The MEGABARE model:
interim documentation

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ABARE

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ABARE is a professionally independent government economic research agency.

Foreword

Many of the major policy problems facing Australia are increasingly of a global nature. Policies to deal with the enhanced greenhouse effect, trade liberalisation under the Uruguay Round and APEC initiatives are among the most prominent current examples. Policy action in many countries will affect the Australian economy especially through their effects on international flows of commodities and capital. To adequately analyse these issues, a model of the global economy is clearly needed.

The MEGABARE model has been developed at ABARE to provide such a global perspective on major Australian policy issues. It currently divides the world into 30 regions, including Australia, identifying 37 industries within each region. A model such as MEGABARE is under continual development but it has already been applied to a variety of issues such as greenhouse policy, trade liberalisation and the economic repercussions of changing demographics in the Asian region.

In this ‘interim’ documentation, the central features of what has come to be regarded as the ‘basic’ version of MEGABARE are outlined. It is intended that more detailed and more technical documentation will be produced in the future.

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Acknowledgments

Kevin Hanslow is responsible for the design of the MEGABARE model and all of the special features that it contains. In particular, he is the originator of the ‘technology bundle’ approach. He also undertook all of the computer coding, developed the calibration methods that are described in appendixes C and D and prepared all of the diagrams. The remainder of this interim documentation was written by Mike Hinchy in close consultation with Kevin Hanslow. John Olejniczak was responsible for the econometric analysis reported (and for developing a procedure in the SAS® System that greatly assists in the processing and interpretation of MEGABARE simulation results).

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1. Introduction

1.1 Scope of documentation

MEGABARE is a dynamic model of the world economy currently identifying 30 regions and 37 commodities. Details of the regional and commodity coverage are given in appendix A. While a model such as MEGABARE is under continuous development, what may be regarded as the 'basic' version of the model was used for a large set of simulations reported in ABARE–DFAT (1995). The present report extends the documentation of that model contained in appendix A of the ABARE–DFAT study. It is described as 'interim' documentation in the sense that it does not contain a complete listing of all equations in the model and parameter values. However, such a listing will be published.

MEGABARE draws in part on the structure and the database of the static GTAP (Global Trade Analysis Project) model of world trade. Extensive documentation and discussion of the GTAP model is to be produced shortly (Hertel 1996). While the 'final' documentation for the basic version of MEGABARE will be complete in itself, it is intended to provide extensive cross-referencing to the GTAP study. Apart from detailed documentation, the GTAP study contains an extended discussion of a number of features of GTAP that have been absorbed into MEGABARE.

Although the present documentation does not contain a complete listing of all equations in the model, all of what are thought to be the main behavioural equations are described. While computable general equilibrium (CGE) models contain a very large number of equations, only a small subset of the equations in different models embody different behavioural hypotheses. The bulk of equations either embody the same hypothesis (implementing the neo-classical conditions for a competitive equilibrium) or do not embody any behavioural hypothesis (such as 'accounting' equations defining aggregates in terms of their elements).

An advantage in not attempting an exhaustive documentation is that there is more scope to discuss the motivation for key behavioural equations. In an exhaustive treatment, the scope for such discussion is limited by the need to describe everything. It is hoped that this study will serve as a useful companion to the full documentation when it is completed.

It is true, of course, that differences in behavioural hypotheses are not the only reason why different CGE models produce different results when applied to the same problem. Different CGE models are usually calibrated to different databases. Parameters that perform identical functions in different models may assume different values. For this reason, a knowledge of data sources is important in interpreting model results. The bulk of data used by MEGABARE comes from the GTAP database, supplemented with data from several other sources, as will be evident from the chapters that follow. Data sources will be described completely in the full documentation.

An attempt has been made to write this ‘interim’ documentation in as non-technical a way as possible. No knowledge is assumed of terms and procedures that are familiar only to specialist CGE modellers. For readers simply wishing to obtain a quick overview of the structure of the model, it is possible to start at chapter 3 after completing this chapter. In chapter 2 a number of technical issues involved in creating a dynamic model from static origins are discussed.

1.2 Origins of MEGABARE

The initial major focus for the development of MEGABARE was the desire to create a dynamic general equilibrium model of the global economy suitable for international greenhouse policy analysis. However, a model capable of performing this function has many other possible applications especially in the area of international trade policy.

The GTAP database and model provided an attractive starting point for MEGABARE. In developing a model such as MEGABARE, the costs of establishing a suitable database greatly exceeds the costs of creating the equations of the model. A major stimulus for the GTAP project was the recognition that major cost savings were possible if the need to develop a new database for each new modelling project could be avoided. If data definitions were standardised, researchers could combine their data gathering efforts. The resulting database would be far superior to that which could be created by any individual working alone.

Researchers in many countries have contributed to the development of the GTAP database which is updated annually. Since 1993 the disaggregation of the world economy in the GTAP database has extended from 16 regions to the current 30 regions and further disaggregation is planned. ABARE is a member of the consortium that oversees the future direction of the GTAP project. (Further information can be obtained about GTAP on the Internet from http://www.agecon.purdue.edu/gtap).

Both the GTAP database and model provided a convenient starting point for MEGABARE as well as a number of other modelling projects. The GTAP model was designed with the intention that it would be used in this fashion. As mentioned above, only a very small subset of equations in CGE models implement distinctive behavioural hypotheses. Rather than having to recode a vast number of equations that would perform the same function in different models, there are economies in starting with a common and well tested core. It may be necessary to add many more equations to implement particular applications. However, only a relatively small number of the core GTAP equations are likely to need modification.

The computer code that implements the special features of MEGABARE is roughly double the volume of the original GTAP code. However, only a relatively small proportion of the original GTAP equations have been changed to introduce new hypotheses. Some equations have been recoded to improve their accuracy under a dynamic simulation but the implied algebraic form of the equation (in nonlinearised form) remains unchanged.

1.3 An overview of creating MEGABARE from GTAP

The actual GTAP model follows in the tradition of the different versions of the SALTER model that were developed by the Industry Commission under contract to the Department of Foreign Affairs and Trade. It is a static CGE model of global trade. Production and consumption in each region are determined as the result of maximising (cost minimising) behaviour. Imports are assumed to be imperfect substitutes with equivalent domestic commodities. Perfectly competitive conditions are assumed and goods and factor markets clear through movements in relative prices. Bilateral trade flows in all commodities across all regions are determined.

In creating a dynamic model from the static GTAP foundations, it is clear that modification to the GTAP equations would be needed in at least two areas. In the most elementary models of economic growth, there are two equations that link the economy at different time periods. One equation describes the growth in the capital stock as the result of investment and depreciation. The other equation describes the growth in the labour force (and population) which is set to grow at an exogenously given rate in elementary models. In more complex models, the rates of growth of the labour force and population are sometimes determined by the model.

In creating MEGABARE, modifications have been made to the GTAP equations governing investment and savings which finance investment. A great deal of additional code has been added to determine the growth in the labour force and population. Drawing on relationships that have been discussed in the economics literature since the time of Malthus, in MEGABARE the rates of growth of the labour force and population are determined by the model.

Given the greenhouse focus of MEGABARE, it was also necessary to incorporate emissions of greenhouse gases as a byproduct of different economic activities. Emission accounting equations were needed to sum emissions into regional and global totals. Additional equations were required to impose various policies intended to curb the growth in emissions.

A further significant modification to the GTAP core was made as a result of the greenhouse focus of MEGABARE. The designers of GTAP readily acknowledge that the equations determining industry demands for inputs may have limitations in simulating the impact of policies that affect energy prices (Hertel and Tsigas 1993). In particular, the GTAP input demand equations do not support substitution options between capital and energy.

In reviewing what alternative to the GTAP equations to adopt, a deliberate decision was made not to adopt the nested CES (constant elasticity of substitution) production function approach. Such an approach has been standard in econometric modelling of the energy sector and is adopted in many other CGE models.

It was believed that it was possible to improve on the nested CES approach in terms of both accuracy and transparency by introducing what has been termed the ‘technology bundle’ approach. Using this approach, a level of detail about different technologies is introduced into MEGABARE that is normally found only in so-called ‘bottom up’ models. An attempt is made to introduce the realism in modelling substitution options that is a feature of ‘bottom up’ models while retaining extensive interactions between the energy and other sectors of the economy that is a feature of ‘top down’ models.

The technology bundle approach is relatively demanding of data. In the ‘basic’ version of MEGABARE, the technology bundle approach was applied only to the electricity and iron and steel industries. However, correctly modelling substitution options in these sectors, especially the electricity sector, is crucial in assessing the impacts of greenhouse policies.

While the technology bundle approach is one of the most distinctive features of MEGABARE at the sectoral level, the most novel feature in terms of overall model structure is the endogenous determination of population and labour force growth. In other dynamic CGE models, these variables are either taken as exogenous and forecasts from other sources used or they are set to grow at some exogenously given rate.

In MEGABARE a detailed demographic module has been developed and population growth rates and the age (in one year age groups from 0 to 100) and sex composition of the population in each region are determined by the model. Birth rates and mortality rates are assumed to respond to economic variables according to parameters based on an econometric analysis undertaken during the development of the module.

There are several reasons for suggesting that the demographic module is a very worthwhile extension. First, a basic test for any model to be used for longer term analysis of a growing world economy is that it should be capable of reproducing the so-called ‘stylised facts’ of economic growth. There is a presumption that the better a model is able to reproduce the ‘stylised facts’ the more realistic the scenarios it can produce for future world growth. It is difficult to see how a model could reproduce some of the ‘stylised facts’ of economic growth without allowing for interaction between demographic and economic variables.

An example involving two ‘stylised facts’ illustrates the type of economic–demographic interaction possible in MEGABARE. These ‘stylised facts’ relate to widely observed outcomes (as evident from the Penn World Tables and discussed in the development economics literature) as developing economies undergo the transition from a sustained period of low, zero or even negative growth to a sustained period of higher growth. The first ‘stylised fact’ is that the workforce as a proportion of the population increases, giving a temporary boost to the growth in GDP per person. The second ‘stylised fact’ is that the ratio of savings to GDP increases. MEGABARE can reproduce both of these ‘stylised facts’ and embodies a mechanism on how they may be related.

As mentioned above, both fertility and mortality rates are related to economic welfare through econometrically estimated parameters. Both these rates decline as welfare improves but the overall impact is a gradual increase in the proportion of the population of working age. While reduced mortality does increase the number of individuals beyond working age, they represent only a small proportion of the population in developing countries due to the high mortality rates. In the younger age groups, the impact of reduced fertility dominates that of reduced mortality. An increase in the proportion of the population of working ages results.

The accompanying increase in the ratio of savings to GDP in MEGABARE also stems from the changing demographics. In MEGABARE the choice between consumption and savings is modelled at the level of individual age groups according to a life cycle hypothesis. Individuals below and above working age are net dissavers (consume more than their income) while those of working age are net savers. As the proportion of the population in the workforce increases, the ratio of net savers to net dissavers increases, resulting in an increase in the ratio of savings to GDP. It is unnecessary to hypothesise any increase in thriftiness by individuals as has sometimes been done in the development literature.

The second reason for believing that the demographic extension is worthwhile is that there seem inherent dangers in drawing on forecasts of GDP and population growth rates from different sources as is often done in running dynamic CGE models. It is clearly possible that these independent forecasts will be inconsistent with the relationship between these variables that is well supported by econometric evidence. An example of this problem may be the IPCC emission scenarios (Leggett, Pepper and Swart 1992) that are widely used in the scientific and economic literature on greenhouse issues.

Simulations with an early version of MEGABARE implied that the time paths for global emissions under the alternative scenarios would lie within a narrower band when allowance is made for the economic–demographic interaction (Hanslow, Hinchy and Fisher 1994).

The final reason for supporting the demographic module is that it permits the analysis of many issues that would not otherwise be possible. There are many important issues relating to the environmental and economic impact of a growing world population and the changing age composition of population in the developed and rapidly growing Asian economies.

In chapter 3 a broad overview of the structure of MEGABARE is given. An attempt is made to identify all areas where MEGABARE introduces different hypotheses from those in the original GTAP model. In chapter 4 more details are given about some of the specialised features of MEGABARE such as the technology bundle and the demographic module. However, before turning to the structure of the model, a fuller discussion of the issues involved in creating dynamic MEGABARE from static foundations is needed.

2. Issues in creating a dynamic model from static origins

2.1 Adding dynamics

The creation of the dynamic MEGABARE model from the basis of the static GTAP model parallels the creation of the dynamic MONASH model from the static ORANI model of the Australian economy. There are many common conceptual and computational problems especially since all models are coded in the GEMPACK (Harrison and Pearson 1994) software. A number of fruitful discussions have taken place between members of ABARE and the Centre of Policy Studies at Monash University on matters of common interest.

It is useful to begin by developing the distinction between *static* and *dynamic* models more precisely. In a static model, it is assumed that the equations specify relationships that hold between all variables at the same instant of time. There is no need to include time as an explicit variable in the equation system.

Suppose a static model of an economic system contains *n* endogenous and *s* exogenous variables. The *n structural* equations of the model may be written in implicit form

$$(2.1) \qquad f^i(x_1,\ldots,x_n,\alpha_1,\ldots,\alpha_s) = 0 \qquad (i = 1,\ldots,n)$$

where the x_i represent endogenous variables and the α_i represent exogenous variables.

A *reduced form* solution to the model will exist if certain well known conditions hold that allow the endogenous variables to be written as functions of the exogenous variables

$$(2.2) \qquad x_i = \phi^i(\alpha_1,\ldots,\alpha_s) \quad (i = 1,\ldots,n)$$

If some exogenous variable, α_k, changes within a given neighbourhood of its original value, α_k^0, the solution for the resulting changes in the endogenous variables is given by

$$(2.3)\qquad \begin{bmatrix} \partial x_1/\partial \alpha_k \\ \cdot \\ \cdot \\ \cdot \\ \partial x_n/\partial \alpha_k \end{bmatrix} = \begin{bmatrix} f_{x1}^1 & \cdot & \cdot & \cdot & f_{xn}^1 \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ f_{x1}^n & \cdot & \cdot & \cdot & f_{xn}^n \end{bmatrix}^{-1} \begin{bmatrix} -f_{\alpha k}^1 \\ \cdot \\ \cdot \\ \cdot \\ -f_{\alpha k}^n \end{bmatrix}$$

Such an equation system emphasises the interdependence of all variables. The change in a particular endogenous variable will be influenced by the structure of many different equations of the system.

Given the initial values of the exogenous variables, the initial equilibrium values of all endogenous variables can be computed. New equilibrium values can also be computed for a change in any given exogenous variable. While it might be imagined that time would elapse while an economic system changed from one equilibrium position to another, no explicit time path of adjustment for the endogenous variables can be computed with a comparative static model. Only the initial and final equilibrium values can be computed.

A typical application of static CGE models, such as GTAP and ORANI, conceptually, involves the solution of equation system (2.3). The database for the model is an initial equilibrium for the economy. Some exogenous variable, such as a tariff level, is changed and the resulting changes in all endogenous variables in the model are computed.

An analysis could be undertaken with a time ordered sequence of changes to the exogenous variables in a comparative static model to generate a time ordered sequence of values for all endogenous variables. Such an approach could represent useful dynamic analysis if it were thought that some exogenous variable would follow a particular time path. However, since the time it takes for a comparative static model to adjust from one equilibrium to another is unspecified, the appropriate time spacing of new values for the exogenous variable would be unclear.

In a *dynamic* as opposed to a comparative static model, the structural equations will include relationships between endogenous variables at different points of time. There are two basic types of dynamic equations in MEGABARE. First, there are equations for *stock* variables that describe the relationship between the opening value of the stock at time t+1 and time t. For example, the capital stock in each region evolves according to an equation of the familiar form

(2.4) $$K_{t+1} = (1 - d)K_t + I_t$$

where K_t represents the opening capital stock in period t, d is the rate of depreciation and I_t is the *flow* of investment during a given time period. Other dynamic stock equations determine the growth in population in each country (given births and deaths in each time period and net migration) and the growth in the labour force (given new entrants and retirements in each period).

There are also dynamic *partial adjustment* equations of the general form

(2.5) $$x_{t+1} = x_t + \beta(x_t^* - x_t) \qquad 0 < \beta < 1$$

where x_t^* is the desired or equilibrium value of some variable, x_t is the actual value and β is the partial adjustment coefficient. Thus, it is assumed that the value of a variable in period t+1 depends on some fraction of the difference from its desired or equilibrium value in the preceding period. Such partial adjustment equations influence savings behaviour by different age groups in each region and the international flow of capital. The actual equations are rather more complex than the simple general form given above and details are given below.

The addition of only one dynamic equation to an otherwise static model fundamentally alters the properties of the model. Suppose that the values of the exogenous variables in the model were held constant for all time. Once an initial value for the lagged endogenous variable was specified, the model would produce different solutions for all endogenous variables in each time period until it attained a steady state (if one existed) unless the initial value specified corresponded to a steady state value. In the case of a purely static model, different values for the exogenous variables in each time period would be needed to produce a sequence of different solutions.

MEGABARE has quite complex dynamic properties stemming mainly from the demographic module. As mentioned above, population is modelled for each region in one year age groups from 0 to 100 and birth and mortality rates are assumed to be responsive to economic variables. Population growth in turn has an impact on economic variables, especially through consumption–savings decisions and labour force growth. It may take an extremely large number of time periods for population growth in all regions to attain a steady state.

In using the static GTAP and ORANI models as a basis for the dynamic MEGABARE and MONASH models, respectively, there is the problem alluded to above of the time period it would take the static models to achieve equilibrium. Both dynamic models are specified as annual models and, hence, it is assumed that goods and factor markets achieve equilibrium within one year unless otherwise specified. At the moment, in MEGABARE lagged adjustment processes are specified only for savings and international capital flows. There would be no technical difficulty in introducing further lagged adjustment processes where they seemed appropriate.

In virtually all dynamic CGE models, the majority of equations will be static (involving relationships between variables at the same period of time) and there will be only a few explicitly dynamic equations. It is usually assumed that most goods and factor markets clear within one year. Some dynamic CGE models incorporate the rational expectations hypothesis for savings and investment decisions whereby expectations are based on the entire future time path of some variable.

The solution procedures that must be used as a result of the size of the MEGABARE model create computational difficulties in introducing the rational expectations hypothesis. However, a prototype version of MEGABARE with rational expectations has been developed and it is expected that a fully operational version will be created. Nevertheless, much debate continues about the merits of the rational expectations hypothesis as opposed to alternative hypotheses about forming expectations. For many types of policy issues, it makes little difference whether expectations are rational or myopic as is evident in comparing simulation results from the GREEN and 12RT models (Manne and Oliveira-Martin 1994).

2.2 Solution procedure

GTAP was coded in a version of the GEMPACK software where all variables had to be entered in percentage change form. MEGABARE was coded in a later version of GEMPACK that allows variables to be entered in both percentage change and levels (actual value) form. Equations in MEGABARE contain both percentage change and levels variables.

The later version of the GEMPACK software also contains a facility for solving explicitly dynamic models as opposed to comparative static models. Solving dynamic models in GEMPACK essentially involves stacking the equations that would hold at different periods of time into a single equation system (Codsi, Pearson and Wilcoxen 1992; Harrison, Pearson and Powell 1994). The stacked equation system is then solved as a single equation system for the values of variables at all periods of time. Equation systems for static and dynamic models can be represented in a mathematically identical form

and the same solution procedure applied (for details of the solution procedure, see Pearson 1991).
However, solving a dynamic model the size of MEGABARE over a large number of time periods as a single equation system would create intractable computer memory requirements. Thus, the ‘comparative static’ solution procedure in GEMPACK was adapted to solve dynamic MEGABARE.

The equations in GTAP express relationships as linear equations in changes or percentage changes in the levels of economic variables. These are termed ‘linearised’ equations. In a typical GTAP application, a shock is applied to some set of exogenous variables and the model solved for the resulting percentage changes in endogenous variables. In MEGABARE, linearised equations are interpreted as referring to annual percentage growth rates or annual changes. Model solutions for endogenous variables in each time period are interpreted as annual percentage growth rates or annual changes in the level of economic variables.

Since the model is defined in terms of discrete time, formally, the formula for the percentage growth rate,

(2.6) $$r_t = \frac{x_{t+1} - x_t}{x_t}$$

is the finite difference approximation to the percentage growth rate if the model were defined in terms of continuous time, where x_i is some variable defined in the model. The change in a variable is the finite difference approximation to the first derivative of a variable if the model were defined in terms of continuous time.

The idea that it is possible to adapt a comparative static solution procedure to solving a dynamic model may be somewhat counterintuitive. However, all that is involved is that a sequential rather than a single step solution procedure is applied to the (stacked) dynamic equation system. The solution from the sequential procedure is mathematically identical to that which would be obtained from the single step procedure.

An overview of the mechanics of the sequential solution procedure will now be given. Suppose that the interest is in how some variable, x, defined in the model will evolve over some sequence of time periods according to the (static and dynamic) equations in the model. Thus, the interest is in obtaining a time ordered sequence of values for x,

(2.7) $$X = \{x_1, \ldots, x_T\}$$

The process of generating this set of values will be referred to as a *simulation* and the set, *X*, will be referred to as the *simulation results* for the variable *x*.

The first step in preparing a simulation will be to decide on a partition of all of the variables defined in the model into endogenous and exogenous. Such a partition is referred to as a model *closure*. If the interest is in the variable *x*, this variable naturally will be among those declared endogenous. A sufficient number of variables must be declared exogenous to ensure that there are as many equations as endogenous variables. Such a condition is necessary for a solution to the equation system to exist.

A time ordered sequence of values for all variables declared exogenous will have to be obtained from sources outside the model (apart from for a special type of variable that must be declared exogenous in the sequential solution procedure as described below). The equations in the model will be solved as many times as there are time periods in the simulation. Exogenous variables will be shocked to the appropriate values at each time period during the simulation.

GEMPACK is designed to solve problems when shocks are applied to a *model solution* (a set of values of variables consistent with the equations of the model). For the first period, the initial solution to the model is the model database which is constructed in such a way as to be consistent with the equations of the model. The model database contains initial values for all variables defined in the model and input–output tables for all regions.

The specified shocks are applied in the first time period and the model is solved in terms of annual growth rates. These annual growth rates are applied to the original values in the database to calculate new database values. If technological change is occurring, input–output coefficients will change. The updated database represents a solution to the model and is used as the initial database in the second period. Such a procedure is repeated until the final time period.

Endogenous variables in the simulation will evolve over time according to an equation of the form

(2.8) $$x_T = x_0 . \prod_{t=0}^{T} (1 + r_t)$$

where x_T is the value of the variable in period T, x_0 is its value in the base period and r_t is the annual percentage growth rate in the variable in each time period determined by solving the model equations in each time period.
Stock variables such as the capital stock in each region evolve over time according to a levels equation of the form of (2.4). However, the evolution of the opening capital stock over time can also be represented in the form of (2.8) where the variable r_t has the interpretation of the annual rate of growth in the capital stock. Rearranging equation (2.4) and dividing by K_t yields

$$\frac{K_{t+1} - K_t}{K_t} = -d + \frac{I_t}{K_t} \tag{2.9}$$

where the left hand side represents the annual rate of growth in the capital stock from period t to t+1.

Stock variables such as the capital stock are declared as *exogenous* variables. Given values for investment and the capital stock in period t (determined from the initial database and subsequently through solving the model), the appropriate shock can be derived to determine the annual growth rate in the capital stock from period t to t+1. Thus, applying the sequential solution procedure to dynamic stock equations has the unusual property that some variables that are declared to be exogenous have their values determined partly by variables that are declared endogenous (assuming investment is so declared). Forward looking variables are defined in terms of the current values of variables, as explained in chapter 4.

In some applications, only one simulation may be of interest. For example, such may be the case if the concern was with the implications of some set of GDP growth rate assumptions for the growth in world population, changing regional demographics and sectoral patterns of economic growth.

For the typical analysis of a policy issue, it will be necessary to run two simulations under different sets of assumptions. One set of assumptions containing particular settings for exogenous policy variables will be used to generate what is sometimes called a *base case* or *baseline* or *business as usual* case simulation. The second set of assumptions will contain some change in the setting of exogenous policy variables and be used to generate a *policy* simulation. The major point of interest will be how the values of given variables differ in each period between the two sets of simulation results. Differences (or percentage differences) in the values of variables between the two sets of results will have to be computed after both simulations have been completed. Thus, with a dynamic model, policy analysis is usually not a one step procedure, in contrast to policy analysis with a comparative static model.

For a policy simulation, a different model closure will often be used from that used in generating the base case. Per worker GDP may have been taken as an exogenous variable in the base case. However, the impact of a policy change on per worker GDP will often be of major interest. Thus, per worker GDP will be declared as an endogenous variable in the policy simulation. To ensure equality between the number of equations and endogenous variables, a variable that was endogenous in the base case must be declared exogenous in the policy simulation. The usual new variable taken to be exogenous in the policy simulation is the rate of implied technological change in each region. This is set at the values derived in the base case.

To conclude, the special way in which MEGABARE is coded and solved in GEMPACK should not obscure the inherently dynamic character of MEGABARE. If MEGABARE could be solved in some form of software for all time periods simultaneously, its dynamic structure would be quite transparent. However, GEMPACK is the only software available capable of solving a dynamic CGE model the size of MEGABARE. The special ‘condensation’ features allow a computationally tractable problem to be created from the almost one million equations in MEGABARE.

3. Overview of model structure

An overview of the structure of MEGABARE is given in diagrams 1–11, while an explanation of the conventions used in the diagrams is given in box 1. In this chapter, the broad structure of MEGABARE will be described referring to the diagrams. The major points where the treatment in MEGABARE differs from that in GTAP will be noted. In the next chapter, a more detailed discussion will be given of the major new features introduced in MEGABARE again referring to the diagrams.

3.1 Macroeconomic aggregates

MEGABARE does not contain a separate macroeconomic module that specifies behavioural relationships between macroeconomic aggregates such as the money supply, budget deficit, aggregate level of investment, interest rates, aggregate prices, the level of unemployment and the balance of payments on current account. Movements in the macroeconomic aggregates defined in MEGABARE are entirely the result of behavioural relationships modelled at the microeconomic level. To the extent that independent relationships exist among macroeconomic aggregates, these relationships would usually be introduced as affecting the short term dynamics of the transition to the time path resulting from the underlying microeconomic relationships. Since MEGABARE is intended for use in longer term policy analysis, there does not appear to be a great loss in ignoring any independent relationships that may exist among macroeconomic aggregates.

In diagram 1 are shown the sources and uses of regional income. The top half of the diagram represents national income from the factor cost side while the bottom half represents national income from the expenditure side. An equality is enforced between these two definitions of national income. Given these income flows, national accounting identities are defined using standard definitions. Appropriate price deflators are also defined to distinguish between real and nominal movements.

At the centre of the diagram lies a ‘conceptual activity’ which in GTAP is called a ‘representative household’ or a ‘super household’. However, it is a not a representative household in the conventional sense of the term since it pays no taxes and receives all tax revenue. A more descriptive term might simply be an ‘income pool’. The reason for the term ‘representative

Box 1: Diagram conventions

The diagrammatic representation of MEGABARE presented here complements the verbal and algebraic description. These diagrams are composed of various shapes and different types of arrows to perform the many functions required of such diagrams.

Ovals

Oval shapes have been used to represent activities in the world economy. These activities may be an economic agent, such as a region or industry (diagrams 1, 8) or a conceptual activity not identifiable as any physical agent. An example of the latter is the global savings pool of diagram 8. While it is helpful to think of each region's savings being gathered together in a central repository and then invested in the various regions, there is no implication that such a central agency exists.

Rectangles

Rectangles have been used to represent the stocks and flows (hereafter in this box called transactions) that occur and are built due to activities. For example, in diagram 8 imports between regions are represented by rectangles.

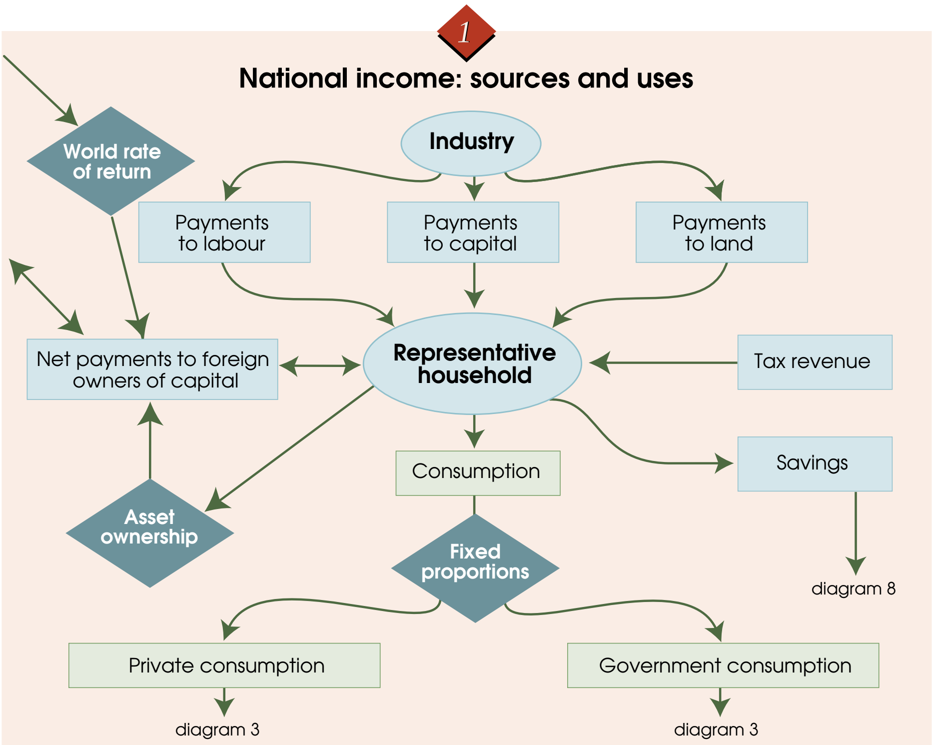
Diamonds

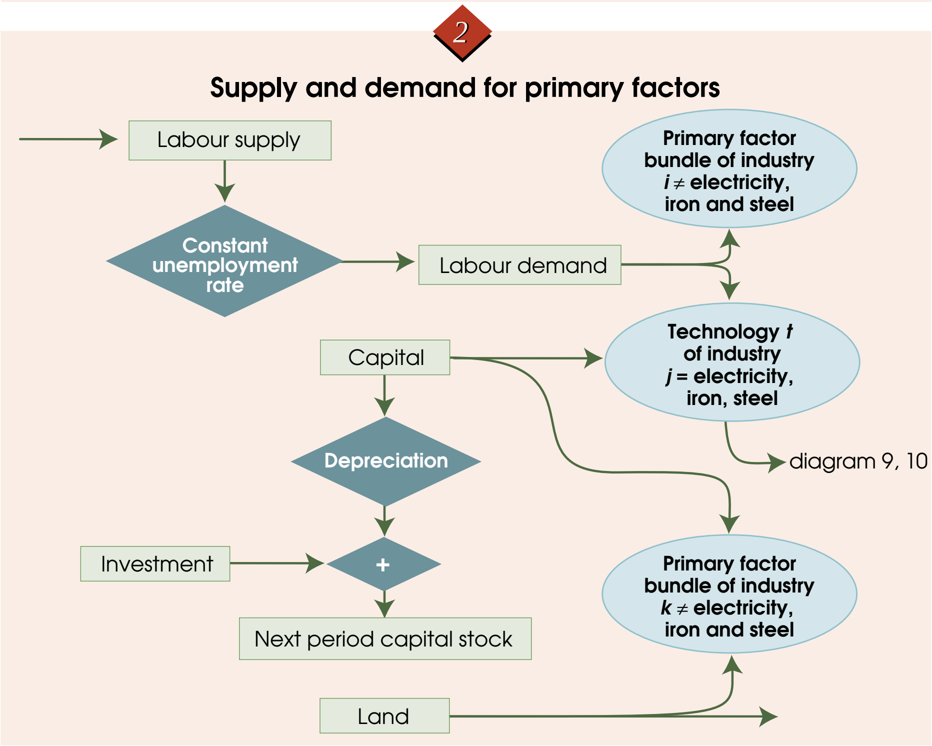
Diamonds are used to identify the factors influencing the magnitudes of transactions. They are used in two ways.

First, if a transaction is a complex function of various factors, the diamond contains a description of those factors, an incoming dashed arrow indicating the activity to which those factors pertain, and an outgoing dashed arrow pointing to the transaction. For example, in diagram 8, imports by region *r* from region *s* are determined by the income of region *r* and the relative prices of commodities from regions *r* and *s*. Two diamonds with associated arrows are used to illustrate this.

Second, if a transaction bears a simple relationship to other transactions, this is indicated by describing the relationship in the diamond, and placing the diamond on the undashed arrows connecting the transactions. For example, total consumption is allocated between government and private consumption in fixed proportions. This is indicated in diagram 1 by a diamond containing the words fixed proportions located on the arrows connecting the consumption rectangle to the private consumption and government consumption rectangles.

The text of the diagrams often refers to items such as 'region *r*' and 'industry *i*'. These should be interpreted as, in the case of region *r* for example, 'the diagram applies for any region, that is, any value of *r*'. Where there is an exclusion, this is indicated, as in diagram 2 where the top right hand oval indicates '$i \neq$ electricity, iron and steel'.


1
National income: sources and uses
World rate of return
Industry
Payments to labour
Payments to capital
Payments to land
Net payments to foreign owners of capital
Representative household
Tax revenue
Consumption
Savings
Asset ownership
Fixed proportions
diagram 8
Private consumption
Government consumption
diagram 3
diagram 3


2
Supply and demand for primary factors
Labour supply
Primary factor bundle of industry i ≠ electricity, iron and steel
Constant unemployment rate
Labour demand
Capital
Technology t of industry j = electricity, iron, steel
diagram 9, 10
Depreciation
Investment
+
Next period capital stock
Primary factor bundle of industry k ≠ electricity, iron and steel
Land

household' is that the designers of GTAP intended that regional welfare should be measured at this point. It is argued that regional welfare is some share weighted sum of private consumption, government consumption and savings divided by the total population (Hertel and Tsigas 1993).

The representative household is seen as reflecting the preferences of society and deciding on the division of national income between expenditure on private consumption, government consumption and savings. In GTAP the representative household determines this allocation by maximising a Cobb-Douglas utility function. The shares are set equal to the actual observed shares in the database. If this formulation were retained in a dynamic model such as MEGABARE, these shares would remain constant for all time.

In MEGABARE a different formulation is adopted and the shares of savings and total consumption in national income are allowed to vary. The allocation is determined basically by a life cycle hypothesis model that determines age specific savings rates (see section 4.3). However, the assumption of a fixed share division of total consumption between private and government was retained in the 'basic' version of MEGABARE.

The definition of national income on the factor cost side in MEGABARE differs from that in GTAP. In addition to payments to domestic primary factors of production (capital, land and labour), net payments to foreign owners of capital occur in MEGABARE. In GTAP, due to lack of data, it is assumed that the regional capital stock is owned entirely by residents of the region. MEGABARE starts from the same assumption for the same reason but since foreign investment occurs period by period in a dynamic simulation, it is necessary to account for the resulting returns to capital.

The treatment of government financial flows in GTAP which is retained in MEGABARE requires some explanation (see Hertel and Tsigas 1993). Government revenue consists entirely of taxes. Government expenditure consists of government consumption and transfer payments to households which is represented as an addition to income for private consumption in diagram 1. The difference between expenditure and revenue indicates the government borrowing requirement. A surplus implies retiring public debt which is an addition to regional savings, while the reverse applies to a deficit. Neither government transfer payments nor the government borrowing requirement are defined explicitly as variables in GTAP, presumably due to lack of data. However, these variables are implied by the equality enforced between national income on the factor cost and expenditure side. As a result, the change in the public sector borrowing requirement can be identified if special assumptions are made.

To further clarify the treatment of the government sector (which includes all levels of government), government consumption in diagram 1 is a 'final demand' category in input–output terminology. The major item of government final consumption is services (in particular 'government services' if the input–output 'services' commodity were disaggregated). Since the government mainly pays for the (non cost recovery) 'public' service, it is treated as the main consumer of the output of the 'public' service under input–output conventions. The actual output of the 'public' service using primary factors and intermediate inputs is classified as output from the services sector.

Much of the output of the 'public' service has the characteristics of a 'public good' (it is available for consumption by all members of society regardless of whether or not they pay directly for it). It is this property that underlies the argument that it is appropriate to include government consumption in a measure of regional welfare.

3.2 Consumer demand

In MEGABARE as in GTAP, consumer demand in each region is modelled as the result of the decisions of a representative consumer maximising utility at given prices subject to the constraint of the amount of national income allocated to private consumption. Given the demographic module in MEGABARE, it would be possible to model consumer decisions at age specific levels and then derive aggregate consumption decisions as a weighted sum of the age specific decisions. The major difficulty would be in obtaining suitable parameter estimates at age specific levels although it may be possible to overcome this problem with suitable calibration procedures.

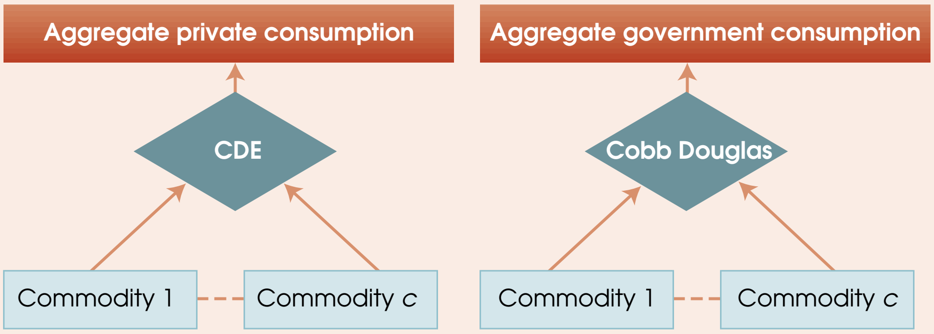
Even with the current form of the model, changes in the age structure of the population within each region affect consumption decisions to the extent that it affects the proportion of national income allocated to private consumption.

In GTAP and MEGABARE private consumption of different commodities in each region is determined by a Constant Difference Elasticity (CDE) expenditure function (diagram 3). The term CDE is used since the functional form implies that the *difference* in the Allen partial elasticities of substitution between pairs of commodities is invariant to the choice of pairs.

A major tradeoff in choosing a functional form for consumer demand in CGE models is to achieve sufficient flexibility to accommodate relevant patterns of consumption without making excessive demands on the number of

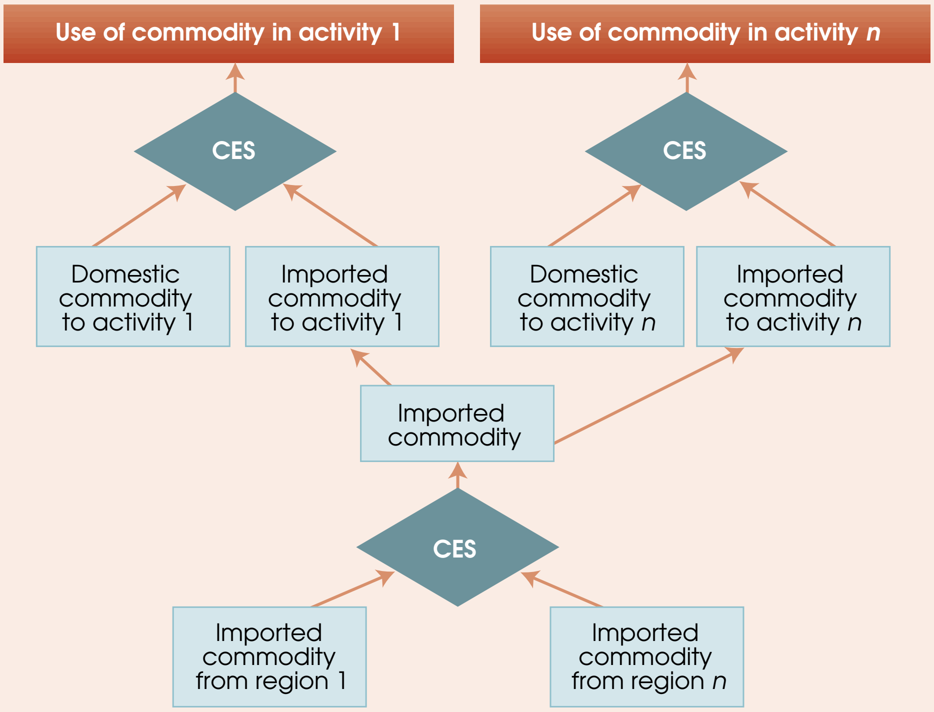
3

Private and government consumption in MEGABARE



4

Domestic/import substitution in MEGABARE



parameters for which estimates must be obtained. The most flexible functional forms can accommodate virtually any type of consumer behaviour but are highly demanding on the number of parameters.

The CDE functional form is more general than the Linear Expenditure System (LES) used in the different versions of the Salter model. In particular, the LES model implies constant marginal budget shares (the change in the budget share as income changes) which is inconsistent with the empirical evidence for countries where there are wide differences in income per person. The marginal budget shares of non-durables (such as food, clothing, beverages and tobacco) decreases as income rises, while those of more durable goods increases. It is important to be able to accommodate such behaviour since simulations with MEGABARE can involve large differences in income per person across regions and for given regions over time. A CDE demand system can accommodate such behaviour and is readily calibrated to existing estimates of income and own-price elasticities of demand.

A reasonably detailed derivation is needed to interpret the CDE functional form. However, it does bear some family relationship to the CRESH functional form discussed below. The interested reader is referred to Hanoch (1975) while Hertel, Peterson, Preckel, Surry and Tsigas (1991) give an exhaustive discussion of the use of CDE demand functions in CGE models. The application of the CDE demand function in GTAP is described in Hertel and Tsigas (1993), Chyc (1993) and Hertel (1996).

Once the choice is made on the quantity of each commodity to consume, the choice between the use of domestic and imported commodities is made according to the Armington assumption discussed below.

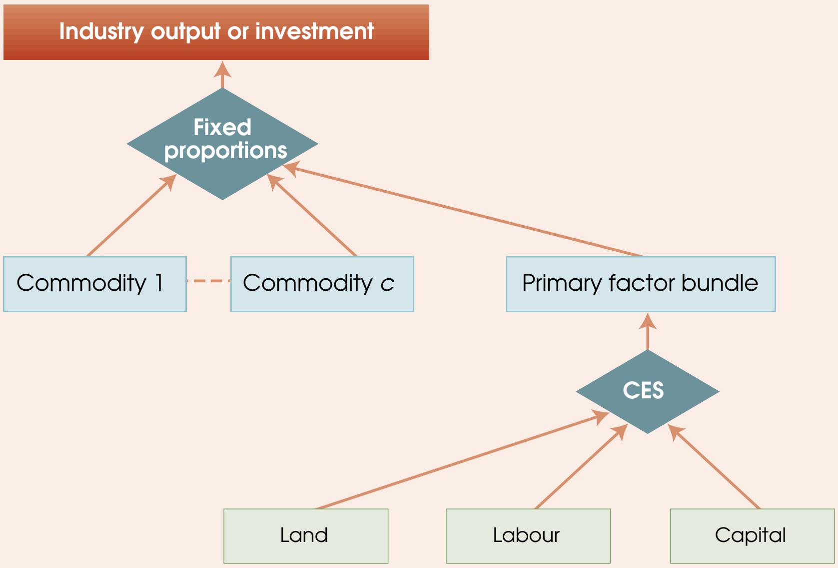
3.3 Government consumption

Aggregate government consumption is allocated across commodities according to a Cobb-Douglas function. Thus, the shares of different commodities in aggregate government consumption are fixed over time. Since the major item consumed by the government is ‘government services’, as discussed above, this does not appear to be a particularly restrictive assumption.

Once the choice of quantities of different commodities is made, the choice between domestic and imported commodities is made, again according to the Armington assumption.

5

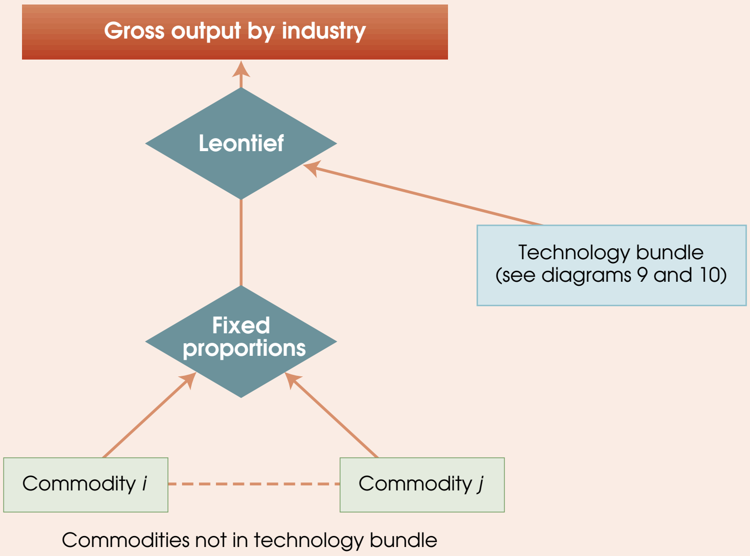
Industry and investment demand in MEGABARE [a]



[a] Excluding electricity and iron and steel industries

6

MEGABARE production structure for industries with a technology bundle



3.4 Industry demand for inputs

In all industries, firms are assumed to choose input combinations to minimise costs (maximise profits) subject to given input (output) prices.

In MEGABARE in all but the electricity and iron and steel industries, the choice among primary factor inputs (capital, land and labour) is made according to a constant returns to scale CES (constant elasticity of substitution) production function (diagram 5). The selected input mix for this ‘primary factor bundle’ together with all other inputs (termed ‘intermediate’ inputs since they are the outputs of other industries) must be used in fixed proportions to output (implying a so-called Leontief production function).

The general form of a CES production function is given by

(3.1) $$Y = A\left(\sum_{i=1}^{n} a_i X_i^{-\varepsilon}\right)^{-1/\varepsilon}$$

where Y is output, the X_i ($i = 1,\ldots,n$) are inputs and the conditions $A > 0$, $\sum_{i=1}^{n} a_i = 1$ and $-1 < \varepsilon < \infty$, $\varepsilon \neq 0$ imply standard properties with constant returns to scale. The elasticity of substitution, σ, is given by $\sigma = \frac{1}{1+\varepsilon}$.

Choosing inputs to minimise costs with a CES production function, using the fact that in a competitive economy factors are paid the value of their marginal product, and converting to percentage change form yields

(3.2) $$p(i) = \sum_{j=1}^{n} \theta(i,j).\, p(i,j)$$

where $p(i)$ is the growth rate in the price of industry i, $\theta(i,j)$ is the share of input j in the total costs of industry i with $\sum_{j=1}^{n} \theta(i,j) = 1$ and $p(i,j)$ is the growth rate in the price of input j used in industry i (see Hertel and Tsigas 1993). Thus, the growth rate in the price of an industry is simply a cost-share weighted sum of the growth rates in the prices of the inputs that it uses. Furthermore, (3.3) $$x(i,j) = \sigma[p(i) - p(i,j)] + y(i)$$

where $x(i,j)$ is the growth rate in the demand for input j used in industry i and $y(i)$ is the growth rate in the output of industry i. Hence, under a CES production function, the input demand equations decompose into a *substitution effect* (the deviation in the growth rate of the price of an input from the cost-share weighted price of all inputs multiplied by the elasticity of substitution) and an *expansion effect* (the growth rate in industry output).

A CES production function implies that the elasticity of substitution must be the same between all pairs of inputs. It is possible to allow for different elasticities of substitution with more general production functions such as the CRESH function discussed below. However, the assumption of the same elasticity of substitution is not particularly restrictive given the way the CES function is applied to input demand in MEGABARE. All industries in MEGABARE, apart from agriculture, use only two primary inputs, capital and labour.

The most restrictive assumption embodied in the overall form of the input demand equation is that there are no substitution possibilities between primary and intermediate inputs. An example often cited to contradict this assumption is the possibility of using more energy efficient (and capital intensive) equipment to substitute for energy. However, as discussed in appendix B, there has been much debate about the econometric evidence on this issue. Another example would be the possibility of using various chemical inputs to raise agricultural output from a given area of land.

While there is no dispute that it would be desirable to relax the no substitution assumption, the problem is to come up with an operational alternative. Imposing a CES production function over all 3 primary inputs and 37 intermediate inputs for each industry in MEGABARE would imply the same pairwise substitution possibilities. Such an assumption is probably even less realistic than the no substitution assumption.

In MEGABARE, the technology bundle approach has been used to replace the GTAP input demand equations in the areas where it is most critical to model substitution options correctly for greenhouse policy analysis. Under this approach, substitution can occur between primary factors and intermediate inputs. Input choices are constrained to be consistent with the characteristics of specified technologies. Conceptually, the preferred option would be to extend the technology bundle to all sectors. However, the technology bundle requires data on the input characteristics of each technology used in an industry. As a result, the need for data is least when an industry as defined in MEGABARE produces only a few outputs using a few technologies. The electricity and iron and steel industries satisfy these characteristics.

In sectors where the technology bundle approach is not applied, there is less reason for confidence that substitution options are modelled correctly. However, in some cases it may be possible to draw on external information that could conceptually compensate for any deficiencies in the modelling of substitution options in these sectors. One way of doing this that has been applied already is through the introduction of *biased technological change*.

Although the primary input factor bundle and intermediate inputs must be used in fixed proportions to output according to the basic input demand specification, the introduction of biased technological change in a simulation in effect relaxes this assumption. Since introducing biased technological change is really an application of the model rather than a basic property and some rather technical issues are involved, the details are given in appendix B. However, the later parts of the appendix do touch on some issues relevant in using MEGABARE to model greenhouse policy problems.

3.5 Sourcing of imports

Private final consumption, government final consumption and the demands of firms for intermediate inputs can be met either from domestically produced goods or imports. In MEGABARE in each region, demand for a commodity by any user of the commodity (private consumer, government or industry) is allocated between domestic production and a composite imported commodity according to a CES function (diagram 4). The demand by a region for each composite imported commodity is then allocated between sources of imports according to a further CES function. Thus, the relative growths in the use of domestic and imported commodities will depend on movements in relative prices and the specified elasticity of substitution (see equation 3.3).

In the 1993 version of GTAP, the choice between sources of the imported composite was modelled at each point of use within a region — that is, for private consumers, government and each industry. Such a treatment was not adopted in MEGABARE or in later versions of GTAP. It adds considerably to the solution time for the model and input–output data with the required detail are not readily available. Experiments were undertaken with MEGABARE and it was found that there was remarkably little difference in the model results between the two different treatments of the sourcing of imports.

The selected method of choosing between imports and domestic production involves the so-called Armington assumption. It embodies the notion that the same commodity from different sources can trade at different prices in the same market, contrary to basic economic theory. The Armington assumption is imposed as a matter of practical necessity. At the level of commodity disaggregation used in CGE models (and even at the highest level of commodity disaggregation used by statistical agencies), the same commodities from different regions usually do not contain the same mix of more fundamental commodities. As a result, it is appropriate to regard the higher level commodities as imperfect substitutes.

The use of a CES function in selecting imports from different regions can also be criticised. It implies the same pairwise elasticity of substitution for imports from all regions. Unfortunately, econometric estimates are not available to introduce a more general assumption.

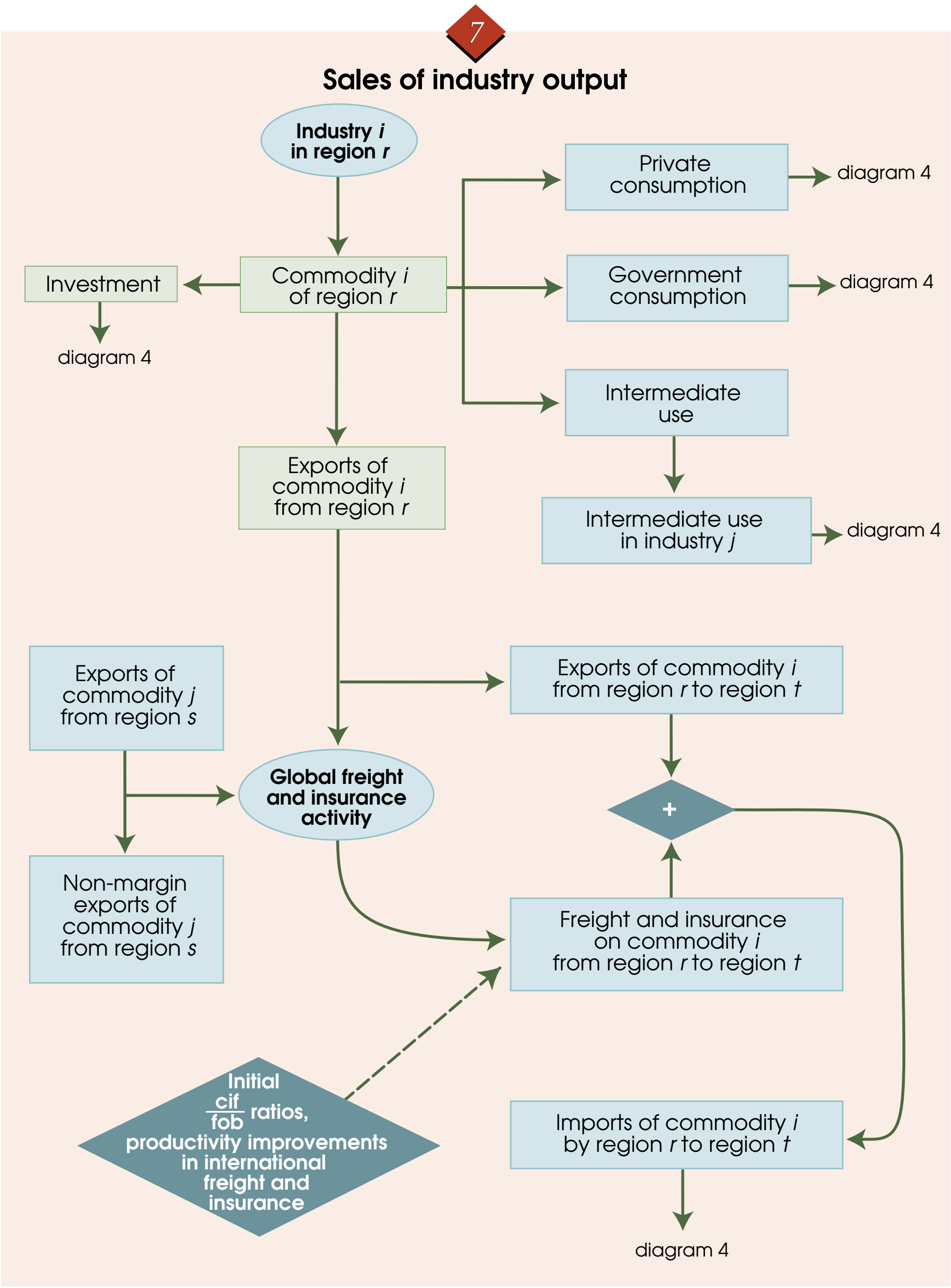
3.6 Equilibrium conditions

In MEGABARE a large number of equilibrium conditions are imposed, reflecting various market clearing conditions. With some exceptions, maximising decisions by agents throughout the global economy determine the demand and supply for commodities and primary factors by region at given prices. Prices at different levels throughout the global economy adjust to ensure equality of demand and supply. As a result, equilibrium quantities including bilateral trade flows are determined. The period of adjustment is usually taken to be one year. Firms earn zero pure profits in equilibrium.

In the factor markets, labour is a homogeneous commodity within each region. Although net migration occurs in MEGABARE unlike GTAP, these flows are not responsive to regional differences in wage rates. Thus, wages across regions may differ. The labour supply as a proportion of the population can also vary in MEGABARE unlike GTAP due to changes in the age structure of the population determined by the demographic module. Labour is mobile across sectors within a region and each sector pays the same wage. Wage rates adjust to equate the supply and demand for labour subject to maintaining a constant rate of unemployment. A constant proportion of the potential workforce in each region in MEGABARE is unemployed and the unemployment rate is notionally set equal to that observed in the base period.

Capital is mobile across regions in MEGABARE. The treatment of international capital flows differs from GTAP and is discussed in more detail in section 4.4. Depending on the hypothesis chosen, there may or may not be a tendency for long run equalisation of rates of return on capital across regions.

Additions to the capital stock are made through investment. Investment draws on the output of each industry in fixed proportions according to the

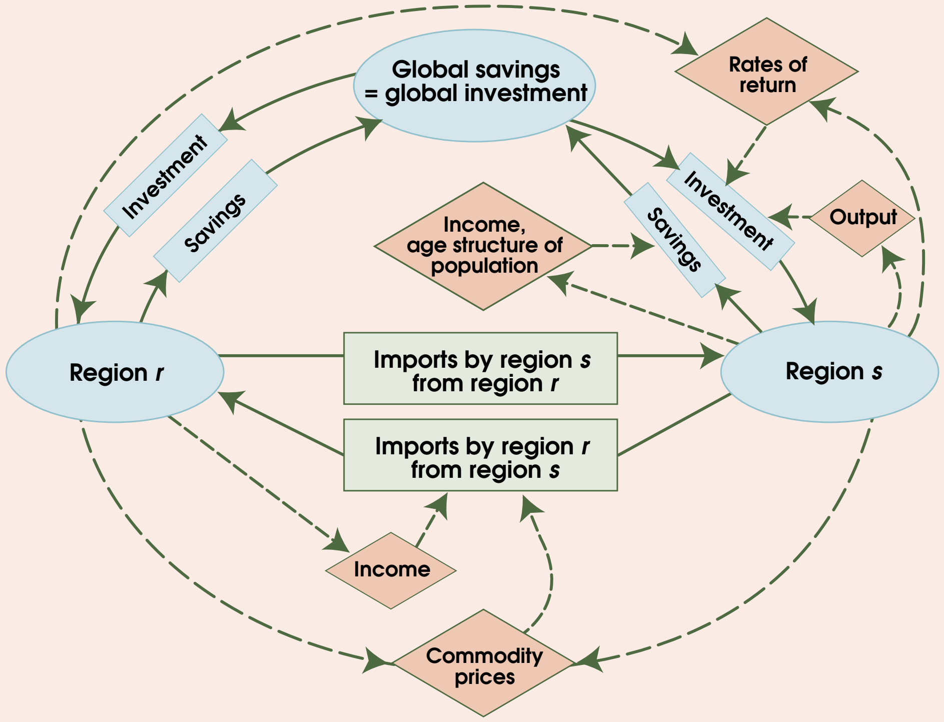


7

Sales of industry output

8

International trade and investment flows



coefficients contained in each regional input output table. Global investment is equal to global savings. Once a regional allocation of investment is made according to the hypotheses in section 4.4, investment is usually allocated across sectors to equalise rates of return on capital. However, coding has been included in MEGABARE to allow various hypotheses about the sector specific nature of capital to be imposed.

Land is in fixed supply in each region. It is also sector specific so that notionally the rental price of land across sectors may differ. In the ‘basic’ version of MEGABARE and GTAP, agriculture is the only industry that uses land as an input.

In commodity markets, prices for a given commodity from a given region are defined at various levels throughout the global economy. The margins between these different prices reflect the costs incurred in moving a commodity from the point of production to the point of end use (see diagram 7).

For tradable commodities (the output of all industries), prices throughout the global economy adjust to ensure the equality of the sum of regional demands with the sum of regional supplies for each commodity. Bilateral trade flows in each commodity are determined simultaneously to satisfy regional excess demand–supply positions at equilibrium global prices. As explained above, regional demands in each time period arise from government consumption, private consumption, industry and investment and are allocated between imports and domestic production according to the Armington CES specification. Regional supply potential in each time period arises from the primary factor endowment of each region (land, labour and capital) and the production possibilities as reflected in the factor demand equations described above.

A balance of trade variable is defined for each region as the difference between the total value of exports and imports. In MEGABARE, unlike GTAP, as a result of the need to keep track of international capital flows, a net foreign earnings variable is defined as the difference between income from investment abroad and investment income accruing to overseas residents. In MEGABARE, a current account position to GDP ratio is also defined.

4. Details of major model features

In this chapter a more detailed treatment is given of the areas where MEGABARE contains distinctive behavioural hypotheses.

4.1 The technology bundle approach

Motivation

The distinction between a ‘top down’ and ‘bottom up’ approach to modelling the energy sector has received a great deal of attention in recent discussions of greenhouse policy. The ‘top down’ models are usually highly aggregative models of complete economic systems and the energy sector is only one of many sectors identified. Production technology in the energy and other sectors is modelled (often using nested production functions) with output related to inputs that can be continuously substituted for one another in response to movements in relative input prices.

‘Bottom up’ models are highly detailed models of the energy sector identifying alternative technologies that can be used in the production of a given output. These models are usually solved by linear programming or nonlinear programming techniques and involve inequality constraints.

The pattern of input use and output response generated by the two types of models as relative input prices vary can differ. It is usually conceded that the ‘bottom up’ models achieve much greater realism in modelling the substitution options in energy production technology but the ‘top down’ models are superior in capturing interactions with the other sectors of the economy. As a result, there is much scope for debate as to what type of model produces the more realistic results.

In MEGABARE, an effort has been made to move toward the realism of the ‘bottom up’ approach in modelling energy production technology while retaining the extensive interaction with other sectors of the economy obtained in ‘top down’ models. The approach can be applied to any sector but at the moment is used only for the electricity and iron and steel sectors due to their key importance in the impact of greenhouse policy.

The basic idea in the technology bundle approach is that output from these sectors is a function of the output from a share weighted combination of different technologies (see diagrams 9 and 10). Each technology uses inputs in fixed proportion to output. The different technologies can be smoothly substituted for one another. Thus, the approach does not capture possible lack of smoothness in substitution between technologies which can be handled by ‘bottom up’ models. In other words, it does not capture the possibility that some discrete difference in the relative costs of using the alternative technologies may be needed before substitution will occur. However, the approach does ensure that the pattern of input use is consistent with known technologies, which is not necessarily the case with ‘top down’ models.

Input combinations

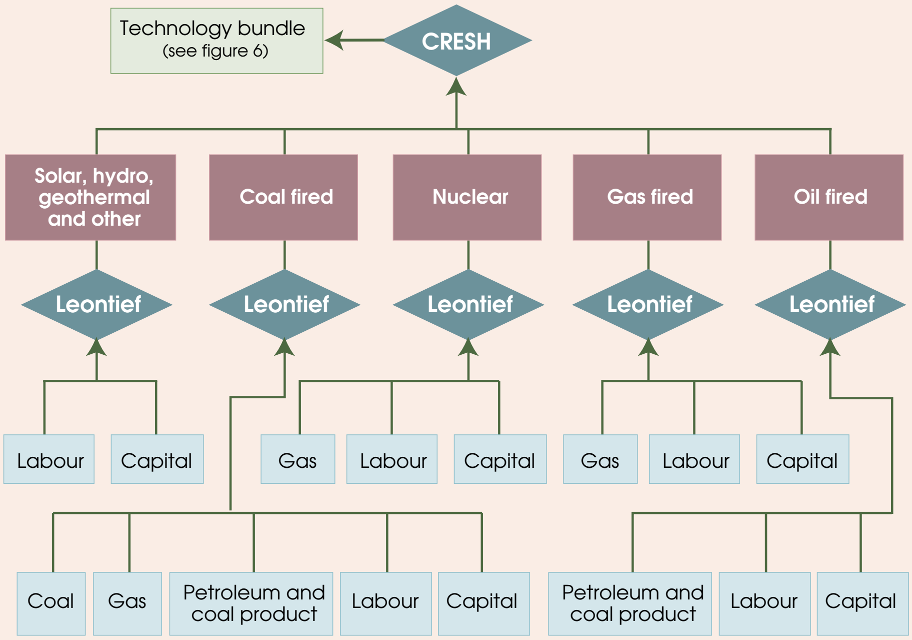
The way in which the technology bundle approach ensures that the pattern of input use is consistent with known technologies is illustrated in figures 1 and 2. Suppose that output for a given industry can be produced with only two technologies that both use two inputs, capital and labour. In figure 1, the input combination used by the more capital intensive technology to produce a given level of output is shown by the point *T1*. The input combination used by the less capital intensive technology to produce the *same* level of industry output is shown by the point *T2*.

There are two extreme possibilities. Either 100 per cent of the given level of industry output is produced by technology *T1* or 100 per cent of the same output is produced by technology *T2*. Intermediate combinations lie on the straight line joining *T1* and *T2*. Such a straight line can be traced out by $\lambda.T1 + (1-\lambda).T2$ as the weight λ is varied between 0 and 1. Thus, $\lambda = 1$ means 100 per cent of output is produced by technology, *T1*, $\lambda = 0$ means 100 per cent of industry output is produced by technology, *T2*, and $0 < \lambda < 1$ means an intermediate combination.

The points *T1* and *T2* establish two *critical regions* shown by the shaded areas in the diagrams. Clearly, it is impossible to use more than 100 per cent of either technology to produce a given level of industry output. Thus, points in the hatched area to the left of *T1* imply input combinations inconsistent with *known* technologies (they could be generated with known technologies only by more than 100 per cent use of technology, *T1*, and, hence, a negative use of technology, *T2*). Similarly, points in the shaded area below *T2* represent technological infeasible input combinations (implying more than 100 per cent use of *T2* and negative use of *T1*).

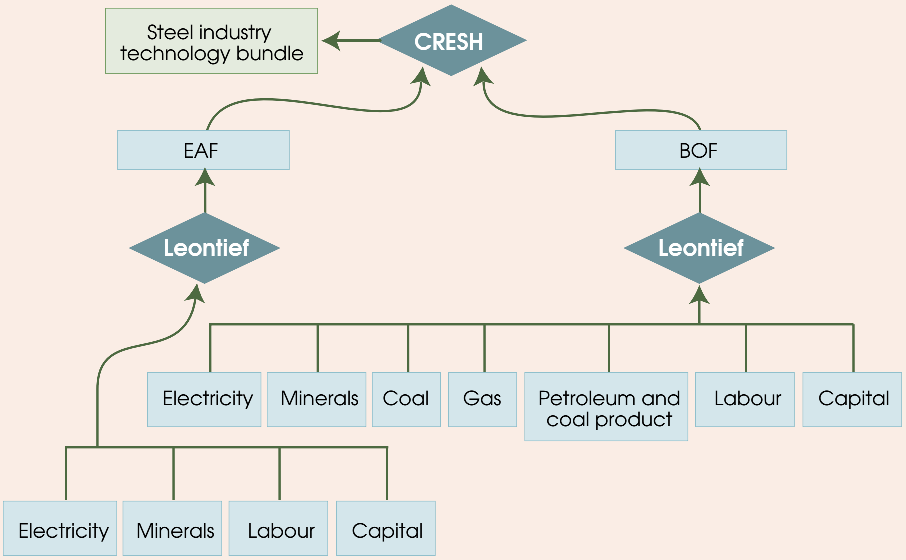
9

Composition of technology bundle in the electricity industry

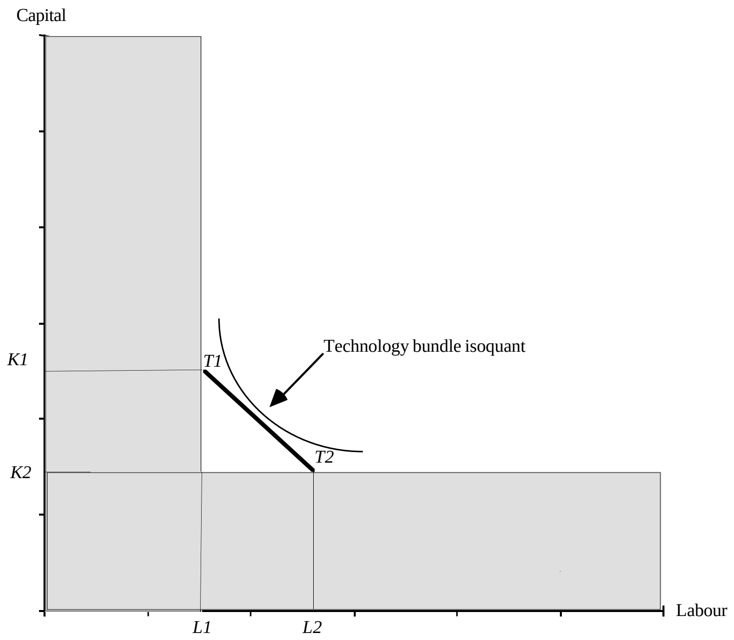


10

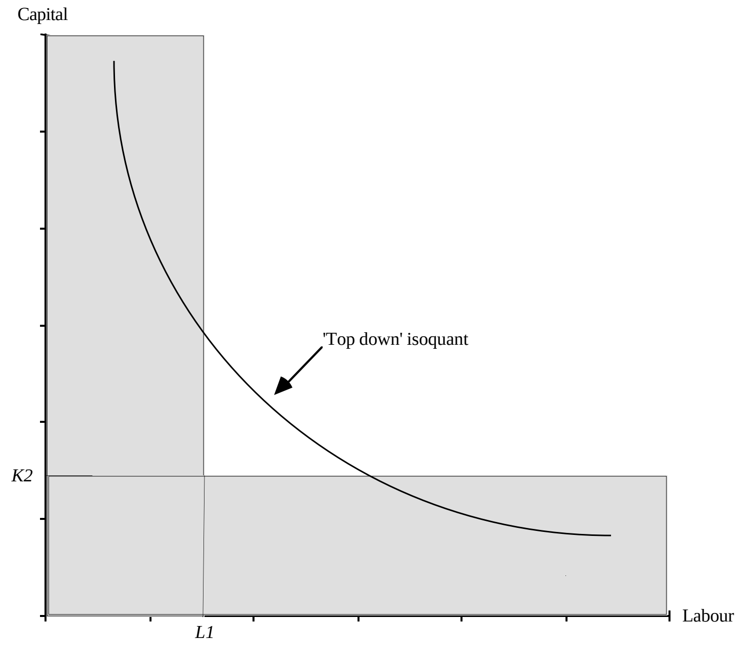
Steel technology bundle in the MEGABARE model



1 Isoquant for technology bundle



2 Isoquant for standard ‘top down’ model



In figure 2 is shown the typical form of *isoquant* (the input combinations needed to produce a given level of industry output) implied by the continuous substitution options modelled in standard ‘top down’ models. Since it is asymptotic to both axes, it crosses into regions of technologically infeasible input combinations. Thus, it can be said, unambiguously, that such models imply the possibility of choosing input combinations inconsistent with known technologies.

In the upper part of figure 1 is shown the technology bundle isoquant. It is evident that it has been drawn above the straight line joining *T1* and *T2*. It is easy to see that the straight line joining *T1* and *T2* represents the isoquant that would be derived if the alternative technologies were *perfect* substitutes. The expression $\lambda.T1 + (1–\lambda).T2$ used to create points on the line joining *T1* and *T2* implies that the technologies can be substituted on a one-to-one basis to produce a given level of industry output.

If the alternative technologies were *imperfect* substitutes, the technology bundle isoquant would be convex with respect to the origin and lie above the perfect substitution isoquant. It is assumed that the alternative technologies are imperfect substitutes. However, before considering the impact of this assumption on the shape and positioning of the isoquant, it is necessary to explain the reasons for the assumption.

The justification for the assumption of imperfect substitutes is somewhat analogous to the justification for the Armington assumption of imperfect substitution between domestic production and imports of the ‘same’ commodity. Just as commodities from different regions defined to be the same have different underlying characteristics, different technologies producing the ‘same’ output have different underlying characteristics. For example, in the case of electricity, available water storage capacity, location and size of coal and natural gas reserves and environmental impacts of alternative technologies place constraints on the substitution options between the alternative technologies.

If the Armington assumption were dropped in favour of perfect substitution, infinitesimally small changes in price relativities would result in shifts of the entire global production of commodities from one country to another. Similarly, the assumption of perfect substitutability among alternative technologies would result in ‘bing-bang’ switches of 100 per cent of industry production from one technology to another. An assumption of imperfect substitutability is imperative if plausible changes in the pattern of the use of alternative technologies are to be derived.

Since the total input use by one technology cannot be released instantaneously to another technology in response to an infinitesimally small change in relative costs, total input requirements to produce a given level of industry output are higher under the assumption of imperfect substitution. Perfect substitutability would result in a more 'efficient' use of inputs. For this reason, the imperfect substitution isoquant lies above the perfect substitution isoquant. Furthermore, imperfect substitution means that 100 per cent of industry production from one technology can be approached but never attained, apart from exceptional cases.

As mentioned above, the standard 'top down' isoquant unambiguously enters a range of technologically infeasible input combinations. Noting the differences in the range and asymptotic properties compared to those of the technology bundle isoquant, it is almost certain that the two isoquants will imply different input combinations within the region of input combinations that cannot be ruled out as technologically infeasible. If the technology bundle isoquant is taken as representing the 'true' isoquant, then it can be said that even within this region, the isoquant in figure 2 is likely to imply at least some 'incorrect' input combinations.

Other features

As discussed above, the technology bundle approach has the potential to achieve a more realistic change in the pattern of input use in response to a change in input prices. Since input use is constrained to be consistent with known technologies, the *output response* will also differ from that obtained from standard 'top down' models and is also potentially more realistic.

A further advantage is that the technology bundle approach is highly transparent, which makes it far easier to assess the plausibility of results obtained compared with those derived under the assumption of continuous substitution. Given some policy change, the relative changes in the use of different technologies can be derived. Under the assumption of continuous substitution, all that can derived are changes in the use of different inputs. It is difficult to determine precisely what such changes might imply about the relative use of different technologies.

The elasticity of substitution parameters in the technology bundle approach can be derived either by reference to the results from 'bottom up' models or from econometric estimates. Avoiding the need to rely on econometric estimates appears to be a distinct advantage. Reference has already been made to the long running controversy in the econometrics literature about capital–energy substitution. There are major technical difficulties in obtaining reliable econometric estimates of the elasticity of substitution, and these are discussed in appendix B. Any estimates of elasticities of substitution may be highly dependent on the choice of functional form and type of nesting used. It may be difficult to introduce the assumptions used in estimation into a CGE model which means that the estimated parameter values may not be strictly valid as applied in a CGE model. Of course, such a problem applies throughout CGE models.

A further point is that a simulation may involve data values outside the range of those used in making econometric estimates. By calibrating the parameters of the technology bundle to the results from experiments with a ‘bottom up’ model, it is possible to cover a wider range of data values that might occur in a simulation.

If a decision is made to use econometric estimates in the technology bundle approach, an attempt at independent validation can be made by reference to the results from ‘bottom up’ models. Independent validation is more difficult for econometric estimates used under the assumption of continuous substitution.

To determine elasticities of substitution through calibration, input prices can be varied in a ‘bottom up’ model and the pattern of technology use observed. The appropriate parameters in the energy production module in MEGABARE, holding all other variables constant, can then be selected to produce a similar pattern of response. Some work in calibrating the MEGABARE technology bundle for the Australian electricity industry against the MENSA model has been undertaken and further work is planned both for Australia and other countries.

While the technology bundle approach has many attractive features, data intensiveness is the main practical limitation as discussed above. Data on the pattern of input use associated with each technology for the same year as the MEGABARE database was obtained from various publications (IEA 1993a,b; International Iron and Steel Institute 1992). Thus, the pattern of input use represents an average for a given technology within a region rather than the pattern associated with any particular plant.

Equations

The technology bundle approach is introduced using a CRESH (constant ratio of elasticities of substitution, homothetic) production function. The general explicit form of a CRESH production function (Hanoch 1971; Dixon, Parmenter, Sutton and Vincent 1982) is given by

$$\sum_{i=1}^{n}\left(\frac{x_i}{Y}\right)^{d_i}\frac{D_i}{d_i}=\kappa \tag{4.1}$$

where Y represents output and the x_i ($i = 1,\ldots,n$) represent inputs or in the case of the technology bundle approach, the outputs from different technologies. D_i, d_i and κ are parameters with all $d_i < 1$ and $\neq 0$, all $D_i > 0$ and the D_is and κ are normalised so that $\sum_{i=1}^{n} D_i = 1$. One of the properties of a CRESH production function is that while the implied elasticities of substitution vary (slowly) with the pattern of input use, they maintain a constant ratio.

The major attraction of the CRESH production function over the more familiar CES function is that the elasticities of substitution between given pairs of inputs may differ. Under the CES specification, all pairs of inputs must have the same elasticity of substitution. If $d_i = d$ for all i, the CRESH production function reduces to a CES function.

The electricity and iron and steel industries are regarded as choosing technologies to minimise production costs for given input prices. The solution of a cost minimisation problem subject to a CRESH production function and derivation of the consequent input demand equations in percentage change form is described in Dixon, Parmenter, Sutton and Vincent (1982, pp. 83–6). Using these results, the demand for technology i to produce the output of industry j in region r is given by

$$qtech(i,j,r) = qtb(j,r) - ESUBTB(i,j).[ptech(i,j,r) - ptb(j,r)] \tag{4.2}$$

where

$qtech(i,j,r)$	=	growth rate in the output from technology i used in industry j in region r
$ptech(i,j,r)$	=	growth rate in the price of output produced by technology i used in industry j in region r
$qtb(j,r)$	=	growth rate in the output from the technology bundle of industry j in region r
$ptb(j,r)$	=	growth rate in the price of the technology bundle of industry j in region r

ESUBTB(*i*,*j*) = CRESH parameter for technology *i* used in industry *j*.

Equation (4.2) can be decomposed into a substitution effect (represented by the rightmost term) and an expansion effect as in the case of the CES production function discussed in section 3.4 (see equation 3.3). However, now the substitution is between different technologies rather than inputs, the elasticities of substitution between the different technologies can differ rather than be constant and the expansion effect is represented by a share weighted sum of the outputs from the different technologies rather than a single output.

The expansion effect is given by the growth rate in industry output, *qtb*(*j*,*r*), made up of the share weighted growth rates in outputs from the different technologies

$$qtb(j,r) = \sum_i techshr(i,j,r).qtech(i,j,r) \tag{4.3}$$

where *techshr*(*i*,*j*,*r*) is the share of output from technology *i* in the output of industry *j*.

The substitution effect depends on the underlying growth rates in the costs of the alternative technologies and the relevant elasticities of substitution. The growth rate in the price of a technology, *ptech*(*i*,*j*,*r*), is the cost weighted share of the growth rates of the prices of all inputs used by that technology

$$ptech(i,j,r) = \sum_k stech(i,k,j,r).pft(i,k,j,r) \tag{4.4}$$

where

stech(*i*,*k*,*j*,*r*) = share of commodity *k* in total costs of inputs used in technology *i* in industry *j* in region *r*

pft(*i*,*k*,*j*,*r*) = growth rate of price of commodity *k* used in technology *i* in industry *j* in region *r*

The growth rate of the industry price, *ptb*(*j*,*r*) is defined by

$$ptb(j,r) = \sum_k STB^*(k,j,r).ptech(k,j,r) \tag{4.5}$$

where *STB*(*l*,*j*,*r*) is the share of technology *l* in the total cost of inputs to all technologies used by industry *j* in country *r* and

$$STB^*(k,j,r) = ESUBTB(k,j).STB(k,j,r) \Big/ \sum_l ESUBTB(l,j).STB(l,j,r) \tag{4.6}$$

is the CRESH parameter weighted value share.

It reflects share weighted movements in the prices of the different technologies used by the industry. These prices reflect movements in input costs as shown by equation (4.4).

The growth rate in output for a given technology will be more responsive to movements in input prices the larger the value of the CRESH parameters, *ESUBTB*(*i*,*j*). The Allen elasticity of substitution between technologies *i* and *k* in industry *j* in region *r* is given by

$$(4.7) \qquad \frac{ESUBTB(i,j).ESUBTB(k,j)}{\sum_{l} STB(l,j,r).ESUBTB(l,j)}$$

4.2 Demographic module

A novel feature of MEGABARE is that population growth is treated as endogenous and is linked to economic variables. Population growth so determined will in turn affect economic variables, especially through its impact on savings behaviour and the growth in the labour force.

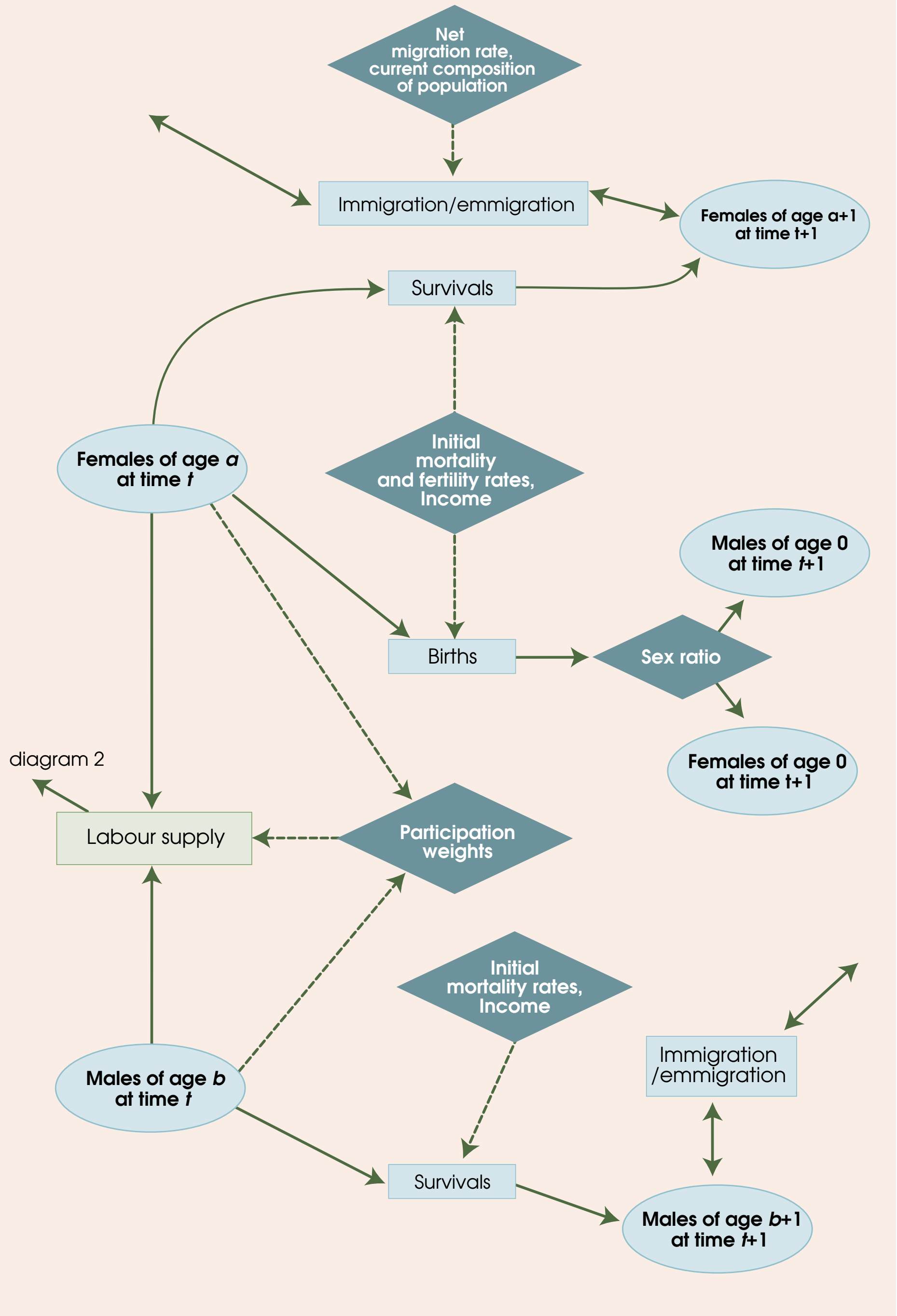
There is a clear historical relationship across countries between the level of per person income and rates of population growth. In OECD economies, both birth rates and mortality rates have declined with rising levels of per person incomes. The overall impact has been to reduce the rate of population growth (after allowing for immigration). A similar pattern has been evident in rapidly growing Asian economies.

An overview of the demographic module is given in diagram 11. Population, by gender, in one year age groups (one year cohorts) from 0 to 100 are determined by the model for each region. Since the growth in population between time periods is the result of births, deaths and net migration, equations are needed to determine these variables on an age and gender basis. Equations are also needed to determine the transition between different age groups in each time period.

The equations determining birth rates and mortality are based on an econometric analysis. In the case of mortality, the actual econometric analysis was carried out on life expectancy because of a lack of data on mortality rates. Mortality rates are linked to the results of the life expectancy econometric analysis by equations described below.

11

Demographic structure of MEGABARE



For the econometric analysis, cross-sectional data for 1991 were drawn from United Nations sources supplemented by Britannica world data (United Nations 1992; Encyclopaedia Britannica 1994). While it would have been desirable to undertake a time series analysis, times series of sufficient length were not available for enough countries to create a suitable data set. Using the cross-sectional data, the world was divided into low, middle and high income countries according to GNP per person in 1991 US dollars (low income, GNP per person < $540, middle income, GNP per person $541–7000 and high income, GNP per person >$7000). There were 37 observations for low income countries, 40 for middle income countries and 18 for high income countries.

Birth rates

Birth rates for women, by age group, were regressed on GNP per person and dummy variables representing the dominant religion in each country. A double logarithmic form of the equation was found to satisfy various tests for the appropriate functional form. For low and middle income countries, the estimated elasticity of birth rates with respect to GNP per person was significant at the 95 per cent level for all age groups. For high income countries, the estimated elasticities were not statistically significant across all age groups and in the model the corresponding coefficients are set equal to zero. The estimated elasticities for low and middle income countries which underlie the coefficients used in the model are shown in table 4.1.

A similar smooth pattern of response is evident for both low and middle income countries. If the *absolute* value of the elasticities were plotted against age group, the relationship would be 'U' shaped. Thus, the greatest reduction in birth rates as GNP per person rises occurs in very young and older women. There is an increasing tendency to confine births to the 20 to 34 age group. Since MEGABARE tracks population in one year age groups, a parabolic

4.1 ***Estimated elasticities of birth rates for women in a given age group with respect to GNP per person***

Age group	Low income	Middle income
15–19	–0.5127	–0.2162
20–24	–0.2749	–0.2060
25–29	–0.1730	–0.1545
30–34	–0.1703	–0.2271
35–39	–0.2506	–0.3534
40–44	–0.4912	–0.5652
45–50	–0.8190	–0.6820

interpolation procedure was applied to the above ‘U’ shaped relationship to derive elasticities for one year age groups.

During the course of a simulation, a region that begins as a low income region may pass through being a middle income region and eventually become a high income region. To select the appropriate econometric estimates as a region passes between income classes, birth rates for a given region are expressed as a weighted average of the econometric estimates for the three income classes. The weighting scheme varies smoothly as GNP per person in a region varies and is implemented by what is known as a kernel smoothing approach. The weighting scheme is designed to give the most appropriate weights to the econometric estimates for the three income classes depending on the level of GNP per person in a region in relation to median GNP per person in each income class. For example, when GNP per person in a region is near the median for a particular income class, nearly all the weight is given to the econometric estimates for that income class. At the boundary point between two income classes, equal weight is given to the econometric estimates for the adjacent classes.

Data on fertility rates in the base period are read into the model. Fertility rates then evolve according to the equation

$$(4.7)\qquad frate(a,r,t) = \sum\nolimits_{I\in\{L,H,M\}}\left[W(r,I,t).\,felas(I,a).pcgnp(r,t)\right] + fdrift(a,r,t)$$

where the summation is over the three income classes low (*L*), middle (*M*) and high (*H*) and

frate(*a*,*r*,*t*) = growth rate of fertility rate for women of age *a* in region *r* from time *t* to *t*+1,
W(*r*,*I*,*t*) = a weight based on the difference between the per person GNP of region *r* and the median per person GNP of income group *I*,
felas(*I*,*a*) = interpolated econometrically estimated elasticity of the fertility rate for women of age *a* in a region of income group *I* with respect to per person GNP,
pcgnp(*r*,*t*) = growth rate of per person GNP for region *r* from time *t* to *t*+1,
fdrift(*a*,*r*,*t*) = this term is non-zero only for high income regions — for high income regions it represents the drift in the fertility rate toward that of highest income region for women of age *a* in region *r* from time *t* to *t*+1.

The weighting system in (4.8) is derived from the kernel smoothing equation

$$(4.8) \qquad W(r,I,t) = \exp\left(-\beta.\left[\ln\left(PCGNP(r,t)/PCGNP(I)\right)\right]^2\right)\Big/W^*(r,t)$$

where

PCGNP(r,t) = per person GNP for region *r* at time *t*,
PCGNP(l) = the median per person GNP for income group *I*,

and $W^*(r,t)$ is defined so that $\sum_{I\in\{L,M,H\}} W(r,I,t) = 1$.

The fertility drift term which is non-zero for regions in the high income class only is defined by

$$(4.9) \qquad fdrift(a,r,t) = \lambda.\alpha.\left[FRATE(a,R,t)/FRATE(a,r,t) - 1\right]$$

where

FRATE(a,R,t) = fertility rate for women of age *a* in region *R*, where region *R* is the region with the highest GNP per person at time *t*,
FRATE(a,r,t) = fertility rate for women of age *a* in region *r* at time *t*,
λ = binary variable equal to 1 for high income regions and zero otherwise,
α = speed of adjustment parameter.

The hypothesis underlying the inclusion of the fertility drift term is that there may be a lagged adjustment in fertility rates, especially for rapidly growing economies once they enter the high income class. Fertility rates for such economies often exceed those of economies where similar levels of GNP per person have been maintained for longer periods of time. It is hypothesised that there will be an eventual decline in the fertility rates for the rapidly growing economies and, indeed, ultimately fertility rates for all high income regions will converge to those of the highest income region. Further study of this hypothesis using time series data would be possible.

The gender composition of births is determined from the ratio of male to female births for each region in the base period that is read into the model as data. It is assumed that this ratio applies across all age groups and remains constant through time.

Life expectancy

There were insufficient data on mortality rates at different age groups across enough countries to undertake an econometric analysis of the responsiveness of mortality rates to economic variables. Instead it was necessary to adopt an indirect approach in relating mortality rates to economic variables. Adequate data were available to permit an econometric analysis of the relationship between life expectancy and economic variables. The results of this analysis were then used to derive equations for age specific and gender specific mortality rates.

For the econometric analysis of life expectancy, again cross-sectional data for 1991 was used for the same grouping of countries as in the analysis of birth rates. Life expectancy was regressed on GNP per person and again a double logarithmic equation was found to be an acceptable functional form. All but one of the coefficients were significant at the 95 per cent level and the estimated elasticities are shown in table 4.2.

4.2 *Estimated elasticities of life expectancy with respect to GNP per person for males and females*

Gender	Low income	Middle income	High income
Male	0.1400	0.0754	0.0120
Female	0.1418	0.0848	0.0233

The response of life expectancies to changes in GNP per person decreases in moving from low to high income regions. It is also always slightly greater for females than males.

Initial data on life expectancies are read into MEGABARE. Life expectancies then evolve according to an equation using a similar weighting procedure to that applied to birth rates. Thus, as a region moves from the low income class through to the high income class, the weights on the econometric estimates for the three income classes vary appropriately. The equation for the growth rate in life expectancy is

$$e0(g,r,t) = \sum\nolimits_{I \in \{L,H,M\}} \left[W(r,I,t).e0elas(I,g).pcgnp(r,t) \right] \tag{4.10}$$

where

$e0(g,r,t)$ = growth rate of the life expectancy for gender g in region r from time t to t+1,

$e0elas(I,g)$ = elasticity, with respect to per person GNP, of the life expectancy for gender g in a region of income group I,

and $W(r,I,t)$ is as previously defined. Life expectancy is restricted not to exceed 85.

Mortality rates

Given changes in life expectancies determined by equation (4.10), the problem is to develop an equation to determine changes in mortality rates across age and gender groups that will be consistent with the change in life expectancies. The equation adopted reflects the hypothesis that the change in mortality rates across age groups is unlikely to be uniform. Instead the greatest change is likely to occur where mortality rates are the highest as in the case of the very young and elderly. Improved health services that accompany increased income can reduce infant mortality significantly and extend the life of the elderly by overcoming health problems that previously would have proved fatal.

The equation that performs the required adjustment in mortality rates is given by

$$\Delta \ln\left(1/MRATE(g,a,r,t)-1\right)=m\_shift(g,r,t) \tag{4.11}$$

where $MRATE(g,a,r,t)$ is the mortality rate for gender g of age a in region r at time t, Δ means ‘the change from the current to the next period’ and $m\_shift(g,r,t)$ is chosen so that the mortality rates at time $t+1$ imply changes in life expectancies consistent with equation (4.10).

Equation (4.11) can be interpreted as applying a uniform change consistent with the required change in life expectancy to the (inverse) logit of mortalities. The use of the logit transform ensures that the adjusted mortalities will lie strictly in the range of 0 to 1. It also attenuates the uniform change at some values and damps it for other values. In particular, the maximum change in mortality rates will occur when the rate is 0.5 while the minimum change occurs when the rate is near 0 or 1. Mortality rates seldom exceed 0.5. Thus, according to equation (4.11), the greatest changes in mortality rates will occur when they are the highest which typically will be those rates applying to infants and the elderly.

For some regions in MEGABARE, data are not available on gender specific mortality rates for one year age groups from 0 to 100. Such data are required as initial (base period) data by the model. To generate the required data, a set of mortality rates for another region is taken and then calibrated to the data available for the region in question. Details of the procedure applied are described in appendix C.

Net migration

Net migration rates are held as close to constant at initial levels as possible, subject to global net migration flows being zero for each age and gender. The age and gender composition of net migration to a region is chosen to be as close as possible to the existing age and gender composition of the population of the region.

Net migration to each region is determined by the following equations

(4.12) $NM(g,a,r,t) = NMRATE(r).POP(g,a,r,t).adj1(g,a,t)$ if $NM(g,a,r,t)>0$ and

$$NM(g,a,r,t) = NMRATE(r).POP(g,a,r,t)/adj1(g,a,t) \text{ if } NM(g,a,r,t)<0,$$

where

$NMRATE(r)$ = the initial period net migration rate for region r,
$NM(g,a,r,t)$ = net migration of persons of gender g and age a to region r at time t,
$POP(g,a,r,t)$ = population of gender g and age a in region r at time t,

and $adj1(g,a,t)$ is a positive adjustment factor determined so that the constraint $\sum_r NM(g,a,r,t) = 0$ is satisfied.

Labour supply

Labour supply and demand are modelled as growing at the same rate as the working age population. The working age population is defined as those persons between 15 and 65 years of age, with a reduced weighting applied to those between 15 and 20 and between 60 and 65. The weighting scheme is applied to adjust for individuals gradually entering and leaving the workforce (see immediately below equation (d.14) in appendix D for details).

4.3 Consumption–savings decision

As mentioned above, the treatment of the consumption–savings decision in MEGABARE overrides the GTAP equations. Given the detailed demographic accounting in MEGABARE, it seemed highly desirable to model consumption–savings decisions at the level of individual age groups. Such an approach would allow the modelling of changes in aggregate consumption and savings in response to changes in the age structure of the population. The major difficulty in introducing such an approach is that the only savings data contained in the MEGABARE database relates to aggregate regional savings. Furthermore, data on age specific savings rates are not available for the regions covered by MEGABARE.

The approach taken is to use the data in the MEGABARE database to calibrate a model from which estimates of regional age specific savings rates are derived. Equations are then developed that describe the evolution of these savings rates over time.

In each region, the pattern of consumption and savings for individuals of a given age is assumed to be consistent with a life cycle model. According to this model, consumption by an individual of a given age is proportional to the wealth of that individual. The ratio of current consumption to current wealth will vary over the life of the individual. At a given period of time, observed consumption–savings patterns will represent the decisions of individuals at different stages in the life cycle. It is this observation that is used in calibrating the life cycle model to the data for a specific time period in the MEGABARE database.

Wealth is defined to consist of both financial and human wealth. Financial wealth is represented by the assets an individual has accumulated by past savings. Human wealth is equivalent to current and discounted future earnings where the real interest rate is used as the discount factor. According to the life cycle model, the ratio of current consumption to current wealth for an individual of a given age will depend on the rate of time preference of the individual (the preference to consume now rather than save for future consumption), the real rate of interest (if this differs from the rate of time preference) and the life expectancy of the individual.

The life cycle model is calibrated to the MEGABARE database to determine the share of different age groups in aggregate savings in each region. In this calibration procedure, regional data on the replacement value of the capital stock are used as a proxy for financial wealth while labour earnings are used in estimating human wealth. Details of the life cycle model and the calibration procedure are given in appendix D.

The estimated shares of national savings for different age groups show the expected pattern. Shares are negative indicating dissaving for young people of pre-working age and retirees. Positive shares are obtained for age groups within the workforce.

The calibration procedure is carried out prior to a simulation run. Shares of national savings by age group are then read into the model and taken as the actual base period shares during a simulation run.

Given initial savings by age groups, savings then evolve according to the equation

$$save(a,r,t) - pop(a,r,t) = y(r,t) - pop(r,t) + adj(r,t) \tag{4.13}$$

where

$save(a,r,t)$ = growth rate of nominal net savings of age group a in region r from time t to t+1,
$pop(a,r,t)$ = growth rate of population of age a in region r from time t to t+1,
$y(r,t)$ = growth rate of nominal income of region r from time t to t+1,
$pop(r,t)$ = growth rate of population of region r from time t to t+1,
$adj(r,t)$ = adjustment term.

If the adjustment term, $adj(r,t)$, in equation (4.13) were zero always, savings per person in a given age group would simply grow at the same rate as national income per person. Nevertheless, even if age specific savings rates remained constant, the ratio of aggregate savings to national income could change markedly due to the changing age composition of the population. An example of this type of result was given in chapter 1.

The assumption of constant age specific savings rates may not always lead to plausible results. Simulations of changes in savings implied by the life cycle model have shown that large changes in the net asset (foreign debt) positions of countries can result if their populations are aging at different rates (Masson 1992). In developed countries, the increasing aging of the population would imply significant declines in aggregate savings ratios. A growing proportion of savings of the working population would be absorbed in transfer payments to those that dissave, especially the elderly. Recognition of such emerging problems in developed countries has already prompted policy action to modify life cycle savings patterns through measures such as compulsory superannuation.

Given sults of simulation experiments, it was decided that it was appropriate to modify the assumption of constant age specific savings rates under [illegible] reaction function' that takes the form

$$adj(t) = sign(SAVE(a,r,t)).\{\gamma_1.[OSHR(r,t)/SSHR(r,t)-1]-\gamma_2.\Delta[CA(r,t)/GDP(r,t)]\} \qquad (4.14)$$

where

OSHR(*r*,*t*)	=	share of world financial assets owned by region *r* at time *t*,
SSHR(*r*,*t*)	=	share of world net nominal savings undertaken by region *r* at time *t*,
CA(*r*,*t*)	=	current account surplus of region *r* at time *t*,
GDP(*r*,*t*)	=	GDP of region *r* at time *t*,

Δ means 'the change from the current to the next period', and *sign*(*X*) is –1 (1) if *X* is negative (non-negative).

The equation involves both a delayed and an immediate adjustment component. The delayed component is represented by the first square bracketed term. As demographic changes result in the share of a region in global savings deviating from its share of world financial assets, a partially offsetting uniform proportional change in the savings of each age group occurs. The response is delayed since it will take time for a change in net assets (foreign debt position) to occur.

An immediate response is represented by the second square bracketed term and occurs if the current account deficit to GDP ratio changes. Changes in the current account to GDP ratio are taken as a 'leading indicator' of likely future changes in the net asset position of a country as measured by the first square bracketed term. The purpose of the *sign*(*SAVE*(*a*,*r*,*t*)) term is simply to pick the sign for the required adjustment depending on whether an age group is a net saver or dissaver.

One interpretation of the 'savings reaction function' is that it represents a proxy for the impacts of various policy actions that might occur if the events triggering the function took place. For example, governments faced with the prospect of a deteriorating net asset (foreign debt) position are likely to take action to raise regional savings. In this sense, the reaction function could be viewed as a way of incorporating forward looking behaviour into the savings equation.

4.4 International capital mobility

Behavioural equations

As mentioned above, the equations for international capital mobility in MEGABARE replace those in GTAP. However, as in GTAP, a choice is offered between two equations to determine the allocation of international investment across regions. The choice will be governed partly by the particular model application.

Global investment is defined to equal global savings. However, it is assumed that savings will always finance investment in the region of origin before financing investment abroad. Such an assumption is intended to reflect the idea that there will be greater risks in investing abroad than at home.

The net rate of return on capital in region r, $RR(r,t)$ at period t, plays a key role in the allocation of investment across regions. $RR(r,t)$ is defined as the ratio of the rental for capital services, $RENTAL(r,t)$, to the purchase price of capital goods, $PCGDS(r,t)$, less the (constant) rate of depreciation, $DEPR(r)$

$$RR(r,t) = RENTAL(r,t)\ /\ PCGDS(r,t) - DEPR(r) \qquad (4.15)$$

[Note that $RR(r)$ is identical to the GTAP variable $RORC(r)$ that is incorrectly defined as equal to $PCGDS(r)\ /\ RENTAL(r) - DEPR(r)$ in some versions of the GTAP documentation but defined correctly in the computer code.]

The alternative equations for allocation of global investment involve different assumptions about the speed of decay of imperfections in world capital markets. The first equation is given by

$$rinv(r,t) = gdp(r,t) + \rho.\left[RR\_w(t).RR(r,t+1)/RR(r,0) - RRG(t)\right] \qquad (4.16)$$

where

$rinv(r,t)$ = growth rate of real investment in region r from time t to t+1,
ρ = flexibility parameter, $\rho > 0$,
$gdp(r,t)$ = growth rate of real GDP for region r from time t to t+1,
$RR(r,t)$ = the rate of return to capital in region r at time t,
$RR\_w(t)$ = the rate of return to capital for the world at time t,

and $RRG(t)$, can be interpreted as a global rate of return (or world rate of interest). The variable $RR\_w(t)$ is a weighted sum of the regional rates of return on capital whereas the variable $RRG(t)$ adjusts to ensure equality between global savings and investment.
In equation (4.16) it is assumed that the growth rate of real investment in region r will increase with the growth rate in GDP, the expected rate of return in region r (represented by $RR(r,t+1)$) and the world rate of return. The growth rate of real investment will decrease with the base period rate of return in region r and the global rate of return, $RRG(t)$. The extent of change in the growth of investment in response to changes in rates of return will be larger the greater the value of ρ.

A basic condition for a steady state in the standard version and many extensions of the neo-classical growth model is that there is a constant capital to output ratio. Such a condition implies a constant investment to GDP ratio if there is a constant rate of depreciation. In equation (4.16), a constant investment to GDP ratio is implied if the expected rate of return in region r is equal to the base period rate of return and the world rate of return, $RR\_w(t)$, is equal to the global rate of return, $RRG(t)$. Base period regional rates of return can be interpreted as representing a state of long run equilibrium in world capital markets under equation (4.17). Differences in base periods rates of return would reflect fundamental differences in risk premiums among regions. No mechanism for long term rates of return to equalise across regions is embodied in (4.16). Thus, re-establishing the base period pattern of rates of return would represent a condition for long run equilibrium in world capital markets.

A natural alternative hypothesis is that rates of return across regions should be equalised for long run equilibrium in world capital markets. It is well known from experience with several models that short term equalisation across regions tends to result in excessive flows of capital from developed to developing countries. Thus, it is necessary to assume some degree of imperfection in world capital markets to achieve a plausible pattern of international capital flows. However, in some applications of MEGABARE, it may be appropriate to assume a tendency to long run equalisation of rates of return. Such may be the case if it is assumed that there is long run convergence in welfare levels across economies. In this case differences across economies that support differences in risk premiums may tend to diminish. Results reported in ABARE–DFAT (1995) were generated under such assumptions.

The equation reflecting the hypothesis of long run equalisation of rates of returns is given by

(4.17) $$rinv(r,t) = gdp(r,t) + \rho.\left[RR(r,t+1) - RRG(t)\right]$$

The speed at which equalisation of rates of return occurs can be governed by the way in which the expected rate of return in period t+1 is related to the rate of return in period t and through suitable choice of a value for ρ. Long run equilibrium in world capital markets will occur when the expected rate of return in each region, $RR(r,t+1)$, is equal to the world rate of return (world rate of interest), $RRG(t)$. If such a state is reached, investment in each region will grow at the same rate as GDP.

The GEMPACK coding of these equations is of some interest. It illustrates some techniques for coding dynamics, such as the $RR(r,t+1)$ variable, using the sequential solution method. It also may be of interest for readers familiar with GTAP since some variables that have the same name in the international capital mobility modules of MEGABARE and GTAP are defined differently.

GEMPACK coding

$$rorc(r) = \frac{RENTAL(r)}{RORC(r).PCGDS(r)}.[rental(r) - pcgds(r)]$$

The GEMPACK coding retains the GTAP notation for $RR(r)$ of $RORC(r)$. Expressing equation (4.15) in growth rate (linearised) form

(4.18)

where variables in lower case represent the percentage change in the corresponding levels variables in upper case.

To express this equation in terms of variables that can be derived from the database, from the definition of $RORC(r)$

(4.19) $$\frac{RENTAL(r)}{RORC(r).PCGDS(r)} = \frac{RORC(r) + DEPR(r)}{RORC(r)}$$

The right hand side of this equation can be interpreted as the ratio of gross to net returns

(4.20) $$GRNETRATIO(r) = \frac{RORC(r) + DEPR(r)}{RORC(r)}$$

Substit $rinv(r) = gdp(r) +$

$$RORFLEX(r).L\_rorc\_w.[(I\_rorc(r) + rorc(r)/100) - rorg]$$

(4.21) $$rorc(r) = GRNETRATIO(r).[pcgds(r) - rental(r)]$$

which is the equation that appears for *rorc*(*r*) in MEGABARE (and GTAP).

The GEMPACK form for equation (4.16) is

(4.22)

where *L_rorc_w* is defined in GEMPACK to operate like a levels variable and is identical to *RR_w*(*t*) in (4.16). *I_rorc*(*r*) is defined to operate in GEMPACK as an index variable such that

(4.23) $$I\_rorc(r,T+1) = \prod_{t=0}^{T} (1 + rorc(r,T)/100)$$

Since $rorc(r,t)/100 = (RR(r,t+1)/RR(r,t)) - 1$,

(4.24) $$\begin{aligned} I\_rorc(r,t+1) &= RR(r,t+1)/RR(r,0) \\ &= I\_rorc(r,t).(1 + rorc(r,t)/100) \end{aligned}$$

which shows that (*I_rorc*(*r*)+*rorc*(*r*)/100) in (4.22) is identical to *RR*(*r*,*t*+1)/*RR*(*r*,*t*) in (4.16).

In GTAP, *rorg*, is defined as the percentage change in the global rate of return. In MEGABARE, *rorg*, can be interpreted as a levels variable equivalent to the global rate of return. It adjusts to ensure that regional investment sums to global savings. In MEGABARE, the world rate of return variable, *L_rorc_w*, is calculated from the database for the model for each time period whereas *rorg* is determined by the model. Equality between the values of these variables is one of the conditions for equilibrium in the world capital market in (4.16).

The variable *RORFLEX*(*r*) plays the role of an exogenously set parameter that influences the degree of international capital mobility in both GTAP and MEGABARE. The specific equation where *RORFLEX* is defined in GTAP does not apply in MEGABARE. In MEGABARE, *RORFLEX*(*r*) determines the responsiveness of regional investment to differences in rates of return as defined in (4.15) and (4.16).

The GEMPACK form of equation (4.16) is

(4.25) $rinv(r) = gdp(r) + RORFLEX(r).[(L\_rorc(r) + rorc(r) / 100) - rorg]$

where *L_rorc*(*r*) is defined to operate like a levels variable equal to *RR*(*r*,*t*).

Appendix A: Regional and commodity coverage of MEGABARE

In table A1 is shown the country aggregation of the world into 30 regions in MEGABARE. In table A2, the 37 industries or sectors covered by MEGABARE are shown.

A1 ***Thirty region country aggregation***

1 AUS	Australia
2 NZL	New Zealand
3 JPN	Japan
4 KOR	South Korea
5 IDN	Indonesia
6 MYS	Malaysia
7 PHL	Philippines
8 SGP	Singapore
9 THA	Thailand
10 CHN	China
11 HKG	Hong Kong
12 TWN	Taiwan
13 IDI	India
14 RAS	Rest of South Asia (includes: Bangladesh, Bhutan, Nepal, Sri Lanka, Pakistan)
15 CAN	Canada
16 USA	United States
17 MEX	Mexico
18 CAM	Central America and the Caribbean (includes: Antigua & Barbuda, Bahamas, Barbados, Belize, Cuba, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, St Kitts & Nevis, St Lucia, St Vincent, Suriname, Trinidad & Tobago)
19 ARG	Argentina
20 BRA	Brazil
21 CHL	Chile
22 RSM	Rest of South America (includes: Bolivia, Colombia, Ecuador, Fr. Guiana, Guyana, Paraguay, Peru, Venezuela, Uruguay)
23 E_U	European Union 12
24 EU3	Austria, Finland, Sweden
25 EFT EFTA	(includes Iceland, Norway, Switzerland)

Continued on next page

A1 *Continued*

26 CEA	Central European Associates (includes: Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia)
27 FSU	Former Soviet Union (USSR table from Tom Wahl), (includes: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan)
28 MEA	Middle East and North Africa (includes: Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Tunisia, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Republic, Yemen Arab Republic)
29 SSA	Sub Saharan Africa (includes: Angola, Benin, Botswana, Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cameroon, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea-Bissau, Ivory Coast, Kenya, Liberia, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, ,Rwanda, Sao Tome & Principe, Senegal, Seychelles Islands, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe)
30 ROW	Other Economies (includes: Albania, Afganistan, Bosnia-Herzegovinia, Burma, Cambodia, Croatia, Cyprus, Fiji, Laos, Macedonia, Maldives, Malta, Monolia, Nauru, North Korea, Solomon Islands, Papau New Guinea, Tonga, Turkey, Tuvalu, Vanuatu, Viet Nam, Western Samoa, Yugoslavia Fed. Republic)

A2 Thirty-seven industries in MEGABARE

1. paddy rice
2. wheat
3. grains (other than rice and wheat)
4. non-grain crops
5. wool
6. other livestock (other than wool)
7. forestry
8. fishing
9. coal
10. oil
11. gas
12. other minerals
13. processed rice
14. meat product
15. milk products
16. other food products
17. beverages and tobacco
18. textiles
19. wearing apparel
20. leather and fur
21. lumber and wood
22. pulp, paper and printing
23. petroleum and coal products
24. chemicals, rubber and plastics
25. non-metallic mineral products
26. primary ferrous metals
27. non-ferrous metals
28. fabricated metal products nec
29. transport industries
30. machinery and equipment
31. other manufacturing
32. electricity, gas and water
33. construction
34. trade and transport
35. other services (private)
36. other services (government)
37. ownership of dwellings

Appendix B: Modelling biased technological change

Technological change has been a dominating feature of economic growth since the Industrial Revolution and is likely to continue to be so in any realistic scenario for future growth. In MEGABARE simulations, the overall rate of technological change for given regions is sometimes determined endogenously and sometimes set exogenously as discussed in chapter 2. The model can be run with the bias in technological change determined either endogenously or set exogenously in either of the above cases. The ability to model biased technological change in some applications creates the possibility to use external information about relationships that are not explicitly modelled, as will be explained below.

The standard definitions of the biases in technological change used in economics apply to a static situation where input prices are fixed. Coding for technological change in GTAP that was inherited by MEGABARE reflects these definitions. However, general equilibrium models are highly interdependent equation systems as emphasised by (2.3). If technological change is introduced in any form, inevitably, relative prices will change. Thus, technological change that may be unbiased at the industry level in a partial equilibrium closure may turn out to be ‘biased’ in terms of its impacts in a general equilibrium closure.

The basic way that technological change is incorporated into MEGABARE equations will be described first. Several applications relevant to greenhouse policy will then be discussed.

Equations

To illustrate how the standard technological change definitions are incorporated into MEGABARE, an industry will be taken where the technology bundle approach does not apply. Thus, inputs (including a composite primary factor input) must be used in fixed proportion to output. However, substitution is permitted between the primary factors according to the CES specification. The concern will be with a specific industry in a specific region (j and r are set at specific integer values) and it will be referred to simply as the ‘industry’.

The equations in the model for industry demand for intermediate inputs and the primary factor bundle take the basic form

(b.1) $$qf(i,j,r)+af(i,j,r)=qo(j,r)-ao(j,r)$$

where the variables for the industry are defined as
$qf(i,j,r)$ = growth rate in demand for input i
$af(i,j,r)$ = growth rate in the efficiency of the use of input i
$qo(j,r)$ = growth rate in the output of the industry
$ao(j,r)$ = growth rate in the efficiency of the industry.

The interpretation of the technological change variables is brought out most clearly by writing the growth rate in industry output as a cost-share weighted function of the growth rates in industry inputs. Such a relationship can be derived from equation (b.1) using the zero pure profits condition

(b.2) $$po(j,r)+qo(j,r)=\sum_i \phi_{ij}.\left(pf(i,j,r)+qf(i,j,r)\right)$$

where
$pf(i,j,r)$ = growth rate in the price of input i
$po(j,r)$ = growth rate in the price of output of the industry
and $\sum_{i\in j\in r}\phi_{ij}=1$ and ϕ_{ij} is the cost share of input i.

Substituting equation (b.1) into equation (b.2) yields

(b.3) $$po(j,r)+qo(j,r)=\sum_i \phi_{ij}.\left(pf(i,j,r)+qo(j,r)-ao(j,r)-af(i,j,r)\right)$$

Since the input cost shares sum to unity, $qo(j,r)$ can be eliminated from equation (b.3) and $ao(j,r)$ brought outside the summation and to the left hand side to yield

(b.4) $$po(j,r)+ao(j,r)=\sum_i \phi_{ij}.\left(pf(i,j,r)-af(i,j,r)\right)$$

(The zero pure profits condition is coded in this way in some CGE models.)

Subtracting equation (b.4) from equation (b.2) yields

(b.5) $$\begin{aligned}qo(j,r)-ao(j,r)&=\sum_i \phi_{ij}.\left(qf(i,j,r)+af(i,j,r)\right)\\&=cswbi(j,r)\end{aligned}$$

(The name given to the summation term is an acronym for 'cost-share weighted bundle of inputs'.)

To focus purely on technological change, the following assumptions are made. It is assumed that the growth rate in industry output, *qo*(*j*,*r*), and the growth rate in the efficiency of the industry, *ao*(*j*,*r*), are set exogenously and constant. As a result, the growth rate in *cswbi*(*j*,*r*) is also determined. Finally, it is assumed that all input prices are growing at the same exogenous and constant rate.

The term *ao*(*j*,*r*) represents the overall rate of technological change for the industry (the difference between the growth rate in output and the growth rate in an index of inputs, *cswbi*(*j*,*r*)). The *af*(*i*,*j*,*r*) variables determine whether there is any bias in technological change and, if so, how it is allocated across inputs.

Suppose that *qf**(*i*,*j*,*r*) represents the rate of growth in all inputs *i* if technological change were unbiased (*af*(*i*,*j*,*r*) = 0 for all *i*). Then equation (b.1) implies

$$qf^*(i,j,r) = qo(j,r) - ao(j,r) \tag{b.1´}$$

If technological change were biased, then equation (b.5) implies that the *af*(*i*,*j*,*r*) variables have to be chosen is such a way that

$$qo(j,r) - ao(j,r) = \sum_i \phi_{ij}.\left(qf^*(i,j,r) + af(i,j,r)\right) \tag{b.6}$$

Eliminating *qf**(*i*,*j*,*r*) using equation (b.1′) and the fact that the input cost shares sum to unity yields

$$\sum_i \phi_{ij}.af(i,j,r) = 0 \tag{b.7}$$

Thus, it is evident that the *af*(*i*,*j*,*r*) variables are not independent. They can be chosen only in such a way that is consistent with the growth in output, *qo*(*j*,*r*), and overall rate of technological change, *ao*(*j*,*r*). In particular, if for some input *i*, with a non-zero input cost share, *af*(*i*,*j*,*r*) ≠ 0, then for at least one other input *l*, *af*(*l*,*j*,*r*) ≠ 0 and *sign*[*af*(*l*,*j*,*r*)] ≠ *sign*[*af*(*i*,*j*,*r*)].

If technological change is biased in the sense defined above, then the different intermediate inputs and the primary input composite can grow at different rates to that of output. Without biased technological change, such a result is impossible given the basic specification of the intermediate input demand equation for non-technology bundle industries. No price induced substitution is allowed between intermediate inputs and the primary input composite.

Some ways in which the modelling of biased technological change can be combined with external information to reproduce the effects of behavioural relationships not necessarily modelled directly will now be discussed.

Partial equilibrium applications

A relevant example of how external information can be combined with the technological change coding in MEGABARE is the modelling of so-called ‘no regrets’ options. For designated industries, using external information, the *ao*(*j*,*r*) variable could be given a surge over some time period to capture the ‘something for nothing’ element in ‘no regrets’. Again using external information, the appropriate *af*(*i*,*j*,*r*) variables would be set to have an energy saving bias over the same time period. In a partial equilibrium closure, the increase in the value of *ao*(*j*,*r*) means that a given growth rate in output is achieved for a lower growth rate in the cost-share weighted bundle of inputs, *cswbi*(*j*,*r*). The energy saving bias would result in a decreased growth rate in energy inputs.

Once values for the appropriate *af*(*i*,*j*,*r*) are set to achieve the desired energy saving bias, the choice of the other *af*(*i*,*j*,*r*) is constrained in the way described above. It is usually thought that more energy efficient techniques would be introduced using more capital intensive production processes. Thus, using external information if available, the appropriate *af*(*i*,*j*,*r*) terms (in the primary input demand function) would be set to create a capital using bias. Given the way the choice of the *af*(*i*,*j*,*r*) are constrained, there may be no option other than to create a capital using bias if capital costs are a reasonably high share of input costs.

Modelling ‘no regrets’ options in this manner clearly results in a welfare gain at the sector level in a partial equilibrium closure. However, when account is taken of the general equilibrium repercussions, the overall welfare impact on the sector and the economy is less certain. In a recent application where ‘no regrets’ options were modelled somewhat analogously with a static CGE model of the US economy (Rose and Lin 1995), the overall result was a slight welfare loss for the economy, mainly stemming from the impact on industries producing energy and their reduced demand for inputs. Such a result illustrates one reason why ‘top down’ (general equilibrium models) can produce different results from ‘bottom up’ (partial equilibrium models).

General equilibrium implications

An example will now be given of how external information can be used in modelling technological change that could compensate conceptually for any deficiencies in the modelling of capital–energy substitution options outside of industries where the technology bundle approach applies.

In a typical dynamic MEGABARE simulation where technological change is modelled, a general equilibrium closure will be used. Thus, the growth rates in input prices will not be fixed but determined endogenously. For industries where the technology bundle approach is used, relative input prices will change and the relative proportions in which intermediate inputs and a primary input composite are used will change. The same may be true for industries where the technology bundle does not apply if biased technological change is modelled. Although price induced substitution is not permitted in these industries, *biased* technological change can alter the relative proportions between intermediate inputs and the primary input composite.

From the simulation results, it will not be apparent for any industry whether there is price induced substitution only, biased technological change only or some combination of the two. Only someone familiar with the equation structure of the model would know that any change in relative proportions between intermediate inputs and the primary factor composite in non-technology bundle industries would be due entirely to biased technological change (since price induced substitution is not permitted).

In real world data, relative input prices will change as will relative input use. Econometricians wishing to estimate elasticities of substitution will have to somehow distinguish between price induced substitution and biased technical change. In the usual approaches adopted, there is essentially an 'identification' problem (too few equations to determine uniquely the number of parameters to be estimated). Estimates can be derived if a particular functional form is chosen but if it is the incorrect form, the estimates may be 'biased' (in the statistical sense) (see Diamond, McFadden and Rodriguez 1978).

In view of these difficulties in obtaining reliable estimates of the elasticity of substitution (and the bias in technological change), it is not surprising that there has been a long standing controversy in the energy economics literature about whether capital and energy are substitutes or complements. Capital and energy have been variously estimated to be both substitutes and complements in different econometric studies (for a concise review of the literature see Chang 1994). A further problem is that most econometric studies deal with the relationship between economy-wide energy and capital aggregates. It is clearly possible that capital and energy are substitutes or complements in some sectors and neither substitutes nor complements in others as implied by the overall form of the input demand specification in MEGABARE.

As a result of the many difficult issues in correctly modelling substitution and biased technical change, it is always desirable to draw on as much external information as is available in deciding on a plausible range for MEGABARE simulation results. For example, in preparing the simulations reported in ABARE–DFAT (1995), discussions were held with experts in energy efficiency and a literature review was undertaken to decide what were appropriate rates of decline in the ratio of carbon dioxide emissions to GDP for different regions and the world.

The model was run under the usual assumption that there would be positive overall technological change in all regions. Thus, there is some element of ‘no regrets’ gains in the results. The model was first run under the assumption of unbiased technical change (as defined in the partial equilibrium sense) which is usually the maintained hypothesis. It turned out that the desired declines in the ratios of emissions to GDP would not be achieved. The model was then re-run under the assumption that technological change would have a sufficient energy (fossil fuel) saving bias in different regions to allow these rates of decline to be attained. Results reported in the study were derived under this assumption.

There are two extreme interpretations of the outcome of this experiment if it is assumed that the exogenously set rates of decline in the ratio of emissions to GDP are the ‘true’ rates. If the substitution options (and strictly all of the equations and settings for exogenous variables) in the model are specified correctly, there will be a real energy saving bias in future technological change. Such a bias would not be implausible given concern about global warming and the possible policy responses. The alternative extreme interpretation is that in the future technological change will be unbiased and the need to introduce an energy saving bias is due entirely to the incorrect specification of substitution options in the model. Clearly there is a continuum of possibilities between these extremes.

Appendix C: Generation of age and gender specific mortality rates for MEGABARE

The demographic module of MEGABARE requires gender specific mortality rates for one year age groups from 0 to 100. This appendix describes how a preliminary set of mortality rates can be adjusted to conform to summary statistics of mortality while still preserving a realistic pattern of mortality across age groups. Such a procedure is necessary since life tables will not be available for all regions represented in the MEGABARE database.

Define

$MORT1(g,a,r)$ = preliminary mortality rate for cohort of gender g and age a in region r
$MORT(g,a,r)$ = final mortality rate for cohort of gender g and age a in region r

The preliminary mortality rates will typically be the mortality rates for some other region, perhaps scaled to have the same crude death rate as the region for which they are to be used. The final mortality rates are generated by transforming the logits of the components of *MORT*1 to produce values of *MORT* that imply the infant mortality rate, gender specific life expectancies and crude death rate in the UN population statistics.

Formally, the logit $\mu(g,a,r)$ of $MORT1(g,a,r)$ is defined by

(c.1) $$MORT1(g,a,r) = 1 \big/ \left\{1 + \exp\left(\mu(g,a,r)\right)\right\}$$

Then changes $\Delta\mu(g,a,r)$ in $\mu(g,a,r)$ are chosen so that $MORT(g,a,r)$ defined by

(c.2) $$MORT(g,a,r) = 1 \big/ \left\{1 + \exp\left(\mu(g,a,r) + \Delta\mu(g,a,r)\right)\right\}$$

satisfies

(c.3) $$imr(r) = \sum\nolimits_g POP(g,0,r).MORT(g,0,r) \Big/ \sum\nolimits_g POP(g,0,r)$$

(c.4) $$life\_exp(g,r) = \sum\nolimits_{a=1}^{A} \pi(g,a,r)$$

(c.5) $CDR(r) = \sum_{(a,g)} POP(g,a,r).MORT(g,a,r) \Big/ \sum_{(a,g)} POP(g,a,r)$
where

A = assumed maximum possible age
$imr(r)$ = infant mortality rate for region r
$life\_exp(g,r)$ = life expectancy for individuals of gender g in region r
$CDR(r)$ = crude death rate for region r
$\pi(g,a,r)$ = probability of an individual of gender g in region r surviving until at least age a

The survival probabilities are related to the mortality rates by

(c.6)
$$\begin{aligned} \pi(g,a,r) &= 1 && a = 0 \\ &= \prod_{b<a} \left(1 - MORT(g,b,r)\right) && a > 0 \end{aligned}$$

and the definition of life expectancy has used the fact that for any non-negative integer valued random variable X

(c.7)
$$E(X) = \sum_{x=1}^{\infty} prob(X \geq x)$$

The values of $\Delta\mu(g,a,r)$ must be consistent with equations (c.3), (c.4) and (c.5). Plainly there may be many possible sets of $\Delta\mu(g,a,r)$ values, as there are more components in $\Delta\mu(g,a,r)$ than there are equations to determine them. So $\Delta\mu(g,a,r)$ is assumed to be the particular function of age

(c.8)
$$\Delta\mu(g,a,r) = (A - a)/A.\left[f1(r) + a.\,f2(g,r)\right] + \exp(-a/A).\,f3(r)$$

Thus the values of $\Delta\mu(g,a,r)$ are functions of $f1$, $f2$ and $f3$, the number of components of these latter three variables being equal to the number of equations specified by (c.3), (c.4) and (c.5).

Appendix D: Generation of age specific savings rates by calibrating MEGABARE data to a life cycle consumption–savings model

Description of the life cycle consumption–savings model

The life cycle consumption-savings optimisation problem is to

choose

(d.1) $$\{C(a): 0 \leq a \leq A\}$$

to maximise

(d.2) $$\sum_{a=0}^{A} \ln(C(a)).(1+\gamma)^{-a}.\pi(a)$$

subject to

(d.3) $$F(a+1) = (1+r).F(a) + L(a) - C(a)$$

initial condition, $F(0) = F_0$

and terminal condition

(d.4) $$F(A+1) = F(A)/2$$

where

$C(a)$ = consumption by agent of age *a*
$F(a)$ = financial wealth of agent of age *a*
$L(a)$ = income other than interest on financial wealth of agent of age *a* (predominantly labour income, hence the use of the notation '*L*')
$\pi(a)$ = probability of living until at least age *a*
r = interest rate (assumed constant through time)
γ = pure rate of time preference of agents
A = assumed maximum possible age of an agent (that is, $\pi(A+1) = 0$))

It is not assumed that agents plan to completely exhaust their financial assets by the maximum age *A*, only that they will be rapidly depleting these assets by that age. This captures the uncertainty associated with the maximum duration of life.

This problem can be simplified by defining

$$\text{(d.5)} \qquad \begin{aligned} X(a) &= C(a) - L(a) \\ &= (1+r).F(a) - F(a+1) \end{aligned}$$

and observing that the terminal condition is equivalent to

$$\text{(d.6)} \qquad F(A+1) = F_\infty$$

for a value of F_∞ chosen to ensure (d.4) holds. The lagrangean for the respecified equation is

$$\text{(d.7)} \qquad \ell = \sum_{a=0}^{A} \begin{Bmatrix} \ln\big(X(a)+L(a)\big).(1+\gamma)^{-a}.\pi(a) \\ +\lambda.(1+r)^{-a}.X(a) \end{Bmatrix}$$

since

$$\text{(d.8)} \qquad F(A+1) = (1+r)^{A}.\Big\{(1+r).F(0) - \sum_{a=0}^{A}(1+r)^{-a}.X(a)\Big\}$$

The first order condition from equation (d.7) is

$$\text{(d.9)} \qquad \begin{aligned} \partial\ell/\partial X(a) &= (1+\gamma)^{-a}.\pi(a)\big/\big(X(a)+L(a)\big) + \lambda.(1+r)^{-a} \\ &= 0 \end{aligned}$$

This equation together with equation (d.4) determines $X(a)$ and λ. The values of $F(a)$ can be determined from the values of $X(a)$ and the initial condition, $F(0) = F_0$.

Calibrating the parameters of the life cycle consumption–savings model using MEGABARE base period data

For each region the MEGABARE database contains, for the initial period of the simulation:

- the value of net savings (header *SAVE*)
- the replacement value of the capital stock (header *VKB*)
- the value of depreciation (header *VDEP*)
- private consumption (coefficient *PRIVEXP*)
- government consumption (coefficient *GOVEXP*)
- returns to capital (component of coefficient *VOA* corresponding to capital — designated as ‘*VCAP*’ in the following)

- participation weights, used to define the number of individuals in the working age population (header *PWGT*)
- population by age and gender (header *POP*)
- mortality rates by age and gender (header *MORT*).

Population (mortality rates) by age can be determined from the last two items. The population (mortality rate) of age group *a* will be designated as '*POP*(*a*)' ('*MORT*(*a*)') in what follows.

In the initial period database, all returns to capital in a region — *VCAP* — are assumed to accrue to residents of the region. This feature is inherited from GTAP.

Calibration entails equating expressions derived from these data with equivalent expressions derived from the model of the previous section, and determining the values of F_0 and γ required to satisfy these equations.

Net savings is

(d.10) $$SAVE = \sum_{a=0}^{A} POP(a).\left(F(a+1) - F(a)\right)$$

The replacement value of the capital stock is used as a proxy for financial wealth, hence

(d.11) $$VKB = \sum_{a=0}^{A+1} POP(a).F(a)$$

The (constant) interest rate *r* from the life cycle model is set equal to the net rate of return on capital, thus

(d.12) $$r = (VCAP - VDEP)/VKB$$

Gross income is the sum of government consumption, private consumption, net savings and depreciation. This is equal to the sum across all age groups of income from all sources. It is necessary to make an assumption about how non-interest income is apportioned to individuals in each age group. The allocation assumed is that all individuals of working age receive the same amount of non-interest income. The allocation of non-interest income is confined to working age groups since the majority of this income is labour income. A measure of the working age population is defined by

(d.13) $$WAP = \sum_{a=15}^{64} POP(a).PWGT(a)$$

and the non-interest earnings of an individual in age group *a* is assumed to be (d.14) $$L(a)=\begin{pmatrix} PRIVEXP+GOVEXP \\ +SAVE+VDEP-VCAP \end{pmatrix}.PWGT(a)/WAP$$

The participation weights are one for age groups between 20–21 and 59–60, and increase (decrease) linearly from 0 to 1 (1 to 0) for age groups 15–16 to 19–20 (60–61 to 64–65). This pattern is designed to capture the gradual entrance (exit) of the young (old) from the workforce.

Finally, survival probabilities are related to mortality rates by

(d.15) $$\begin{aligned} \pi(a) &= 1 && a=0 \\ &= \prod\nolimits_{b<a}(1-MORT(b)) && a>0 \end{aligned}$$

Having derived some of the equations used in the calibration procedure, it is helpful to identify which equations are part of the procedure rather than intermediate steps in the derivations. The equations of the calibration procedure are:

$F(0) = F_0$
(d.4)
(d.9)
(d.10)
(d.11)
(d.12)
(d.13)
(d.14)
(d.15)

It is of further help in understanding the calibration procedure to describe how these equations determine the outputs of the procedure. Equation (d.13) is merely a definition. Equations (d.12), (d.14), (d.15) determine the values of variables that are fixed for the life cycle optimisation problem, that is, r, $L(a)$ and $\pi(a)$. As noted in the first section, equations $F(0) = F_0$, (d.4) and (d.9) determine $F(a)$ for given F_0 and γ. Equating two aggregate values derived from the life cycle with data from the MEGABARE database in equations (d.10) and (d.11) determines what the values of F_0 and γ must be.

The share of each age group in national net savings is the output of the calibration procedure which is used in MEGABARE during model simulations. This share is coefficient *shr_SAVE* in the TABLO code, and this is also its name in appendix A of ABARE–DFAT (1995).

Plainly the above procedure could easily accommodate more detailed data on income distribution — for example, variability of wages across time and age.

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