



OECD DEVELOPMENT CENTRE

Working Paper No. 48
(Formerly Technical Paper No. 48)

TRADE POLICIES IN A GLOBAL CONTEXT: TECHNICAL SPECIFICATIONS OF THE RURAL/URBAN-NORTH/SOUTH (RUNS) APPLIED GENERAL EQUILIBRIUM MODEL

by

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Research programme on:
Developing Country Agriculture and International Economic Trends



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RÉSUMÉ

Le modèle Rural/Urban-Nord/Sud (RUNS) est un modèle global d'équilibre général appliqué, axé sur l'agriculture. RUNS fut initialement conçu au début des années 80 et a été employé durant cette décennie pour analyser les tendances des marchés agricoles mondiaux et les politiques agricoles. Entre autres, les analyses de RUNS furent utilisées dans plusieurs *World Development Reports*, publiés par la Banque mondiale. Actuellement, RUNS fait partie intégrante du programme 1990-92, du Centre de Développement, sur l'Agriculture des Pays en Voie de Développement et les Tendances Economiques Internationales, sous la direction de Ian Goldin.

Ce texte est une révision de la description technique complète du modèle RUNS. Il remplace le Document Technique 33 lequel exposait la structure du modèle jusqu'en Décembre 1990. Les parties I et II du document présentent une introduction et un aperçu général du modèle et sont destinées à un large public. La partie III donne une description détaillée de chaque bloc du modèle, y compris une liste complète des équations du modèle. Cette partie est surtout destinée aux spécialistes de la modélisation, quoique, en principe, accessible aux autres économistes. La partie IV décrit la base de données sous-jacente au modèle RUNS. La partie V présente les résultats d'une simulation de libéralisation complète des politiques agricoles au sein des pays de l'OCDE. La dernière partie conclut avec une liste des modifications prévues du modèle RUNS.

SUMMARY

The Rural/Urban-North/South Model (RUNS) is a global applied general equilibrium model, with a focus on agriculture. RUNS was initially developed in the early 1980's and has been used throughout the 1980's to provide analyses of world agricultural trends and agricultural policies. Amongst other things, RUNS was used to provide background analyses for several World Bank World Development Reports. RUNS is now integrated into the Development Centre's 1990-1992 programme on Developing Country Agriculture and International Economic Trends, under the direction of Ian Goldin.

This paper provides an updated full technical specification of the RUNS model. It replaces and revises Technical Paper 33 which documented the model structure as of December 1990. Parts I and II of the paper provide an introduction and a general description of the model and is intended for a broad audience. Part III provides a detailed description of each block of the RUNS model, including a full set of model equations. This part is mainly intended for modeling specialists, though it should also be accessible to other quantitative economists. Part IV describes the data set underlying the RUNS model. Part V presents the results of an OECD agricultural trade liberalization scenario. This is followed by a concluding section which details the planned future changes in the RUNS model.

PREFACE

The importance of agriculture and agricultural policies in the current Uruguay Round negotiations on trade liberalization has refocussed attention on the role of agriculture in development, and the tensions between the developed and developing regions and within the developed regions themselves. Within the framework of the Development Centre's 1990-1992 programme on Developing Country Agriculture and International Economic Trends, the Centre is analysing the consequences of the potential Uruguay Round conclusions, and alternative trade scenarios, using a global general equilibrium model. The model will also be used to assess other issues related to agriculture: structural adjustment and development, integration of Eastern Europe in the world economy, the fallacy of composition issue, and the effects of capital flows on agricultural trade and growth. The global modeling effort is being undertaken in collaboration with the World Bank and the OECD's Directorate for Food, Agriculture and Fisheries.

The Development Centre's work programme on agriculture incorporates several components: a conceptual component to provide analytical guidance to the broader issues; the global general equilibrium model to analyse overall trends and policy consequences; country archetype models to look at more specific issues; country case studies; and a component to analyse the links between economic reform and technological change in agriculture.

This paper provides a technical description of the global applied general equilibrium (GE) model. The GE model is called the *Rural/Urban-North South Model*, or the RUNS model. RUNS's main focus is agriculture. In particular, RUNS models the trade flows between the developed and developing regions, and the various flows between the rural and urban economies within a same region. The paper provides a description of the revised version of RUNS, reflecting model developments over the past year. The paper ends with an example of the use of the model. This highlights the policy significance of the modelling work.

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President, OECD Development Centre
November 1991

I. INTRODUCTION*

Since the early 1980s, when agricultural policies came under scrutiny by politicians and economists, expenditures in support of agriculture in the OECD countries have been increasing continuously. In 1989, the OECD countries spent approximately \$250 US billion in direct net budgetary outlays to support farm income and prices.¹ Nevertheless, the agricultural trade negotiations held at Punta del Este are only likely to yield a set of sector specific amendments to existing policies, despite the fact that the Round was initiated under a commitment of a major global reform of the world agricultural system. Since the beginning of the Round, world market prices of the major agricultural commodities have stabilised, and have thus partially reduced the immediate threat on budgetary expenditures. This latter point illustrates how governments are more concerned with the direct and static costs of their support to farmers, whatever their levels and implications for economy wide efficiency, than with the sustainability of agricultural policies over time. In this sense, sustainability deals with the possibility of keeping budgetary costs under control, while granting farmers some guaranteed level of support. This notion of sustainability clearly depends on the long run trends in world market prices.

The increasing concern about the costs of agricultural policies has led to improvements in the measurement and modelling of agricultural protection. The OECD Secretariat has developed the concept of the *producer subsidy equivalent* (PSE) as an aggregate indicator of the level of support to agriculture. PSEs have been calculated for the major agricultural commodities in most OECD countries since 1978, and provide a comprehensive and updated data base for comparison and monitoring of agricultural policies among OECD countries. Moreover, PSEs are relatively easy to use in models aimed at yielding a wider assessment of such policies. The Ministerial Trade Mandate (MTM) model, developed by the Directorate for Food, Agriculture and Fisheries, integrates the PSE data into a multi-sector, multi-country model.² It is a one period model which exclusively contains agricultural sectors. It has recently been extended to include LDCs. However, large distortions, like those implied by most agricultural policies, are likely to affect the economy as a whole. These distortions drain resources out of the non-agricultural sectors and impose additional costs to consumers, not only by raising food prices, but also by inflicting a sub-optimal allocation of resources and demands.

An applied general equilibrium (AGE) model is the natural tool for assessing these social costs.³ The WALRAS model, developed by the Growth Studies Division of OECD, is a recent example.⁴ The WALRAS model is a world wide model which incorporates agricultural as well as non-agricultural sectors into a fully interdependent framework. It supplies comparative static assessments of the

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¹ See OECD (1990a), Table IV.8, page 111.

² See OECD (1987).

³ See Shoven and Whalley (1984) for a useful and concise introductory survey of AGE modeling. Dervis, de Melo and Robinson (1982) provide an in-depth analysis of the use of AGE models for development policy.

⁴ See OECD (1990b).

agricultural policies in the major OECD countries. The model estimates that OECD agricultural support policies represent a static cost of about 1 per cent of GDP for the entire OECD area for the 1986-88 period.⁵

Comparative static analysis provides an elegant short cut to evaluate long run costs and benefits of policy changes, but fails to provide an insight on the sustainability of existing agricultural policies and the transitional costs of any reform. For policy recommendations to be made, policy analysis should be integrated in an inter-temporal framework which takes into account endogenous growth differentials between agriculture and non-agriculture, and between developed and less developed countries.

There have been two attempts to enlarge the comparative static framework in order to shed some light on the dynamic effects of removing agricultural support. First, a model developed at the International Institute for Applied Systems Analysis (IIASA) is a world AGE dynamic model which simulates agricultural policy effects over the period 1980-2000.⁶ Though it provides a very detailed description of the world agricultural system, its non-agricultural side is rather rudimentary and it fails to identify some key linkages between agriculture and industries in LDCs; for example, the oil versus food dilemma, or the role of food wages on industrialisation. The Rural/Urban-North/South Model (RUNS) is the second world AGE model which deals with agricultural policies in a dynamic context. Agricultural policies, in RUNS, are explicitly founded on income distribution targets between farm and non-farm incomes. The RUNS model endogenously calculates the social cost of imposing an income parity target between rural and urban groups in developed countries given the underlying trends of world market prices. It can also evaluate the cost of minimising urban labour costs in LDC manufacturing sectors.

RUNS was developed at the *Centre d'Economie Mathématique et d'Econométrie* at the Free University of Brussels during the early eighties.⁷ Since then, it has been used to analyse various issues, such as the effect of North-South growth differentials on world food trade imbalances (Burniaux, 1987), the economy and world wide impacts of the EEC Common Agricultural Policy (Burniaux and Waelbroeck, 1985, and Burniaux, 1989), and the evaluation of *agricultural development led industrialisation* policies (Adelman, Burniaux, and Waelbroeck, 1989).

The Development Centre of the OECD, as part of its research programme on agriculture and development, has decided to analyse several new issues with the RUNS model. At the top of the agenda the Development Centre desires to undertake a broad analysis of the upcoming conclusion of the Uruguay Round. The broader objectives include an analysis of structural adjustment and liberalization, integration of Eastern Europe and its global implications on agricultural markets, the issue of fallacy of composition, and the effects of capital flows on agricultural trade and growth. The present technical paper is intended to provide a complete description of the current version of the RUNS model. This provides a base for further development of the RUNS model, including new commodities, and changes in model specification.

⁵ This compares with 0.6 per cent of GDP in direct expenditures in the EEC and the US. See Zietz and Valdés (1989).

⁶ See Fischer, G., K. Frohberg, M.A. Keyzer, and K.S. Parikh (1988).

⁷ A detailed discussion of the model specification and structure is available in French, see Burniaux (1987).

The key changes from Technical Paper 33 include the following:

- An entirely new base data set. The current model is based in 1985 rather than 1978. The new base data set is country-based rather than region based. All country data is consistent with published National Income and Product Accounts.
- The model now covers the period 1985-2002 (rather than 1978-1995). All agricultural policy instruments have been updated as well as the exogenous trends and capital flow projections.
- Estimates of non-agricultural protection rates have been introduced into the base simulation.
- The number of regions in the model has been expanded from 10 to 22. The model no longer contains a residual rest of the world. The model numéraire has been modified (see Part III, Section O).
- The number of agricultural commodities has been increased from 13 to 15.
- The Constant Elasticity of Substitution (CET) specification has been implemented in the non-agricultural production structure (see Annex 3).
- An alternative macro closure has been developed (see Annex 5).

The next section presents a broad overview of the model. This is followed by Section III which gives a complete description of each block of the model. In this section, each block will be described in broad terms, and the full set of equations of the block will be presented. Section IV briefly describes the data and parameters. Section V presents the results from one simulation which is intended to show the usefulness of the RUNS model in analyzing global agricultural policies. The final section presents some concluding remarks and directions for future research.

II. OVERVIEW OF THE RUNS MODEL

In the early eighties, the World Bank funded an AGE modelling project undertaken at the Free University of Brussels. This was one of the first attempts to analyse North-South trade policies within a global and fully integrated analytical framework. Two world wide AGE models were developed. The first was primarily designed to address overall trade issues focusing on interdependencies within developing countries.⁸ In a second stage, RUNS was developed by integrating the industrial part of the first model and regional models of the industrialised countries. RUNS was also intended to focus on global agricultural policies, requiring a much more detailed specification of agriculture than the first model.

The model coverage of RUNS is world wide, with six OECD countries/regions, fourteen developing countries/regions, and Eastern Europe and the Soviet Union split into two regions. There are 22 regions in all. All regions have a fully specified general equilibrium model, there is no residual *rest of the world* component. Table 1a presents a list of the RUNS regions and Annex I details the regional groupings.

Table 1a: Regional coverage of RUNS

<u>OECD</u>	<u>Developing Regions</u>
United States	Low Income Asia
Canada	China
Australia/New Zealand	India
Japan	Upper Income Asia
European Economic Community	Indonesia
European Free Trade Area	Africa
	Nigeria
	South Africa
	Maghreb
	Mediterranean
<u>Other</u>	Gulf Region
	Latin America
Eastern European Economies	Brazil
Soviet Union	Mexico

The RUNS model incorporates 20 commodities, 15 of which are agricultural commodities. Table 1b presents the list of commodities. Agricultural commodities are further defined according to a food/non-food split.

⁸ See Carrin, Gunning and Waelbroeck (1983).

Table 1b: Commodity coverage of RUNS

<u>Agriculture</u>		<u>Non-Agriculture</u>
<u>Food</u>	<u>Non-Food</u>	
Wheat	Wool	Other manufacturing
Rice (paddy)	Cotton	Energy
Coarse Grains ⁹	Other non-food	Services
Sugar (refined)		Equipment goods
Beef, Veal, & Sheep		Fertilizers
Other Meats		
Coffee		
Cocoa		
Tea		
Oils and oil cakes		
Dairy and dairy products		
Other foods ¹⁰		

The following list describes some of the main features of the RUNS model.

- All country/region sub-models have a common specification. Each sub-model is composed of two distinct economies: rural and urban. The rural sector produces only agricultural commodities, i.e. off farm incomes in rural areas are counted as part of the urban economy. Though this is recognised as a limitation of the present version of the model, identifying off farm rural incomes is subject to significant data uncertainties.
- There is a degree of labour mobility between the rural and urban economies modeled according to the Harris-Todaro tradition.¹¹ Capital is only mobile over time. There is no inter-regional factor migration.
- The RUNS model is dynamic, covering the period 1985-2002. A temporary static equilibrium is calculated every three years. The static equilibria are recursively linked via capital accumulation and labour force growth and migration. Both producers and consumers have myopic expectations. Many authors have pointed out that myopic expectations better portray the decision making process in the real world where there exists incomplete information on futures markets.¹² This is particularly true in agriculture where products with delayed output responses are well known for exhibiting irregular cycles (e.g. coffee, cocoa, pigs) which are incompatible with perfect foresight of future prices.

⁹ Maize, rye, barley, etc.

¹⁰ Fruit, vegetables, alcoholic beverages, etc.

¹¹ See Harris and Todaro (1970).

¹² See, for instance, Bovenberg (1989) for a critical discussion of issues raised by intertemporal GE models with perfect foresight.

- Due to their greater homogeneity and their detailed sectoral breakdown, agricultural goods are not differentiated by origin. Though questionable for some widely aggregated sectors, such as other food, there exists econometric evidence which supports the assumption of large long run substitution elasticities for agricultural commodities such as wheat, rice, and dairy.¹³
- Demand for non-agricultural commodities is modeled via a set of nested constant elasticity of substitution (CES) functions. At the top level, demand for the non-agricultural commodities has been modeled using the Armington assumption. This assumption implies that domestic goods and imported goods are imperfect substitutes. A set of composite goods (i.e. an aggregation of domestic and imported commodities) is introduced as a convenient way to represent the Armington specification. At the next level, demand for imports are differentiated by region of origin, again using a CES specification.
- Non-agricultural production is modeled using the Constant Elasticity of Transformation specification (CET). This assumption is symmetric to the Armington assumption for the export market. Domestic producers view the domestic market as different from the export market. Producers produce two goods, a domestic good and an export good, along a transformation frontier, with supply of each good dependent on relative prices.
- Agricultural supply is described by two production sectors: crops and livestock, i.e. the model uses a multi-input/multi-output production function. The livestock sector supplies meats (ruminant and non-ruminant), dairy, and wool. The crops sector produces all other agricultural commodities. Rural production is characterised by decreasing returns to scale. The supply of land, which is a key factor of production, is bounded above by a region-specific maximum potential supply. The structure of production is different for the two sectors.
- Production in the crops sector is characterised by substitutions between three key factors: fertilizers, a composite of land and tractors, and a composite of labour, irrigated land, and draught cattle.¹⁴ This essentially defines the choice between using land and machinery where land is relatively abundant, or using more intensive techniques where land is scarce. Demand for other inputs are modeled using fixed coefficients.
- Production in the livestock sector is characterised by substitutions between four main inputs: wheat, coarse grains, oil-based feed, and land. In essence, output is defined by the choice of range-fed versus ranch-fed production. All other inputs are modeled using fixed coefficients.
- Production in the urban sector exhibits constant returns to scale and is characterised by a top-level Leontief structure for intermediate inputs and a value added aggregate. Demand for intermediate inputs are further broken down, using the Armington assumption, between domestic and imported goods. Value added is a composite of capital and labour, with an

¹³ See Tyers and Anderson (1989).

¹⁴ The individual factors within each composite aggregate are assumed to be perfect complements.

exogenous productivity term. A CES specification is used for the value added composite.

- Rural and urban household demand is modeled according to the *Extended Linear Expenditure System* (ELES). The ELES implicitly allows a role for substitution of current consumption versus future consumption. Household-specific income and price elasticities are used to calibrate the parameters of the ELES.
- The ratio of agricultural to non-agricultural prices, further referred to as the rural/urban terms of trade, plays a key role in equilibrating commodity and factor flows between the rural and urban economies. Agricultural policies in both developed and developing economies typically aim to control the rural/urban terms of trade. This has been reflected in the RUNS model by making the domestic price of agricultural commodities expressed as a function of price policy equations. In other words, domestic agricultural prices only partially reflect world market conditions. Thus, the concept of the PSE is directly integrated into the RUNS model, as agricultural policies are not defined using *ad valorem* equivalents, rather the subsidy/tariffs levies are variable and are governed by the price policy equations. The model also incorporates another policy instrument in the form of a sector specific input subsidy. The initial PSE data is split according to price (or border) measures and direct income support measures, with the latter being used to calculate the initial input subsidy.
- The model also incorporates some downward partial rigidity of the real wage in the urban sector. Rigidities of both agricultural prices and urban wages allow the model to address key aspects of the food price dilemma in some LDCs.
- Model closure is neo-classical; investment is residually determined as the sum of domestic and foreign savings. Macro closure is assured by exogenously fixing the balance of trade for each region. (See Annex 5 for an alternative closure rule for RUNS.)
- The model is currently implemented as a set of three FORTRAN programs. The first program is used to calibrate the parameters of the model. As with most AGE models, the set of parameters is split into two groups. The first group contains a set of key parameters which are either directly estimated or gleaned from outside studies and documents. This group usually contains the key supply, demand, and substitution elasticities. The second group of parameters are calibrated using the set of key parameters and the base data. Annexes 3 and 5 provide a description of the calibration of the ELES and the agricultural production function. The result of the calibration program is a data set of parameters and initial data which should re-produce the initial base data in the first year of the simulation program.¹⁵

The second program is the simulation program, i.e. it is the implementation of the equations as they are described in this paper. Each simulation depends on a control file which allows the user to define the specificity of the

¹⁵ The simulation program has an option which permits testing of the calibration process, it is referred to as a residual check.

simulation. Examples of different simulations include modification of the exogenous capital flows or the exogenous energy prices, variations of the price transmission equations, implementation of a new set of agricultural input subsidies, introduction of tariffs and/or subsidies on non-agricultural trade, changes in urban wage specifications, etc. The output of the simulation program is a set of data with the variable results for all variables, for all regions, for each time period.

The simulation program is also used to calibrate the trend parameters of the model to observed or desired (i.e. exogenous) trends. This step of the calibration process occurs prior to defining the base simulation.

The third program provides a post-simulation analysis of either a single simulation run, and/or the comparison of two simulations, where one of the simulations is typically the base run.

RUNS has successfully been implemented on Macintoshes (using the Mac OS), on PCs (using MS-DOS¹⁶), on 386/486 based machines (using a DOS-Extender), and on VAXes (under both UNIX and VMS). A typical simulation on a 80486 PC takes about 15 minutes.¹⁷

All three programs are documented by a 100 page Users' Manual.

The following section describes the model specification. Each sub-section will describe the different blocks of the intra-temporal (static) equilibrium. There are two sub-sections which describe the transition (or factor accumulation) equations. Annex 8 provides a complete list of variables, parameters, exogenous variables, and policy instruments. Annex 9 describes the links between the RUNS model and its associated SAM. Readers may want to take a quick look at the SAM in order to understand the structure and linkages underlying the RUNS model.

The subscript i will refer to the subset of agricultural commodities, the subscript m will refer to the subset of non-agricultural commodities, the subscript k will refer to all commodities, the subscripts r and u represent respectively the rural and urban sectors. Note that both time and region subscripts are not used unless they are necessary for formulating an equation (e.g. the price transmission equations, or allocating imports across regions).

¹⁶ Due to the size of the programs, the MS-DOS version operates in single precision.

¹⁷ Note, though the program is dynamic-recursive, the program does solve over 65,000 equations (though not simultaneously). Within each time period, the program requires from 100 to 200 iterations to converge.

III. DESCRIPTION OF THE RUNS MODEL

In order to simplify the description of the model, it is useful to introduce the notion of a composite good. As stated above, all urban commodities are differentiated by origin, i.e. domestic vs. imported. Demand for urban commodities (both as intermediate or as final demand) is always a three step process. At the top level, an agent will derive a demand for a composite urban good (based on a specific optimisation process, e.g. the ELES in case of household consumption). At the next level, an agent will minimise expenditures on the composite good depending on the relative price of the domestic component versus the imported component, and the degree of product substitutability. At the third and final level, the agent will minimise the cost of purchasing the import quantity based on the relative price across all regions. At both the second and the third levels, the RUNS model assumes that the composite good is aggregated using a constant elasticity of substitution (CES) specification, i.e. the Armington assumption. Annex 2 describes with greater detail the Armington assumption.

A. Expenditure Equations

Table 2 gives the expenditure equations for the four institutions, rural and urban households, government, and the capital (or investment) sector. Note that in the case of urban commodities, these equations represent final demands for the composite good. Households consume all commodities (agricultural plus non-agricultural, though consumption of equipment and fertilizers is always zero). Both rural and urban households are modeled according to the ELES specification (see Annex 4 for a description of the ELES). The income and price elasticities are household specific. Consumption in the ELES is composed of two elements. The first element is often referred to as the *subsistence minima*.¹⁸ The second component is a constant share of *supernumerary* income, i.e. residual income after total purchases of the subsistence minima.

Table 2: Expenditure equations

$$(1) \quad C_{r,k} = L_r \left[\theta_{r,k} + \mu_{r,k} \left(\frac{Y_{d_r} - \sum_{k'} p_{c k'} \theta_{r,k'}}{p_{c k}} \right) \right]$$

$$(2) \quad C_{u,k} = L_u \left[\theta_{u,k} + \mu_{u,k} \left(\frac{Y_{d_u} - \sum_{k'} p_{c k'} \theta_{u,k'}}{p_{c k}} \right) \right]$$

$$(3) \quad G_m = \zeta_{g,m} T G$$

$$(4) \quad I_m = \zeta_{i,m} (I_r + I_u) / p_m$$

¹⁸ Though this is a logical interpretation of the ELES specification, in the calibration process, there is nothing which guarantees that the subsistence minima are positive.

Equations (1) and (2) represent the household consumption equations. L is labour supply, Y_d disposable income, and p_c consumer prices. The ELES parameters θ (subsistence minima) and μ (marginal propensity to consume) are described in Annex 4.

The government and investment sectors only consume non-agricultural commodities in fixed shares, see equations (3) and (4). TG is total real government expenditure. In equation (4), $I_r + I_u$, is total nominal investment in both rural and urban sectors, and p is the domestic price of the non-agricultural composite.

B. Urban Production

Production in the urban sector is modeled according to a commonly used structure, Leontief fixed coefficients for intermediate inputs and a value added aggregate. The value added aggregate is a CES composite of capital and labour. A further simplification is made by assuming the CES value added aggregation function is the same across all sectors (i.e. the capital-labour ratio is not sector specific).

Table 3: Urban Production

$$(5) \quad V_{u,m} = \sum_{m=1}^{n_{manu}} a_{mm'} XD_m$$

$$(6) \quad VA_u = \sum_m va_m XD_m$$

$$(7) \quad L_u^d = \frac{\delta_1^{\epsilon_u} \left(\frac{pva_u}{w_u} \right)^{\epsilon_u} (1+\gamma_u)^{t\epsilon_u} \delta_k^{-\epsilon_u/(1-\epsilon_u)} K_u}{\left[1 - \delta_1^{\epsilon_u} \left(\frac{pva_u}{w_u} \right)^{\epsilon_u-1} (1+\gamma_u)^{t(\epsilon_u-1)} \right]^{1-\epsilon_u}}$$

$$(8) \quad VA_u = \frac{(1+\gamma_u)^t \delta_k^{-\epsilon_u/(1-\epsilon_u)} K_u}{\left[1 - \delta_1^{\epsilon_u} \left(\frac{pva_u}{w_u} \right)^{\epsilon_u-1} (1+\gamma_u)^{t(\epsilon_u-1)} \right]^{1-\epsilon_u}}$$

Equation (5) defines total intermediate demand per activity in urban production. $a_{mm'}$ are the input output coefficients and XD total domestic output of urban commodities. Equation (6) defines total value added which within each

sector as a fixed proportion of domestic gross output. Equation (7) defines labour demand derived from cost minimisation of the CES value added aggregate of capital and labour (see Annex 6 for a derivation of the factor demand equations). L^d is the demand for labour, pva_u is the price of urban value added, w_u is the actual nominal wage, and K_u is the urban capital stock. δ_l and δ_k are the CES share parameters, ε_u is the CES elasticity, and γ_u is the exogenous trend of urban value added. A similar equation exists for capital demand. However, instead of this, the model includes the derived optimal value added level as a function of capital, the nominal wage and the price of value added, see equation (8). In essence, equation (8) defines the price of value added, if solved for pva_u .

C. Agricultural Production

With a few exceptions, it is difficult to derive separate production structures for individual agricultural commodities.¹⁹ Therefore, agricultural commodities have been grouped into two production sectors: crops and livestock. Each of the two sectors is described by a distinct production structure which express how various inputs are transformed into a set of agricultural products (X_i). In other words, the model does not distinguish between inputs used in growing wheat from those for coarse grains.²⁰ Derived demand for the aggregate input from individual crops, sum up into a total demand for a crop specific aggregated input, R_{cr} . In a similar way, we define total demand for a livestock specific input, R_{lv} .

Individual agricultural commodities are produced under decreasing returns with respect to a single composite input. This composite input includes commodity inputs from both the rural and urban sectors (e.g. feed, seed, energy, services), land (both irrigated and non-irrigated), labour, farm equipment, cattle, and fertilizers. This input is not differentiated across the various sectors belonging respectively to the crops and livestock sectors, though the crop specific input, R_{cr} , is different from the livestock specific input, R_{lv} . Formally, we can write:

$$\sum_{i \in \text{Crops}} X_i = f_{cr}(R_{cr}) = H_{cr}(L, K, T, \dots)$$

$$\sum_{i \in \text{Livs}} X_i = f_{lv}(R_{lv}) = H_{lv}(L, K, T, \dots)$$

i.e. total output in the crops/livestock sectors, are a sector specific function of a composite input, which in turn is a specific function of inputs (X is sectoral supply, and L, K, T are symbols for agricultural inputs).

Individual agricultural commodities will have different marginal costs. Part of the composite input of both R_{cr} and R_{lv} are predetermined and fixed in the short

¹⁹ There are some notable exceptions. For example, the Agricultural Trade Division of the OECD's Directorate for Food, Agriculture and Fisheries has undertaken a significant effort to estimate sector specific production structures for the EEC.

²⁰ The crops sector includes wheat, coarse grains, rice, sugar, tea, cocoa, coffee, oils, other food, cotton, other non-food. The livestock sector includes meats (ruminants and non-ruminants, dairy and wool. (The next version of RUNS is likely to include a third production sector named tree crops which will include tea, cocoa and coffee.)

term in each region. The various agricultural activities compete for this fixed amount of primary resources, composed of land, draught animals, labour, and farm machinery. This is a key mechanism in reproducing the complexity of the world agricultural system where all commodities are linked together by chains of substitutions. For instance, an increase in the world price of coffee will raise world prices of other commodities to the extent that factors are not product specific.

Production functions for individual commodities use a generalised form of the Cobb-Douglas specification, and are downward constrained by a lower bound minimum subsistence level of production (M_i). The following equation gives the inverse form of this production function, and is easily checked to be a standard Cobb-Douglas specification if the parameter c is set to zero:

$$R = \left(\frac{1}{\alpha}\right)^{1/\beta} \frac{\beta}{1+\beta} \left(\frac{1}{(1+\gamma)^t}\right)^{1/\beta} X^{(1+\beta)/\beta} + c X$$

Farmers maximise their net profits from each production separately, given the farm gate price, pp , the price of the composite input, pr , and an exogenous technological trend γ , i.e.

$$\max pp X - pr R$$

s.t.

$$M \leq X \leq CD(R, \gamma)$$

First order conditions yield a commodity supply function which is given by equation (9) in Table 4. Commodity output is an increasing function of the relative price ratio (pp/pr), bounded below by the minimum subsistence level. The supply equation can be substituted back into the composite input demand equation to yield equation (10).

The supply price elasticity is given by:

$$\epsilon = \frac{\beta}{1 - c \frac{pr}{pp}}$$

One of the advantages to this formulation of agricultural supply is that the supply system is easily calibrated using price supply elasticities which have been frequently estimated and are readily available from the literature. See Annex 7 for a more in depth analysis of the agricultural production function.

Equation (11) defines the aggregate composite input demand in the crops sector (where the set Crops contains the indices for the crops sectors), and equation (12) is the aggregate composite input demand in the livestock sector (where the sum is over the livestock sectors).

Table 4: Agricultural Production

$$(9) \quad X_i = \alpha_i (1+\gamma)^t \left(\frac{pp_i}{pr_i} - c_i \right)^{\beta_i} \geq M_i \quad \text{if } \frac{pp_i}{pr_i} \geq c_i$$

$$(10) \quad R_i = \alpha_i (1+\gamma)^t \left(\frac{pp_i}{pr_i} - c_i \right)^{\beta_i} \left[\frac{\beta_i}{1+\beta_i} \left(\frac{pp_i}{pr_i} - c_i \right) + c_i \right] \quad \text{if } \frac{pp_i}{pr_i} \geq c_i$$

$$(11) \quad R_{cr} = \sum_{i \in \text{Crops}} R_i$$

$$(12) \quad R_{lv} = \sum_{i \in \text{Livs}} R_i$$

D. Production Structure In the Crops Sector

We turn now to the structure of production in the crops sector, i.e. the allocation of the total composite input, R_{cr} . At this stage, farmers have decided their optimal mix of products by solving the above supply system for a given set of prices. The next stage in their decision is to minimise the cost of the composite input by making the optimal choice of the various intermediate inputs and factor use. While intermediate inputs are in infinite supply, the endowment of each primary factor, apart from labour, is pre-determined in each period. RUNS identifies five agricultural primary resources: labour (L_r), dry land (DL), irrigated land, (IL), draught cattle (LST), and farm machinery (DST). All are assumed to be perfectly mobile between the various crop and livestock products.

There have been numerous studies on the ways in which intermediate inputs and primary factors combine to produce farm gate products. One emerging view, describes the production process in agriculture as based on archetypal substitutions and complementarities between factors.²¹ In countries where land is scarce, farmers resort to intensive use of irrigation techniques. Soil protection requirements and the small size of cultivated parcels rule out any intensive use of tractors. Rice terraces in Thailand illustrate the complementary uses of labour, irrigation, and fertilizers in response to land area constraints. This is referred to as a *biological technology*. On the other extreme, North American agriculture features the complementary use of abundant land resources and motorised traction, described as a *mechanical technology*, and the latter has helped to overcome the relatively high cost of labour.

This taxonomy has been slightly modified in the RUNS model. First, the strict complementarity between labour and fertilizers, as implied by the biological technology, has been waived as being too restrictive. For instance, agricultural development in Europe has been intensive in chemical use in response to both

²¹ For example, see Binswanger and Ruttan (1978).

land and labour scarcities. Second, we treat tractor and draught cattle use as distinct factors with the former being part of the mechanical technology and the latter considered as an ingredient of biologically based agriculture. There are indeed agrotechnical and economic reasons for using bullocks on wet land as best suited for traction. On the other hand, irrigation sometimes creates a need for mechanisation by making multi-cropping possible. Some African dry soils are so unstable that they can only be ploughed by draught animals. In spite of these exceptions, we took as the most widely held view that tractors have technical and economic comparative advantages in regions with abundant land and scarce labour. Draught animals are advantageous in regions with scarce irrigated land and abundant labour.²²

The representation of these complex patterns is a matter of judgement, any practical solution will be regarded as an oversimplification, especially when it has to be implemented on a world wide basis. The aggregate resource input for crops, R_{cr} , incorporates these patterns of substitutions and complementarities through embodied fixed coefficient and CES functions. Figure (1) graphically depicts the structure of production in the crops sector. Demand for seeds, feed, and urban products (except for fertilizers) are specified as fixed coefficient functions. The residual resource is modeled as a three factor CES function between fertilizers, the composite factor "land-tractor", and the composite factor "labour-irrigation-draught cattle".

Equation (13) in Table 5, describes the demand for seeds as proportional to crop input in each sector. Equation (14) describes the demand for feed as proportional to the stock of draught animals. Equation (15) describes the demand for fuels as proportional to the stock of tractors.²³ Equation (16) describes the demand for other urban commodities (other manufacturing, services, and equipment) as proportional to the total crop input, R_c . Equation (17) defines the residual composite input, i.e. the total input in crops, R_c , less the inputs defined in equations (13)-(16).

Equations (18)-(21) define the factor demands derived from the CES aggregation of the inputs fertilizer, "land+tractors", and "labour+irrigation+draught cattle". Equation (21) defines the price of the CES aggregate. The "land+tractor" aggregate is denoted by A, with a price p_a . The "labour+irrigation+draught cattle" aggregate is denoted by W, with a price p_w . The aggregate CES price is denoted by p_{cr} . The CES elasticity of substitution is ϵ_{cr} , and the share parameters are denoted by α_c . Finally, equation (22) defines the unit value of the composite input in the crops sector.

²² See, for example, World Bank (1983) and Lele (1975).

²³ Note that demand for urban intermediates is in terms of the composite good, i.e. domestic and imported. This demand is further disaggregated according to the Armington CES specification.

Figure 1. Input Demand in Crop Sector

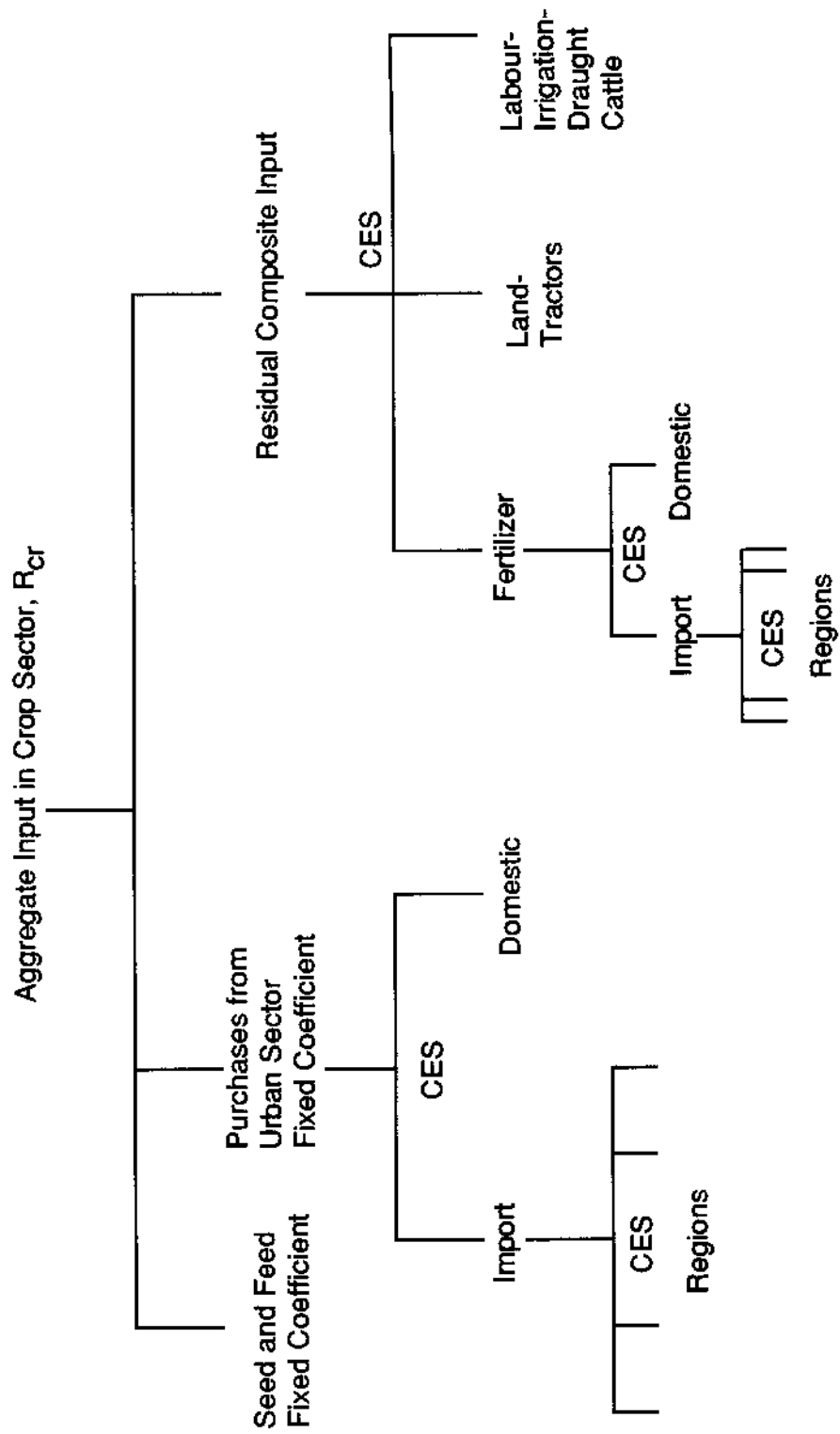


Table 5: Production Equations in the Crops Sector

(13) $Seed_{cr,i} = a_{cr,i} R_i \quad i \in \text{Crops}$

(14) $Feed_{cr,i} = a_{cr,i} LST$

(15) $V_{cr,ener} = a_{cr,ener} DST$

(16) $V_{cr,m'} = a_{cr,m'} R_{cr} \quad m' \in \{ \text{manu, serv, equip} \}$

(17) $AKLF_{cr} = R_{cr} - \left[\sum_i (Seed_{cr,i} + Feed_{cr,i}) + \sum_{m \neq fert} V_{cr,m} \right]$

(18) $V_{cr,fert} = ac_1^{\epsilon_{cr}} \left(\frac{p_{cr}}{p_{fert}} \right)^{\epsilon_{cr}} AKLF_{cr}$

(19) $A_{cr} = ac_2^{\epsilon_{cr}} \left(\frac{p_{cr}}{p_a} \right)^{\epsilon_{cr}} AKLF_{cr}$

(20) $W_{cr} = ac_3^{\epsilon_{cr}} \left(\frac{p_{cr}}{p_w} \right)^{\epsilon_{cr}} AKLF_{cr}$

(21) $p_{cr} = \left(ac_1^{\epsilon_{cr}} p_{fert}^{1-\epsilon_{cr}} + ac_2^{\epsilon_{cr}} p_a^{1-\epsilon_{cr}} + ac_3^{\epsilon_{cr}} p_w^{1-\epsilon_{cr}} \right)^{\frac{1}{1-\epsilon_{cr}}}$

(22) $p_{cr} = \frac{\sum_i p_i (Seed_{cr,i} + Feed_{cr,i}) + \sum_m p_m V_{cr,m} + p_a A_{cr} + p_w W_{cr}}{R_{cr}}$

E. Production Structure in the Livestock Sector

The livestock production function reflects substitution between land and concentrated feedstuffs, i.e. range fed versus ranch fed livestock. It also takes into account substitution between oil cakes (mostly derived from soybean), and cereals. The latter is a major component of current negotiations between the US and the EEC. The flexibility by which the concentrated feedstuff industry adjusts feedstuff mixes to prices is undoubtedly an important factor that will enable agriculture to adjust to the removal of protection.

These substitutions are introduced by way of a four factor CES function. The four components are wheat, coarse grains, oils, and the composite "land+tractor" resource. The other intermediate inputs include other primary feedstuffs, such as

sugar beet residues. These latter, as well as use of urban commodities are treated using fixed proportions. Finally, there is a fixed coefficient component consisting of livestock. Figure (2) graphically depicts the production structure of the livestock sector, which embodies the various CES and perfect substitute aggregates.

Equation (23) in Table 6 describes the intermediate use of feedstuffs other than the three feedstuff components of the CES aggregate. Equation (24) defines the proportional input of livestock.²⁴ Equation (25) defines the energy input as proportional to the stock of tractors. Equation (26) defines the input for the other composite urban commodities (note that in general only the coefficient for services is different from zero). Equation (27) defines the residual CES aggregate of feedstuffs and the "land+tractor" composite (note the sum over other, excludes wheat, coarse grains and oils). This aggregate is designated by the variable AKFD. Equations (28)-(32) describe input demand for the components of the CES aggregate, plus the dual price of the CES aggregate (p_{IV}). The CES elasticity is designated by the parameter ϵ_{IV} , the coefficients, a_i , are the CES share parameters. p_p are the agricultural commodity prices. Finally, equation (33) defines the unit price of the composite resource in the livestock sector.

²⁴ The coefficients are all equal to zero except for the meats coefficient, the designation of this variable by the name *Seed* is simply for notational convenience.

Figure 2. Input Demand in Livestock Sector

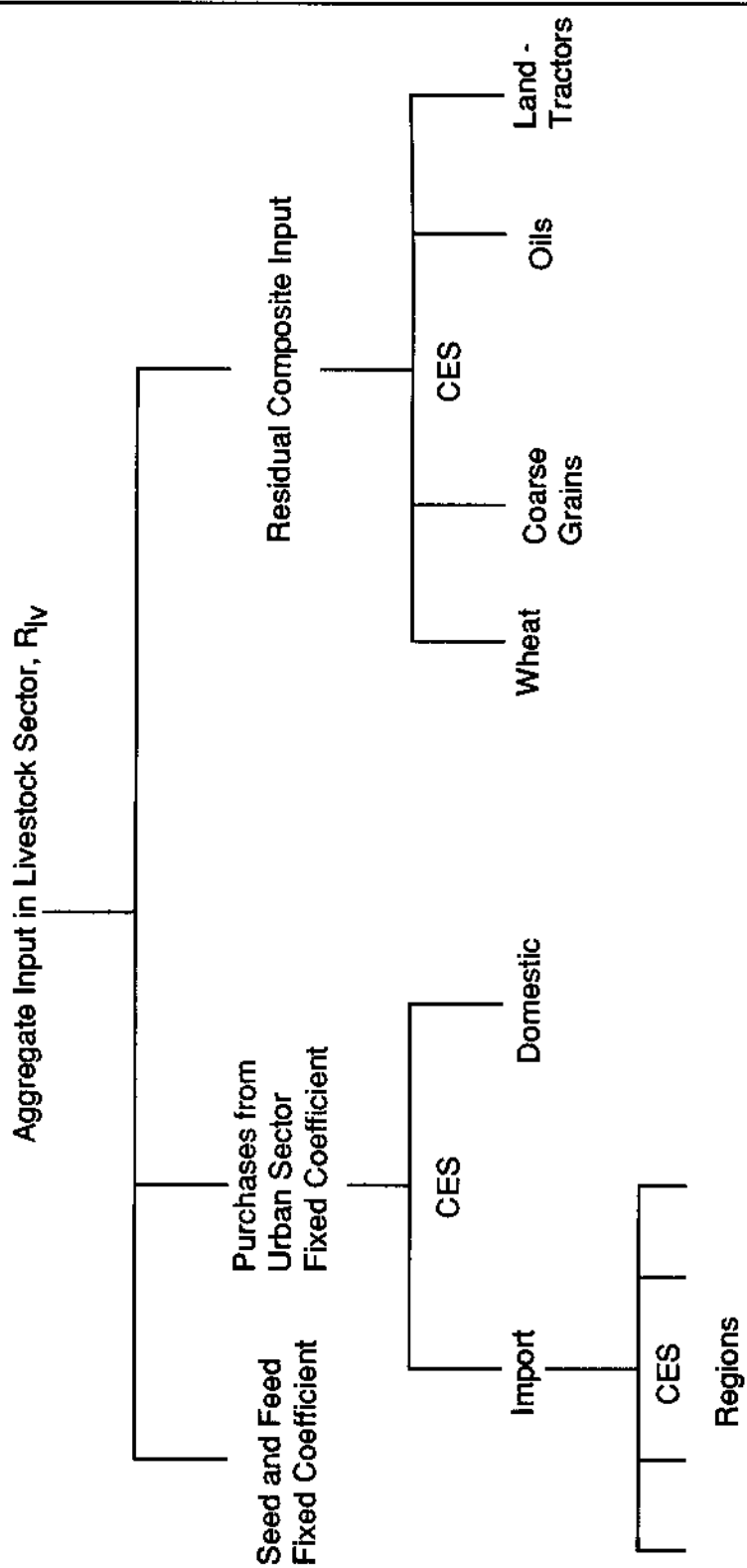


Table 6: Production Equations In the Livestock Sector

$$(23) \text{ Feed}_{lv,i'} = a_{lv,i'} (R_{lv}) \quad i' \neq \{\text{wheat, coarse grains, oils}\}$$

$$(24) \text{ Seed}_{lv,i} = a_{lv,i} (R_{lv})$$

$$(25) V_{lv,ener} = a_{lv,ener} \text{ DST}$$

$$(26) V_{lv,m'} = a_{lv,m'} R_{lv} \quad m' \in \{\text{manu, serv, equip, fert}\}$$

$$(27) \text{ AKFD}_{lv} = R_{lv} - \left[\sum_{i' \in \text{Other}} \text{Feed}_{lv,i'} + \sum_i \text{Seed}_{lv,i} + \sum_m V_{cr,m} \right]$$

$$(28) \text{ Feed}_{lv,\text{wheat}} = a_1^{\varepsilon_{lv}} \left(\frac{p_{lv}}{pp_{\text{wheat}}} \right)^{\varepsilon_{lv}} \text{ AKFD}_{lv}$$

$$(29) \text{ Feed}_{lv,\text{cgrains}} = a_2^{\varepsilon_{lv}} \left(\frac{p_{lv}}{pp_{\text{cgrains}}} \right)^{\varepsilon_{lv}} \text{ AKFD}_{lv}$$

$$(30) \text{ Feed}_{lv,\text{oils}} = a_3^{\varepsilon_{lv}} \left(\frac{p_{lv}}{pp_{\text{oils}}} \right)^{\varepsilon_{lv}} \text{ AKFD}_{lv}$$

$$(31) A_{lv} = a_4^{\varepsilon_{lv}} \left(\frac{p_{lv}}{pa_r} \right)^{\varepsilon_{lv}} \text{ AKFD}_{lv}$$

$$(32) p_{lv} = \left(a_1^{\varepsilon_{lv}} pp_{\text{wheat}}^{1-\varepsilon_{lv}} + a_2^{\varepsilon_{lv}} pp_{\text{cgrain}}^{1-\varepsilon_{lv}} + a_3^{\varepsilon_{lv}} pp_{\text{oils}}^{1-\varepsilon_{lv}} + a_4^{\varepsilon_{lv}} pa_r^{1-\varepsilon_{lv}} \right)^{\frac{1}{1-\varepsilon_{lv}}}$$

$$(33) p_{lv} = \frac{\sum_i pp_i (\text{Feed}_{lv,i} + \text{Seed}_{lv,i}) + \sum_m p_m V_{lv,m} + pa_r A_{lv}}{R_{lv}}$$

F. Rural Household Income, Taxes, and Savings

Rural households derive their income from returns to primary factors employed in the two agricultural sectors, producer profits, and income transfers. Equations (34) and (35) in Table 7 define producer profits in the crops and livestock sectors, respectively. Note that one of the policy instruments in RUNS is a sector specific input subsidy, s_i , which is applied to the total cost of inputs.

Equation (36) defines total rural income as the sum of factor returns and agricultural producer profits. Equation (37) defines total rural disposable income. Y_{Tr} represents total transfers which will be defined below. These transfers include

rural shares of income generated by trade taxes. Equation (38) describes rural taxes which are a constant share of real rural GDP, multiplied by the government price deflator, pg . Equation (39) defines real rural GDP. Finally, equation (40) defines rural household savings as the residual of disposable rural income after consumer purchases.

Table 7: Rural Income

$$(34) \quad \Pi_{cr} = \sum_{i \in \text{Crops}} [pp_i X_i - pr_i R_i]$$

$$(35) \quad \Pi_{lv} = \sum_{i \in \text{Livs}} [pp_i X_i - pr_i R_i]$$

$$(36) \quad Y_r = pa_r (A_{cr} + A_{lv}) + pw_r W_{lv} + \Pi_{cr} + \Pi_{lv}$$

$$(37) \quad Y_{dr} = Y_r - TAX_r + YT_r$$

$$(38) \quad TAX_r = pg (\kappa_r VA_r)$$

$$(39) \quad VA_r = A_{cr} + A_{lv} + W_{lv} + \sum_i [X_i - (1-s_i) R_i]$$

$$(40) \quad S_r = Y_{dr} - \sum_k pc_k C_{r,k}$$

G. Urban Household Income, Taxes, and Savings

Urban households derive their income from urban value added. Disposable income is defined as total urban income, less taxes, plus transfers. Transfers will be defined below. Equation (41) in Table 8 defines total urban income. Equation (42) defines urban disposable income. Equation (43) defines nominal urban taxes. Finally, equation (44) defines residual urban household savings.

Table 8: Urban Income

$$(41) \quad Y_u = pva_u VA_u$$

$$(42) \quad Y_{du} = Y_u - TAX_u + YT_u$$

$$(43) \quad TAX_u = pg (\kappa_u VA_u)$$

$$(44) \quad S_u = Y_{du} - \sum_k pc_k C_{u,k}$$

H. Trade Specification

The trade specification differs between agricultural commodities and non-agricultural commodities. Agricultural commodities are considered to be homogeneous, while trade in non-agricultural commodities is specified using the *Armington* specification. This means that intermediate and final demand for non-agricultural goods is in terms of a composite good which is differentiated by origin.

For each agricultural commodity i , a net trade balance, NT , is calculated as the residual between domestic supply, X , and total domestic demand. Total domestic demand includes rural and urban household consumption, agricultural intermediate demand (seed and feed), and an exogenous component, changes in stocks, which incorporates both stock changes and waste. Equation (45) in Table 9 describes net trade in agriculture.

For non-agricultural commodities, each country minimises the cost of its domestic demand given that products from different countries, including the home one, are imperfect substitutes. At a first stage, total domestic demand in a country is treated as a CES aggregate of the home produced commodity, XS_m , and of a composite imported good TM_m . In the second stage, the latter is then considered as a CES aggregate of exports from all other countries. Equation (46) defines total domestic demand for the non-agricultural composite good. This demand incorporates rural and urban household consumption, government and investment demand, and rural and urban intermediate demand. Equation (47) defines domestic absorption of domestic production. Equation (48) defines domestic absorption for the import aggregate.

On the output side, domestic producers supply differentiated goods for the domestic market and the export market using a *constant elasticity of transformation* (CET) production frontier (see Annex 3 for a description of the CET specification). Equation (49) describes the supply of goods for the domestic market, equation (50) describes export supply. XD is total gross output and is an aggregate composite of XS , domestic sales, and ES , foreign sales. The elasticity of substitution is given by σ_e , and cd and ce are the CET share parameters. The relevant prices are pd , the domestic sales price, pe , the export price, and px , the unit output price. Equation (51) defines the CET aggregation function for the domestic producer. (Note equations (49)-(51) hold for sectors modeled using the CET specification). Equation (52) describes the commodity equilibrium in the case of perfect substitutability between domestic and foreign markets, in which case domestic output can be equated to domestic sales plus foreign sales.

In total the model has five separate goods in each of the non-agricultural sectors, with five distinct prices:

X	Total domestic absorption ($X=CES(XS, TM)$) with price p
XS	Domestic sales of domestic production with price pd
XD	Aggregate domestic output ($XD=CET(XS, ES)$) with price px
TM	Aggregate domestic imports with price pm
ES	Foreign sales of domestic production with price pe

Table 9: Trade Equations

$$(45) \quad NT_i = X_i - [C_{r,i} + C_{u,i} + \text{Seed}_{cr,i} + \text{Feed}_{cr,i} + \text{Seed}_{lv,i} + \text{Feed}_{lv,i} + St_i]$$

$$(46) \quad X_m = C_{r,m} + C_{u,m} + G_m + I_m + V_{cr,m} + V_{lv,m} + V_{u,m}$$

$$(47) \quad XS_m = \left(ad_m^{\zeta_m} \left(\frac{p_m}{pd_m} \right)^{\zeta_m} X_m \right)$$

$$(48) \quad TM_m = \left(am_m^{\zeta_m} \left(\frac{p_m}{pm_m} \right)^{\zeta_m} X_m \right)$$

$$(49) \quad XS_m = cd_m \left(\frac{pd_m}{px_m} \right)^{\sigma_e} XD_m \quad m = \{ \text{CET} \}$$

$$\text{where } \rho_e = 1 + \frac{1}{\sigma_e}$$

$$(50) \quad ES_m = ce_m \left(\frac{pe_m}{px_m} \right)^{\sigma_e} XD_m \quad m = \{ \text{CET} \}$$

$$(51) \quad XD_m = \left(cd^{\frac{1}{1-\rho_e}} XS_m^{\rho_e} + ce^{\frac{1}{1-\rho_e}} ES_m^{\rho_e} \right)^{1/\rho_e} \quad m = \{ \text{CET} \}$$

$$(52) \quad XD_m = XS_m + ES_m \quad m \neq \{ \text{CET} \}$$

$$(53) \quad E_m^{r,r} = \left(\Phi_m^{r,r} \right)^{\epsilon_m^r} \left(\frac{pe_m^r (1 + \tau_{e,m}^{r,r}) (1 + \tau_{m,m}^{r,r})}{pm_m^r} \right)^{\epsilon_m^r} TM_m^r$$

$$(54) \quad TE_m^r = \sum_r \left(\Phi_m^{r,r} \right)^{\epsilon_m^r} \left(\frac{pe_m^r (1 + \tau_{e,m}^{r,r}) (1 + \tau_{m,m}^{r,r})}{pm_m^r} \right)^{\epsilon_m^r} TM_m^r$$

Equation (53) describes the second nest of the Armington specification, i.e. the split of the aggregate import across the regions, thereby defining import demand from each region. In equation (53), we explicitly put the regional indices. The variable $E_m^{r',r}$ is the level of imports for good m , in country r , originating in country r' , i.e. for country r , it is the split of total imports TM_m^r , according to the Armington specification. This import depends on the ratio of prices between the originating country's export price inclusive of export taxes/subsidies and the destination countries import taxes/subsidies, and on the other hand the aggregate import price, p_m , in the destination country.²⁵ In other words, a country desiring to export more, must lower its export price relative to the aggregate import price of the target country. Finally, equation (54) defines export demand as perceived in the home country. It is the sum across the world, of imports by each country of the home country's good. Note the reversal of the indices.

I. Prices

A distinctive feature of RUNS is that it departs from the strictly neo-classical paradigm by incorporating behavioural price rigidities. Agricultural policies around the world are governed by the important distributional implications of real food prices:

"All consumers would like food prices to be lower, to take a smaller portion of their family budgets. All farmers would like their crop prices to be higher, to provide them greater return for their efforts and investments."²⁶

This is translated into RUNS by assuming that both sides of the rural/urban terms of trade are subject to rigidities. First, agricultural prices are domestically set with regard to policy considerations aimed either at protecting producers, as in most of the OECD, or to protecting consumers, as is the case in many LDCs. Second, urban wages are semi-rigid with respect to some level of wage indexation.

Agricultural prices are determined by a policy equation which is estimated for each commodity and for each region. Many models incorporate agricultural policies as constant *ad valorem* price wedges between domestic and world prices. In reality, nominal protection rates in agriculture fluctuate sharply from year to year, related to fluctuations in world prices and exchange rates. For example, the average wheat PSE for the OECD as whole rose from 24 per cent in 1984 to 61 per cent in 1986, before falling back to 40 per cent in 1988.²⁷ These fluctuations resulted mainly from world market price fluctuations. This reflects the extent to which agricultural policies are often targeted on some internal price parity with little consideration given to the level of world market prices.

²⁵ While the Instruments for the non-agricultural wedges have always been present in the model, comprehensive estimates for these instruments did not exist. In collaboration with the World Bank, a comprehensive set of non-agricultural wedges has recently been developed for the RUNS model and are now included as part of the base simulation. These wedges not only measure statutory tariff rates, but also attempt to incorporate non-tariff barriers as well. See Roland-Holst (1991).

²⁶ Timmer et. al., (1983)

²⁷ See OECD, 1989. Producer subsidy equivalent (PSE) is an aggregate measure of protection which essentially defines the ratio of the domestic producer price to a representative world price.

In RUNS, we chose a flexible specification which makes it possible to express domestic agricultural prices (pp_r) with respect to both domestic non-agricultural prices (pp_u) and to agricultural world prices (pw). The following two equations provide two identical notations for this price policy equation:

$$\frac{pp_r}{pp_u} = \left(\varphi + (1-\varphi) \frac{pw}{pp_u} \right) (1 + \tau^*)$$

$$\frac{pp_r}{pw} = \left(\varphi \frac{pp_u}{pw} + (1-\varphi) \right) (1 + \tau^*)$$

A value of 1 for φ makes the rural/urban price ratio (pp_r/pp_u) constant and the industrial output sensitive to changes in the urban real exchange rate only. Such an agricultural price policy implies insulating the domestic economy from world price changes of agricultural commodities, hence, it will be called a *non-adjusting* policy. In such a case, the nominal protection rate, (pp_r/pw), varies from its initial benchmark value τ^* , as a residual between the change of the domestic non-agricultural price, pp_u , and that of the agricultural world price, pw .²⁸ Agricultural policies based on variable import levies and export refunds, as in Europe, clearly belong to this category. A recent EEC proposal at the Uruguay Rounds may suggest a possible shift towards a more *adjusting* policy.

On the other hand, a value of 0 for φ corresponds to the usual *ad valorem* tariff case (τ^*). It is referred to as an *adjusting* policy and coincides with those countries where farmers have to respond to world market price signals. The urban sector of an *adjusting* country has to support more of the shocks transmitted by the world agricultural markets. For instance, an increase in world agricultural prices, if it is passed through the domestic market, like in Brazil or Argentina, would trigger a shift in agricultural supply towards exports. This, in turn, would result in domestic food price increases and upward pressure on the nominal urban wage, leading to a weakening of the competitiveness of manufactured exports.

To illustrate how these policies interact, let us express total industrial output as a function of the price ratio (pp_u/w_u), and urban capital, K_u (assuming there is some level of unemployment):

$$X_u = CES\left(\frac{pp_u}{w_u}, K_u\right)$$

where pp_u denotes the aggregate non-agricultural producer price, w_u is a fixed urban wage such that $w_u \geq w_u^e$, w_u^e is the equilibrium wage, and K_u is the predetermined urban capital stock.

For a medium term model like RUNS, it is not recommended to treat the urban nominal wage as exogenously fixed and we need to identify a more realistic concept, such as a downward partial rigidity of the urban real wage. The rigidity is partial since the nominal wage, w_u , is a function of the average consumer price and

²⁸ The normalisation rule of the benchmark year implies that $pp_u = pw = 1$. Hence, $pp_r = (1 + \tau^*)$.

the full-employment equilibrium wage, w_u^e . Therefore, as long as w_u exceeds w_u^e , w_u is a function of the aggregate agricultural price pp_r , the urban price pp_u , the world non-agricultural price p_m , treated as the *numéraire*, and the level of the equilibrium wage, w_u^e . We can write:

$$X_u = CES\left(\frac{pp_u}{pp_r}, pp_u, w_u^e, K_u\right) \quad \text{if } w_u > w_u^e$$

$$X_u = CES(K_u) \quad \text{if } w_u = w_u^e$$

The equation above illustrates that as long as full employment is not reached in the urban sector, the output level in industries and services is sensitive to the rural/urban terms of trade defined as the ratio between agricultural (pp_r) and non-agricultural (pp_u) prices. It reveals why many LDCs discriminate their domestic prices against agriculture in order to promote their industrial development. On the other hand, in developed countries, such as in Europe, agricultural policies aim to compensate farmers' incomes from being squeezed by deteriorating real prices. This leads to a negative impact on industrial growth and employment.

a) Wages and Urban Labour Market Equilibrium

Equation (55) in Table 10a describes the equilibrium nominal wage, i.e. the wage that clears the labour market (all else given).²⁹ Equation (56) defines the urban consumer price index. Equation (57) defines the equilibrium real wage. Equations (58a) and (58b) define the two possible wage regimes. If the actual nominal wage clears the labour market, then the actual real wage equals the equilibrium real wage. If, on the other hand, the nominal wage is higher than the equilibrium nominal wage, then the actual real wage is a weighted average of the equilibrium real wage and a sticky real wage. The sticky real wage is itself defined by a weighted average of a reference real wage growth rate and the equilibrium real wage growth rate, applied to the previous actual real wage. For reference, there are three real wages: rw_u - the actual real wage, rw_u^e - the equilibrium real wage, and $rw_u^{\hat{}}$ - the reference real wage. The weights, ω_1 and ω_2 are exogenous parameters under user control which can be modified in every simulation period. Finally, equation (59) defines the actual nominal wage.

²⁹ It is not the *true* equilibrium wage since a price clearing labour market is likely to affect other variables, such as migration which would lead to a different equilibrium wage.

Table 10a Wage Equations

$$(55) \quad w_u^e = \delta_l \left(\frac{VA_u}{L_u} \right)^{\frac{1}{\epsilon_u}} (1+\gamma_u)^{\frac{-t(1-\epsilon_u)}{\epsilon_u}} pva_u$$

$$(56) \quad cpi_u = \frac{\sum_k p_{ck} C_{u,k}}{\sum_k C_{u,k}}$$

$$(57) \quad rw_u^e = w_u^e / cpi_u$$

$$(58a) \quad rw_u = rw_u^e \quad \text{if } w_u = w_u^e$$

$$(58b) \quad rw_u = \omega_2 rw_u^e + (1-\omega_2) rw^* \quad \text{if } w_u > w_u^e$$

$$\text{where } rw^* = rw_{u,t-1} \left[\omega_1 \frac{rw_{u,t}^*}{rw_{u,t-1}} + (1-\omega_1) \frac{rw_{u,t}^e}{rw_{u,t-1}^e} \right]$$

$$(59) \quad w_u = cpi_u rw_u$$

b) Agricultural Price Equations

Equation (60) in Table 10b, implements the agricultural price policy equations. Three modifications are introduced compared to the equations above. First, the urban price is multiplied through. Second, lag effects are introduced (thereby the necessity of introducing the time index). Third, the domestic price for meats is a function of the input cost of meat and *not* the gdp price index. The parameters, ϕ , have been estimated for each commodity and each region.

Table 10b Agricultural Price Equations

$$(60a) \quad pp'_{i,t} = (\phi_i^1 pw_{i,t} + \phi_i^2 pw_{i,t-1} + \phi_i^3 pw_{i,t-2} + \phi_i^4 PGDP_t + \phi_i^5 PGDP_{t-1} + \phi_i^6 PGDP_{t-2})(1 + \tau_i^0)$$

$$pp_{i,t} = pp'_{i,t} / (1 + \tau_i^0)$$

$i \neq \text{meats}$

$$(60b) \quad pp'_{i,t} = (\phi_i^1 pw_{i,t} + \phi_i^2 pw_{i,t-1} + \phi_i^3 pw_{i,t-2} + \phi_i^4 pr_{iv,t} + \phi_i^5 pr_{iv,t-1} + \phi_i^6 pr_{iv,t-2})(1 + \tau_i^0)$$

$$pp_{i,t} = pp'_{i,t} / (1 + \tau_i^0)$$

$i = \text{meats}$

and

$$\sum_I \phi_i^j = 1.0$$

c) Other Price Equations

Equation (61) in Table 10c defines consumer prices. For the agricultural commodities, this is simply the domestic agricultural price as defined by the price equation (60), i.e. there is no wedge between prices perceived by the farmers and the consumers. For non-agricultural commodities, it is the price vector of the composite non-agricultural goods, i.e. it is a CES aggregate of the domestic urban price and the import price.

Equation (62) defines the price of the composite input for agricultural production in each sector. Though all crops face the same production structure, the individual input price varies due to a sector specific input subsidy. The same is true for the livestock sectors.

Equation (63) describes the urban producer price in each sector. Given the technology, it is simply defined as the unit cost of production. For the non-CET sectors, the domestic sales price of domestic goods is equal to the producer price, as defined in equation (64). Equation (65) defines the aggregate import price. This price is the CES dual price, defined over the export price of commodities from all regions, inclusive of (origin specific) export subsidies/taxes, and (origin specific) import taxes/subsidies. Equation (66) defines the CES dual price of the non-agricultural composite commodity, i.e. the CES aggregate price of the domestically produced good and the aggregate import. Equation (67) defines the equilibrium condition for the export market. In essence, this equation defines the equilibrium

export price (in the implementation of the model, p_e is calculated using tâtonnement). Equation (68) defines the remaining domestic price of non-agricultural exports. For the non-CET sectors the export price is equal to the producer price, p_x , which is equal to the domestic sales price, p_d . An exception is made for the energy sector where the export price is exogenous. The exogenous real price is under user control for every simulation period. The price wedge between the producer price and the export price gives rise to an additional income flow which will be defined below.

Table 10c Other Price Equations

$$(61) \quad p_{Ck} = p_{pi} \quad 1 \leq k \leq nag$$

$$p_{Ck} = p_m \quad k \geq nag$$

$$(62) \quad p_{ri} = (1-s_i) p_{r_{cr}} \quad i \in \text{Crops}$$

$$p_{ri} = (1-s_i) p_{r_{lv}} \quad i \in \text{Livs}$$

$$(63) \quad p_{x_m} = \sum_{m'} a_{m'm} p_{m'} + v_{a_m} p_{va_u}$$

$$(64) \quad p_{d_m} = p_{x_m} \quad m \neq \{ \text{CET} \}$$

$$(65) \quad p_{m_{r,m}} = \left(\sum_r \left(\Phi_m^{r,r} \right)^{\epsilon_m^r} \left(p_{e_m}^{r'} (1 + \tau_{e,m}^{r',r}) (1 + \tau_{m,m}^{r',r}) \right)^{1 - \epsilon_m^r} \right)^{\frac{1}{1 - \epsilon_m^r}}$$

$$(66) \quad p_m = \left(ad_m^{\zeta_m} p_d^{1 - \zeta_m} + am_m^{\zeta_m} p_m^{1 - \zeta_m} \right)^{\frac{1}{1 - \zeta_m}}$$

$$(67) \quad ES_m = TE_m \quad m = \{ \text{CET} \}$$

$$(68) \quad p_{e_m} = p_{x_m} \quad m \neq \{ \text{CET, ener} \}$$

$$p_{e_m} = \overline{p_{e_m}} \text{ POECD} \quad m \in \{ \text{ener} \}$$

J. Trade Income and Income Transfers

There are several distinct price wedges in the RUNS model which all generate income. In general this income will be split across four domestic institutions: rural and urban households, the investment account, and the government. The share parameters are exogenous.

Table 11 Trade Income and Transfers

$$(69) \quad YTA = \sum_i \frac{NT_i}{1+\tau_i^o} (pw_i - pp_i')$$

$$(70) \quad YTe = \sum_m \sum_r E_m^{r,r} pe_m^r \tau_{e,m}^{r,r}$$

$$(71) \quad YTm = \sum_m \sum_r E_m^{r,r} pe_m^r (1+\tau_{e,m}^{r,r}) \tau_{m,m}^{r,r}$$

$$(72) \quad YTex = TE_{ener} (pe_{ener} - px_{ener})$$

$$(73) \quad YTu = YTe + YTm + YTex$$

$$(74) \quad YTst = \sum_i St_i pp_i$$

$$(75) \quad YTue = \rho^{ue} w_u (L_u - L_u^d)$$

$$(76) \quad YTr = \chi_r^a YTa - \chi_r^{st} YTst + \chi_r^u YTu$$

$$(77) \quad YTU = \chi_u^a YTa - \chi_u^{st} YTst + \chi_u^u YTu + YTue$$

Equation (69) in Table 11 defines income generated by the distortions in the agricultural markets, i.e. the price wedge between domestic and world prices. For example, if a country is a food exporter (such as Europe), and the domestic price is greater than the world price, this is equivalent to an export subsidy, i.e. a negative flow. The net trade of agricultural products is divided by the initial price wedge due to the base year normalisation rule.

Equation (70) defines the aggregate income from export subsidies/taxes on non-agricultural exports from the home country. Equation (71) defines the aggregate income from import taxes/subsidies on non-agricultural imports into the home country. Equation (72) defines income generated by the price wedge between the producer price and the export price of energy. Equation (73) is the sum of income generated by distortions in trade in the manufacturing sector: import/export tariffs/subsidies and the exogenous energy price. Equation (74) defines income generated by the net change in agricultural stocks. Equation (75) defines unemployment income.³⁰ Equation (76) defines total income transfers to

³⁰ The unemployment compensation rate, ρ^{ue} , is non-zero only in the OECD countries.

rural households. Equation (77) defines total income transfers to urban households.

K. Government and Investment Accounts

The government's revenues are generated from household taxes and the residual share of income generated by stocks and trade. Its expenditures, apart from expenditures on goods and services (see equation (3)), include input subsidies in agriculture and unemployment compensation. Real government expenditures grow at some exogenous rate with respect to the total growth rate of domestic GDP. Equation (78) defines net government revenues. Equation (79) defines government savings. Equation (80) defines real government expenditures on goods and services. Equation (81) defines total real gross domestic product.

Rural investment is equal to a share of total rural savings, where total rural savings includes a component of net foreign savings. This allows for a transfer of resources from the rural sector to the urban sector. Urban investment is equal to urban household savings, plus government savings, a share of foreign savings, plus a share of total rural savings. Equations (82) and (83) respectively define rural and urban investment. Equation (84) defines total real investment.

Table 12 Government and Investment Accounts

$$(78) \quad Y_g = TAX_r + TAX_u + \chi_g^a Y T^a - \chi_g^{st} Y T^{st} + \chi_g^u Y T^u - \sum_i \frac{S_i}{1-S_i} p r_i R_i - Y T^{ue}$$

$$(79) \quad S_g = Y_g - \sum_m p_m G_m + \chi_g^{aid} S_f$$

$$(80) \quad T G_t = (1+r_g) T G_{t-1}$$

$$\text{where } r_g = xgr (gdp_t/gdp_{t-1} - 1.0)$$

$$(81) \quad gdp = VA_r + VA_u$$

$$(82) \quad I_r = (1-\chi_r^{ui}) \left[S_r + \chi_r^{aid} S_f \right]$$

$$(83) \quad I_u = S_g + S_u + \chi_u^{aid} S_f + \chi_r^{ui} \left[S_r + \chi_r^{aid} S_f \right]$$

$$(84) \quad T I = \sum_m I_m$$

L. Factors of Production

In the rural sector there are five primary factors of production: labour, farm machinery, land (irrigated and non-irrigated), and draught cattle. All of them are assumed to be perfectly mobile between the various crop and livestock products. In the urban sector, there are two primary factors: labour and capital. The model does not allow for any inter-regional factor mobility, however, labour and capital are partially mobile between the rural and urban sectors. Labour migration from the rural to the urban sector occurs within each period, responding to real income differentials.³¹ The model incorporates a minimum non-zero level of migration which predisposes labour to move to the cities, a so-called *city lights* effect.³²

While labour is treated as homogeneous within each region, capital is specific to the rural and urban sectors respectively. This leaves room for some long run level of capital mobility in response to a change in the ratio between rural and urban factor prices. Assume for instance, that real food prices fall. This will result in a decline in rural saving and therefore in investment capacity. The opposite occurs in the urban sector, ultimately leading to a deepening of the urban capital stock.

Whereas urban capital moves freely between the various non-agricultural industries and services, more specificity is assumed in the allocation of rural factors which rules out that capital in agriculture can be instantaneously and entirely reallocated within a given period. A vintage structure is assumed in which the farmer has to decide whether to allocate investment in bringing new land under cultivation, or in irrigating existing land.

Equation (85) in Table 13 shows that the total labour force grows at an exogenously given rate. Equation (86) describes the labour migration function. Equation (87) describes the supply of urban labour which is comprised of two components: an exogenous growth component, and a within period rural to urban migration component. Equation (88) defines rural labour as the residual between the total labour force and the urban labour force. Equation (89) defines the capital stock.³³

Components of rural investment also are adjusted at the beginning of each period except for the stock of feed cattle. Equation (90) describes the stock of feed cattle as a function of the previous period's stock of feed cattle, adjusted for a natural growth rate, the current period's investment in feed cattle, and the previous period's level of slaughter, which is a fixed proportion of the supply of meats. Equation (91) defines the stock of draught cattle, equal to the previous period's stock adjusted for a natural growth rate, plus investment. Equation (92) defines the stock of farm equipment. Land clearing investments are subject to decreasing

³¹ The migration function is a variant of the familiar Harris-Todaro model.

³² See Mundlak, 1979.

³³ As written, equation (89) states that the capital stock does not change within a period. This is true for periods treated as one-year increments. For periods treated as three-year increments, an assumption is made about the growth rate of capital which depends on the current period's investment level, therefore, the current period's capital stock is not pre-determined. The multi-period formula is given by:

$$K_t = (1-\delta)^n K_{t-n} + \frac{\gamma^n - (1-\delta)^n}{\gamma - (1-\delta)} I_{u,t-n}/PINV_{t-n} \quad \text{where } \gamma = \left(\frac{I_{u,t}/PINV_t}{I_{u,t-n}/PINV_{t-n}} \right)^{1/n}$$

returns to scale as the total land area in each region cannot exceed some upper bound potential. Various studies have estimated the maximum amount of land which could be brought under cultivation on each continent. The most comprehensive, undertaken at the Agricultural University of Wageningen, takes into account a set of climatic, pedological, and hydrographical parameters.³⁴ These estimates of maximum land potentials have been integrated into RUNS. As the actual land area approaches this upper bound, the higher the marginal cost of developing new land. Equation (93) defines the desired amount of land stock. The actual amount of total land cultivated is given by equation (94) and is a function of the upper bound potential, LMax, the initial land stock, L₀, and the desired amount. Equation (95) defines the actual stock of irrigated land which is a function of the desired stock, adjusted for the maximum land potential. Finally, equation (96) defines the stock of dry land, as the residual between total land and irrigated land. The split of rural investment into the four components, I_r, is described below.

Table 13 Primary Factor Stocks

$$(85) \quad TLAB_t = (1 + \gamma_{flab}) TLAB_{t-1}$$

$$(86) \quad MG = \mu_0 \left[\frac{Yd_u/L_u}{Yd_r/L_r} - \mu_1 \right]^{\mu_2} \left[\frac{L_u}{L_r} \right]^{\mu_3} (1 + \gamma_u)^{\mu_4} L_r^{\mu_5}$$

$$(87) \quad L_{u,t} = (1 + \gamma_u) L_{u,t-1} + MG_t$$

$$(88) \quad L_r = TLAB - L_u$$

$$(89) \quad K_{u,t} = (1 - \delta_{ku}) K_{u,t-1} + I_{u,t-1}/PINV_{t-1}$$

$$(90) \quad FC_t = (1 + \gamma_{fc}) FC_{t-1} + I_r^{fc} - (1 + \gamma_{meat})^{-t} X_{meat,t-1} / \xi_{sl}$$

$$(91) \quad LST_t = (1 + \gamma_{fc}) LST_{t-1} + I_r^{lst}$$

$$(92) \quad DST_t = (1 - \delta_{tr}) DST_{t-1} + I_r^{dst}$$

$$(93) \quad TL_t^* = TL_{t-1} + I_r^{dl} + I_r^{il}$$

$$(94) \quad TL_t = TL_0 + \frac{(LMax - TL_0) \cdot (TL_t^* - TL_0)}{(LMax - TL_0) + (TL_t^* - TL_0)}$$

$$(95) \quad IL_t = (IL_{t-1} + I_r^{il}) (TL_t/TL_t^*)$$

$$(96) \quad DL_t = TL_t - IL_t$$

³⁴ See Burlingh, Van Heemst, and Staring, 1975.

M. Rural Composite Factors and Prices

The agricultural material balances are expressed in terms of the two rural composite resources, whose components have, respectively, the same marginal cost rate of change at equilibrium, as they are considered to be perfect substitutes in the short term. The primary factors are combined into composites using linear separable functions which convert the physical units of each rural factor supply into benchmark year dollar values of the uses of the two composite resources.³⁵ These functions are linear in all terms, with the exception of irrigated land for which a negative quadratic term introduces diminishing returns to scale.

Equation (97) in Table (14) defines the aggregation of the composite supply of "land+tractors". Equation (98) defines the aggregation of the composite supply of "labour+irrigated land+draught cattle". Equations (99) and (100) define the equilibrium conditions for the two rural composite factors and will generate values for the composite factor prices, pa_r and pw_r . The model is solved by using a simple tâtonnement algorithm which calculates a set of equilibrium prices which satisfies a set of material balance equations. In each period, four factor balances have to hold in each region, together with the global agricultural balances in each sector.

Table 14 Rural Composite Factors and Prices

$$(97) \quad SLa = \delta_1^a \left[\delta_2^a TL + \delta_3^a DST \right]$$

$$(98) \quad SLw = \delta_1^w \left[\delta_2^w IL - \delta_3^w \left(\frac{IL^2}{TL} \right) + \delta_4^w L_r + \delta_5^w LST \right]$$

$$(99) \quad A_{cr} + A_{lv} = SLa$$

$$(100) \quad W_{cr} = SLw$$

N. Price Indices

Equation (101) in Table 15 describes the gdp deflator, note gdp defines *real* gdp. Equation (102) defines the government expenditure index. Likewise, equation (103) defines the investment expenditure index. Equation (104) defines the OECD manufacturing and services export price index. The regional index, r^* , sums over the OECD regions, the commodity index, m^* , sums over other manufacturing, services, and equipment.

³⁵ These functions are derived from a world meta-production function estimated by Mundlak and Hellinghausen (1982).

Table 15 Price Indices

$$(101) \text{ PGDP} = \frac{Y_r + Y_u}{\text{gdp}}$$

$$(102) \text{ pg} = \left[\sum_m p_m G_m \right] / \text{TG}$$

$$(103) \text{ pinv} = (I_r + I_u) / \text{TI}$$

$$(104) \text{ POECD} = \frac{\sum_r \sum_{m'} (p_{e_{r,m'}} \text{TE}_{r,m'})}{\sum_r \sum_{m'} \text{TE}_{r,m'}}$$

O. Equilibrium and Closure

We have already described equilibrium on the key factor markets: urban labour, and the two composite agricultural factors. The last equilibrium market is the world agricultural market. A world price is calculated for each commodity which clears the world market, i.e. a price such that the sum of net trade over all regions is equal to zero. Equation (105) in Table 16 defines the global equilibrium condition for world agricultural markets.³⁶

There are three key macro accounts: government closure, investment-savings closure, and the balance of trade. We have seen above that the government deficit is endogenous. Investment is equal to savings, i.e. the sum of household savings, plus government savings, plus foreign savings is equal to the sum of urban and rural investment. The final closure rule is that the balance of trade (evaluated in world prices) is exogenous, i.e. the balance of trade is equal to our foreign savings variable, S_f . The effect of this closure rule, is to make the real exchange rate the key equilibrating mechanism. A negative terms-of-trade shock, forces a devaluation of the real exchange rate in order to achieve the exogenously determined trade balance. Equation (106) defines the balance of trade in world prices. Equation (107) defines the balance of trade closure, however, this equation is not explicit in the model due to Walras' Law. Equation (108) defines the nominal flow of foreign capital with respect to the OECD export price index. This insures the homogeneity of the model in prices.

The model requires a numéraire. The choice of the numéraire is a user option. There are two choices. The user may specify the price of urban value added in any one of the regions to be numéraire (i.e. $p_{va_u} = 1$ for one of the

³⁶ The benchmark normalisation rule requires the adjustment of net trade by the base year price wedge.

regions), or else, the the user may set POECD to 1. The latter is the normal rule for most simulations.³⁷

Table 16 Equilibrium and Closure

$$(105) \sum_r \frac{NT_{r,i}}{1+\tau_{r,i}} = 0$$

$$(106) \text{balpw}_r = \sum_i p w_i \frac{NT_{r,i}}{1+\tau_{r,i}} + \left[\sum_m p e_{r,m} T E_{r,m} - \sum_m \sum_{r'} E_m^{r',r} p e_{r,m} (1+\tau_{e,m}^{r',r}) \right]$$

$$(107) \text{balpw} = -S_f$$

$$(108) S_f = \text{POECD } \overline{S_f}$$

P. Rural Investment

As stated above, a vintage structure is assumed in which the farmer has to decide whether he will spend his saving in bringing new land into cultivation or irrigating existing land. This investment decision implies maximisation of the expected net return from his total investment, under the constraint of a convex transformation function between one kind of investment and another. Given that farmers' expectations are myopic, the investment structure will gradually change over time so as to reflect the relative scarcity of land and labour endowments.

The investment optimisation problem can be summarised by the following equations, where I_r denotes the gross increments in dry land, I_r^{dl} , irrigated land, I_r^{il} , tractors, I_r^{dst} , and draught cattle, I_r^{lst} , respectively. The optimisation rests on relative prices, $(p_{ir_j}, j=dl, il, dst, lst)$ which reflect the net return of each investment type as a price ratio between the price of the corresponding composite resource to which it contributes and a linear cost function. The optimisation problem is formulated as:

$$\max (p_{irdl} I_r^{dl} + p_{iril} I_r^{il} + p_{irdst} I_r^{dst} + p_{irlst} I_r^{lst})$$

$$\text{s.t. } I_r/p_i \geq \text{CES}(I_r^{dl}, I_r^{il}, I_r^{dst}, I_r^{lst})$$

First order conditions yield the yearly increments of each resource which then effect the future endowments of the various resources through standard accumulation functions (see equations (91)-(96)).

³⁷ If the numéraire is POECD, the program uses a modified tâtonnement to achieve convergence. If the calculated POECD is greater than 1, all factor prices in the OECD regions are reduced by a small amount. They are increased if POECD is greater than 1.

Investment in feed cattle is not undertaken as part of this optimisation process. Instead, the stock of feed cattle grows in proportion to the supply of meats. Equation (109) in Table 17 defines investment in feed cattle. This investment is subtracted from the rural investment pool, and it is the residual amount which is allocated across the four primary rural investment goods.

Table 17 Rural Investment

$$(109) \quad I_r^{fc} = I_r^{fc} (1 + \gamma_{meat})^{-t} \frac{X_{meat,t}}{X_{meat,t-1}}$$

$$(110) \quad U_t = \frac{W_{cr,t}/L_{r,t}}{W_{cr,0}/L_{r,0}}$$

$$(111) \quad PNI_r = \left[(\beta_{dl}^{eir} + \beta_{dst}^{eir}) p a_r^{1-eir} + (\beta_{il}^{eir} + \beta_{lst}^{eir}) p w_r^{1-eir} \right]^{\frac{1}{1-eir}}$$

$$(112) \quad p_{irdl} = (c_{dl} U + (1-c_{dl}) p_{inv}) / (p a_r / PNI_r)$$

$$(113) \quad p_{irdst} = (c_{dst} p d_{eqpt} + (1-c_{dst}) p d_{ener}) / (p a_r / PNI_r)$$

$$(114) \quad p_{irlst} = (c_{lst}^1 p p_{meat} + c_{lst}^2 p r_{iv} + (1-c_{lst}^1 - c_{lst}^2) U) / (p w_r / PNI_r)$$

$$(115) \quad p_{iril} = (c_{il} U + (1-c_{il}) p_{inv}) / (p w_r / PNI_r)$$

$$(116) \quad p_{ir} = \left[\sum_j \beta_j^{eir} p_{ir_j}^{1-eir} \right]^{\frac{1}{1-eir}} \quad j = dl, dst, lst, il$$

$$(117) \quad I_r^j = \beta_j^{eir} p_{ir_j}^{-eir} p_{ir}^{-1(1-eir)} (I_r - p p_{meat} I_r^{fc}) \quad j = dl, dst, lst, il$$

Equation (110) defines an index of labour utilisation in the rural sector. Equation (111) defines an investment price which is necessary to normalise the opportunity cost of investment. Equations (112)-(115) define respectively, the opportunity cost of investing in dry land, tractors, draught cattle, and irrigated land. Equation (116) defines the CES dual price of aggregate rural investment. Finally, equation (117) defines investment demand for each of the four rural investment goods.

IV. DATA AND PARAMETRISATION

The model rests primarily on a 1985 data base. It is composed of two key elements. The first element is a seven sector country SAM which has been developed for each country of the world. The Development Centre has undertaken a significant effort to acquire country input/output tables and/or Social Accounting Matrices (SAMs) for each country of the world. Where these were not available, countries were assigned an *archetypical* SAM structure (for example, Bangladesh might be assigned the Pakistan SAM structure). All country SAMs were standardized at the seven sector level of aggregation, transformed into 1985 US\$ using the prevailing exchange rate, and all were adjusted to match published national income and product accounts for 1985. Subsequently, they are aggregated to form the model's regional SAMs. The seven sectors are food, non-food, manufacturing, energy, services, equipment, and fertilizers.

The second key component is the *Supply Utilisation Accounts Data* (SUA) compiled by the Food and Agriculture Organisation (FAO).³⁸ The SUA data is used to further disaggregate the food/non-food sectors of the base SAMs, into the final agricultural sectors of the model. The primary factors in agriculture are based on the FAO Production Yearbook Data. Finally, the bilateral trade matrices are based on initial estimates provided by the CHELEM data base.³⁹ These initial trade matrices are adjusted, using a bi-proportional adjustment technique (RAS), to obtain trade matrices consistent with the regional aggregate trade statistics.

Most AGE models contain many more parameters than can be estimated using traditional statistical inference. RUNS, similar to most AGE models, contains a set of exogenous parameters which are collected from the literature and introduced into the model. In the case of RUNS, these parameters include supply and demand elasticities for agricultural commodities, labour migration elasticities, marginal productivity elasticities of the various rural factors, and trade substitution elasticities for the non-agricultural commodities. Many of these parameters have been widely estimated. Moreover, the agricultural commodity breakdown of RUNS is similar to several other models. Therefore, it is possible to rely on these models for the agricultural supply and demand elasticities; for example, the USDA's GOL model or the more recent MTM model developed by the OECD Secretariat.⁴⁰ The remaining parameters are calibrated on the basis of the benchmark 1985 data and the set of exogenous parameters.⁴¹

An exception to this calibration method is the treatment of the price policy equations. They have been estimated using data covering the period 1964-1978, from the FAO producer price data bank. For the OECD countries, however, these estimates are complemented and updated on the basis of the OECD Secretariat's PSEs/CSEs. Each commodity specific PSE has been split into two components: a price support component and a non-price support component. The former is treated as a price wedge between domestic and world prices and is ruled by the price policy equations. The latter is introduced as an exogenous input subsidy. These estimated parameters serve only to define a base case scenario. They are not aimed at producing any kind of forecasts. The model is primarily used to

³⁸ See Sichra (1978).

³⁹ See CEPII (1988).

⁴⁰ See OECD (1987).

⁴¹ For examples of the calibration process see Annex 4 on the ELES for calibration of the ELES parameters or Annex 7 on the agricultural production function for calibration of the supply equation.

analyse policy experiments which are implemented by exogenously changing the price policy equations.

All the simulated policy changes are evaluated in comparison with a base case scenario in which some exogenous parameters are calibrated in order to reproduce existing trends over the 1985-1990 period. This involves GDP growth in each region as well as production growth in each agricultural sector. In addition, the base case scenario contains a set of exogenous assumptions related to future current account deficits in each region, and real world energy prices.

V. DESCRIPTION OF A POLICY SIMULATION

This section describes the results of a single liberalization scenario - partial agricultural trade liberalization within the six OECD regions: United States, Canada, Australia/New Zealand, EEC, and EFTA, beginning in 1993. We do not intend to provide a full description of the results which have been previously described in earlier papers.⁴² These earlier papers also provide comparisons with other studies, such as the WALRAS model, the IIASA model, and partial equilibrium results such as those of Tyers and Anderson.⁴³

The RUNS model has undergone some transformations over the last 18 months which has modified some of the quantitative results which have been previously reported. The major modifications are:

- Changing the base year from 1978 to 1985, simultaneously updating the entire data base.
- Expanding regional coverage from 10 regions to 22 regions.
- Dairy has been split from the *other food* sector. This was deemed essential due to the high level of protection in the dairy sector. Splitting of the livestock sector into ruminants and non-ruminants.
- Introduction of the CET specification in the non-agricultural sectors.
- New estimates of the agricultural protection measures.

The liberalization scenario entails the following changes from the base simulation (only in the six OECD regions):

- Agricultural input subsidies are reduced by 30% in all agricultural sectors in the year 1993 and are maintained at that level for the rest of the simulation time horizon. In the base simulation, the input subsidies are set at their observed levels through 1990, and are maintained at their 1990 levels for the remaining years.
- The price transmission elasticity is set to 1 in 1993 (i.e. equivalent to full tariffication) and the equivalent tariffs/subsidies are cut by 30% from the average of their 1985-1990 levels.⁴⁴ In the base simulation, the price transmission equation is calibrated so that the price wedge generated by the model matches the observed price wedge through the year 1990. After 1990, the price wedge is endogenous and is generated by the price transmission equation, using the calibration parameter calculated for the year 1990.

Table 18 presents the historical levels of the policy instruments for the six OECD regions in the years 1985, 1986, 1987 and 1990. The tables clearly show

⁴² See, for example, Burniaux (1989) and Burniaux et. al. (1990).

⁴³ Goldin and Knudsen provide an extensive survey of agricultural trade liberalisation studies, including results from both partial equilibrium and general equilibrium models.

⁴⁴ In the model formulation we have $pp/pw = \text{wedge}$. This implies $pp = (1+\tau)pw$. The simulation involves reducing τ by 30%, not the wedge.

that the 1985-1987 period represented a peak period for agricultural protection in the OECD regions. Despite the decrease in protection observed in 1990, the level of protection in many regions is significant for many of the commodities. There is also a significant difference in the price wedges observed in the group represented by the United States, Canada, and Australia/New Zealand, compared to the group represented by Japan, the EEC, and EFTA.

Agricultural liberalization within the OECD regions leads to an increase world agricultural prices, see Table 19.⁴⁵ This is consistent with most studies of agricultural trade liberalization. These increases must be taken as indicative. They do show that the short run impact on prices is significant, but stabilise over time for most of the commodities. The impact on world prices is greatest for those commodities with the highest level of base protection.

⁴⁵ The numbers in each column represent the percent change in the world price compared to the base case in the respective years. For example, the world wheat price in the liberalisation scenario is 3.6% greater in 1993 as compared to the base case 1993 level, however, the change is only 4.5% in the year 2002. In general, the longer run impact is less than the short run impact as producers need time to shift resources.

Table 18: Base-Run Agricultural Policy Instruments⁴⁶

United States

	<i>Price Wedge</i>				<i>Input Subsidies</i>			
	1985	1986	1987	1990	1985	1986	1987	1990
Wheat	1.03	1.09	1.34	1.19	38.1	55.2	49.0	31.7
Rice	1.00	1.00	1.00	1.00	52.4	71.6	50.2	48.8
Coarse Grains	1.00	1.00	1.00	1.00	21.7	47.9	45.8	24.2
Sugar	3.38	2.62	2.63	1.62	8.8	10.1	8.6	8.4
Beef, Veal	1.25	1.43	1.41	1.31	7.9	8.3	7.7	6.7
Other Meats	1.00	1.03	1.11	1.01	7.8	8.4	8.4	7.1
Oils	1.00	1.00	1.00	1.00	9.7	12.7	10.5	7.1
Dairy	3.29	3.70	2.70	2.23	9.3	8.3	7.7	6.8

Canada

	<i>Price Wedge</i>				<i>Input Subsidies</i>			
	1985	1986	1987	1990	1985	1986	1987	1990
Wheat	1.26	1.38	1.39	1.13	22.0	33.5	33.9	17.0
Rice	1.00	1.00	1.00	1.00	0.0	0.0	0.0	0.0
Coarse Grains	1.44	1.64	1.28	1.14	16.6	38.0	33.5	13.9
Sugar	1.15	1.13	1.12	1.09	42.4	50.0	30.7	9.5
Beef, Veal	1.14	1.44	1.52	1.54	17.1	18.6	17.6	16.9
Other Meats	1.04	1.01	1.10	1.10	16.8	16.5	16.7	18.3
Oils	1.09	1.10	1.07	1.06	21.5	31.7	23.8	16.0
Dairy	3.29	3.80	2.92	2.28	16.2	15.8	17.5	19.8

Australia/New Zealand

	<i>Price Wedge</i>				<i>Input Subsidies</i>			
	1985	1986	1987	1990	1985	1986	1987	1990
Wheat	1.02	1.01	1.00	1.01	9.8	20.1	14.1	17.3
Rice	1.11	1.13	1.12	1.06	21.9	19.9	17.9	19.6
Coarse Grains	1.00	1.00	1.00	1.00	8.9	9.9	8.7	7.0
Sugar	1.17	1.14	1.13	1.10	10.6	7.8	7.3	6.6
Beef, Veal	1.04	1.02	1.00	1.00	15.1	23.5	10.1	7.4
Other Meats	1.07	1.08	1.06	1.06	4.1	4.1	3.9	3.5
Oils	1.00	1.00	1.00	1.00	9.8	12.7	12.6	12.4
Dairy	1.55	1.77	1.52	1.36	19.2	8.9	9.1	0.3

⁴⁶ The price wedge is the ratio of the domestic price to the world price. For a net food exporter, this implies an export subsidy if the price wedge is greater than one. For a net food importer, this implies an import tariff if the price wedge is greater than one. Input subsidies are in per cent.

Japan

	<i>Price Wedge</i>				<i>Input Subsidies</i>			
	1985	1986	1987	1990	1985	1986	1987	1990
Wheat	5.05	8.30	8.16	6.21	22.4	29.6	28.6	17.1
Rice	4.48	6.53	6.61	4.48	13.8	19.9	17.9	19.7
Coarse Grains	5.20	8.70	8.06	5.04	22.7	31.2	27.0	11.7
Sugar	2.92	3.06	2.87	2.14	12.8	10.8	8.8	6.8
Beef, Veal	2.17	2.85	2.34	1.99	6.2	21.5	13.3	11.4
Other Meats	1.28	1.35	1.43	1.33	1.9	13.0	12.8	13.6
Oils	1.00	1.00	1.00	1.00	86.3	30.9	23.4	15.8
Dairy	4.30	7.94	6.13	4.53	13.4	13.9	15.1	14.0

European Economic Community

	<i>Price Wedge</i>				<i>Input Subsidies</i>			
	1985	1986	1987	1990	1985	1986	1987	1990
Wheat	1.18	2.05	2.20	1.65	7.7	6.6	6.2	7.2
Rice	2.65	3.69	2.24	2.14	8.0	6.0	6.5	7.8
Coarse Grains	1.26	2.24	2.81	1.91	4.0	3.7	3.1	3.9
Sugar	3.38	3.43	3.94	2.18	-2.2	-2.3	-7.1	-2.7
Beef, Veal	1.94	1.96	1.86	1.98	9.1	7.9	8.9	13.7
Other Meats	1.12	1.36	1.45	1.28	6.6	5.8	6.2	6.4
Oils	1.00	1.00	1.00	1.00	35.3	68.9	67.1	67.3
Dairy	2.65	3.65	3.06	2.89	5.1	4.8	4.6	7.2

European Free Trade Area

	<i>Price Wedge</i>				<i>Input Subsidies</i>			
	1985	1986	1987	1990	1985	1986	1987	1990
Wheat	1.91	2.90	3.54	3.34	5.8	4.0	5.4	6.2
Rice	1.00	1.00	1.00	1.00	0.0	0.0	0.0	0.0
Coarse Grains	1.95	2.80	2.88	2.76	11.7	9.8	16.7	16.7
Sugar	3.52	3.84	3.84	2.80	0.9	1.0	0.3	7.1
Beef, Veal	2.54	2.35	2.34	2.65	18.5	18.4	19.7	21.9
Other Meats	1.72	2.21	2.61	2.17	9.5	9.6	10.0	11.3
Oils	2.10	3.27	2.98	4.13	4.8	3.5	12.6	13.1
Dairy	3.76	4.96	4.18	3.96	22.0	20.8	21.6	24.7

Table 19: Percent Change in 2002 in World Agricultural Prices Compared to Base Run

	1993	2002
	(Percentage)	
Wheat	3.6	4.5
Rice	1.8	2.4
Coarse Grains	1.8	3.6
Sugar	5.7	6.3
Beef	5.3	6.4
Other Meats	2.1	3.3
Oils	2.8	4.0
Dairy	9.0	9.5

Table 20 presents some indicators of the welfare effects of trade liberalisation. This table gives percent changes in the indicators for the final year of the simulation, i.e. 2002. It does not indicate the dynamic gains or losses. Overall, the partial trade liberalisation in the OECD does not benefit the developing regions. While all benefit from an increase in rural GDP (mostly due to the higher agricultural prices), in most regions this is offset by a reduction in urban GDP. The OECD regions are all gainers, particularly Europe and Japan.

It is difficult to assess the regional results without referring to the specific features of each region; notably the degree to which regions adjust to changes in world prices, the degree of wage rigidity, and the net trade position. In all developing regions, however, one can expect an increase in food prices, which is confirmed by the next to the last column in Table 20. This has an undesirable impact on urban value added. The semi-rigidity of urban wages with respect to the price of food leads to losses in productivity in the urban sector. The urban sector is likewise hurt by increased world competitiveness as the OECD regions reduce the price of urban exports in order to pay for the increased imports of agricultural commodities. A striking feature of the results presented in Table 20 is the consistent positive change in the parity index between rural and urban per capita incomes in all developing regions. However, the parity index in the OECD declines by 5.6%. This will increase the inevitable tension between the farm and the city which plays a key role not only in developing countries, but also within the OECD.

**Table 20: Welfare Impacts of Partial OECD Trade Liberalization
Percent Changes in 2002 Compared with Base Run**

	Real Income ^a	Rural Value Added	Urban Value Added	Rural/ Urban Income ^b	Food Prices ^c	Terms of Trade
Low Income	-0.29	0.68	-0.61	1.42	0.38	0.63
Asia	-0.63	0.67	-1.13	2.40	0.80	0.82
China	-0.22	0.66	-0.56	1.32	0.28	0.67
India	0.05	0.44	-0.08	0.77	0.25	2.00
Africa	-0.75	0.55	-1.18	2.28	1.17	0.42
Nigeria	-0.63	3.32	-1.05	0.23	-1.13	-1.91
Middle Income	-0.58	1.03	-0.79	2.54	1.58	0.00
Indonesia	-0.36	0.58	-0.54	1.31	0.71	0.13
South Africa	-0.36	2.51	-0.75	3.50	1.64	0.98
Maghreb	-1.06	1.29	-1.27	4.09	1.89	-1.04
Mediterranean	-0.62	1.01	-0.78	2.97	2.04	0.00
Latin America	-0.05	0.95	-0.20	1.65	1.14	0.92
Latin America	-0.08	1.36	-0.27	2.21	1.32	1.02
Brazil	0.26	0.73	0.17	0.95	0.86	1.52
Mexico	-0.37	0.61	-0.47	1.70	1.11	-0.36
Upper Income	-0.34	1.16	-0.47	2.98	1.94	-0.08
Asia	-0.34	1.26	-0.50	3.15	1.85	0.46
Gulf Region	-0.33	0.88	-0.41	2.66	2.16	-1.42
OECD	1.98	-6.83	2.32	-6.86	-5.56	-0.44
USA	0.47	-6.21	0.66	-3.78	-4.40	-0.27
Canada	0.86	-7.91	1.25	-6.64	-4.49	-0.22
ANZ	0.50	-1.53	0.67	-4.96	0.43	1.95
Japan	2.41	-3.23	2.50	-11.70	-11.78	-0.82
EEC	4.00	-7.90	4.73	-9.54	-4.96	-0.55
EFTA	2.79	-10.46	3.40	-7.06	-11.45	-0.55
Other	-1.16	0.67	-1.46	-0.42	1.46	0.70
E. Europe	-0.59	1.13	-0.89	-0.06	0.96	1.15
USSR	-1.39	0.47	-1.70	-0.54	1.67	0.31

- a) Real income is nominal value added at market prices, deflated by the consumption price index.
- b) Rural/Urban Income is the change in the ratio of real rural disposable income per capita to real urban disposable income per capita.
- c) The food price is the ratio of average food price to the consumption price index.

VI. CONCLUDING REMARKS

This paper has provided a complete description of the current version of the RUNS model. The model specification, like the model itself, is not static. In consultation with outside experts and in collaboration with colleagues at the World Bank and within the OECD Secretariat, the Development Centre is planning to introduce the following modifications to the RUNS model:

- Introduce several new agricultural commodities. In particular, split oils into oil seeds and processed oils (especially oil cakes, used in animal feed), and introduce rubber.
- Modify agricultural production to introduce a third sector, namely, tree crops. I.e. the crops sector would be split into two. The tree crops sector would produce coffee, cocoa, and tea.
- Modify the demand structure for the other food aggregates (both 'other food' and 'other non-food'). Currently these are treated as perfectly homogeneous, i.e. European vegetables are treated the same as tropical fruits. This specification will be replaced by an Armington specification in these two sectors.
- Introduce sector-specific capital-labour ratios in the urban sectors.
- Introduce more region-specific and more accurate agricultural policies, particularly in the OECD regions.
- Split manufacturing into light manufacturing and other.
- Introduce an imperfect competition specification for the non-agricultural commodities.

Over the next year, the Development Centre and the World Bank will be using the RUNS model to evaluate a variety of issues of significant concern to both the OECD countries and the larger world community. Amongst these issues are: the impact of the Uruguay Round on growth and trade; the impact of changes in agricultural productivity; the interactions between agricultural and non-agricultural protection; the use of trade policy in tropical products to improve the terms of trade (fallacy of composition); structural adjustment and development; and the re-allocation of savings flows, both intra-and inter-regional.

ANNEX 1

DEFINITION OF THE RUNS REGIONS

1. **Low Income Asia (LIA)**
Afghanistan, Bangladesh, Bhutan, Burma, Kampuchea, Democratic Republic of Korea, Laos, Maldives, Mongolia, Nepal, Pakistan, Sri Lanka, Viet Nam
2. **China (CHN)**
3. **India (IND)**
4. **Upper Income Asia (UIA)**
Brunei, Fiji, French Polynesia, Hong Kong, Republic of Korea, Macao, Malaysia, New Caledonia, New Hebrides, Papua New Guinea, Philippines, Singapore, Taiwan, Thailand, Tonga.
5. **Indonesia (IDN)**
6. **Africa (AFR)**
Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, People's Republic of the Congo, Côte d'Ivoire, Equatorial Guinea, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaïre, Zambia, Zimbabwe.
7. **Nigeria (NGA)**
8. **South Africa (ZAF)**
9. **Maghreb (MAG)**
Algeria, Morocco, Tunisia
10. **Mediterranean (MED)**
Cyprus, Arab Republic of Egypt, Israel, Jordan, Lebanon, Libya, Malta, Syrian Arab Republic, Turkey
11. **Gulf Region (OIL)**
Bahrain, Iraq, Islamic Republic of Iran, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen Arab Republic, People's Democratic Republic of Yemen

12. Latin America (LAT)

Anguilla, Antigua and Barbuda, Argentina, The Bahamas, Barbados, Belize, Bermuda, Bolivia, Chile, Columbia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela, Virgin Islands.

13. Brazil (BRA)

14. Mexico (MEX)

15. United States (USA)

16. Canada (CAN)

17. Australia/New Zealand (ANZ)

Australia, New Zealand

18. Japan (JPN)

19. European Economic Community (EEC)

Belgium, Denmark, France, Federal Republic of Germany (including the former German Democratic Republic), Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, United Kingdom.

20. European Free Trade Area (EFTA)

Austria, Finland, Iceland, Norway, Sweden, Switzerland.

21. European Economies in Transition (EET)

Albania, Bulgaria, Czechoslovakia, Hungary, Poland, Romania, Yugoslavia.

22. Soviet Union (USR)

ANNEX 2

ANALYTICAL FORMULATION OF THE ARMINGTON ASSUMPTION

Figure A-1 is a heuristic description of the decision making process of a domestic agent under the Armington assumption.⁴⁷ At the top level the agent maximises some function (utility or profits), leading to a derived demand for a composite good. Let X be the derived demand for the composite good. At the second level X is allocated to demand for a domestic good and demand for an imported good. Formally we have:

$$\min P_d D + P_m M$$

s.t.

$$X = \text{CES}(D, M) = \left[\alpha_d D^{-\rho} + \alpha_m M^{-\rho} \right]^{-1/\rho}$$

where D is domestic demand, M import demand, P_d and P_m domestic and import price, respectively. This is the formulation of the Armington assumption. $\sigma = 1/(1+\rho)$ is the elasticity of substitution. Solving the Lagrangian yields:

$$D = \alpha_d^\sigma \left(\frac{P_x}{P_d} \right)^\sigma X \quad M = \alpha_m^\sigma \left(\frac{P_x}{P_m} \right)^\sigma X$$

and P_x is the composite or *aggregate* price given by the formula:

$$P_x = \left[\alpha_d^\sigma P_d^{1-\sigma} + \alpha_m^\sigma P_m^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

At the second level, agents minimise the cost of purchasing the composite import M , from the various regions, based on relative prices:

⁴⁷ See Armington (1969). Note that we use a CES aggregation function to implement the Armington assumption. The Armington assumption essentially only assumes product differentiation with respect to the region of origin and is not synonymous with the CES implementation. Other functional forms have been used such as the almost ideal demand system (AIDS).

$$\min \sum_{r=1}^{nreg} P E_r E_r$$

s.t.

$$M = \left[\sum_{r=1}^{nreg} \alpha_r E_r^{-\omega} \right]^{-1/\omega}$$

where PE_r is the price of imports from region r , E_r is the volume of imports from region r , α_r are the CES share parameters, and $\lambda = 1/(1+\omega)$ is the elasticity of substitution. Note that in the actual formulation in the RUNS model PE_r is inclusive of export and import subsidies/taxes which are both origin and destination specific. Solving the Lagrangian yields:

$$E_r = \alpha_r^\lambda \left(\frac{P_m}{PE_r} \right)^\lambda M$$

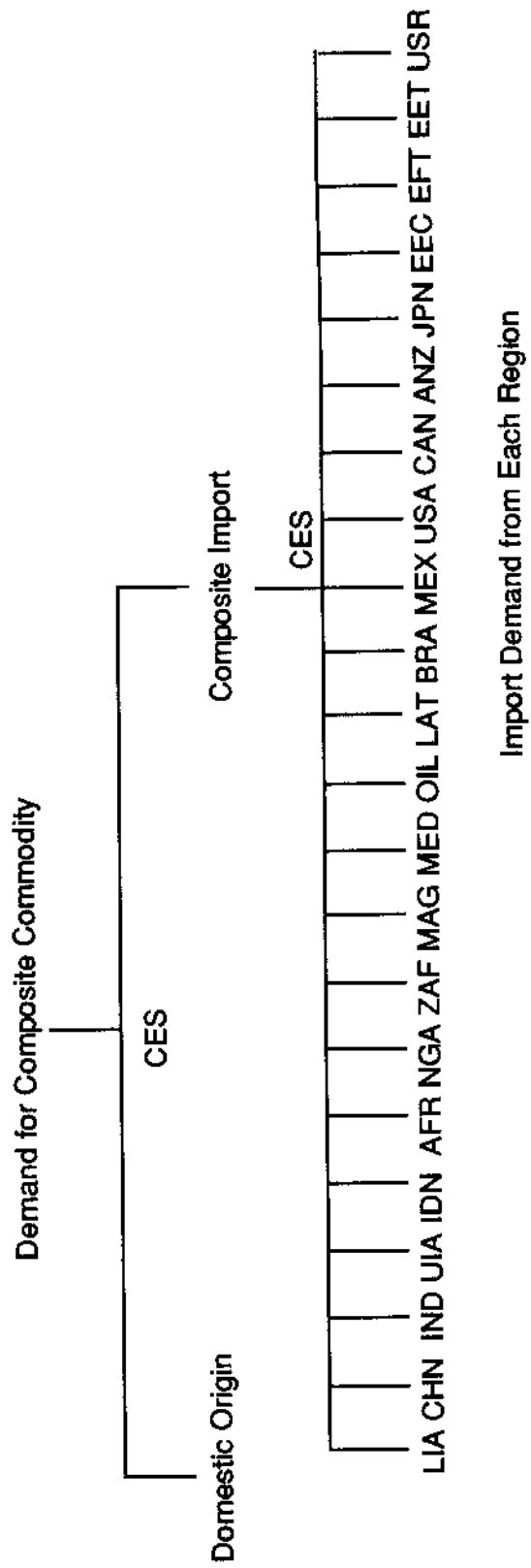
where P_m is the composite price or *aggregate* price of imports:

$$P_m = \left[\sum_{r=1}^{nreg} \alpha_r^\lambda PE_r^{1-\lambda} \right]^{\frac{1}{1-\lambda}}$$

Note that in the formulation of the equations, we will often work exclusively with the reduced form equations, in which case the share parameters will incorporate the appropriate exponent. For example, the formula for imports by region will be:

$$E_r = \alpha_r \left(\frac{P_m}{PE_r} \right)^\lambda M$$

Figure A-1: Armington Demand Structure



ANNEX 3

THE CONSTANT ELASTICITY OF TRANSFORMATION SPECIFICATION (CET)

The Constant Elasticity of Transformation (CET) specification allows producers to differentiate between production sold on the domestic market and on foreign markets, it is somewhat symmetric to the Armington assumption which is used on the import side. The CET introduces two additional price wedges, a wedge between the domestic producer price and the domestic sale price, and a wedge between the domestic producer price and the export price (exclusive of any taxes and subsidies). In the non-CET specification the producer price, the sale price and the export price are all equivalent.

Domestic producers solve the following maximisation problem:

$$\max P_d D + P_e E$$

s.t.

$$X = \left[\alpha_d D^\rho + \alpha_e E^\rho \right]^{1/\rho}$$

where P_d is the price of domestically produced goods sold on the domestic market, D is the quantity of domestically produced goods sold on the domestic market, P_e is the price of domestically produced goods sold abroad (the export price), E is the quantity of exports, and X is the volume of goods produced domestically. P_x is composite price, or the domestic output price. Domestic producers supply an aggregate output X , which is then sold on two markets, the domestic and foreign markets, in order to maximise revenues, and subject to a transformation frontier, which in the formulation above is of the CES type.

First-order conditions yield the optimal allocation:

$$(1) \quad D = \frac{\alpha_e}{\alpha_d} \left[\frac{P_d}{P_x} \right]^\Lambda X$$

$$(2) \quad E = \frac{\alpha_d}{\alpha_e} \left[\frac{P_e}{P_x} \right]^\Lambda X$$

where we have the following relations:

$$(3) \quad \Lambda = \frac{1}{\rho-1} \quad \left(\text{or } \rho = \frac{\Lambda+1}{\Lambda} \right)$$

$$(4) \quad \frac{\alpha_d}{\alpha_e} = \alpha_d^{-\Lambda} \quad \frac{\alpha_e}{\alpha_d} = \alpha_e^{-\Lambda}$$

where Λ is the elasticity of substitution. P_x is the price of the composite output, and can be defined in two ways:

$$(5) \quad P_x = \left[\overline{\alpha_d} P_d^{1+\Lambda} + \overline{\alpha_e} P_e^{1+\Lambda} \right]^{\frac{1}{1+\Lambda}}$$

$$(6) \quad P_x X = P_d D + P_e E$$

In the implementation of the CET in the RUNS model, equations (1) and (2) are implemented as above, with the aggregation constraint as well. P_x is calculated in fact from the supply side, i.e. it is the unit cost of output. P_e is calculated via tâtonnement in order to equilibrate export supply and demand. P_d can be calculated as a residual using equation (5).

ANNEX 4

THE EXTENDED LINEAR EXPENDITURE SYSTEM (ELES)

The ELES is based on consumers maximising their intertemporal utility between the bundle of current consumption and an expected future consumption which is represented in the form of savings. The ELES has several attractive features. It allows for commodity specific income elasticities. For example, food demand is often less sensitive to changes in income, than demand for non-agricultural goods. This is an important feature of the RUNS model which focuses on rural/urban issues. A second feature of the ELES, in contrast with the well known Stone-Geary linear expenditure system, is the extension to an intertemporal utility maximisation problem by incorporating savings as the delayed expenditure of a future representative good.

The utility function of the ELES has the following form:⁴⁷

$$U = \sum_{i=1}^n \mu_i \ln(C_i - \theta_i) + \mu_s \ln(S)$$

$$\text{with } \sum_{i=1}^n \mu_i + \mu_s = 1$$

where U is utility, C is consumption, S is total savings, and μ and θ are ELES parameters which are given an interpretation below. n is the number of consumer goods.

It is easy enough to derive the demand equations, the consumer solves the following problem:

$$\max \sum_{i=1}^n \mu_i \ln(C_i - \theta_i) + \mu_s \ln(S)$$

s.t.

$$\sum_{i=1}^n P_i C_i + S = Y$$

where P_i are consumer prices, and Y is disposable income. The constraint is simply the consumer budget constraint.

The first order conditions are:

⁴⁷ See Luch (1973).

$$\frac{\mu_i}{C_i - \theta_i} = \lambda P_i \quad 1 \leq i \leq n$$

$$\frac{\mu_s}{S} = \lambda$$

$$\sum_{i=1}^n P_i C_i + S = Y$$

Through substitution we derive the following:

$$(1) \quad C_i = \theta_i + \frac{\mu_i}{P_i} \left[Y - \sum_{j=1}^n P_j \theta_j \right] \quad 1 \leq i \leq n$$

$$(2) \quad S = \mu_s \left[Y - \sum_{j=1}^n P_j \theta_j \right]$$

The usual interpretation of the demand function is that consumer demand is a combination of two elements, a subsistence minima, θ , and a share of disposable income after purchase of the subsistence minima (the μ parameter is sometimes called the marginal propensity to consume). The number $Y - \sum_{j=1}^n P_j \theta_j$ is sometimes referred to as the supernumerary income.

From the demand equation we can derive the income and price elasticities:

$$(3) \quad \eta_i = \frac{\mu_i Y_i}{P_i C_i}$$

$$(4) \quad \epsilon_i = \frac{\theta_i (1 - \mu_i)}{C_i} - 1$$

where η is the income elasticity and ϵ the price elasticity.

Hicksian Equivalent Variation for ELES.

The indirect utility function is immediately derived by inserting equations (1) and (2) into the utility function:

$$v(p,y) = \sum_{i=1}^n \mu_i \ln \left(\frac{\mu_i}{P_i} \left[Y - \sum_{j=1}^n P_j \theta_j \right] \right) + \mu_s \ln \left(\mu_s \left[Y - \sum_{j=1}^n P_j \theta_j \right] \right)$$

or let Y^* be the supernumerary income, then

$$v(p,y) = \sum_{i=1}^n \mu_i \ln\left(\frac{\mu_i}{P_i} Y^*\right) + \mu_s \ln(\mu_s Y^*)$$

where

$$Y^* = Y - \sum_{j=1}^n P_j \theta_j$$

The expenditure function is somewhat more tedious to derive. It is the solution to the following problem:

$$\min \sum_{i=1}^n P_i C_i + S$$

s.t.

$$\sum_{i=1}^n \mu_i \ln(C_i - \theta_i) + \mu_s \ln(S) = u$$

where u is a given utility level. This results in the following formulation for the expenditure function:

$$E(p,u) = \sum_{j=1}^n P_j \theta_j + \frac{e^u}{\mu_s} \prod_{j=1}^n \left[\frac{P_j}{\mu_j} \right]^{\mu_j}$$

or equivalently:

$$E(p,u) = \sum_{j=1}^n P_j \theta_j + \frac{e^u}{e^{\Gamma}}$$

where

$$\Gamma = \sum_{j=1}^n \mu_j \ln\left(\frac{\mu_j}{P_j}\right) + \mu_s \ln(\mu_s)$$

The Hicksian equivalent variation is calculated as:

$$EV = E(p^1, u^1) - E(p^0, u^1)$$

or, the maximum amount the consumer would be prepared to pay at the budget level Y^1 to avoid the change from p^0 to p^1 . If only price p_i changes, then the equivalent variation is:

$$EV = \theta_i (P_i^1 - P_i^0) + \frac{\theta^{u^1}}{\mu_s} \prod_{j=1}^n \left[\frac{P_j}{\mu_j} \right]^{\mu_j} \left[1 - \left(\frac{P_i^0}{P_i^1} \right)^{\mu_i} \right]$$

Calibration

The following describes a possible way to calibrate the ELES system. It assumes that we have estimates of commodity specific income elasticities. It is also possible to calibrate the demand system using price elasticity estimates, or both methods can be combined to provide a third set of calibrated parameters. In fact, for RUNS, we use all three methods.

The calibration process is based on four elements: a consumer price vector (often assumed to be a set of 1s), a vector of consumer purchases (from an input-output table or a SAM), household disposable income (from national accounts), and a set of income elasticities (from household surveys and/or literature searches).

1. Given P , C , Y and η , calculate the marginal propensity to consume (mpc), using equation (3) from above.

$$\mu_i = \frac{\eta_i P_i C_i}{Y}$$

2. Setup equation (1) in matrix form:

$$C = I \theta + M Y - M \Pi \theta = [I - M \Pi] \theta + M Y$$

where I is an $n \times n$ identity matrix, M is a diagonal matrix with element μ_i/P_i on the diagonal, and Π is a matrix where each row is identical, each row being the transpose of the price vector.

The above equation can be solved via matrix inversion for the parameter θ :

$$\theta = [I - M \Pi]^{-1} [C - M Y]$$

Note that if prices are all assumed to be equal to 1, then the diagonal elements of M are simply the marginal propensity to consume, and the Π matrix is entirely composed of 1's.

3. Calculate the associated price elasticities (from equation 4):

$$\epsilon_i = \frac{\theta_i (1 - \mu_i)}{C_i} - 1$$

ANNEX 5

AN ALTERNATIVE CLOSURE RULE FOR RUNS⁴⁹

Macro-Closure In RUNS

The key element of macro-closure in the RUNS model is fixed trade balances (in nominal terms), or in other words, a fixed level of net foreign capital flows. Government savings is endogenous, and within each region, investment equals net savings, i.e. there is no specific investment behavior. In nominal terms we can write:

$$I = S_h + S_g + S_f$$

where I is domestic investment, S_h is household savings, S_g is government savings, and S_f is net foreign capital flows, and S_f is exogenous. S_h is determined by the consumer ELES system, S_g is the difference between government revenues and expenditures.

This formulation of macro-closure is fairly standard in CGE models. It does have two inconveniences, particularly in the context of a model like RUNS, which is both global and dynamic. The first inconvenience is the requirement of generating an exogenous scenario for the net capital flows for all regions for 7 periods through the year 2002, i.e. a total of 154 numbers, which within each period must sum to zero. For the moment, the model relies on projections from macro models, such as the World Bank's GEM and CAPFLO models. However, the projections from these models are rarely globally consistent, and it is up to the user to make judgements on how to allocate the residual. The second effect of this macro-closure is that trade liberalization never leads to an endogenous shift in a country's net trade position in value terms. While there is nothing inherently wrong with the plausibility of this closure, alternatives are possible. The following section describes a simple extension of the current version of the RUNS model to allow for endogenous foreign capital flows.

An Alternative Macro-Closure

We propose a very simple rule: The introduction of a new variable, the forward price of consumption, which equates global savings and investment. The consequences of the rule are:

- Investment becomes a function
- Trade balances are endogenous
- We maintain the consistency requirement that world exports equal world imports

⁴⁹ This annex relies on a mimeo prepared and presented by Paul Armington at a RUNS Workshop held at the OECD Development Centre in Paris in July, 1991.

Domestic Savings

Domestic savings are explicit in the ELES. Under the current formulation, the ELES calculates the level of household savings in *nominal* terms. Nominal savings are never broken down into a volume and a price. The price of household savings represents the relative value of a bundle of future consumption with respect to current consumption. Let us introduce two new variables:

C_f Volume of claims to future consumption

P_f Price of claims to future consumption -- i.e., the forward price of consumption

We have

$$S = C_f P_f$$

The ELES becomes:

$$\text{maximize } U = \sum_{i=1}^n \mu_i \ln(C_i - \theta_i) + \mu_s \ln(C_f)$$

$$\text{subject to } \sum_{i=1}^n P_i C_i + P_f C_f = Y$$

where C is household consumption by commodity, P are the commodity specific consumer prices, and Y is household disposable income. μ and θ are the ELES parameters. The first order conditions are:

$$\frac{\mu_i}{C_i - \theta_i} = \lambda P_i$$

$$\frac{\mu_s}{C_f} = \lambda P_f$$

$$\sum_{i=1}^n P_i C_i + P_f C_f = Y$$

The resulting demand equations are:

$$C_i = \theta_i + \frac{\mu_i}{P_i} \left[Y - \sum_{j=1}^n P_j \theta_j \right]$$

$$C_f = \frac{\mu_s}{P_f} \left[Y - \sum_{j=1}^n P_j \theta_j \right]$$

It is also possible to derive C_f from the budget constraint:

$$C_f = \frac{S}{P_f} = \frac{Y - \sum_{i=1}^n P_i C_i}{P_f}$$

The income elasticities are:

$$\eta_i = \frac{\mu_i Y}{P_i C_i} \quad \eta_f = \frac{\mu_s Y}{P_f C_f}$$

The price elasticities are:

$$\varepsilon_i = \frac{\theta_i (1 - \mu_i)}{C_i} - 1 \quad \varepsilon_f = -1$$

The elasticity of savings with respect to the forward premium is -1. In other words, a 100 basis point rise in the real rate of interest increases the volume of savings by 1 per cent, in the ELES.

Investment

The *supply* of claims to future consumption, or volume of investment, is presently not modeled in RUNS, it is set equal to the volume of net savings. It must be introduced in order to achieve a rational intertemporal allocation in RUNS. The simplest symmetric specification to the demand side of the claims market is:

$$I = \mu_i Y P_f^\alpha$$

where I is the volume of investment, μ_i is ICOR times the long run growth rate. The scale variable is simply Y , since there are no minimum requirements. The elasticity α measures the percentage increase in volume of investment resulting from a 100 basis point fall in the real interest rate, or rise of .01 in P_f .

Solution for the forward premium (or the global real interest rate):

The forward premium is solved at the global level in order to equate world savings and investment:

$$P_f^* \sum_r C_{f,r}^* - P_f^* \sum_r I_r^* = 0$$

Figure 1 presents a graphical picture of the global solution for P_f .

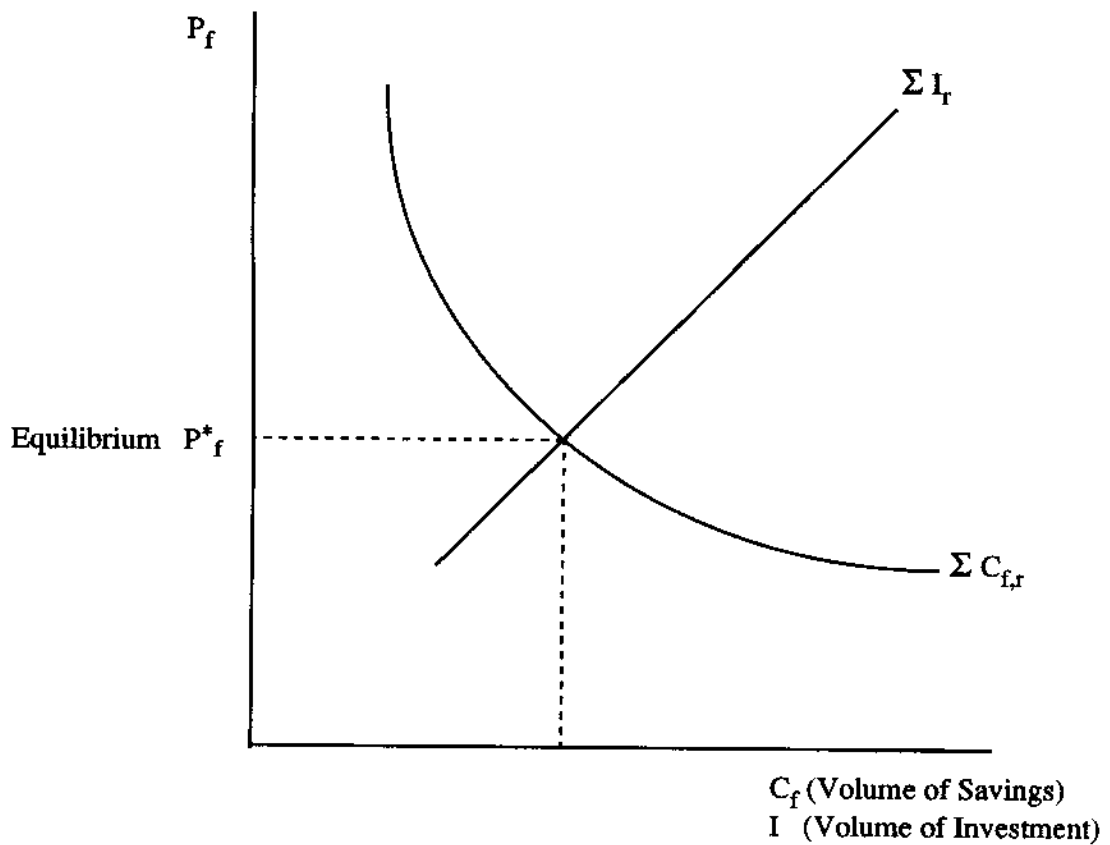


Figure 1: Global Market for Claims to Future Consumption (all regions, r)

For each region, foreign savings (in nominal terms) is now determined residually as:

$$S_f = P_f I - P_f C_f$$

At equilibrium, this formula guarantees that the sum over all regions of the capital flows is equal to zero. Moreover, for each region, the trade balance in nominal terms is simply the negative of the capital flow, therefore world trade balances also sum to zero.

Thus in any solution of RUNS, world exports equals world imports, at the equilibrium world interest rate, using intertemporal functions for investment that can be readily calibrated, and using savings functions that are already implicit in the ELES.

Implementation of the Alternative Macro-Closure in RUNS

Calibration and Parameters

Calibration of the savings function is straightforward, the only modification to the current version of the model is the addition of a price variable, P_f , which is set to 1 in the calibration program.

Calibration of the investment function is almost as easy. The μ_i parameter is readily calibrated to the existing base data:

$$\mu_i = \frac{TI}{GDP_r + GDP_u}$$

where TI is total domestic investment, GDP_r is rural value added, and GDP_u is urban value added.

The key component of the investment function is the elasticity of investment supply with respect to the forward price of foreign claims (i.e. the real interest rate). Existing models provide estimates of the long-run investment elasticities. For example, the GEM model estimates (NIESR) are presented in Table 1 (showing a breakdown of housing investment and business investment):

Table 1: Long-Run Investment Elasticities in GEM

(Percentage change in investment given 100 basis point change in interest rate)

<u>Country</u>	<u>Housing Investment</u>	<u>Business Investment</u>
Canada	-3.10	-0.50
France	-1.83	-3.77
Germany	-2.21	-4.62
Japan	-9.65	-2.02
United Kingdom	-3.41	-4.04
United States	-7.40	-2.73
Italy	-1.94 (total investment)	

The elasticities are fairly large, but seem to be in line with established models. They are in fact quite a bit lower than those found in the MPS model.

Implementation of the Alternative Closure in the RUNS Model

The choice of macro-closure is a user specified option. The following describes the implementation of the alternative closure. (The equation numbers refer to the corresponding equation numbers in the main text of this technical paper.)

The volume of household savings, rural and urban, are determined using the household budget constraint:

$$(40) \quad S_r = \frac{Yd_r - \sum_k pc_k C_{r,k}}{psavw}$$

$$(44) \quad S_u = \frac{Yd_u - \sum_k pc_k C_{u,k}}{psavw}$$

where S_r is rural household savings (in volume), S_u is urban household savings, pc are consumer prices, C_r and C_u are respectively rural and urban current consumption vectors, and $psavw$ is the world price of savings.

The volume of domestic investment is determined by the following equation:

$$(84) \quad TI = \mu_I [VA_r + VA_u] \left[\frac{psavw}{pinv} \right]^\alpha$$

where TI is the volume of investment, VA_r and VA_u are respectively rural and urban value added (in volume), and $pinv$ is the investment price deflator. This equation differs slightly from the equation described above. Due to the homogeneity requirements of the model, the investment equation must be made independent of the numéraire, i.e. a doubling of all prices should not affect the level of the volume of investment. We have chosen the investment price deflator as the relevant deflator for the investment equation.

Foreign savings is determined as a residual:

$$(108) \quad S_f = psavw[TI - S_r - S_u] - S_g$$

where S_g is government savings (in nominal terms). Finally, the world price of savings is determined via *tatōnnement*, in order to achieve global investment-savings balance:

$$(108') \quad \sum_r \left[psavw (S_r^r + S_u^r) + S_g^r \right] = \sum_r psavw TI^r$$

where the index r loops over all regions. Note that government savings is added to household savings in the balancing equation.

ANNEX 6

DERIVATION OF THE URBAN FACTOR DEMAND EQUATIONS

One way to formulate the derived demand for urban factors (capital and labour), from the CES formulation is as a cost minimisation problem. Producers want to minimise the cost of using factors subject to the CES transformation function, with an imbedded technological trend:

$$\min \quad wL + rK$$

s.t.

$$V = (1+\gamma)^t \left[\delta_l L^{-\nu} + \delta_k K^{-\nu} \right]^{-1/\nu}$$

where K and L are respectively capital and labour demand, r and w the rental and wage rates, V is the value added aggregate, γ is an exogenous technological trend, δ are the CES share parameters, and $\epsilon = 1/(1 + \nu)$ is the CES substitution elasticity.

Solving the above we get the following equations for factor demands:

$$(1) \quad L = \frac{(1+\gamma)^{-t} V \left(\frac{w}{\delta_l} \right)^{-\epsilon}}{\left[\delta_l^\epsilon w^{1-\epsilon} + \delta_k^\epsilon r^{1-\epsilon} \right]^{\frac{-\epsilon}{1-\epsilon}}}$$

$$(2) \quad K = \frac{(1+\gamma)^{-t} V \left(\frac{r}{\delta_k} \right)^{-\epsilon}}{\left[\delta_l^\epsilon w^{1-\epsilon} + \delta_k^\epsilon r^{1-\epsilon} \right]^{\frac{-\epsilon}{1-\epsilon}}}$$

The dual price, or the aggregate price of value added is given by:

$$pv = (wL + rK)/V$$

where we can substitute the derived demands for L and K to get:

$$(3) \quad pv = (1+\gamma)^{-t} \left[\delta_l^\epsilon w^{1-\epsilon} + \delta_k^\epsilon r^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}$$

We can isolate r, the rental rate, from equation (3) to get:

$$(4) \quad r = (1+\gamma)^t \text{pv} \delta_k^{-\epsilon/(1-\epsilon)} \left[1 - \delta_l^\epsilon \left(\frac{w}{\text{pv}} \right)^{1-\epsilon} (1+\gamma)^{-t(1-\epsilon)} \right]^{\frac{1}{1-\epsilon}}$$

Finally, we can combine equations (1), (2) and (4) to get labour demand as a function of the wage rate, the price of value added, and the capital stock:

$$(5) \quad L = \frac{\delta_l^\epsilon \left(\frac{w}{\text{pv}} \right)^{-\epsilon} (1+\gamma)^{t\epsilon} \delta_k^{-\epsilon/(1-\epsilon)} K}{\left[1 - \delta_l^\epsilon \left(\frac{w}{\text{pv}} \right)^{1-\epsilon} (1+\gamma)^{-t(1-\epsilon)} \right]^{\frac{-\epsilon}{1-\epsilon}}}$$

We can insert equation (5) into the initial constraint from the optimisation problem to get:

$$(6) \quad V = \frac{(1+\gamma)^t \delta_k^{-\epsilon/(1-\epsilon)} K}{\left[1 - \delta_l^\epsilon \left(\frac{w}{\text{pv}} \right)^{1-\epsilon} (1+\gamma)^{-t(1-\epsilon)} \right]^{\frac{-\epsilon}{1-\epsilon}}}$$

The equilibrium wage rate can be calculated by calculating the ratio of L/V and re-arranging:

$$(7) \quad w = (1+\gamma)^{-t(1-\epsilon)/\epsilon} \delta_l \left(\frac{V}{L} \right)^{1/\epsilon} \text{pv}$$

ANNEX 7

AN ANALYSIS OF THE AGRICULTURAL SUPPLY FUNCTION

One of the aims of the agricultural supply specification is to permit calibration of the supply system while maintaining consistency with the information from the input-output table and supply price elasticities which are abundant in the econometric literature. The production function for each individual commodity has a generalised Cobb-Douglas specification: the production of a given commodity X , which is bounded below by a *minimum subsistence* level M , is a function of an aggregate input R and a technological progress coefficient γ . Given that part of the input R , is required in fixed proportion of the output, cX , farmer optimising behaviour is limited to the amount of input in excess of the minimum fixed proportion requirement ($R-cX$):

$$(1) \quad X = a(R - cX)^b (1+\gamma)^{dt} \quad \text{with } 0 < b < 1; 0 < c < 1; X > M$$

The production function (1) implies decreasing returns to scale since we assume *a priori* that the supply elasticity relative to the aggregate input R is less than unity:

$$(2) \quad \varepsilon_{(X/R)} = \frac{bR}{R-cX(1-b)} < 1$$

It is easy to verify that equations (1) and (2) become the usual Cobb-Douglas specification when c is set to zero:

$$(1a) \quad X = a R^b (1+\gamma)^{dt}$$

$$(2a) \quad \varepsilon_{(X/R)} = b$$

From equation (1), we can derive the inverse demand for the aggregate input R , as a function of the commodity supply, X :

$$(3) \quad R = a^{-1/b} X^{1/b} (1+\gamma)^{-td/b} + cX \quad \text{with } R > cM$$

Applying the first order conditions under the production technology constraint defined by equation (3), yields the optimal level of supply relative to the ratio between the producer price pp , and the price of the composite input pr . In order to simplify the notation, we will assume that pr is the numéraire:

$$(4) \quad X = a^{\frac{1}{1-b}} b^{\frac{b}{1-b}} (pp - c)^{\frac{b}{1-b}} (1+\gamma)^{\frac{td}{1-b}}$$

Let

$$b = \frac{\beta}{1+\beta}; \quad d = \frac{1}{1+\beta}; \quad \text{and } a = \alpha^{\frac{1}{1+\beta}} \left(\frac{\beta}{1+\beta} \right)^{-\beta}$$

We can re-write (4):

$$(5) \quad X = \alpha (pp - c)^\beta (1+\gamma)^t$$

From (5), we can derive the supply price elasticity:

$$(6) \quad \varepsilon(X/pp) = \frac{\beta}{1 - \frac{c}{pp}}$$

We can verify that for positive supply elasticities, and c coefficients less than pp , the β parameters are always positive, and the b parameters never exceed unity. Decreasing returns to scale is therefore guaranteed, at any positive supply price elasticity. We can replace the parameters in equation (4) to derive an equation for R which was described in section III.C of the paper:

$$(7) \quad R = \alpha^\beta \left(\frac{\beta}{1+\beta} \right) X^{\frac{1+\beta}{\beta}} (1+\gamma)^{\frac{-t}{\beta}} + cX$$

Next, we describe the transformation function, i.e. a two commodity model, with agricultural outputs X_1 and X_2 , competing for a fixed amount of total aggregate input $R = R_1 + R_2$. Let $\rho = 1/b$, we can derive the transformation function from equation (3):

$$(8) \quad R = R_1 + R_2 = c_1 X_1 + c_2 X_2 + a_1^{\rho_1} X_1^{\rho_1} (1+\gamma_1)^{-\rho_1 d_1 t} \\ + a_2^{\rho_2} X_2^{\rho_2} (1+\gamma_2)^{-\rho_2 d_2 t}$$

First and second derivatives of the transformation function highlight some of its properties (see also Figure A-2):

$$(9) \quad \frac{dX_1}{dX_2} = - \frac{a_2^{-\rho_2} \rho_2 (1+\gamma_2)^{-\rho_2 d_2 t} X_2^{\rho_2-1} + c_2}{a_1^{-\rho_1} \rho_1 (1+\gamma_1)^{-\rho_1 d_1 t} X_1^{\rho_1-1} + c_1} = - \frac{pp_2}{pp_1}$$

$$(10) \quad \frac{d^2 X_1}{d^2 X_2} = - \frac{a_2^{-\rho_2} (1+\gamma_2)^{-\rho_2 d_2 t} \rho_2 (\rho_2-1) X_2^{\rho_2-2}}{a_1^{-\rho_1} (1+\gamma_1)^{-\rho_1 d_1 t} \rho_1 (\rho_1-1) X_1^{\rho_1-2}}$$

With b less than unity, the second derivative is always negative ($\rho-1 > 0$), and implies that the transformation function is convex to the origin. The first derivative is bounded above by $pp_2 = c_2$ and below by $pp_1 = c_1$. As shown in

figure A-2, this means that the function intersects the axes with non-zero prices. In practice, however, the function is bounded by minimum subsistence levels M_1 and M_2 . In addition, the transformation function shifts upward according to the trend coefficients γ_1 and γ_2 .

An increase in the available amount of aggregate input R induces the numéraire input price, p_r , to decrease, and the producer prices pp_1 and pp_2 to increase in the same proportion. The way a change in total input availability affects the transformation function can be analysed through derivation of the output ratio (X_1/X_2) with respect to an equiproportional change in producer prices. Assuming no technological trends, we have:

$$(11) \quad \frac{X_1}{X_2} = \frac{\alpha_1}{\alpha_2} (pp - c_1)^{\beta_1} (pp - c_2)^{-\beta_2} \quad \text{with } pp = pp_1 = pp_2$$

and

$$(12) \quad \varepsilon\left(\frac{X_1/X_2}{pp}\right) = \frac{X_1}{X_2} (\varepsilon(X_1/pp_1) - \varepsilon(X_2/pp_2))$$

Therefore the transformation function (8) is homothetic only for c and β values which imply equal supply price elasticities for both commodities. In all other cases, an increase in the total amount of input R , will change the output structure, with the transformation possibility frontier shifting up or down relative to the 45 degree line, according to the respective supply responses.

From expression (11), we can derive the transformation price elasticity as the ratio of the supply price elasticities of the two commodities:

$$(13) \quad \varepsilon\left(\frac{X_1/X_2}{pp_1/pp_2}\right) = \frac{\beta_1 \frac{pp_1}{pp_1 - c_1}}{\beta_2 \frac{pp_2}{pp_2 - c_2}} = \frac{\varepsilon_1}{\varepsilon_2}$$

The above supply system offers an easy way to integrate supply estimates from the econometric literature into the fully consistent optimising framework which is required when one works with GE models. As the next section shows, it is easy to calibrate the agricultural supply system given an existing input-output structure.

Calibration

The supply functions prove to be relatively easy to calibrate given the base data and the set of supply elasticities which are abundant in the literature. The equations we wish to calibrate are (dropping the sector subscript):

$$(1) \quad X = \alpha(pp/pr - c)^\beta$$

$$(2) \quad R = X \left[\frac{\beta}{1+\beta} (pp/pr - c) + c \right]$$

Let p represent the ratio p_p/p_r , where p_p is the output price, and p_r is the unit input price. (Currently, in the calibration phase, p_p is assumed to be 1, and p_r is $(1-s_i)$ where s_i is the sectoral input subsidy.) The base data gives us the value of X and R , we allow r to equal R/X , i.e. r is the ratio of total input to total output. From equation (1) we can deduce the supply price elasticity which is given.

$$(3) \quad \epsilon = \frac{\beta}{1-c \frac{p_r}{p_p}} = \frac{p\beta}{p-c}$$

We can re-write equation (2) using the ratio R/X , and replacing the parameter β , with its equivalent from equation (3):

$$(4) \quad \beta = \epsilon(p-c)/p$$

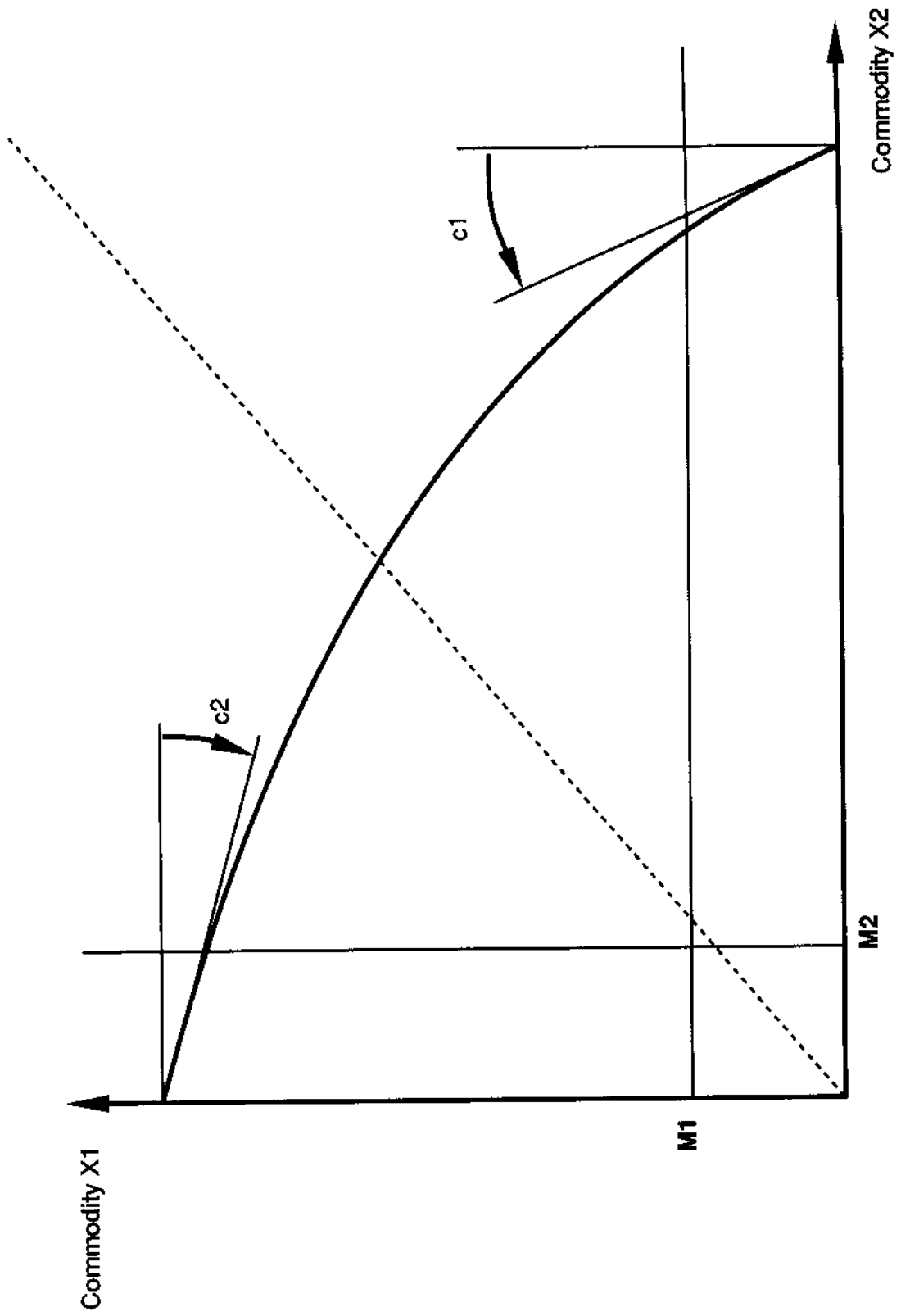
$$(5) \quad r = \frac{p[\epsilon(p-c) + c]}{\epsilon(p-c) + p} = \frac{R}{X}$$

Finally from equation (5), we can readily deduce the coefficient c , which will be a function of r , ϵ and p , which are all known elements:

$$(6) \quad c = \frac{p[\epsilon(p-r) - r]}{\epsilon(p-r) - p}$$

To finish the calibration, β can be calculated from equation (4) once c has been calculated. Finally, α , can be calibrated using equation (1).

Figure A-2 : Agricultural transformation function in RUNS



ANNEX 8

DEFINITIONS OF INDICES, VARIABLES, AND PARAMETERS

Indices

i	Agricultural sectors
m	Non-agricultural sectors
k	Agricultural and non-agricultural sectors
cr	The crops production sector
lv	The livestock production sector
r	Rural sector
u	Urban sector
r,r'	Regional indices
t	Time index
j	Rural investment goods (dl, dst, lst, il)

Variables

Prices block

p_{ck}	Consumer prices
p_{pi}	Domestic agricultural prices
p_{ri}	Sectoral unit input prices
p_{icr}	Price of inner CES composite in crops sector
p_{ilv}	Price of inner CES composite in livestock sector
p_{rcr}	Unit price of aggregate input in crops sector
p_{rlv}	Unit price of aggregate input in livestock sector
p_{ar}	Price of the composite "labour-irrigation-draught"
p_{wr}	Price of the composite "land-tractors"
w_u	Actual urban nominal wage
w_u°	Equilibrium nominal wage
rw_u	Actual urban real wage
rw_u°	Equilibrium real wage
pva_u	Price of urban value added
p_m	Price of urban composite commodities
px_m	Domestic producer price of urban commodities
pd_m	Domestic sales price of urban commodities
pe_m	Domestic price of exports of urban commodities
pm_m	Aggregate import price of urban commodities
pir_j	Return on individual rural investment goods
pi_r	Aggregate rural investment price
PGDP	GDP deflator
pg	Government expenditure deflator
PINV	Investment expenditure deflator
cpi_u	Urban consumer price index
POECD	Price index of OECD manufacturing and services exports

Urban Production block

$V_{u,m}$	Intermediate input demand
VA_u	Urban value added
L_u^d	Demand for urban labour
XD_m	Total domestic output
XS_m	Domestic sales of domestic output
X_m	Total domestic demand for urban composites
ES_m	Foreign sales of domestic output (Export supply)
TE_m	Export demand for domestic output
TM_m	Aggregate import demand
$E_m^{r,r'}$	Import demand in region r for commodity originating in region r'

Rural Production Block

X_i	Domestic output
R_i	Sectoral aggregate input
R_{cr}	Aggregate input in crops sector
R_{lv}	Aggregate input in livestock sector
$Seed_{cr,i}$	Seed demand in crops sector
$Feed_{cr,i}$	Feed demand in crops sector
$V_{cr,m}$	Demand for urban intermediates in crops sector
A_{cr}	Demand for "land-tractors" in crops sector
W_{cr}	Demand for "labour-irrigation-draught" in crops sector
$Seed_{lv,i}$	Seed demand in livestock sector
$Feed_{lv,i}$	Feed demand in livestock sector
$V_{lv,m}$	Demand for urban intermediates in livestock sector
A_{lv}	Demand for "land-tractors" in livestock sector
NT_i	Net agricultural trade

Income and expenditure blocks

$C_{r,k}$	Final demand for rural private consumption
$C_{u,k}$	Final demand for urban private consumption
G_m	Final demand for government consumption
I_m	Final demand for investment goods
Y_r	Total rural income
YT_r	Income transfers to rural households
TAX_r	Rural household taxes
Yd_r	Rural disposable income
S_r	Rural household savings
VA_r	Real rural value added
Y_u	Total urban income
YT_u	Income transfers to urban households
TAX_u	Urban household taxes
Yd_u	Urban disposable income
S_u	Urban household savings
Π_{cr}	Producer surplus in crops sector
Π_{lv}	Producer surplus in livestock sector
YTa	Income generated by agricultural price wedges
YT^e	Income generated by export subsidies/taxes
YT^m	Income generated by import subsidies/taxes
YT^{ex}	Income generated by energy price wedges

Y^{Tu}	Total income generated by non-agricultural trade wedges
Y^{Tst}	Income generated by changes in stocks
Y^{Tue}	Unemployment compensation
Y_g	Net government revenues
S_g	Net government savings
TG	Real government expenditures
gdp	Real gross domestic product
I_r	Nominal rural investment
I_u	Nominal urban investment
TI	Total real investment
$balpw$	Balance of trade in world prices
S_f	Nominal value of foreign savings

Factors

L_r	Rural labour force
L_u	Urban labour force
L_u^d	Demand for urban labour
MG	Rural to urban labour migration
$TLAB$	Total labour force
SLa	Supply of the composite "land-tractors"
SLw	Supply of the composite "labour-irrigation-draught"
K_u	Urban capital stock
LST	Stock of cattle
DST	Stock of farm equipment
DL	Stock of dry land
IL	Stock of irrigated land
TL	Stock of total land
I_r^{fc}	Investment in livestock
I_r^{lst}	Investment in draught cattle
I_r^{dst}	Investment in farm equipment
I_r^{dl}	Investment in dry land
I_r^{il}	Investment in irrigated land

Exogenous Variables and Policy Instruments

γ_u	Growth parameter in urban value added
γ_i	Growth parameter in agricultural supply function
γ_{lab}	Growth rate of total labour force
γ_u	Growth rate of the urban labour force
γ_{fc}	Natural growth rate of cattle (birth rate less death rate)
ξ_{sl}	Livestock slaughter rate
δ_{ku}	Depreciation rate of urban capital
δ_{tr}	Depreciation rate of farm equipment
κ_r	Rural income tax rate
κ_u	Urban income tax rate
St_i	Net changes in stocks and waste

$\tau_{e,m}^{r,r'}$	Export subsidy/tax in region r on commodities originating in region r'
$\tau_{m,m}^{r,r'}$	Import subsidy/tax in region r on commodities originating in region r'
rw_u^*	Reference real wage
ω_1	Weight of reference real wage on sticky real wage
ω_2	Weight of equilibrium real wage on actual real wage
$\phi_i^{(\theta)}$	Price transmission coefficients
s_i	Sectoral agricultural input subsidies
τ_i^0	Base year price wedges
p_{eener}	Real price of energy commodity
ρ^{ue}	Unemployment compensation rate
$\chi_r^a, \chi_u^a, \chi_g^a$	Institutional shares of agricultural price wedge income
$\chi_r^u, \chi_u^u, \chi_g^u$	Institutional shares of non-agricultural price wedge income
$\chi_r^{st}, \chi_u^{st}, \chi_g^{st}$	Institutional shares of stock income
$\chi_r^{aid}, \chi_u^{aid}, \chi_g^{aid}$	Household savings shares of foreign savings
χ_r^{uf}	Share of total rural savings transferred to urban investment
S_f	Real foreign savings
LMAX	Maximum potential of cultivated land area

Parameters

$\theta_{r,k}$	Rural ELES subsistence minima
$\theta_{u,k}$	Urban ELES subsistence minima
$\mu_{r,k}$	Rural ELES marginal propensity to consume
$\mu_{u,k}$	Urban ELES marginal propensity to consume
$\zeta_{g,m}$	Government expenditure shares
$\zeta_{i,m}$	Investment expenditure shares
δ_i, δ_k	Share parameters in urban value added CES
ϵ_u	CES elasticity in urban value added function
$a_{mm'}$	Urban input-output table
va_m	Urban value added coefficients
α_i	Scale parameter in agricultural supply function
β_i	Exponent in agricultural supply function
c_i	Minimum price parameter in agricultural supply function
$as_{cr,l}$	Seed share parameters in crops sector
$af_{cr,l}$	Feed share parameters in crops sector
$am_{cr,m}$	Non-agricultural share parameters in crops sector

$ac(3)$	Share parameters for inner CES composite in crops sector
ϵ_{cr}	Elasticity for inner CES composite in crops sector
$as_{lv,i}$	Seed share parameters in livestock sector
$af_{lv,i}$	Feed share parameters in livestock sector
$am_{lv,m}$	Non-agricultural share parameters in livestock sector
$al(4)$	Share parameters for inner CES composite in livestock sector
ϵ_{lv}	Elasticity for inner CES composite in livestock sector
ad_m	Domestic Armington share parameter (1st level)
am_m	Import Armington share parameter (1st level)
ζ_m	Armington elasticity (1st level)
$\Phi_m^{r,r'}$	Armington share parameters (2nd level)
ϵ_m^r	Armington elasticity (2nd level)
cd_m	CET domestic share parameters
ce_m	CET export share parameters
σ_e	CET elasticity of substitution
ρ_e	CET exponent
$\delta^a(3)$	Land-Tractor aggregation coefficients
$\delta^w(5)$	Labour-Irrigation-Draught Cattle aggregation coefficients
$\mu(6)$	Parameters for the labour migration function
β_j	CES share parameters in rural investment function
ϵ_{ir}	CES elasticity in rural investment function
c_{dl}	Share parameter in investment cost function for dry land
c_{dst}	Share parameter in investment cost function for farm equipment
$c_{lst}^{(2)}$	Share parameters in investment cost function for draught cattle
c_{il}	Share parameter in investment cost function for irrigated land

ANNEX 9

SAM STRUCTURE OF THE MODEL⁵⁰

A Social Accounting Matrix (SAM) provides a tabular snapshot of the economy at one point in time. Table A-1 presents a descriptive SAM for the RUNS model that shows the transactions among agents in the economy captured by the AGE model.⁵¹ Each nonzero cell in the SAM represents the value of an economic transaction between actors. The model equations describe every entry in the SAM. The accounts in the SAM effectively define the transactions and income flows among five basic actors in the economy: suppliers/enterprises, households, government, capital account, and rest of the world. A row documents the income to an account, the corresponding column documents the outflow, and the row and column sums must balance for each account. In equilibrium, this balance implies: (1) costs (plus distributed earnings) exhaust revenues for producers, (2) expenditure (plus taxes and savings) equals income for each agent in the model, and (3) demand equals supply of each commodity.

Accounts 1 and 2 of the sample SAM, represent the workings of farms. Down the columns, we have the input structure of the crops and livestock sector respectively.⁵² Along the rows, we have farm revenues from the sale of production and government input subsidies.

Accounts 3 and 4 represent the supply and demand components of agricultural commodities. Columns 3 and 4 represent supply which is the sum of domestic production, plus depletion of stocks, and imports (from ROW). Along the rows we have demand: intermediate demand from farms and final demand from households, stock increases, and ROW.

The next set of accounts (5)-(10) describe the workings of the urban economy. The first three deal with supply and demand for the composite non-agricultural commodities, the latter three (8)-(10) deal with supply and demand for domestic production of non-agricultural commodities. Columns (5)-(6) give the supply of the composite good. The supply is given by domestic sales of domestic production (in this case, the make matrix is diagonal), and imports. Columns (8)-(10) describe the production structure of non-agricultural commodities. The input-output table is given by the intersection of columns (8)-(10) with rows (5)-(6). Urban value added is given in rows (13) and (14).

Value added is described by rows (11)-(14). Rural value added is divided into two components, payments to factors of production and a producer surplus. Urban value added is simply divided between labour and capital. The intersection of columns (11)-(14) and rows (15)-(16) describe the distribution of income from factors to households. RUNS uses a very simple distribution function, rural value added is allocated to rural households, and urban value added is allocated to urban households.

⁵⁰ Parts of this annex were inspired by Robinson, Kilkenny, and Hanson (1990).

⁵¹ For an introduction to Social Accounting Matrices, see King (1985). Pyatt and Round (1985) provide a number of examples of the uses of SAM's.

⁵² Note that in this SAM we have aggregated the agricultural *commodities* into two sectors, food and non-food. We have also aggregated other manufacturing, equipment, and fertilizers, into one sector named manufacturing.

Columns (15) and (16) describe the consumption patterns of households, the payment of taxes, and net savings.

Account 17 describes government revenues and expenditures. Along the row, the government receives revenues from household taxes, a significant amount from the investment account, and a share of revenues from the depletion of agricultural stocks. The investment account is simply the consolidation of the financial intermediation sector of the economy. The revenues the government gets from this account is simply net government savings, i.e. the budget deficit. If net government savings were positive, then this sum would enter as a positive flow from government to the investment account. This SAM does violate one standard rule for SAMs: one account equals one flow. The net transfer from households to the government (taxes), does net out unemployment compensation, which would enter as a flow from government to households.

Account 18, as mentioned above is the consolidated financial sector, often referred to as the investment account. It also consolidates rural and urban savings, even though in the RUNS model these are kept separate. Apart from household savings, the investment account receives a flow from ROW, i.e. capital flows from the rest of the world. If there is a capital outflow, e.g. Japan, this value would enter as a positive entry in the investment column, towards ROW.

We have already described the stocks account. There is a small payment from stocks to households and the government. This is the net income generated by the change in stocks. The final row and column, 20, describe the flows between the domestic economy and the rest of the world. Down the column, we have the value of exports, both agricultural and non-agricultural. A small item is entered as a payment from ROW to urban households and the government. This is the net payment from the rest of the world generated by the price wedge between domestic and world agricultural prices. The SAM uses the convention that all entries are positive flows. Note that this payment is normally divided between both households and the government. For this SAM, the rural share turns out to be zero. There is also a positive capital flow from ROW. Along the row, we have imports, as an outflow from the domestic economy.

It is readily seen that the SAM is square, and balanced.

Table A-1: Benchmark SAM for Latin America (Millions of 1985 US\$)

	1	2	3	4	5	6	7	8	9	10	11
	Crops	Livestock	Food	Non-Food	Manu	Energy	Services	Manu	Energy	Services	Rural Factors
Agricultural Activities											
1 Crops			48,418	1,861							
2 Livestock			20,909	482							
Agricultural Commodities											
3 Food	488	2,259									
4 Non-Food	0	0									
Non-Agricultural Commodities											
5 Manufacturing	5,894	0						16,465	1,758	11,539	
6 Energy	885	291						5,535	0	2,448	
7 Services	14,380	6,118						35,820	8,789	0	
Non-Agricultural Activities											
8 Manufacturing					143,463	0	0				
8 Energy					0	2,815	0				
10 Services					0	0	150,302				
Rural Value Added											
11 Rural Factors	11,534	9,181									
12 Rural Surplus	18,898	9,542									
Urban Value Added											
13 Urban Labour								61,507	8,924	90,457	
14 Urban Capital								41,005	5,949	50,304	
Institutions											
15 Rural Households											14,714
16 Urban Households											
17 Government											
18 Investment											
19 Stocks			2,037	2							
20 Rest of the World			807	0	40,512	11,131	15,265				
21 Total	53,278	21,391	72,171	2,344	183,975	13,946	168,566	160,332	25,420	164,748	14,714

Table A-1: Benchmark SAM for Latin America (Millions of 1985 US\$)

	12	13	14	15	16	17	18	19	20	21
	Rural Surplus	Urban Labour	Urban Capital	Rural Households	Urban Households	Government	Investment	Stocks	ROW	Receipts
	12	13	14	15	16	17	18	19	20	21
Agricultural Activities										
1 Crops						1,598				51,876
2 Livestock						0				21,261
Agricultural Commodities										
3 Food										
4 Non-Food								361	11,628	72,171
Non-Agricultural Commodities								6	976	2,344
5 Manufacturing							59,545			183,575
6 Energy						16,675	0			13,946
7 Services						1,656	2,550			185,567
Non-Agricultural Activities										
8 Manufacturing									16,868	180,382
9 Energy									22,605	25,423
10 Services									14,446	184,748
Rural Value Added										
11 Rural Factors										14,714
12 Rural Surplus	28,440									28,440
Urban Value Added										
13 Urban Labour		160,887								160,887
14 Urban Capital			107,258							107,258
Institutions										
15 Rural Households						0		0	0	49,154
16 Urban Households						0		836	367	268,379
17 Government						0	9,092	836	367	46,145
18 Investment						0			397	71,187
19 Stocks						0				2,036
20 Rest of the World						0				67,715
21 Total	28,440	160,887	107,258	43,154	268,379	46,145	71,187	2,036		67,715

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