	EFTA	22	Cuba
8	USSR	23	Egypt
9	Japan	24	Nigeria
10	Korea	25	Sub-Saharan Africa
11	Taiwan	26	South Africa
12	China	27	Other East Europe
13	Indonesia	28	Other Asia
14	Philippines	29	Other Latin America
15	Thailand	30	Other North Africa & Middle East

possibility frontier which corresponds to the various output combinations which that region could produce. The factor endowments and technology of the region lie behind the shape and position of the production possibility frontier. We assume that each region chooses its output to maximise the value -- at producer prices -- of its output. Our approach is not inconsistent with that adopted by many more detailed economic models, which do explicitly recognize individual industries and their input requirements. Indeed, where competitive assumptions are made (in particular the assumption that all producers face the same input prices), the more detailed models also imply that production as a whole is organized so as to maximise the value of output. Hence, more complex models can very often be reduced to the simpler form that we have adopted. The overall shape of the national production possibility frontier is implied indirectly by the modelling of industry technologies and factor supplies. The advantage of the more complex models is that they provide a clearer picture of the mechanisms behind changes in output patterns -- such as changes in factor prices. The disadvantage of these models is that they require a large amount of data -- or alternatively rely on more or less arbitrary assumptions. For example, assumptions regarding the mobility of factors between industries have an indirect but critical effect on the ease with which the economy as a whole can substitute between alternative outputs. Our simpler approach takes empirical estimates of the reduced form, economy-wide supply elasticities as its starting point. This is only possible, of course, because Tyers has collected a set of these elasticities.

Usage of each good in each foreign region is divided into three parts: human consumption, animal consumption, and autonomous usage. To model human consumption we postulate a single, utility-maximising, consumer who is subject to a budget constraint. Animal consumption is limited to 2 goods -- Wheat and Coarse Grains -- and represents an intermediate input into the three livestock industries (5, 6 and 7). Aggregate feedstock demand is dependent upon aggregate livestock production. The demands for specific types of feedstock are dependent on their relative prices. Autonomous usage of each good is held exogenous. For the agricultural products, this category corresponds chiefly to changes in the rate of increase of stockpiles. For the eighth, non-agricultural, good it also includes non-export final demands such as investment and government usage.

Each region faces a balance of trade constraint. Human consumption in that region expands or contracts to allow this constraint to be met.

Border prices may differ from world prices by given transport costs. Domestic producer and consumer prices may differ from border prices by the extent of any subsidies or taxes on production or consumption. Since all behavioural equations are homogeneous in price (money-neutral), changes in a region's nominal exchange rate would (if allowed) affect only the nominal price level in that region, whilst leaving all real magnitudes unchanged. Instead, we have assumed without substantive loss of generality that all regional nominal exchange rates are fixed. Exchange rates do not figure in our description of the model; we implicitly assume that all prices are specified in the same currency, say, $US. Real exchange rates, on the other hand, are endogenously determined through the effect on each region's balance of trade of changes in world prices.

2.1 Equations of the Model

Table 2.2 lists the equation system of the model. Most variables are in percentage change form, denoted by lower case letters.

TABLE 2.2: EQUATIONS OF THE MODEL

	Equation	Subscript Range[1]	Number	Description
(1)	$q_{ij} = \bar{z}_j + \bar{f}_{ij} + \sum_{k=1}^{g} \eta_{ikj} p^P_{kj}$	i=1,..,g j=2,..,c	g(c-1)	Production of good i by region j
(2)	$c_{ij} = \epsilon_{ij} c_j - \sum_{k=1}^{g} \tau_{ikj} p^C_{kj}$	i=1,..,g j=2,..,c	g(c-1)	Human consumption of good i by region j
(3)	$(af)_j = \sum_{k=5}^{7} S^Q_{kj} q_{kj}$	j=2,..,c	c-1	Aggregate feedstock demand in region j
(4)	$(fs)_{ij} = (af)_j + \sigma^f (p^P_{ij} - \sum_{k=2}^{3} S^P_{kj} p^P_{kj})$	i=2,3 j= 2,..,c	2(c-1)	Individual feedstock demands in region j
(5)	$(cg)_{ij} = (1-S^F_{ij}) c_{ij} + S^F_{ij} (fs)_{ij}$	i=2,3 j= 2,..,c	2(c-1)	Human plus feedstock demands for grains
(6)	$p^b_{ij} = p_j + \bar{h}_{ij}$	i=1,..,g j=1,..,c	gc	Border price of good i, region j
(7)	$p^P_{ij} = p^b_{ij} + \bar{t}^P_{ij}$	i=1,..,g j=2,..,c	g(c-1)	Producer price of good i, region j

[1] In this column, g is the number of goods (8) and c is the number of regions (30) distinguished in the model. Region 1, Australia, is excluded from most of the equations, as Australian behaviour is determined by the ORANI model. A bar marks normally exogenous variables.

... continued

TABLE 2.2 (continued) **EQUATIONS OF THE MODEL**

Equation		Subscript Range	Number	Description
(8)	$p^c_{ij} = p^b_{ij} + \bar{t}^c_{ij}$	i=1,..,g j=2,..,c	g(c-1)	Consumer price of good i, region j
(9)	$100\Delta M_{ij} = c_{ij}C_{ij}P^b_{ij} - q_{ij}Q_{ij}P^b_{ij} + 100\Delta\bar{S}_{ij}$	i=1,4,..,g j=2,..,c	(g-2)(c-1)	Net imports of nonfeedstocks
(10)	$100\Delta M_{ij} = (cg)_{ij}(CG)_{ij}P^b_{ij} - q_{ij}Q_{ij}P^b_{ij} + 100\Delta\bar{S}_{ij}$	i=2,3 j=2,..,c	2(c-1)	Net imports of feedstocks
(11)	$\sum_{j=1}^{c} \Delta M_{ij}/H_{ij} = 0$	i=1,..,g	g	World market clears for good i
(12)	$\sum_{i=1}^{g}(100\Delta M_{ij} + M_{ij}P^b_{ij}p^b_{ij}) = 100\Delta B_j$	j=2,..,c	c-1	Balance of trade deficit in border prices
(13)	$100\Delta B_j = \lambda Y_j$	j=2,..,c	c-1	Balance of trade constraint
(14)	$\Delta M_{i1} = \bar{a}_i + \sum_{k=1}^{g} \beta_{ik}p^b_{i1}$	i=1,..,g	g	Net imports by Australia
	Total Number of Equations =		6gc + 7c - 3g - 7	

Ordinary changes (Δ notation) are used when variables may have an initial value of zero or may change sign. All variables are listed either in Table 2.3 or in Table 2.4. Coefficients are given in upper case, or in Greek letters. They are listed in Table 2.5

Subscripts i and k run over the g goods; the first (g-1) are foods and the gth comprises all nonfoods. The j subscripts run over the c regions. Most of the equations deal only with the 'foreign' regions (j=2,..,c).

Although they are included in our model, the equations and variables of ORANI are not fully listed in Table 2.2 to 2.5. From the point of view of the rest of the world, Australia's behaviour is sufficiently described by equation (14), which relates Australia's net imports to the prices paid for them, and to changes in Australian industry policy. The linkage between ORANI and our modelling of the foreign regions is described in Subsection 2.2.

Equation 1: Production Supplies

In each foreign region (2,..,c), production of each good is proportional to both the total productive capacity of the region, z_j, and also to a commodity-specific technical change variable, f_{ij}. However, in most applications both of these variables are exogenous and set to zero. Supplies are usually affected only by relative changes in the producers' prices, p^p_{kj}, via the matrix of own- and cross-price supply elasticities, η_{ikj}. These supply elasticities are consistent with neoclassical optimizing behaviour. Their derivation is described in Section 2.3 below.

TABLE 2.3: TYPICAL LIST OF EXOGENOUS VARIABLES

Variable[1]	Subscript Range	Number	Description
t^p_{ij}	i=1,..,g j=2,..,c	g(c-1)	Power of subsidy on production of good i in region j
t^c_{ij}	i=1,..,g j=2,..,c	g(c-1)	Power of tax on consumption of good i in region j
a	i=1,..,g	g	Autonomous change in Australian imports of good i measured at border prices
z_j	j=2,..,c	c-1	Productive capacity, region j
f_{ij}	i=1,..,g j=2,..,c	g(c-1)	Technical change in production of good i in region j
h_{ij}	i=1,..,g j=1,..,c	gc	Power of cost of transport of good i to region j
ΔS_{ij}	i=1,..,g j=2,..,c	g(c-1)	Ordinary change in autonomous usage of good i in region j, measured at original producer prices
p_i	i=g	1	Numeraire - price of nonfood good
Total Exogenous Variables	=	5gc + c - 3g	

[1] All exogenous variables except ΔS_{ij} are percentage changes.

TABLE 2.4: TYPICAL LIST OF ENDOGENOUS VARIABLES

Variable[1]	Subscript Range	Number	Description
q_{ij}	$i=1,..,g$ $j=2,..,c$	$g(c-1)$	Production of good i in region j
c_{ij}	$i=1,..,g$ $j=2,..,c$	$g(c-1)$	Human consumption of good i in region j
$(cg)_{ij}$	$i=2,3$ $j=2,..,c$	$2(c-1)$	Total consumption of wheat and coarse grains in region j
p^b_{ij}	$i=1,..,g$ $j=1,..,c$	gc	Border price of good i, region j
p^p_{ij}	$i=1,..,g$ $j=2,..,c$	$g(c-1)$	Producer price of good i, region j
p^c_{ij}	$i=1,..,g$ $j=2,..,c$	$g(c-1)$	Consumer price of good i, region j
ΔM_{ij}	$i=1,..,g$ $j=1,..,c$	gc	Change in net imports of good i, region j
p_i	$i=1,..,g-1$	$g-1$	World prices of food goods
$(af)_j$	$j=2,..,c$	$c-1$	Aggregate feedstock demand, region j
$(fs)_{ij}$	$i=2,3$ $j=2,..,c$	$2(c-1)$	Feedstock demands for wheat and coarse grains in region j
c_j	$j=2,..,c$	$c-1$	Aggregate real consumption in region j
ΔB_j	$j=2,..,c$	$c-1$	Trade deficits
λ		1	Trade deficit/Output
Total Endogenous Variables	=	$6gc + 7c - 3g - 7$	

[1] All endogenous variables except ΔM_{ij} and ΔB_j are percentage changes.

TABLE 2.5: LIST OF COEFFICIENTS USED IN EQUATIONS

Coefficient	Subscript Range	Description
η_{ikj}	i,k=1,..,g j=2,..,c	Own- and cross-price supply elasticities
τ_{ikj}	i,k=1,..,g j=2,..,c	Own- and cross-price demand elasticities
ϵ_{ij}	i=1,..,g j=2,..,c	Expenditure elasticities
S^Q_{kj}	k=5,6,7 j=2,..,c	Share of livestock type k in total value of livestock produced in region j, evaluated at producers prices
σ^f		Worldwide elasticity of substitution between wheat and coarse grain used for feedstock
S^P_{ij}	i=2,3 j=2,..,c	Share of feedstock type i in total value of all feedstocks used in region j, evaluated at producers prices
S^F_{ij}	i=2,3 j=2,..,c	Share of grain type i used for feedstock in total volume of all grain type i consumed in region j
$C_{ij}P^b_{ij}$	i=1,..,g j=1,..,c	Human consumption of good i in region j, valued at border prices
$Q_{ij}P^b_{ij}$	i=1,..,g j=2,..,c	Production of good i in region j, valued at border prices
$(CG)_{ij}P^b_{ij}$	i=1,..,g j=2,..,c	Human plus animal consumption of good i valued at border prices
H_{ij}	i=1,..,g j=1,..,c	Ratio of border price to world price, good i, region j
$M_{ij}P^b_{ij}$	i=1,..,g j=2,..,c	Net imports of good i into region j, valued at border prices
Y_j	j=2,..,c	Total value of production, region j, valued at border prices
β_{ik}	i,k=1,..,g	Derived from ORANI model - shows effect on Australian imports of good i of a 1% increase in the border price of good k.

Equation 2: Human Consumption Demands

In each foreign region (2,..,c), human consumption of each good is related to total real consumption, c_j, via the expenditure elasticities, ϵ_{ij}. Demands are also affected by relative changes in the consumers' prices, p^c_{ij}, via the own- and cross-price demand elasticities, τ_{ikj}. Values for both expenditure and price elasticities are consistent with neoclassical optimizing behaviour. Their derivation is described in Section 2.3 below. Note our sign convention for the τ_{ikj}.[2]

Equations 3 and 4: Animal Feedstock Demands

Demands for the overall level of feedstock demand in each foreign region are given by equation (3). It states that the need for animal food in general is proportional to the aggregate output of the livestock industries goods 5, 6 and 7 (Dairy, Ruminant Meat and Non-Ruminant Meat). Equation (4) apportions this overall demand between goods 2 and 3 (Wheat and Coarse Grains), according to their relative prices. The parameter σ^f, which is the same for all regions, is the elasticity of substitution between the two grain types. We assigned it the value of 0.5.

Equation 5: Total Consumption Demands

Changes in total consumption demand are simply the sum of changes in human and animal feedstock demands.

Equation 6: International Price Transmission

Changes in world prices, p_i, are related to changes in border prices, p^b_{ij}, via changes in transport costs, h_{ij}. Normally, the h_{ij} are exogenously held at zero change. The levels form of (6) is:

$$P^b_{ij} = H_{ij} P_i$$

i.e., the H_{ij} are the ratios of border prices to world prices. By holding them constant, we imply that transport costs form a constant fraction of cargo value. Note that the prices of imports to region j are independent of their source. Our treatment of transport costs is consistent with the fiction that, for each good, there is a single depot through which all world trade passes. Exports are shipped first to the depot, and then to their final destination. 'World' prices are the prices paid at the depot. To set the initial value of the H_{ij}, we located the depot for each good in the region which exported most of that good. That is, the world price is the price charged by the principal exporter of each good. Finally, note that 'shipping' is not included in any of the 8 commodities modelled. Hence, the revenue from transport does not explicitly accrue to any region. We meet this difficulty in our formulation of regional balance of trade constraints - see equation (13) below.

<u>Equations 7 and 8: Domestic Price Transmission</u>

Equation (7) relates changes in local producer prices, p^p_{ij}, to changes in border prices, p^b_{ij}, <u>via</u> changes in the producer policy variable, t^p_{ij}. The levels form of (7) is:

$$P^p_{ij} = T^p_{ij} P^b_{ij}$$

i.e., the T^p_{ij} are the ratios of producer prices to border prices. Their value depends on a wide range of government measures, including direct subsidies, tariffs, quotas and price stabilization schemes.

Equation (8) relates changes in local consumer prices, p^c_{ij}, to changes in border prices, p^b_{ij}, <u>via</u> changes in the consumer policy variable, t^c_{ij}. The levels form is:

$$P^c_{ij} = T^c_{ij} P^b_{ij}$$

i.e., the T^c_{ij} are the ratios of consumer prices to border prices. Again, their value reflects a range of government measures.

Equations 9 and 10: Net Imports

Changes in net imports are found by subtracting absolute changes in production from the changes in consumption and autonomous usage. Absolute changes in consumption and production are found by multiplying the percentage changes by the corresponding levels amounts. For the feedstock goods 2 and 3, 'consumption' includes consumption by animals. Changes in net import quantities, ΔM_{ij}, are expressed as changes in the value of these imports at the original border price level. Hence the weights $C_{ij}P^b_{ij}$ and $Q_{ij}P^b_{ij}$ show the values of these flows at the original border prices.

Equation 11: International Market Clearing

Net import volumes of each good must sum to zero on a global basis. The denominator H_{ij} converts the ΔM_{ij}, which are quantities measured as values at original border prices, to quantities measured as values at original world prices. Hence it is valid to sum over regions. Note that the j subscript includes Australia (region 1).

Equation 12: Balance of Trade Deficits

For each foreign region, the change in the balance of trade, ΔB_j, is defined as the change in the total value of net imports, valued at border prices. The first term of the summation on the left hand side shows (100 times) the change in volume of imports at the original border prices; the second term shows (100 times) the effect of the change in border prices on the value of the original import volume. (Remember that ΔM_{ij} is measured in commodity- and region-specific physical units each worth one dollar at original border prices.)

Equation 13: National Budget Constraints

It might seem that a natural choice of national budget constraint would be to set each region's balance of trade deficit, B_j, to zero change: $\Delta B_j = 0$. However, such a setting would be impractical for two reasons. First, our accounting identities imply that if all but one of the ΔB_j are determined, the remaining ΔB_j is also determined. Hence we can only set (c-1) of the ΔB_j -- the last one will be determined by the system.

The second problem is that even if we set (c-1) of the ΔB_j to zero, the remaining ΔB_j will not, in general, have a zero value. Our treatment of transport costs implies that $\Sigma B_j \neq 0$, for the B_j are evaluated at border prices rather than at world prices. The sum is instead equal to world expenditure on shipping. The sum of changes following a shock, $\Sigma\Delta B_j$, is equal to the change in world expenditure on shipping. If the effect of the shock is to expand trade, so that more shipping is used, $\Sigma\Delta B_j$ will exceed zero. On average, that is, the regions will move towards deficit, evaluated at border prices. Only by coincidence would $\Sigma\Delta B_j = 0$. In general, if we set (c-1) of the ΔB_j to zero, the remaining ΔB_j would be equal to the change in world expenditure on shipping. Thus model results would not be independent of the choice of which one of the ΔB_j was to be endogenously determined.

This difficulty arises because our model's data base and equations provide no way of distributing the revenue earned by shipping between the regions. We adopt a makeshift formula to distribute (changes in) shipping revenue between the regions in a neutral manner -- according to the size of their economies. We assume that following a shock, each foreign region's trade balance, measured as a percentage of its original total production, Y_j, will change by the same amount, λ:

$$100\Delta B_j = \lambda Y_j \qquad\qquad j = 2,..,c$$

Note that ΔB_1, the Australian balance of trade, is determined by equation (14) below. National output, Y_j, is defined as the total value of production at border prices. Thus:

$$Y_j = \sum_{i=1}^{g} Q_{ij} P^b_{ij}.$$

leading to equation (13).

Equation 14: Net Imports by Australia

Equation (14) relates Australia's net imports to the prices paid for them (via the matrix of coefficients β_{ik}) and to changes in Australian industry policy represented by the exogenous variables, a_i. Values for the β_{ik} and the a_i are derived from the ORANI model, as described below in subsection 2.2.

Model Closure

A probable choice of exogenous variables is shown in Table 2.3. The policy variables t^p_{ij}, t^c_{ij} and a_i may be shocked to represent changes in government price support schemes. For the experiments reported here, the remaining variables have been left unchanged. By holding q_j and f_{ij} constant we specify that technology in each region is unchanged. Transport costs, H_{ij}, are left unchanged. Zero change in the autonomous demands, ΔS_{ij}, implies that quantities of goods flowing to inventories, investment and government remain fixed in real terms. Finally, one price - the world price of nonfoods - is arbitrarily chosen to fix the price level. The effect of increasing this would simply be to increase all other prices by the same amount, whilst leaving quantity variables unchanged.

2.2 Incorporating ORANI into the World Food Trade Model

In this subsection we describe how the ORANI model of the Australian economy can be linked to our model of the rest of the world which is described by equations 1 to 13 of Table 2.2. We show how the formal requirements for such a linkage may be met by (a) establishing a mapping between the differing commodity classifications of ORANI and our world model, and (b) dropping ORANI's export demand equations. In principle, the two models may be united into one. However, to keep the dimensions of our model manageable, it is convenient to include in the world model only those ORANI equations which affect the rest of the world. Such a world model yields results which are consistent with ORANI but do not include detailed information about Australia. To obtain the latter, we can use results from the world model as an input into the ordinary ORANI model.

ORANI is fully described by the book-length study of Dixon et al.(1982). Briefly, the current standard version distinguishes 112 industries, 114 commodities and 10 occupational groups. There are intermediate, investment, household, government and export demands. Domestic users choose between imports and domestic goods of the same class on the basis of their relative prices. Imports are available in infinitely elastic supply at exogenous world prices, while export prices are negatively influenced by export volumes. That is, world demand curves are modelled as downward-sloping. Like our world model, ORANI takes the form of a series of linear equations relating percentage changes in variables.

For the linking of two economic models to be meaningful, some variables must be common to both models. For our purposes, this means that we must find some counterpart in ORANI of the Australian border prices and the net imports to Australia which appear in the world model. ORANI distinguishes the price of exported good i from the price of imported good i. The world model, on the other hand, treats all goods of type i as identical, whatever their region of origin. To accommodate the simpler specification of the world model, we must add to ORANI the condition that import and export prices of the same class of good are identical.[3]

Similarly, the 'net imports' of the world model do not appear in the list of ORANI variables. Instead, exports and imports are defined separately. To remedy this, we simply add to ORANI equations defining net imports of good i, NMB_i as the difference between the quantities of imports and exports of that good, measured in physical units each worth one dollar at original border prices.

Finally, we need to devise a mapping between the 114 goods recognised by ORANI, and the 8 distinguished by the world model. For the changes in net imports, this is given by a matrix **S**:

WORLD MODEL		ORANI
$\Delta \mathbf{M}_1$ =	**S** .	$\Delta \mathbf{NMB}$
8×1	8×114	114×1

where S_{ni} is the share of net imports of ORANI category i allocated to world category n. The transpose of **S** can be used to convert changes in the 8 Australian border prices of the world model, $\mathbf{p}^{bA}$, into changes in ORANI's 114 border prices, **p**.[4]

$$\underset{114\times 8}{S'} \cdot \underset{8\times 1}{p^{bA}} = \underset{114\times 1}{p}$$

If two economic models are to be linked, no variable which appears in both models may be endogenous in both individual models. Otherwise, the combined equation system would be overdetermined. By design, equations (1) to (13) of our world model do not restrict the behaviour of Australia in any way. Conversely, the standard version of ORANI contains very few behavioural equations describing the behaviour of the rest of the world. Hence, few 'double endogeneity' problems arise. The only ORANI equations which conflict with our world model are those linking export prices and volumes. Demand schedules for the rest of the world are already implicit in equations (1) to (13) of the world model. To maintain consistency, it is necesary to delete the export demand equations from ORANI.

In summary, to link ORANI with our world model it is necessary both to add equations linking export prices to import prices, and mapping from 114 goods to 8, and also to drop the export demand equations. Then, the two models may be linked simply by treating the two sets of equations as one simultaneous unit. We rejected this option as unwieldy. Instead we chose to include in our expanded model only those ORANI equations which were absolutely necessary to solve the world model. The remaining ORANI equations, which serve to determine variables of purely Australian significance, could then be solved independently.

Using matrix notation, ORANI can be schematically represented as:

$$\mathbf{x}^1 = \mathbf{B}\mathbf{x}^2$$

where B is a matrix of coefficients and $\mathbf{x}^1$ and $\mathbf{x}^2$, respectively, are the endogenous and the exogenous variables. For the purposes of the world model we are only interested in a small subset of the ORANI variables - the Australian border prices of, and net imports of, the 114 ORANI commodities. Accordingly, we can form an excerpt from the ORANI solution matrix, B, as follows:

$$\underset{114\times1}{\Delta NMB} = \underset{114\times114}{C} \,.\, \underset{114\times1}{p} + \underset{114\times114}{D} \,.\, \underset{114\times1}{\alpha}$$

Here, the vector ΔNMB shows total changes in net imports of ORANI's 114 commodities, C shows the part of these changes due to exogenous unit changes in the 114 Australian border prices, p, and D shows the effect of exogenous changes in Australian policy, α. Applying our mapping matrix S, we get:

$$\underset{8\times1}{\Delta M_1} = \underset{8\times114}{S} \,.\, \underset{114\times114}{C} \,.\, \underset{114\times8}{S'} \,.\, \underset{8\times1}{p^{bA}} + \underset{8\times114}{S} \,.\, \underset{114\times114}{D} \,.\, \underset{114\times1}{\alpha}$$

or

$$\underset{8\times1}{\Delta M_1} = \underset{8\times8}{\beta}\, \underset{8\times1}{p^{w}} + \underset{8\times1}{a}$$

where $\beta = S.C.S'$ and $a = S.D.\alpha$. This gives equation 14 of Table 2.2:

$$\Delta M_{i1} = a_i + \sum_{k=1}^{g} \beta_{ik} p_{i1}^{bA} \qquad i=1,..,g$$

which is, in effect, a highly condensed version of ORANI.

To run a simulation, we first use ORANI - with the modifications described above. The effects on net imports of both Australian policy changes, and exogenous 1 per cent changes in world prices give values for β and a. This enables us to parameterize equation (14) of the world model, which may now be solved independently. We obtain results for the foreign regions, and for world prices. To obtain Australian results we now shock the modified ORANI, not only with the Australian policy shock α, but also with the changes in world prices which were (endogenously) predicted by the world model. The derivation of β guarantees that net imports and world price results generated by this final ORANI run are consistent with those from the world model.

2.3 Data Base and Parameter Settings

The construction of the database for the world model fell into four parts. First, we made use of the data gathered by Tyers for his 7-good partial equilibrium model of food trade, showing flows of goods 1 to 7 in and between regions 2 to 30. Where possible, we updated his figures to 1986. Second, data were gathered to allow for our move to a general equilibrium framework. Third was the construction of the matrices of supply and demand elasticities, τ and η. Finally, our modelling of Australia makes use of the ORANI data base.

We updated the bulk of the Tyers flow data, including the consumption volumes, production volumes and stocks increases in each region, world price levels and levels of consumer and producer taxes. We extended these data to allow for our inclusion of the 'other' non-agricultural, good. However, the data on transport costs were not revised. We also gathered data on the usage of grains for animal feed (which was not modelled by Tyers). For a full description of the sources and methodology used to construct the database, see Skene (1988).

Inevitably, our data did not satisfy the condition that, for each good, the sum (over all regions) of net import volumes equal zero. Consequently, we adjusted autonomous usage of each good in each region in such a way that all markets cleared. For each good we first calculated the worldwide excess of production over usage, E_i. Then, autonomous usage of good i in region j, S_{ij}, was adjusted as follows:

$$\Delta S_{ij} = E_i \, Q_{ij} / \sum_{k=2}^{30} Q_{ik} \qquad j = 2,..,30 \quad i=1,..,8$$

where Q_{ij} is the production of good i by region j. In words, for each good autonomous usage in each foreign region was increased by an amount proportional to that region's share in total foreign production of that good. Note that we did not adjust the Australian data, which was derived from the ORANI data base.

The raw material for our construction of the supply and demand elasticity matrices, τ and η, were 58 individual 7x7 submatrices of 'long run' own- and cross-price elasticities gathered by Tyers from a variety of sources. Our aims were (a) to add an extra row and column to these matrices, corresponding to the 'other' good, and (b) to impose on the elasticities properties consistent with neoclassical, optimizing, behaviour. For the supply elasticities, these properties derive from the idea that the behaviour of a multi-industry, competitive economy may be modelled as though it were the behaviour of a single, multi-output, profit-maximising producer. For the demand elasticities, very similar properties follow from the decision to model aggregate consumption behaviour as though there was just one utility-maximising consumer. Two of these properties are that:

$$\tau_{ik}/S_k^c = \sigma_{ik} = \sigma_{ki} = \tau_{ki}/S_i^c \qquad i,k = 1,...,g \quad \text{(Symmetry)}$$

$$\sum_k \tau_{ik} = 0 \qquad i,k = 1,...,g \quad \text{(Homogeneity)}$$

where σ_{ik} is the elasticity of substitution between goods i and k. We imposed bounds on the values of the σ_{ik}, as well as ensuring that they were symmetrical. The second, homogeneity, condition could have been used to derive the elements of the 8th rows and columns as residuals. However, we feared that reliance on this method alone might lead to implausible values for these elements. Therefore, we imposed an additional restriction on the elasticity matrices, that of weak separability between the group of food goods (1 to 7), and the 8th, other, good. This meant, for example, that each region's consumption behaviour was consistent with a utility function of the form:

$$U = f(U_A(c_1, c_2, .., c_7), U_B(c_8))$$

where f, U_A and U_B are arbitrary, region-specific, functional forms. The separability assumption can be interpreted as dividing the consumption (or production) decision into two stages: in the first stage the consumer budget (or productive capacity) is allocated between foods and non-foods; in the second the food budget is divided amongst the food goods. Separability enforces the reasonable idea that neither in production or consumption is there a special relationship between any one type of food and the non-food good. The entire process of constructing the matrices τ and η is described in detail in Appendix 1.

The database used for ORANI was the standard database used by the IAC, namely the 1978-79 Balanced Data Base with Typicalized Agriculture. Its construction is described by Kenderes (1986). We ensured that the net imports by Australia mentioned in the world model were consistent with the corresponding trade flows of the ORANI data base. To do this, we needed the mapping matrix S, which relates the 114 goods recognised by ORANI to the 8 goods of the world model. This matrix is given in Table 2.6. It is a revised version of the mapping described by Higgs (1986).

TABLE 2.6: MAPPING BETWEEN ORANI AND WORLD MODEL COMMODITY CLASSIFICATIONS

	WORLD MODEL	ORANI
1	Rice	30% of ORANI good 5 - OTHER CEREAL GRAINS
2	Wheat	ALL of ORANI good 3 - WHEAT
3	Coarse Grains	70% of ORANI good 5 - OTHER CEREAL GRAINS ALL of ORANI good 4 - BARLEY
4	Sugar	ALL of ORANI good 27 - OTHER FOOD PRODUCTS
5	Dairy	ALL of ORANI good 7 - MILK CATTLE PIGS ALL of ORANI good 21 - MILK PRODUCTS
6	Ruminant Meat	85% of ORANI good 20 - MEAT PRODUCTS ALL of ORANI good 2 - SHEEP ALL of ORANI good 6 - MEAT CATTLE
7	Non-ruminant Meat	15% of ORANI good 20 - MEAT PRODUCTS
8	Other Goods	ALL of ORANI goods 1, 8-19, 22-26, 28-114

NOTE: The mapping shows, for example, that there is a one-to-one correspondence between the world model's 'wheat' commodity and ORANI's 'wheat' commodity, while the world model's commodity 'coarse grains' consists of 70 per cent of the ORANI commodity 'other cereal grains' and all of the ORANI commodity 'barley'.

SOURCE: Based on the mapping described by Higgs(1986), p.289.

3 CONCLUDING REMARKS

The model described in Section 2 was implemented via a series of computer programs, some of which were especially written for the purpose while others formed part of the GEMPACK suite of programs (see Codsi and Pearson, 1988). Appendix 2 shows how the model equations were represented in GEMPACK TABLO format. Pearce (1988b) provides a guide to running the model on the IAC computer.

The model has been used to simulate the effects of unilateral abolition of all restrictions on agricultural trade, and of abolition by only the members of the GATT group. The results, which are reported in Horridge, Pearce and Walker (1988) and in Pearce (1988a), were in conformity with those produced by other models. They suggested that removal of agricultural protection would raise world food prices and increase the volume of food trade. Benefits would accrue both to food exporters and to countries which abolished trade barriers. The general equilibrium methodology allowed us to quantify these benefits via the changes in each country's aggregate consumption level. The linearisation of the model facilitated the analysis of these results: it allowed the total effect of global liberalization to be decomposed into the effects of individual moves towards freer trade.

Experience with the model has suggested several possibilities for improvement. While any disaggregation of world production into a few categories must impose limitations, it seems particularly desirable to distinguish wool, one of Australia's major agricultural exports, from the remainder of the 'other' sector. Similarly, the agricultural output mix of tropical countries is not well represented by the disaggregation adopted here.

More generally, we may question whether the assumption of homogeneous goods (e.g., that grain produced in one country is a perfect substitute for that produced in another) fits the consumption of the non-agricultural goods as well as it does the agricultural. The 'other' exports by Australia include quite different products to the 'other' exports of, say, Japan. The practical implication of this point is that export demand curves for the 'other' good tend to be rather flat in our model. One solution might be to introduce the idea of imperfect substitution between each country's version of the 'other' good.

NOTES

1 Our debts to Rodney Tyers are acknowledged at several points in the paper. Several past and present Industries Assistance Commission staff have also contributed to this work, in particular Wayne Crook, Ed Lekawski, Ross Mannion, John Skene, Alex Strzelecki, Ron Tillack, Dave Vincent and Agnes Walker.

2 As Equation (2) of the model is written, we expect the own-price demand elasticities to be positive. The reason for this convention is that the demand elasticities τ and the supply elasticities η are processed by the same computer program, which implements the procedure described in Appendix 1. We found it convenient for the elements of both τ and η to have the same expected signs.

3 ORANI distinguishes two variants of each commodity: an imported type and a domestically produced type. Both types are used locally, but only the domestic type is exported. Substitution in use between domestic and imported types is governed by a CES or Armington relation, which relates the usage shares of domestic and imported types to their relative prices. If we assume that (i) import and export prices of each good moved together (to conform with the world model schema) and that (ii) domestic and export prices of each good moved together, then the ratio of import and domestic prices would be constant, precluding the Armington substitution mechanism which has strongly influenced the results of most reported ORANI simulations. At first sight, therefore, our assumption (i) seems to contravene the the spirit in which ORANI has normally been used.

Actually, this problem is not of practical significance. Partly as a result of an inward-looking industrial policy, there are few goods which Australia both imports and exports in significant quantities. Import-competing industries tend not to pursue export opportunities. Within ORANI, this stylised fact is captured *via* an insulation of the export market from the domestic market for each import-competing good. Assumption (ii) does not hold; instead a variable export subsidy is supposed to maintain export prices at the level which holds export volumes constant. For these goods, our assumption (i) does not preclude changes in the ratio of imported and domestic prices. For those goods which are exported in significant quantities, on the other hand, assumption (ii) holds true, at least to a first approximation. That is, export subsidies are held constant within ORANI, and export volumes vary endogenously. Here, assumption (i) does indeed rule out substitution between domestic and imported variants. Little is lost, however, for these exportable products are only imported in tiny quantities.

4 The 'world' prices which appear in ORANI, **p**, are in fact Australian border prices (f.o.b. for exports, c.i.f. for imports).

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APPENDIX 1: TREATMENT OF THE DEMAND AND SUPPLY ELASTICITIES

In this section we describe our formation of the matrices of own- and cross-price elasticities of supply and demand for each region. We describe our treatment of the demand elasticities first. Our treatment of the supply elasticities is nearly identical. The minor differences are commented on at the end.

Our aim is to use the 7 x 7 matrices of own- and cross-price demand elasticities and the vectors of expenditure elasticities collected by Tyers for his partial equilibrium, 7 good model as a basis for the elasticities in our 8 good, general equilibrium model. As well as being of larger dimension, the elasticity matrices for our model are to be consistent with utility-maximising behaviour by a single consumer. This restriction was not imposed on the original Tyers elasticities. Finally, we impose a (weak) restriction on the form of the underlying utility function.

For each region j and good i, our database of flows supplies values for a set of consumer budget shares S^c_{ij}. The Tyers' elasticity estimates comprise, for each region but for the food goods (i,k=1,..,7) only, a vector of expenditure elasticities, ϵ_{ij}, and a submatrix of uncompensated demand elasticities, τ^u_{ikj}. As each region is treated independently, we will drop the j (region) subscripts from now on. We remind the reader of our sign convention for these demand elasticities: diagonal elements of τ are expected to be positive (See Note 2 to the main text).

STEP 1 Conventionally defined compensated own- and cross-price demand elasticities, $(-\tau^r_{ik})$ in our notation, are derived from the Tyers uncompensated demand elasticities, $(-\tau^u_{ik})$, by the Slutsky formula:

$$\tau^r_{ik} = \tau^u_{ik} - S^c_k \epsilon_i \qquad i,k = 1,..,7$$

This yields estimates of compensated own- and cross-price demand elasticities for the food goods only. Also, we can use the fact that the share-weighted sum of expenditure elasticities must be unity to calculate the expenditure elasticity for the final, nonfood, good:

$$S^c_8 \epsilon_8 = 1 - \sum_{k=1}^{7} S^c_k \epsilon_k$$

<u>STEP 2</u> consists of judgemental methods of ensuring that the 7 x 7 submatrices of estimates of compensated own- and cross-price demand elasticities contain sensible values, and satisfy utility-maximising conditions. We were wary of attaching too much credence to the estimates gathered by Tyers. First, the elasticities are gathered from various sources and may refer to different time periods. Budget shares at the time the elasticities were estimated may differ from shares used in our database. Second, Tyers' matrices contain many zero elements, some of which may perhaps be better interpreted as 'missing observations'. To judge their plausibility, we found it convenient to convert the matrices of compensated demand elasticities into matrices of substitution elasticities, <u>via</u>:

$$\sigma^r_{ik} = \tau^r_{ik}/S^c_k \qquad i,k = 1,..,7$$

where σ^r_{ik} is the negative of the Allen elasticity of substitution between goods i and k. Note that under our convention we expect σ^r_{ik} to be negative for $i \neq k$ wherever i and k are substitutes, and all σ^r_{ii} values to be positive. We adjusted all values of σ^r_{ik} so that they had a maximum absolute value of 10. We then enforced the symmetry requirement that:

$$\sigma_{ik} = \sigma_{ki} \qquad i,k = 1,..,7 \qquad i \neq k$$

This reqirement was not, in general, satisfied by the σ^r_{ik} derived directly from the Tyers data. We massaged the data as follows: For each pair of diagonally opposite elasticities that were different but of the same sign, we calculated the mean of their two values:

$$(\text{mean } \sigma) = (\sigma^r_{ik} + \sigma^r_{ki})/2,$$

and assigned this average value to each member of the pair:

$$\sigma^s_{ik} = \sigma^s_{ki} = (\text{mean } \sigma)$$

If the two substitution elasticities were of opposite sign, we replaced the value of the one which did not have the expected sign with the value of its diagonally-opposite partner. Similarly, if only one substitution elasticity was zero, we assigned it the value of its opposite partner. After modifying the substitution elasticities in this way, we converted them back to compensated own- and cross-price elasticities, using the formula:

$$\tau^s_{ik} = S^c_k \sigma^s_{ik} \qquad i,k=1,..,7$$

The result, τ^s, is a submatrix of compensated price elasticities of demand (food x food only) that satisfies the symmetry conditions implied by any utility-maximising behaviour.

<u>STEP 3</u> At this point, the 7 x 7 submatrix of elasticities could in theory be used to calculate the additional row and column needed for the complete 8 x 8 matrix of elasticities by using certain aggregation conditions implied by any utility-maximising behaviour. For example, homogeneity requires that each row of the <u>complete</u> matrix of compensated demand elasticities add to zero. We could use this fact to calculate the elasticity of demand for each food with respect to the price of nonfoods, thus:

$$\tau^s_{i8} = -\sum_{k=1}^{7} \tau^s_{ik} \qquad i = 1,..,7$$

This would provide all but one element of the final column of elasticities. The symmetry and homogeneity requirements would then jointly imply that:

$$\sum_{i=1}^{8} S_i^C \tau_{ik}^S = 0 \qquad k = 1,..,8$$

We could then use this to find the final row of the elasticity matrix. Such a procedure would give maximum weight to the elasticities provided by Tyers, whilst satisfying optimizing requirements. Own- and cross-price elasticities for the additional, nonfood good would be calculated as residuals. Because of this, deficiencies in the Tyers data might be reflected in implausible values for the final row and column of the elasticity matrices for some regions. To reduce this problem, we decided to impose a minimal restriction on consumer behaviour, namely that the underlying utility function had the form:

$$U = U(F^1(x_1, x_2, ..x_7), F^2(x_8))$$

Essentially this divides the consumption decision into two stages. The budget is first allocated between foods and nonfoods; then the food budget is allocated between the various foods. The assumption rules out any special relationship between one type of food and the nonfood good. Since the nonfood good is highly aggregated, this seems an appropriate assumption. Effectively it provides another way of finding the extra row and column of elasticities, τ_{8k} and τ_{i8}, as well using the row and column adding-up properties mentioned above. The resultant τ_{8k} and τ_{i8} are more likely to be sensible. At the same time, not all of the current values of the τ_{ik}^S (i,k=1,..,7) will, in general, be consistent with <u>both</u> sets of conditions. Hence we attempted to alter the τ_{ik}^S as little as possible, whilst meeting restrictions implied by our particular form of the utility function. We formalized this problem as follows. First, defining c_r as real consumption, we write the demand equations as:

$$x_i = -\sum_{k=1}^{7} \tau_{ik} p_k - \tau_{i8} p_8 + \epsilon_i c_r$$

$$x_8 = -\sum_{k=1}^{7} \tau_{8k} p_k - \tau_{88} p_8 + \epsilon_8 c_r$$

General utility-maximising constraints imply:

$$\tau_{ik}/S_k = \tau_{ki}/S_i \qquad \text{(Symmetry)} \qquad i,k=1,..,8$$

$$\sum_{k=1}^{8} \tau_{ik} = 0 \qquad \text{(Homogeneity)} \qquad i=1,..,8$$

Our special form for the utility function means that the demand equation for good 8 can be written as (see Theil,1980,Section 9.3):

$$x_8 = \sigma(1-S_8')(p_8 - p_f) + \epsilon_8 c_r$$

where σ is the elasticity of substitution between foods as a whole and the nonfood good, and p_f is a Frisch price index of goods 1 to 7, i.e.,

$$p_f = \sum_{k=1}^{7} S_k' p_k/(1-S_8')$$

The S' are marginal shares, i.e., $S_k'=S_k\epsilon_k$.

Thus $$x_8 = \sigma(1-S_8')p_8 - \sigma\sum_{k=1}^{7} S_k' p_k + \epsilon_8 c_r$$

or $$\tau_{8k} = -\sigma S_k' \qquad k=1,..,7$$

and $$\tau_{88} = \sigma(1-S_8')$$

Our desire to modify the Tyers elasticities as little as possible is formalized as a standard optimization problem. We choose τ_{ik} and σ to minimize the quadratic loss function:

$$\sum_{i,k} W_{ik}(\tau_{ik} - \tau_{ik}^{s})^2, \qquad i,k=1,..,7$$

where **W** is a matrix of weights (which we set to unity) and τ^s our current matrix of elasticities. Our system of constraints can be condensed down to:

$$\tau_{ik}S_i = \tau_{ki}S_k \qquad \text{(Symmetry)} \qquad i,k=1,..,7$$

$$\sum_{k=1}^{7} \tau_{ik} = \sigma S_8 \epsilon_i \qquad \text{(Separability)} \qquad i=1,..,7$$

Form Lagrangean:

$$L = \sum_{i,k} W_{ik}(\tau_{ik} - \tau_{ik}^{s})^2 - \sum_{i,k} \mu_{ik}(\tau_{ik}S_i - \tau_{ki}S_k) - \sum_i \lambda_i(\sigma S_8 \epsilon_i - \sum_{k=1}^{7} \tau_{ik})$$

The first order conditions are:

$$L_\sigma = \sum_i \lambda_i S_8 \epsilon_i = 0 \qquad \text{so} \qquad \sum \lambda_i \epsilon_i = 0$$

$$L_{\tau_{ik}} = 2W_{ik}(\tau_{ik} - \tau_{ik}^s) - \mu_{ik}S_i + \mu_{ki}S_k - \lambda_i = 0$$

Next we observe that for i=k the restriction $\tau_{ik}S_i=\tau_{ki}S_k$ cannot fail to hold, and so $\mu_{ii}=0$ for i=1,..,7. As well we note that as a matter of logical necessity, $\mu_{ik}=-\mu_{ki}$ for $i\neq k$ and i,k=1,..,7. Hence the FOC may be written:

$$\sum \lambda_i \epsilon_i = 0$$

$$2W_{ik}(\tau_{ik} - \tau_{ik}^s) - \mu_{ik}(S_i + S_k) - \lambda_i = 0 \qquad i>k$$

$$2W_{ik}(\tau_{ik} - \tau_{ik}^s) + \mu_{ki}(S_k + S_i) - \lambda_i = 0 \qquad i<k$$

$$2W_{ii}(\tau_{ii} - \tau_{ii}^s) - \lambda_i = 0 \qquad i=1,..7$$

$$\tau_{ik}S_i = \tau_{ki}S_k \qquad i>k$$

$$\sum_k \tau_{ik} = \sigma S_8 \epsilon_i \qquad i=1,..7$$

By swapping i and k subscripts, we rewrite the third equation above as:

$$2W_{ki}(\tau_{ki} - \tau_{ki}^s) + \mu_{ik}(S_i + S_k) - \lambda_k = 0 \qquad i>k$$

Then, using the second equation above:

$$2W_{ki}(\tau_{ki} - \tau_{ki}^s) - \lambda_k = -\mu_{ik}(S_i + S_k) = -2W_{ik}(\tau_{ik} - \tau_{ik}^s) + \lambda_i \qquad i>k$$

The fourth equation above gives:

$$\lambda_i = 2W_{ii}(\tau_{ii} - \tau_{ii}^s) \qquad i=1,..,7$$

Consolidating, the revised FOC conditions are

$$\sum_i W_{ii}(\tau_{ii} - \tau_{ii}^s)\epsilon_i = 0$$

$$W_{ik}(\tau_{ik} - \tau_{ik}^s) - W_{ii}(\tau_{ii} - \tau_{ii}^s)$$
$$= -W_{ki}(\tau_{ki} - \tau_{ki}^s) + W_{kk}(\tau_{kk} - \tau_{kk}^s) \qquad i>k$$

$$\tau_{ik}S_i - \tau_{ki}S_k = 0 \qquad i>k$$

$$\sum_k \tau_{ik} - \sigma S_8 \epsilon_i = 0 \qquad i=1,..,7$$

There are 50 ($=7^2+1$) variables, the τ_{ik} and σ, and 50 linear equations. We solved this system numerically for each region in turn, to obtain our final values for the τ_{ik} (i,k=1,..,7). The final row and column of each τ matrix was obtained by using the formulae from above:

$$\tau_{8k} = - \sigma S'_k \qquad k=1,..,7$$

$$\tau_{88} = \sigma(1-S'_8)$$

$$\tau_{i8}S_i = \tau_{8i}S_8 \qquad i=1,..,7$$

Optimizing behaviour imposes a further, second-order condition on the matrices of substitution elasticities -- that they be negative definite. We did not test this directly. Instead we checked that all own-price elasticities were of the correct sign, and that cross-price elasticities tended to be both of smaller absolute value and of opposite sign. The absence of large, perversely-signed, cross-price elasticities was a strong indication that the second-order conditions had been met.

Finally, our treatment of Tyers' 7 x 7 matrices of supply elasticities was almost the same as our treatment of his demand elasticities, with only two differences: First, there was no need to convert elasticities from uncompensated to compensated form. We treated the raw supply elasticities as we did the compensated demand elasticities. Second, we assumed that each regional production function was homothetic. In terms of the algebra above, the analogues of the expenditure elasticities were all set to unity.

APPENDIX 2: GEMPACK TABLO INPUT FILE FOR THE WORLD MODEL

The world model set out in Tables 2.1 to 2.5 above was implemented using the GEMPACK suite of programs. For an overview of GEMPACK, see Codsi and Pearson (1988). The first stage in the solution of a model via GEMPACK is to construct an input file which accurately defines all the equations and variables of the model. This file forms the input to the TABLO program which then creates FORTRAN programs which are used to solve the model.

We have reproduced our input to TABLO in the pages following, because it constitutes the most precise record possible of the model as actually implemented. The input follows the syntactical conventions defined in the TABLO manual, GEMPACK Document No. 20. Even without the manual, comparison with Tables 2.1 to 2.5 should allow fairly easy understanding of the TABLO input. The equations, which are probably the easiest place to start, appear at the end. Preceding them are definitions of the coefficients and variables which are used.

The following hints may be useful. Comments are enclosed between exclamation marks, proper names between the '#' symbol. Statements may occupy several lines but always end with a semicolon. In equations, if a coefficient multiplies a variable, the coefficient must be written first.

```
! WORLD FOOD TRADE MODEL TABLO INPUT            VERSION 2   MARCH 1988 !
!**********************************************************************!
!              SETS                                                    !
!**********************************************************************!
SET REG # regions # (R01,R02,R03,R04,R05,R06,R07,R08,R09,R10,
                     R11,R12,R13,R14,R15,R16,R17,R18,R19,R20,
                     R21,R22,R23,R24,R25,R26,R27,R28,R29,R30);
SET FOREIGN # other regions #
                    (    R02,R03,R04,R05,R06,R07,R08,R09,R10,
                     R11,R12,R13,R14,R15,R16,R17,R18,R19,R20,
                     R21,R22,R23,R24,R25,R26,R27,R28,R29,R30);
SUBSET FOREIGN is subset of REG ;
SET HOME # AUSTRALIA # ( R01);
SUBSET HOME is subset of REG ;
SET COM # commodities #
                   (Rice,Wheat,CoarseG,Sugar,Dairy,RuMeat,NrMeat,Other);
SET FEED # Goods used for animal FEED # (Wheat,CoarseG);
SUBSET FEED is subset of COM ;
SET NONFEED # Goods not used as FEED #
                                 (Rice,Sugar,Dairy,RuMeat,NrMeat,Other);
SUBSET NONFEED is subset of COM ;
SET ANIMAL # Goods requiring FEED # (Dairy,RuMeat,NrMeat);
SUBSET ANIMAL is subset of COM ;
!**********************************************************************!
!              FILES                                                   !
!**********************************************************************!
FILE fid     # flows data file # ;
FILE dempar  # demand parameters file # ;
FILE suppar  # supply parameters file # ;
FILE ozdata  # ELASTICITIES OF NET IMPORTS BY AUSTRALIA # ;

!**********************************************************************!
!              VARIABLES                                               !
!**********************************************************************!
VARIABLE (all,i,COM) (all,j,FOREIGN)
      tp(i,j) # power of subsidy on production of good i in region j#;
VARIABLE (all,i,COM) (all,j,FOREIGN)
```

```
        tc(i,j)  # power of tax on consumption of good i in region j#;
VARIABLE (all,j,FOREIGN)
        Z(j)  # productive capacity of region j#;
VARIABLE (all,i,COM) (all,j,REG)
        h(i,j)  # power of transport cost of good i to region j#;
VARIABLE (all,i,COM) (all,j,FOREIGN)
        f(i,j)  # technical change in production of good i in region j#;
VARIABLE (all,i,COM) (all,j,FOREIGN)
        DelS(i,j)  # change in autonomous usage, good i, region j#;
        ! DelS shows volumes, measured at original producer prices !
VARIABLE (all,i,COM)
        P(i)  # world price of good i#;
VARIABLE (all,i,COM)
        qw(i)  # total world production of good i #;
VARIABLE (all,i,COM)
        cw(i)  # total world USAGE of good i #;
VARIABLE  (all,i,COM) (all,j,FOREIGN)
        q(i,j)  # production of good i in region j#;
VARIABLE (all,i,COM) (all,j,FOREIGN)
        c(i,j)  # human consumption of good i in region j#;
VARIABLE (all,j,FOREIGN)
        agg_c(j)  # aggregate consumption in region j#;
VARIABLE (all,i,FEED) (all,j,FOREIGN)
        cg(i,j)  # total human + animal consumption good i in region j#;
VARIABLE (all,i,COM) (all,j,REG)
        pb(i,j)  # border price of good i in region j#;
VARIABLE (all,i,COM) (all,j,FOREIGN)
        pp(i,j)  # producer price of good i in region j#;
VARIABLE (all,i,COM) (all,j,FOREIGN)
        pc(i,j)  # consumer price of good i in region j#;
VARIABLE (all,i,COM) (all,j,REG)
        DelM(i,j)  # change in imports of good i into region j#;
        ! DelM shows volumes, measured at original border prices !
VARIABLE (all,j,FOREIGN)
        af(j)  # aggregate feedstock demand in region j#;
VARIABLE (all,i,FEED) (all,j,FOREIGN)
        fs(i,j)  # feedstock demands for good i, region j#;
VARIABLE (all,j,FOREIGN)
```

```
        DelB(j)  # Balance of Trade, region j#;
        ! DelB shows change in the borderprice value of imports !
 VARIABLE LAMBDA # Change in Balance of Trade for each foreign region #;
! LAMBDA is measured as percent of original production at border prices!
 VARIABLE (all,i,COM)
        ozlib(i)
   # effect on Australias imports,good i,of Australian liberalisation #;

!*********************************************************************!
!                DATA READS                                           !
!*********************************************************************!
COEFFICIENT (all,i,COM) (all,k,COM) (all,j,REG) ETA(i,k,j);
READ (all,i,COM)(all,k,COM)ETA(i,k,"R01") FROM FILE suppar Header "SE01";
READ (all,i,COM)(all,k,COM)ETA(i,k,"R02") FROM FILE suppar Header "SE02";
           ..............................etc
READ (all,i,COM)(all,k,COM)ETA(i,k,"R30") FROM FILE suppar Header "SE30";

COEFFICIENT (all,i,COM) (all,k,COM) (all,j,REG) TOR(i,k,j);
READ (all,i,COM)(all,k,COM)TOR(i,k,"R01") FROM FILE dempar Header "DE01";
READ (all,i,COM)(all,k,COM)TOR(i,k,"R02") FROM FILE dempar Header "DE02";
           ..............................etc
READ (all,i,COM)(all,k,COM)TOR(i,k,"R30") FROM FILE dempar Header "DE30";

COEFFICIENT (all,i,COM) (all,j,REG) EPSILON(i,j);
 READ EPSILON FROM FILE dempar HEADER "EXPL"  ;

COEFFICIENT (all,i,COM) (all,j,REG) HCONP(i,j);
    READ HCONP FROM FILE fid HEADER "QQ09"  ;
    ! human consumption at producers prices !

COEFFICIENT (all,i,FEED) (all,j,REG) ACONP(i,j);
    READ ACONP FROM FILE fid HEADER "QQ10"  ;
    ! animal consumption at producers prices !

COEFFICIENT (all,i,COM) (all,j,REG) PRODP(i,j);
    READ PRODP FROM FILE fid HEADER "QQ05"  ;
    ! production at producers prices !

COEFFICIENT (all,i,COM) (all,j,REG) HL(i,j);
    READ HL FROM FILE fid HEADER "QQ02"  ;
    ! transport margins !
```

```
COEFFICIENT (all,i,COM) (all,j,REG) TPL(i,j);
    READ TPL FROM FILE fid HEADER "QQ03"  ;
    ! producer taxes !

COEFFICIENT (all,i,COM) (all,k,COM)  BETA(i,k);
READ BETA  FROM FILE ozdata HEADER "BETA";
! Data derived from ORANI, showing the effect on Australian net imports!
! of good i, of a one per cent change in the Australian Border Price of!
! good k !                                                              !

!**********************************************************************!
!                  FORMULAE                                            !
!**********************************************************************!
COEFFICIENT SIGMA;
    FORMULA SIGMA = 0.5;

ZERODIVIDE DEFAULT 0.5;
COEFFICIENT (all,i,ANIMAL) (all,j,REG) SQ(i,j);
    FORMULA (all,i,ANIMAL) (all,j,REG)
        SQ(i,j) = PRODP(i,j)/SUM(k,ANIMAL,PRODP(k,j));

COEFFICIENT (all,i,FEED) (all,j,REG) SP(i,j);
    FORMULA (all,i,FEED) (all,j,REG)
        SP(i,j) = ACONP(i,j)/SUM(k,FEED,ACONP(k,j));

COEFFICIENT (all,i,FEED) (all,j,REG) SH(i,j);
    FORMULA (all,i,FEED) (all,j,REG)
        SH(i,j) = HCONP(i,j)/(HCONP(i,j) + ACONP(i,j));

COEFFICIENT (all,i,FEED) (all,j,REG) SF(i,j);
    FORMULA (all,i,FEED) (all,j,REG)
        SF(i,j) = ACONP(i,j)/(HCONP(i,j) + ACONP(i,j));

COEFFICIENT (all,i,COM) (all,j,REG) MPB(i,j);
    FORMULA (all,i,FEED) (all,j,REG)
       MPB(i,j)=[ACONP(i,j)+HCONP(i,j)+STOCKP(I,J)-PRODP(i,j)]/TPL(i,j);
    FORMULA (all,i,NONFEED) (all,j,REG)
        MPB(i,j) = [HCONP(i,j)+STOCKP(I,J)-PRODP(i,j)]/TPL(i,j);
! MPB is net imports measured at border prices !

COEFFICIENT  (all,j,REG) GDP(j);
    FORMULA  (all,j,REG)
```

```
        GDP(j) = SUM(i,COM,  [PRODP(i,j)/TPL(i,j)] );
! aggregate production at border prices !

COEFFICIENT  (all,j,REG) BT(j);
    FORMULA  (all,j,REG)
        BT(j) = SUM(i,COM, MPB(i,j)  );
! balance of trade deficit at border prices !

!*****************************************************************!
!               EQUATIONS                                         !
!*****************************************************************!

EQUATION SUPPLY
# 1    Production of good i by region j #
   (all,i,COM) (all,j,FOREIGN)
  q(i,j) = Z(j) + f(i,j) + SUM(k,COM, ETA(i,k,j)*pp(k,j));

EQUATION DEMAND_HUM
# 2    Human consumption of good i by region j #
   (all,i,COM) (all,j,FOREIGN)
  c(i,j) = EPSILON(i,j)*agg_c(j) - SUM(k,COM, TOR(i,k,j)*pc(k,j));

EQUATION DEMAND_AF
# 3    Aggregate feedstock demand in region j #
   (all,j,FOREIGN)
  af(j) = SUM(k,ANIMAL, SQ(k,j)*q(k,j));

EQUATION DEMAND_FS
# 4   Individual feedstock demand in region j #
   (all,i,FEED) (all,j,FOREIGN)
  fs(i,j) = af(j) - SIGMA*[pp(i,j) - SUM(k,FEED, SP(k,j)*pp(k,j))];

EQUATION DEMAND_TOT
# 5   Human + animal demands for grains #
   (all,i,FEED) (all,j,FOREIGN)
  cg(i,j) =  SH(i,j)*c(i,j) + SF(i,j)*fs(i,j);

EQUATION PRICE_BORD
# 6   Border price of good i, region j #
   (all,i,COM) (all,j,REG)
  pb(i,j) =  p(i) + h(i,j);

EQUATION PRICE_PROD
```

```
# 7   Producer price of good i, region j #
    (all,i,COM) (all,j,FOREIGN)
  pp(i,j) =  pb(i,j) + tp(i,j);

EQUATION PRICE_CONS
# 8   Consumer price of good i, region j #
    (all,i,COM) (all,j,FOREIGN)
  pc(i,j) =  pb(i,j) + tc(i,j);

EQUATION NET_IMPORTS1
# 9   import volumes measured at original border prices #
    (all,i,NONFEED) (all,j,FOREIGN)
  100.0*TPL(i,j)*DelM(i,j)
    = HCONP(i,j)*c(i,j) - PRODP(i,j)*q(i,j) - 100.0*DelS(i,j);
EQUATION NET_IMPORTS2
# 10  import volumes measured at original border prices #
    (all,i,FEED) (all,j,FOREIGN)
  100.0*TPL(i,j)*DelM(i,j)
    = (HCONP(i,j)+ACONP(i,j))*cg(i,j)-PRODP(i,j)*q(i,j)-100.0*DelS(i,j);

EQUATION MARKET_CLEAR
# 11  World market clears for good i #
    (all,i,COM)
  0 = SUM(j,REG,[1.0/HL(i,j)]*DelM(i,j));    ! measured at world prices !

EQUATION TRADE_BALANCE1
# 12  Definition of Balance of trade for region j, at border prices #
    (all,j,FOREIGN)
  100.0*DelB(j) =  SUM(i,COM, 100.0*DelM(i,j) + MPB(i,j)*pb(i,j) );

EQUATION TRADE_BALANCE2
# 13  Balance of trade constraint #
    (all,j,FOREIGN)
  100.0*GDP(j)*DelB(j)
  - BT(j)*SUM(i,COM, [PRODP(i,j)/TPL(i,j)]*[pb(i,j)+q(i,j)] )
  = GDP(j)*GDP(j)*LAMBDA;
! Ratio of Balance of trade to aggregate production         !
! changes by  an equal percentage for all foreign regions !

EQUATION OZ_IMPORTS
# 14  AUSTRALIAN import volumes  -  from ORANI #
```

```
  (all,i,com)
DelM(i,"R01")
  = OZLIB(i) + SUM(k,COM, BETA(i,k)*pb(k,"R01") );
```