An Overview of MONASH

by

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MONASH: A Disaggregated, Dynamic Model of the Australian Economy

Chapter 1. Introduction

This book describes MONASH, a dynamic computable general equilibrium (CGE) model of the Australian economy. In standard applications, MONASH is run with about 100 industries. Via a suite of add-on programs, results can be generated for 57 sub-national regions, 340 occupations and numerous types of households.

Our objective in building MONASH was to make a practical contribution to economic decision-making in Australia. In trying to achieve this objective, we have produced a model with several innovations which we think will be of interest to economists even if they have no particular concern for Australian problems. These innovations are largely associated with closures. With different closures MONASH produces: estimates of changes in technology and consumer preferences (historical closure); explanations of historical developments such as the rapid growth since the mid-1980s in Australia's international trade (decomposition closure); forecasts for industries, regions, occupations and households (forecast closure); and projections of the deviations from forecast paths that would be caused by the implementation of proposed policies and by other shocks to the economic environment (policy closure).

In writing the book, our aim is to make the model available to people who want to use, improve, assess or adapt it. The book contains copious interpretative material and full technical documentation.

1. Main ideas

The main ideas in the book are: (a) CGE models can be used in forecasting; and (b) forecasts matter for policy analysis. We demonstrate these ideas in Chapter 2 by describing a MONASH application.

The key to generating believable CGE forecasts is to use in the model detailed information available from expert groups specializing in the analysis of different aspects of the economy. In MONASH we incorporate forecasts by specialists in various areas including: the domestic macro economy; Australian economic policy; world commodity markets; international tourism; production technologies; and consumer preferences.

We have found that our CGE forecasts are readily saleable to public and private organizations concerned with investment, employment, training and education issues. These organizations must base their decisions on views of the future. In forming these views, they struggle to interpret the array of partial forecasts available from specialist groups. Via a CGE model, we can assist, first by imposing consistency and then by tracing out the implications of the specialists' forecasts for sales of different products, employment in different occupations and population in different regions.

Over the last forty years, CGE models have been used almost exclusively as aids to "what if" (usually policy) analysis. In almost all cases it has been assumed that the effects of the shocks under consideration are independent of the path that the economy would have followed without the policy shocks. Thus, for "what if" analysis, a common implicit assumption is that realistic basecase forecasts are unnecessary. Contrary to this view, we find that "what if" answers depend significantly on the basecase forecasts. This is not surprising when we are concerned with unemployment and other adjustment costs. However, we find that basecase forecasts are important even when our concern is the long-run welfare implications of a policy change. For example, we find that the simulated long-run effects of tariff cuts on cars are influenced by the basecase forecasts for such variables as the rate of technical progress in the car industry relative to rates in other industries, the rate of preference shift between imported and domestic cars, and the price of imported cars relative to the prices of other traded goods.

2. *Background and innovations*

MONASH has evolved from ORANI (Dixon *et al.* 1977 and 1982). ORANI is a detailed comparative static model of the Australian economy. Since its first application in 1977, ORANI has been used in countless simulations by a large number of people concerned with the effects on the Australian economy of mineral discoveries, new technologies, major infrastructure projects, labour market reforms, booms and slumps in commodity prices, and changes in policy instruments such as tax rates, subsidies, public spending, interest rates, tariffs, and environmental and other regulations governing the conduct of firms in different industries. Reviews of several hundred published ORANI applications can be found in Parmenter and Meagher (1985), Powell and Lawson (1990), Vincent (1990), Powell and Snape (1993) and Dee (1994). In addition to its Australian applications, ORANI has been used as a starting template for models of many other countries including: Papua New Guinea (Vincent *et al.* 1990); South Africa (Horridge *et al.*, 1995 and 1996); Denmark (Frandsen *et al.*, 1994); Thailand (Warr, 1997, Arunsmith, 1998 and Siksamat, 1998); South Korea (Vincent, 1982 and Dee, 1986); Taiwan (Huang *et al.*, 1999, and Lee, 2000); China (Adams *et al.*, 2000); Philippines (Warr and Coxhead, 1993, Warr, 1995 and Beutre, 1996); Indonesia (Dee, 1991, Edimon, 1998 and Wittwer, 1999); Pakistan (Naqvi, 1997); Ivory Coast, Columbia, Chile and Kenya (Dick *et al.*, 1982a & b, 1983 and 1984); and New Zealand (Nana and Philpott, 1983). Undoubtedly the most significant application and extension of ORANI technology outside Australia has been in the creation of the GTAP model (Hertel, 1997).

We attribute the success of ORANI to five factors. First, it is documented in detail (see, for example, Dixon *et al.* 1982 and Horridge *et al.* 1993). Second, considerable effort was made through annual training courses to make ORANI accessible to potential users and builders of CGE models. The idea of dissemination via training courses has been adopted successfully by

Tom Hertel and his colleagues at the GTAP project. Third, the use in ORANI models of the simple Johansen/Euler solution technique implemented via Ken Pearson's GEMPACK programs[1] allows modellers to deal with very large systems of non-linear equations while staying firmly in control of the mathematics underlying the computations. This facilitates the diagnosis of computational failures caused by, for example, singularity of the relevant Jacobian matrix. Fourth, ORANI contains considerable detail, making it a suitable framework for handing a wide variety of issues. The flexibility of ORANI in applications is further enhanced by the use of different closures. Fifth, users of ORANI have established a strong tradition of explaining their results via back-of-the-envelope (BOTE) calculations, see for example, Dixon, *et al.* (1984) and Higgs (1986). Such calculations have allowed ORANI users to identifying the principal mechanisms and data items underlying particular results. This has been important in two ways: in detecting and overcoming modelling weaknesses; and in gaining the interest of policy advisors, journal editors and others who need to assess model-generated results but do not have time to look at copious documentation.

With MONASH, we retain the strong points of ORANI: this book provides comprehensive technical documentation; each year we conduct MONASH training courses; MONASH is solved by the Johansen/Euler technique implemented through GEMPACK; MONASH emphasizes detail and closure flexibility; and MONASH results are supported by comprehensive BOTE calculations. At the same time, MONASH is a considerable advance over ORANI, especially with regard to dynamics and closure options. These aspects of MONASH are reviewed in the next two subsections.

2.1 Dynamics

MONASH incorporates three types of inter-temporal links: physical capital accumulation; financial asset/liability accumulation; and lagged adjustment processes.

(a) Physical capital accumulation

As for most dynamic CGE models, capital in industry j accumulates in MONASH according to:

$$K_j(t+1) = K_j(t)*(1-D_j) + I_j(t) \tag{2.1}$$

where

$K_j(t)$ is the quantity of capital available for use in industry j during year t;
$I_j(t)$ is the quantity of new capital created for industry j during year t; and
D_j is the rate of depreciation, treated as a known parameter.[2]

With a given starting point [$K_j(0)$] and with a mechanism for determining investment [$I_j(t)$], (2.1) can be used to trace out the path of j's capital stock. In most applications of MONASH and

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[1] Pearson (1988), Codsi and Pearson (1988), Codsi *et al.* (1992), Harrison and Pearson (1996) and Harrison *et al.* (1996).

[2] An attractive alternative to (2.1) is the vintage approach in which depreciation rates and capital productivity depend on the age of the different components of an industry's capital stock. This approach has been used in many studies involving the estimation of capital stocks, production functions and technical change, e.g. Salter (1960), Johansen (1972) and Jorgenson *et al*. (1987). Among the few CGE groups to incorporate vintage specifications in their models are the Norwegians, see for example, Førsund *et al.* (1985).

of other dynamic CGE models, the mechanism for determining j's investment can be represented by[3]:

$$E_t[ROR_j(t)] = -1 \ + \ \frac{E_t[Q_j(t+1)]}{C_j(t)} * \frac{1}{1+r} \ + \ (1-D_j) * \frac{E_t[C_j(t+1)]}{C_j(t)} * \frac{1}{1+r} \tag{2.2}$$

and

$$E_t[ROR_j(t)] = f_{jt}\left(\frac{K_j(t+1)}{K_j(t)} - 1\right) \quad . \tag{2.3}$$

In these equations:

E_t denotes an expectation held in year t;
$ROR_j(t)$ is the rate of return on industry j's investment undertaken in year t;
$Q_j(t+1)$ is the rental on j's capital in year t+1;
r is the rate of interest;
$C_j(t)$ is the cost of an extra unit of capital installed for industry j in year t; and
f_{jt} is a non-decreasing function.

Equation (2.2) defines the expected rate of return for industry j in year t as the expected present value of an extra dollar of investment: a dollar of investment buys $1/C_j(t)$ units of capital which are expected in year t to generate rentals in year t+1 of $E_t[Q_j(t+1)]/C_j(t)$ and to reduce the need for investment expenditures by $(1-D_j)*E_t[C_j(t+1)]/C_j(t)$. Equation (2.3) defines an investment-supply curve: it shows how the rate of return that investors require if they are to advance an extra dollar to industry j depends on the rate of growth of j's capital stock.

Within the framework (2.1) to (2.3) we can distinguish two broad approaches: diminishing availability of investment funds and increasing installation costs. These provide alternative methods for damping simulated short-run investment responses to shocks such as changes in world commodity prices.

In MONASH, we adopt the first approach. We assume that the f_{jt} functions in (2.3) have positive slopes, that is we assume that if industry j has already attracted considerable investment funds giving it a high rate of capital growth, then it must have a high expected rate of return to attract the marginal investor. The values of the slopes are set to be consistent with the available econometric evidence. By choosing relatively large values, we prevent MONASH from implying unrealistically large short-run investment responses to changes in anticipated capital rentals and in other components of the RHS of (2.2).

Other builders of dynamic CGE models have generally adopted the second approach of damping investment responses by assuming that $C_j(t)$ is an increasing function of $I_j(t)$[4]. With this

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[3] Equations (2.2) and (2.3) simplify MONASH by omitting taxes and by treating the interest rate as a constant.

[4] See for example Bovenberg and Goulder (1991), Dixon *et al.* (1992, ch. 5) and McKibbin and Wilcoxen (1993a & b). McKibbin and Sachs (1991) damp investment responses not only via increasing installation costs but also via the assumption that some firms must rely on current profits as a major source of funds for investment. Jorgenson and Wilcoxen (1992 and 1993) and Malakellis (1998 and 2000) adopt neither damping strategy. In effect they assume that f_{jt} is the zero function and that $C_j(t)$ is independent of $I_j(t)$. In the absence of an investment damping strategy, low export demand and supply elasticities must be used to avoid violent investment fluctuations. The low trade elasticity approach is not suitable for a small open economy like Australia.

approach it is usual to assume that investment funds are available in infinitely elastic supply at the going rate of interest (f_{jt} is the zero function). However, to us it is unattractive to rely on the notion of increasing installation costs as the principal mechanism for achieving realistic investment responses. For most firms, costs per unit of construction services and other inputs to capital creation are at most only weakly dependent on variations in the firm's own investment.

MONASH allows two methods for handling expectations: static and forward-looking. Under static expectations $E_t[Q_j(t+1)]$ and $E_t[C_j(t+1)]$ appearing on the RHS of (2.2) are replaced with current rentals and current unit costs of capital or by these variables extrapolated using the current rate of inflation. Under forward-looking expectations the expectational terms on the RHS of (2.2) are replaced by simulated outcomes, that is

$$E_t[Q_j(t+1)] = Q_j(t+1) \quad \text{and} \quad E_t[C_j(t+1)] = C_j(t+1) \quad . \tag{2.4}$$

A practical advantage of static specifications is that they allow a recursive solution method. The solution for year 1 can be computed from assumptions for year 1 and data from year 0 and possibly earlier years. Then the solution for year 2 can be computed from assumptions for year 2 and data from year 1 and possibly earlier years, and so on. With forward-looking specifications such as (2.4), the recursive approach breaks down. Investment in year 1 depends on rental rates and other variables in year 2. Consequently, the solution for year 1 cannot be computed before the solution for year 2. Similarly, the solution for year 2 cannot be computed before the solution for year 3, and so on.

Until the 1990s, nearly all detailed dynamic CGE models used various forms of static or extrapolative expectations, allowing them to preserve a recursive structure. The leading example of an early recursive dynamic CGE model is Hudson and Jorgenson's (1974) study of US energy. Another detailed recursive model is the work on Norway by Longva *et al.* (1985).

Non-recursive specifications involving forward-looking expectations can be traced back to dynamic economy-wide planning models (see for example Adelman and Thorbeche, 1966). However, in these planning models, price-responsive behavior was given almost no role. An early example of a non-recursive model with price-responsive behavior is Dervis (1975). The development of modern, non-recursive CGE models can be followed through Ballard and Goulder (1985), Goulder and Summers (1989), Bovenberg and Goulder (1991), Jorgenson and Wilcoxen (1993) and Mercenier and Sampaio de Souza (1994). With the advent of cheap computing and user-friendly packages such as GEMPACK and GAMS[5], non-recursive specifications have rapidly gained popularity. For example, most of the models presented in Harrison and Hougaard Jensen (2000) are non-recursive.

There are two broad strategies for handling non-recursive computations. The first is to solve all years simultaneously, i.e., we present the computer with a single set of equations covering the relationships between variables within each year and between variables in different years. This strategy was implicit in dynamic economy-wide planning models in which a solution was computed by maximizing a function of the path of consumption subject to all of the intra- and inter-temporal production and trade constraints under which the economy operates. The potential for applying the simultaneous strategy to modern dynamic CGE models was recognized by Wilcoxen (1985 and 1987) and Bovenberg (1985). Malakellis (2000) is a recent application of the strategy using a method automated in GEMPACK by Codsi *et al.* (1992).

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[5] For GEMPACK see earlier reference to papers by Pearson and his colleagues. For GAMS see Brooke *et al.* (1996) and Rutherford (1999).

The second broad strategy is to adopt an iterative method. This is the strategy used in MONASH. Our particular iterative method is reminiscent of the Fair-Taylor algorithm.[6] We guess a path for the expected rates of return, $E_t[ROR_j(t)]$, and solve the model recursively with (2.2) excluded. Then we use (2.2) to compute an implied path for the expected rates of return. This implied path is used in modifying our guessed path. The recursive solution excluding (2.2) is repeated and a new implied path is calculated. The process continues until the guessed path and the implied path are the same. Because MONASH is a detailed model and is normally run with more than 100 industries, forward-looking solutions present a considerable computational burden. For this reason, and because we are not convinced of the descriptive superiority of forward-looking expectations, we have in most MONASH applications assumed static or extrapolative expectations. Nevertheless, as reported in subsection 7.1(d), computation of solutions with forward-looking expectations is practical.

(b) Financial asset/liability accumulation

The second type of inter-temporal link in MONASH is concerned with deficits and liabilities. Two deficits and their related liabilities dominate the political discussion of macroeconomic issues in Australia: the current account deficit, with its related net foreign liabilities; and the budget deficit, with its related government debt. To facilitate the application of MONASH to the public debate, we have included detailed specifications of these deficits together with accumulation equations for related financial assets and liabilities.

We model accumulation of financial assets and liabilities via inter-temporal relationships of the form:

$$D_q(t+1) = D_q(t) * V_q(t,t+1) + \left[\frac{D_q(t) + D_q(t+1)}{2}\right] * R_q(t) + J_q(t) * V_q(t_m, t+1) \;, \quad (2.5)$$

where

$D_q(t)$ is the level of asset or liability type q at the beginning of year t;

$R_q(t)$ is the average rate of interest or dividend rate applying to asset or liability q during year t;

$J_q(t)$ is active accumulation of q during year t;

$V_q(t,t+1)$ is the factor which translates q's value from the beginning of year t to the beginning of year t+1; and

$V_q(t_m,t+1)$ is the factor which translates q's value from the middle of year t to the beginning of year t+1.

By active accumulation we mean new borrowing or investment beyond accumulation of interest and dividends. For example, in a simple foreign debt equation the deficit on the balance of trade is active accumulation while accrued interest and valuation effects are passive accumulation.[7] Payment (receipt) of interest and dividends is recorded as active decumulation of a liability (asset), a negative component of $J_q(t)$. We assume that active accumulation takes place in the middle of each year. Thus, in deriving the level of q for the beginning of year t+1, we use

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[6] This algorithm was proposed by Fair (1979) and later extended by Fair and Taylor (1983). Other iterative methods that have been applied in dynamic CGE models with forward-looking expectations include shooting (explained in Press *et al.* 1986 and Roberts and Shipman 1972) and multiple shooting (Lipton *et al.* 1982 and Roberts and Shipman 1972). For a discussion of all these algorithms and of the simultaneous approach see Dixon *et al.* (1992, ch. 5).

[7] The concepts of active accumulation and passive accumulation were developed and applied in Dixon and McDonald (1986).

different translation factors [$V_q(t_m, t+1)$ and $V_q(t, t+1)$] for $J_q(t)$ and $D_q(t)$. We also use different translation factors for different q's. Where q is debt incurred by Australians repayable in foreign currency, the V's involve changes in the exchange rate between the middle of year t and the beginning of year t+1 and between the beginning of year t and the beginning of year t+1. Where q is foreign equity holdings in Australian industry j, the V's involve changes in j's asset price, and where q is equity holdings by Australians in other countries, the V's involve changes in both the exchange rate and asset prices.

Modelling of deficits and accumulation relationships adds complexity to MONASH, e.g. the tracking of start-of-year, middle-of-year and end-of year variables. However, there are considerable benefits. Not only does MONASH produce forecast and policy deviation results for politically important deficits and liabilities, but it also captures effects not otherwise available in general equilibrium models. For example, by taking account of foreign equity holdings, MONASH shows that the benefits of labour force deregulation in Australia's black coal industry accrue significantly to foreigners[8]. More generally, by recording assets and liabilities, MONASH generates results for the wealth of Australian residents which can be taken into account in welfare analyses.

(c) Lagged adjustment processes

The final source of inter-temporal equations in MONASH is lagged adjustment in the labour market and in investment.

In most CGE applications, it is assumed that wages adjust to clear labour markets. In a few applications,[9] it is assumed that wages are unaffected by the policy shock under consideration, thus allowing for involuntary unemployment. In MONASH, we can take an in-between position, with wages being sticky in the short run and flexible in the long run. This is done via inter-temporal equations which can be represented in simplified form by:

$$\frac{W(t)}{W_f(t)} - \frac{W(t-1)}{W_f(t-1)} = \alpha\left(\frac{E(t)}{E_f(t)} - 1\right) , \tag{2.6}$$

where

W(t) and E(t) are the real wage rate and employment in year t in a policy simulation;
$W_f(t)$ and $E_f(t)$ are basecase forecasts (generated in a forecast simulation without the policy shock) of the real wage rate and employment in year t; and α is a positive parameter.

In (2.6) we assume that while employment is above its forecast level, the real wage rate moves further and further above its forecast level. This implies that shocks favourable to labour produce short-run increases in employment and long-run increases in real wages.

In modelling investment we often find that our base period data imply disequilibria, i.e., inconsistencies between the levels of investment and rates of return on one hand and our theory of investment behaviour on the other hand. In simulations we eliminate these disequilibria via inter-temporal equations of the form:

$$DISEQ(t) = \beta * DISEQ(t-1) \tag{2.7}$$

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[8] Foreign ownership was included in a stylized CGE model by Dixon *et al.* (1984), in ORANI by Horridge (1987) and in GTAP by Walmsley (1999). Unlike MONASH, these earlier models were comparative static.

[9] For example, ORANI in short-run mode, Dixon *et al.*, (1982, ch. 7).

where β has a value between 0 and 1.

2.2 Closures of the MONASH model

For each year, MONASH takes the form

$$F(X) = 0 \tag{2.8}$$

where F is an m-vector of differentiable functions of n variables X, and n>m. The variables X include prices and quantities applying for a given year and the m equations in (2.8) impose the usual CGE conditions such as: demands equal supplies; demands and supplies reflect utility and profit maximizing behaviour; prices equal unit costs; and end-of-year capital stocks equal depreciated opening capital stocks plus investment.

In using MONASH we always have available a solution (X_{initial}) of (2.8) derived mainly from input-output data for a particular year. In simulations, we compute the movements in m variables (the endogenous variables) away from their values in the initial solution caused by movements in the remaining n – m variables (the exogenous variables) away from their values in the initial solution. In most simulations the movements in the exogenous variables are from one year to the next. If the starting solution is derived from data for year t, then our first computation creates a solution for year t+1. This solution can in turn become an initial solution for a computation which creates a solution for year t+2. In such a sequence of annual computations, links between one year and the next are recognized by ensuring, for example, that the quantities of opening capital stocks in the year τ computation are the quantities of closing stocks in the year τ-1 computation. In some simulations the movements in the exogenous variables refer to changes over several years rather than one year. For example, in simulations to be discussed in section 5,[10] the initial solution is for 1987 and the movements in the exogenous variables are for the entire period 1987 to 1994. In these simulations, a solution for 1994 is created in a single computation.

We identify four basic choices for the n-m exogenous variables, i.e. four classes of closures: historical; decomposition; forecasting; and policy or deviation closures. All four classes are represented in our analysis of the motor vehicle industry in sections 5 to 7. Historical and decomposition closures are used in single-computation analyses of the period 1987 to 1994 (section 5) and forecasting and policy closures are used in creating year-to-year projections for the period 1998 to 2016 (sections 6 and 7).

(a) Historical and decomposition closures

In a decomposition closure we include in the exogenous set all naturally exogenous variables, i.e., variables not normally explained in a CGE model. These may be observable variables such as tax rates or unobservables such as technology and preference variables.

Historical closures include in their exogenous set two types of variables: observables and assignables.

Observables are those for which movements can be readily observed from statistical sources for the period of interest (1987 to 1994 in the application in section 5). Historical closures vary between applications depending on data availability. For example, in our 1987-1994 application, the observables included a wide array of macro and industry variables but not intermediate input flows of commodity i to industry j. Input-output tables were published for 1987 but not, at the time of our research, for 1994. If input-output data had been available for

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[10] Section 5 is in Chapter 2. Throughout the book we number sections sequentially. Equations, tables and figures carry a section identifier. No chapter identifiers are required in cross referencing.

1994, then flows of i to j could have been included in the observable variables and treated as exogenous in our historical closure. The initial motivation for our historical simulation was the updating of input-output tables from 1987 to 1994. The updated tables are part of the 1994 solution of (2.8). The creation of updated input-output tables is an important payoff from historical simulations. However as we will see in section 5, these simulations have other uses.

Assignable variables are naturally exogenous (and are therefore exogenous in decomposition closures as well as historical closures). The key feature of an assignable variable in an historical simulation is that its movement can be assigned a value (possibly not unique) without contradicting anything that we have observed about the historical period or wish to assume about that period. We clarify this concept later in this subsection in the discussion of (2.9).

With reference to the two closures we can partition the MONASH variables into four parts:

$$X(HD), X(H\overline{D}), X(\overline{H}D), X(\overline{HD})$$

where

H denotes exogenous in the historical closure,
$\overline{H}$ denotes not exogenous (that is endogenous) in the historical closure, and
D and $\overline{D}$ denote exogenous and endogenous in the decomposition closure.

Thus, for example, $X(HD)$ consists of those MONASH variables that are exogenous in both the historical and decomposition closures, and $X(H\overline{D})$ consists of those MONASH variables that are exogenous in the historical closure but endogenous in the decomposition closure.

Table 2.1 gives some examples of the partitioning of variables used in the MONASH simulation reported in section 5. As indicated, variables in $X(HD)$ include population size, foreign currency prices of imports and policy variables such as tax rates, tariff rates and public consumption. Values of these variables are readily observable and are not normally explained in CGE models.

Examples of variables in $X(\overline{HD})$ are demands for intermediate inputs and demands for margins services (e.g. road transport) to facilitate commodity flows from producers to users. In the absence of end-of-period input-output tables, movements in these variables are not readily observable or assignable and are normally explained in CGE models.

Variables in $X(H\overline{D})$ include, at the industry or commodity level, outputs, employment, capital input, investment, exports, imports, private consumption and numerous price deflators. Also included in $X(H\overline{D})$ are several macro variables e.g. the exchange rate and the average wage rate. CGE models normally aim to explain the effects on these variables of policy changes, changes in technology and other changes in the economic environment. Hence these variables are naturally endogenous, i.e. they belong to the $\overline{D}$ set, and because changes in their values can be readily observed they belong to the H set.

$X(\overline{H}D)$ contains the same number of variables as $X(H\overline{D})$ with each variable in $X(H\overline{D})$ having a corresponding variable in $X(\overline{H}D)$. These corresponding variables are predominantly unobservable technological and preference variables. Such variables are not normally explained by CGE models and are therefore exogenous in the decomposition closure. However in the historical closure they are endogenous with the role of giving MONASH enough flexibility to explain the observed movements in the variables in $X(H\overline{D})$. Table 2.1 shows

Table 2.1. Categories of Variables in the Historical and Decomposition Closures

Selected components of $X(H\overline{D})$	**Corresponding components of** $X(\overline{H}D)$
Consumption by commodity	Shifts in household preferences
Total intermediate usage by commodity (deduced from information on outputs, imports and final usage)	Intermediate input saving technical change
Employment and capital inputs by industry	Primary factor saving technical change and capital/labour bias in technical change
Imports by commodity	Shifts in import/domestic preferences
Producer prices by industry	Rates of return on capital or markups on costs
Export volumes and f.o.b. prices	Shifts in foreign demand and domestic supply functions
Macro variables, e.g. aggregate consumption	Shifts in macro functions, e.g. the average propensity to consume

Selected components $X(HD)$
Policy variables, e.g. tax and tariff rates, and public consumption
C.i.f. import prices in foreign currency
Population

Selected components $X(\overline{HD})$
Demands for intermediate inputs and margin services

examples of corresponding pairs from $X(\overline{H}D)$ and $X(H\overline{S})$. As indicated in the table, in our historical simulation we use shifts in household preferences to accommodate observations on consumption by commodity, shifts in commodity-specific intermediate input-saving technical change to accommodate observations on total intermediate usage by commodity, etc.

The principles underlying the four-way partitioning of the MONASH variables in the historical and decomposition closures can be clarified by an example. A stylized version of the MONASH equation for total intermediate usage of commodity i (X_i) is

$$X_i = \sum_j B_{ij} B_i Z_j \tag{2.9}$$

where

Z_j is the activity level (overall level of output) in industry j; and

$B_{ij}B_i$ is the input of i per unit of activity in industry j with B_{ij} and B_i being technological variables which can be used in simulating the effects of changes in the input of i per unit of activity in j and the input of i per unit of activity in all industries.

In decomposition mode, B_{ij} and B_i are exogenous and Z_j and X_i are endogenous. Suppose that movements in the Z_js are not observed but that we have observed the movements over an historical period in X_i (possibly from information on commodity outputs, imports and final usage). Suppose that we wish to assume uniform input-i-using technical change. Then in historical mode we can use movements in B_i to explain the observed movement in X_i and we can assign a uniform value (possibly zero) to the percentage movements in B_{ij} for all j. In this example, Z_j is a member of $X(\overline{HD})$ and the assignable variable B_{ij} is a member of $X(HD)$. X_i is a member of $X(H\overline{D})$ and B_i is the corresponding member of $X(\overline{H}D)$.

Having allocated the MONASH variables to the four categories, we can compute historical and decomposition solutions, starting with the historical solution of the form:

$$X(\overline{H}) = G^H(X(H)) \tag{2.10}$$

where $X(H)$ and $X(\overline{H})$ are the exogenous and endogenous variables in the historical closure, i.e. $X(H) = X(HD) \cup X(H\overline{D})$ and $X(\overline{H}) = X(\overline{H}D) \cup X(\overline{HD})$, and G^H is an m-vector of differentiable functions. By observing and assigning $X(H)$ for two years, s and t, we can use (2.10) to estimate percentage changes over the interval [s,t], $x_{st}(\overline{H})$, in the variables in $X(\overline{H})$. Thus we combine a large amount of disaggregated information on the economy (the movements in the variables in $X(H)$) with a CGE model to estimate movements in a wide variety of technological and preference variables ($X(\overline{H}D)$), together with movements in more standard endogenous variables ($X(\overline{HD})$).

Next we move to the decomposition closure which gives a solution of the form

$$X(\overline{D}) = G^D(X(D)) \quad . \tag{2.11}$$

Following the method pioneered by Johansen (1960), we can express (2.11) in log-differential or percentage change form as

$$x(\overline{D}) = A \ x(D) \tag{2.12}$$

where $x(\overline{D})$ and $x(D)$ are vectors of percentage changes in the variables in $X(\overline{D})$ and $X(D)$, and A is an m by n-m matrix in which the ij-th element is the elasticity of the i-th component of $X(\overline{D})$ with respect to the j-th component of $X(D)$, that is

$$A_{ij} = \frac{\partial \ G_i^D(X(D))}{\partial \ X_j(D)} \frac{X_j(D)}{X_i(\overline{D})} \quad . \tag{2.13}$$

With the completion of the historical simulation, the percentage changes in all variables are known. In particular the vector x(D) is known. Thus we can use (2.12) to compute values for $x(\overline{D})$ over the period s to t.[11]

The advantage of working with (2.12) rather than (2.11) is that (2.12) gives a decomposition of the percentage changes in the variables in $X(\overline{D})$ over the period s to t into the

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[11] To reduce linearization errors we use a mid-point value of A, i.e., we evaluate the elasticities defined in (2.13) with X(D) set at $0.5*(X_s(D) + X_t(D))$. With this mid-point value denoted by A_{st}, we compute $x_{st}(\overline{D}) = A_{st} \ x_{st}(D)$ where $x_{st}(D)$ is a vector of mid-point percentage changes (100 times the change divided by the mid-point level). In applications of MONASH, including that described in section 5, we have found that $x_{st}(\overline{D})$ computed in this way is not substantially different from the true mid-point percentage movements which can be computed via (2.11).

parts attributable to movements in the variables in X(D). This is a legitimate decomposition to the extent that the variables in X(D) are genuinely exogenous, that is can be thought of as varying independently of each other. In setting up the decomposition closure, the exogenous variables are chosen with exactly this property in mind. Thus, in the decomposition closure we find policy variables, technology variables, taste variables and international variables (e.g. foreign currency prices) all of which can be considered as independently determined and all of which can be thought of as having their own effects on endogenous variables such as incomes, consumption, exports, imports, outputs, employment and investment.

In subsection 5.2 we use the historical closure in estimating changes in technology and tastes paying particular attention to technology and taste variables for motor vehicles. Then in subsection 5.3 we use the decomposition closure and (2.12) in computing the effects on the economy of changes in the variables in X(D). Again we pay particular attention to the motor vehicle industry. Our decomposition analysis gives us a basis for assessing the relative importance to the industry of changes in policy variables, technology variables, taste variables and international variables. The relationship between our historical and decomposition simulations is illustrated in Figure 2.1.

(b) Forecasting and policy closures [12]

Forecasting closures are similar in nature to historical closures. Instead of exogenizing everything that we know about the past, in forecasting closures we exogenize everything that we think we know about the future. Thus in MONASH forecasts, we exogenize numerous naturally endogenous variables, including:

- volumes and prices for agricultural and mineral exports. This enables us to take advantage of forecasts prepared by the Australian Bureau of Agricultural and Resource Economics.
- numbers of international tourists. This enables us to take advantage of forecasts prepared by the Bureau of Tourism Research.
- most macro variables. This enables us to take advantage of forecasts prepared by macro specialists such as Access Economics and the Australian Treasury.

To allow these variables to be exogenous we need to endogenize numerous naturally exogenous variables such as the positions of foreign demand curves, the positions of domestic export supply curves and macro coefficients , e.g. the average propensity to consume.

Because we know less about the future than the past, MONASH forecasting closures are more conventional than historical closures. In forecasting closures, tastes and technology are exogenous. As will be seen in section 6, our settings for these variables in forecasting simulations are made by reference to their estimated values from historical simulations.

In common with historical closures, in forecasting closures policy variables are exogenous. In forecasting values for these variables we draw on departments of the Australian government such as the Productivity Commission and the Treasury.

Policy closures are similar to decomposition closures. In policy closures naturally endogenous variables (such as exports of agricultural and mineral products, tourism exports and macro variables) are endogenous. They must be allowed to respond to the policy change under consideration. Correspondingly, in policy closures naturally exogenous variables (such as the

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[12] We adopt a broad interpretation of "policy" in the expressions policy closure and policy simulation. We include not only closures and simulations concerned with the effects of taxes, tariffs, etc., but also those concerned with the effects of other naturally exogenous changes such as improvements in technology and movements in export demand curves.

positions of foreign demand curves, the positions of domestic export supply curves and macro coefficients) are exogenous. They are set at the values revealed in the forecasts.

The relationship between forecasting and policy simulations is similar to that between historical and decomposition simulations. Historical simulations provide values for exogenous variables in corresponding decomposition simulations. Similarly, forecasting simulations provide values for exogenous variables in corresponding policy simulations. However there is one key difference between the relationships. An historical simulation and the corresponding decomposition simulation produce the same solution. This is because all the exogenous variables in the decomposition simulation have the values they had (either endogenously or exogenously) in the historical simulation. In a policy simulation, most, but not all, of the exogenous variables have the values they had in the associated forecast simulation. The policy variables of interest are set at values that are different from those they had in the forecasts. Thus policy simulations generate deviations from forecasts. The relationship between the forecast and policy simulations reported in sections 6 and 7 is illustrated in Figure 2.2.

Because decomposition and policy closures are conventional (i.e., naturally exogenous variables are exogenous and naturally endogenous variables are endogenous), readers may wonder how they differ. The main difference concerns timing. As indicated earlier, decomposition closures are used in medium-term analyses, for example, the study of the effects of changes in technology over a period such as 1987 to 1994. Over such a period, it is reasonable to suppose that changes in technology cause adjustments in real wages but do not affect aggregate employment. Thus, in the decomposition closure used in section 5, aggregate employment is exogenous. In the policy analysis in section 7 we are concerned with year-to-year effects. For each year in the period 1998 to 2016 we generate the effects of cuts in motor vehicle tariffs. In year-to-year analyses we need to recognize wage stickiness and consequent employment effects. Thus, in the policy closure used in section 7, we allow short-run employment responses to policy shocks and other changes in the economic environment.

3. Presentation of the book and reader access to MONASH

Relative to other presentations of CGE models, the presentation here is very detailed. We discuss not only broad theoretical features and particular innovations but also many purely practical issues: e.g. the melding of statistics published in different industrial classifications; the treatment of wholesale, retail and transport margins and the distinction between producers’ and purchasers’ prices; and the modelling of trade in tourism, education and communication services. Such seemingly mundane issues are of critical importance in producing reliable CGE results. Nevertheless, although these issues are often difficult and time-consuming, the CGE literature provides little guidance on how they can be handled. Thus we think that the practical detail included in this book will be of assistance to potential CGE model builders and even to seasoned campaigners.

Consistent with emphasizing practical matters, we have built our presentation of MONASH around its TABLO representation. The TABLO language, part of the GEMPACK suite of computer programs,[13] is close to ordinary algebra. It is used to communicate the structure of an economic model to the rest of GEMPACK which then implements the model by

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[13] The current version of GEMPACK (Release 6.0) is documented in Harrison and Pearson (1993, 1994, 1998a, b & c).

Figure 2.1. Historical and Decomposition Simulations

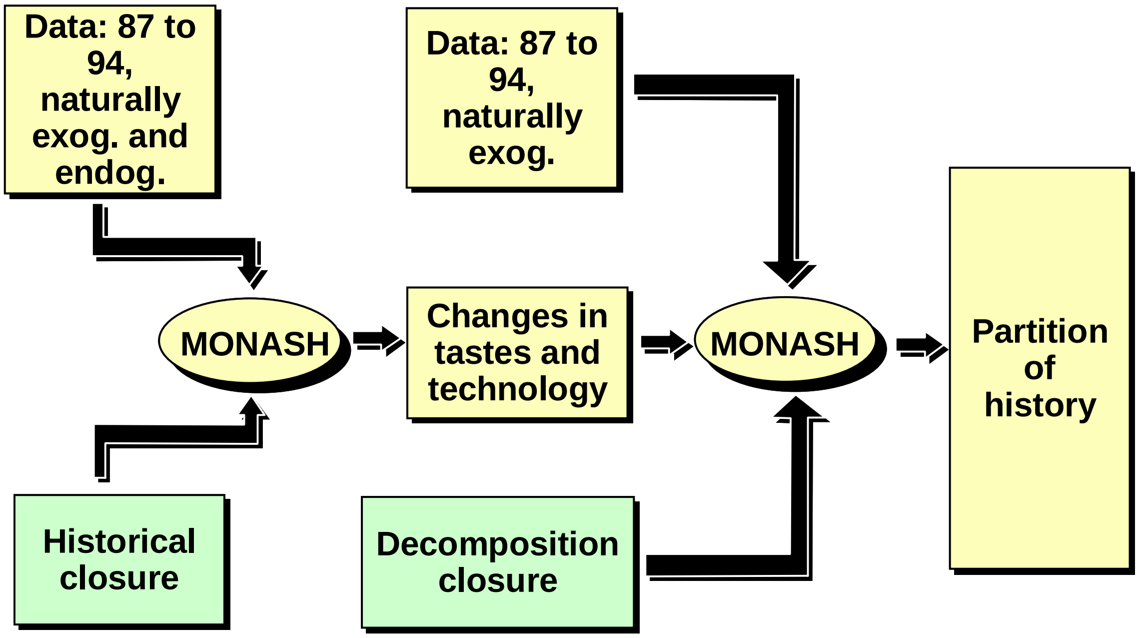
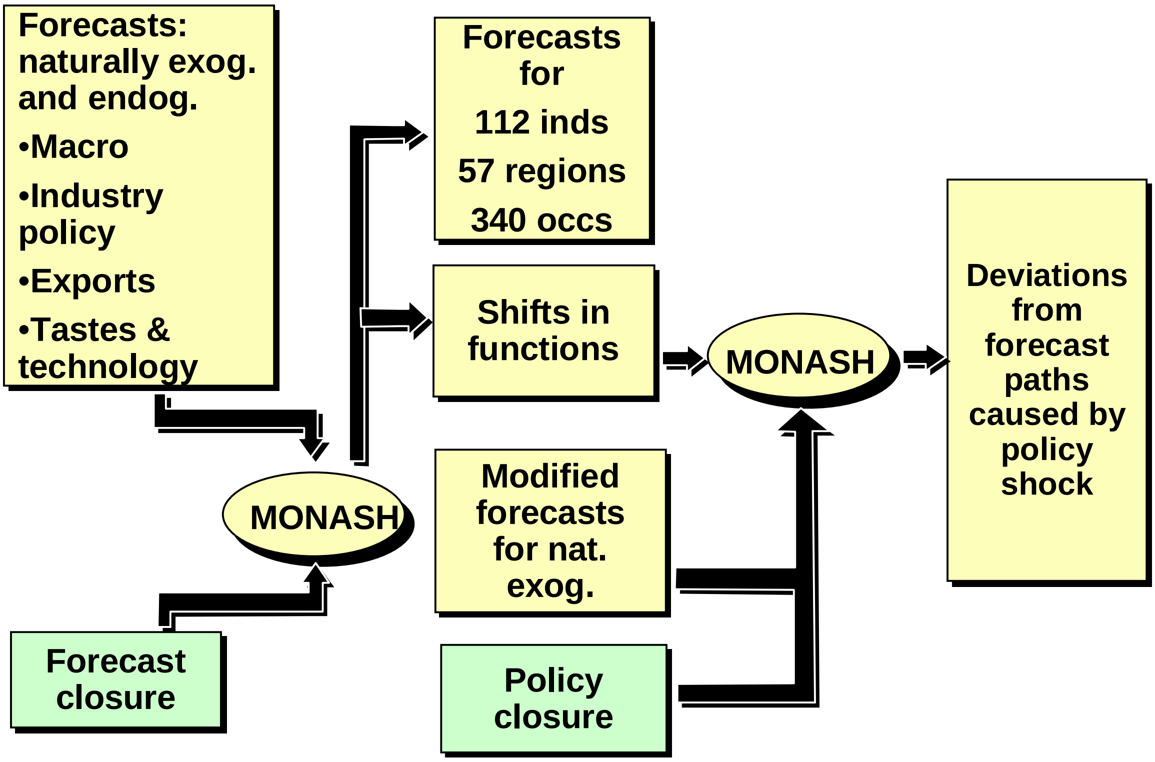


Figure 2.2. Forecast and Policy Simulations



reading data, generating solutions and presenting results. By basing our exposition on TABLO, we immediately equip readers with an ability to use, modify and adapt the model.

The book is self contained. Nevertheless, readers who wish to explore the details of the MONASH model would benefit from having a copy of the MONASH TABLO code on their computers. This will enable them to follow cross-references from the text to the TABLO code by searching on their screens rather than turning dozens of pages. It will also make it easy for them to follow themes of their own interest by for example, looking up all the occurrences in the model of a certain variable. With a copy of the TABLO code together with supporting programs and data, readers will be able to run simulations.

Copies of the MONASH TABLO code can be downloaded free of charge from (***to be advised***). This site also contains instructions for obtaining MONASH data and GEMPACK software, including a windows interface (RunMONASH) for running MONASH forecasts and policy simulations.

3.1 Organization of chapters

Chapter 2 contains our illustrative analysis of the Australian motor vehicle industry over the period 1987 to 2016. We present this application before the chapters describing the MONASH theory. Readers will be in a better position to follow the details of the MONASH model if they are familiar with an application.

Chapter 3 overviews the mathematical structure of MONASH and outlines the solution strategy.

The first part of Chapter 4 is an introduction to the TABLO language and the second part is the TABLO representation of MONASH.

Chapter 5 uses this representation in a comprehensive explanation of the MONASH theory.

Chapter 6 sets out the technical details of the transitions from the bland long-run closure used in decomposition simulations to the more complex closures used in historical, forecasting and policy simulations.

Chapter 7 overviews five extensions of MONASH which produce results for: (a) activity in sub-national regions; (b) employment in detailed occupational classifications; (c) output of goods and services at a sub-input-output level; (d) real incomes of different household types; and (e) labour market adjustment costs associated with microeconomic reforms and other shocks to the economy. The chapter concludes with comments on directions for future research, research funding and academic incentives.

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