CENTRE of POLICY STUDIES and the IMPACT PROJECT

Eleventh Floor, Menzies Building
Monash University, Wellington Road
CLAYTON Vic 3800 AUSTRALIA

Telephone: (03) 9905 2398, (03) 9905 5112 — from overseas: 61 3 9905 2398 or 61 3 9905 5112

Fax: (03) 9905 2426 — 61 3 9905 2426

e-mail: impact@buseco.monash.edu.au

Internet home page: http//www.monash.edu.au/policy/

Paper presented at the Symposium in memory of Professor Leif Johansen and to celebrate the fiftieth anniversary of the publication of his "A Multi-Sectoral Study of Economic Growth" (North Holland 1960)

The Norwegian Academy of Science and Letters

Oslo, May 20-21, 2010

Johansen's Contribution to CGE Modelling: Originator and Guiding Light for 50 Years

by

PETER B. DIXON
Centre of Policy Studies
Monash University

AND

MAUREEN T. RIMMER
Centre of Policy Studies
Monash University

General Paper No. G-203 May 2010

ISSN 1 031 9034 ISBN 978 1 921654 10 7

The Centre of Policy Studies (COPS) is a research centre at Monash University devoted to economy-wide modelling of economic policy issues.

Johansen’s *contribution to CGE modelling: originator and guiding light for 50 years*

by
Peter B. Dixon and Maureen T. Rimmer
Centre of Policy Studies, Monash University

Paper presented at the Symposium in memory of Professor Leif Johansen and to celebrate the fiftieth anniversary of the publication of his “A Multi-Sectoral Study of Economic Growth” (North Holland 1960)

The Norwegian Academy of Science and Letters

Oslo, May 20-21, 2010

Abstract

Fifty years ago the Norwegian economist, Leif Johansen, gave us what is now recognised as the first CGE model. While Johansen was first, he is not the father of the whole field. CGE modelling in different styles sprang largely independently from several sources. This paper describes how Johansen’s style of CGE modelling took root in Australia in the 1970s and has from there spread to the rest of the world. Today, thousands of economists from nearly every country are undertaking Johansen-style CGE modelling to elucidate policy questions in trade, taxation, environment, labour markets, immigration, income distribution, technology, resources, micro-economic reform and macro stabilization.

Key words: CGE modelling; Leif Johansen

JEL codes: C68; B23; B31

Contact author: Peter B. Dixon
Email: peter.dixon@buseco.monash.edu.au

Contents

Johansen's contribution to CGE modelling: originator and guiding light for 50 years

by
Peter B. Dixon and Maureen T. Rimmer
Centre of Policy Studies, Monash University

1. Introduction

Johansen (1960) is one of those rare books that is a complete break with previous literature and the first contribution to a major branch of economics, computable general equilibrium (CGE) modelling.

CGE belongs to the economy-wide class of models, that is, those that provide industry disaggregation in a quantitative description of the whole economy. The original economy-wide model was Leontief's input-output system (Leontief, 1936, 1941). Following Leontief, the next stage of economy-wide modelling was the programming models of Sandee (1960), Manne (1963), Evans (1972) and others. Input-output and programming models lacked clear descriptions of the behaviour of individual agents. In input-output modelling, the *economy* organized production of each commodity (the vector X) to satisfy a vector of final demands (the vector Y) with given technology specified by the input-output coefficient matrix (A). In programming models, the *economy* organized production to maximize a welfare function subject to Leontief's technology specification and subject to constraints on the availability of primary factors.

What Leif Johansen did was identify behaviour by individual agents. This is the defining feature of CGE models that distinguishes them from the earlier economy-wide models.[1] Households in Johansen's model maximize utility subject to their budget constraint. Industries choose inputs to minimize costs subject to production-function constraints and the need to satisfy demands for their outputs. Capitalists allocate capital between industries to maximize their returns. The overall outcome for the economy is determined by the actions of individual agents co-ordinated through price adjustments that equalize demand and supply in product and factor markets.

Johansen conception proved remarkably popular and versatile. In the 50 years since the publication of his book, CGE modelling has attracted a huge group of researchers. The GTAP network alone includes 7,500 CGE practitioners in 150 countries. The issues to which CGE modelling has been applied include:

the effects on

macro, welfare, industry, regional, labour-market, distributional and environmental variables

of

taxes, public consumption and social security payments; tariffs and other interferences in international trade; environmental policies; technological change; international commodity prices; interest rates; wage setting arrangements and union

[1] Definitions of CGE modelling can be found in Bergman (1985, p. 137) and Dixon and Parmenter (1996, p. 5)

behaviour; mineral discoveries (the Dutch disease); immigration; micro-economic reform; and major projects.

While most of these issues have been analysed in single-country, single-period models, there are now numerous CGE models which are either multi-regional or multi-period (dynamic) or both. By going multi-regional, CGE modelling has thrown light on both intra-country and inter-country regional questions. In the first category are issues (important in federations) concerning the effects of tax and expenditure activities of provincial governments. In the second category are issues such as the effects of the formation of trading blocks and the effects of different approaches to reducing world output of greenhouse gases. By going dynamic, CGE modelling has the potential to broaden and deepen its answers to all the questions with which it has been confronted. It has also re-entered the forecasting arena, rather belatedly following the lead of Johansen and his colleagues (Johansen 1974, ch. 10; Bjerkholt and Tveitereid, 1985; and Schreiner and Larsen, 1985).[2] CGE models are now used to generate forecasts of the prospects of different industries, labour force groups and regions. These forecasts feed into investment decisions by private and public sector organizations.

This paper is concerned with the Johansen legacy. In section 2, we describe the distinctive features of his 1960 model and define what we mean by Johansen-style CGE modelling. Section 3 looks at some other early styles of CGE modelling. Then in sections 4 and 5, we show how Johansen-style modelling took root in Australia and then spread to the rest of the world. Section 6 contains concluding remarks and a discussion of the validation of CGE models.

2. The Johansen approach

Johansen built his model of Norway around an input-output table of 1950. He distinguished 22 industries. For each industry, input-demand equations are derived by assuming that firms are price-takers and choose their inputs to minimize the cost of producing any given level of output subject to a production-function constraint reflecting Cobb-Douglas substitution between capital and labour, Hicks-neutral primary-factor-saving technical change and Leontief treatment of intermediate inputs. Imported inputs are either identical to domestic inputs or treated as non-competitive. Johansen assumed that households choose their consumption of each commodity to maximize an additive utility function subject to their budget constraint. Following the lead of his senior colleague, Ragnar Frisch, Johansen exploited additivity to dramatically simplify the estimation of own- and cross-price elasticities.[3] Among the empirically important details that Johansen encapsulated in specifying production and consumption behaviour is the distinction between buyers' prices (that motivate consumption decisions) and sellers' prices (that motivate production decisions): he modelled the gap between the two by introducing a trade-services commodity (a combination of transport, wholesale and retail margins). In handling investment, Johansen distinguished between maintenance and expansion. He modelled maintenance as proportional to existing stocks of structures and equipment, and he

---

[2] Early CGE modellers including Johansen (1960, 1974), Hudson and Jorgenson (1974), Adelman and Robinson (1978) and Taylor *et al.* (1980) gave their results a real time dimension, either historical or future. The subsequent generation of modellers worked mainly in a comparative static framework.

[3] As Frisch (1959) demonstrated, under additivity the n^2 price elasticities can be set on the basis of n-1 expenditure elasticities, budget shares and information on the sensitivity of demand for any one commodity with respect to its own price.

specified expansion of these stocks exogenously. Public expenditure, net exports[4] and inventory accumulation by commodity are exogenous in Johansen's model, and, consistent with a long-run focus, total employment is also exogenous. There is one type of labour which is perfectly mobile across industries, although wages differ by industry according to exogenously given relativities. The overall level of the nominal wage is exogenous and acts as the numeraire. For capital, Johansen assumed that an exogenous aggregate quantity is allocated across industries in accordance with exogenously given relative rates of return. Rather uncomfortably, the structure/equipment composition of this aggregate capital stock morphs costly to suit the requirements of the using industries, becoming more structure-intensive if the industrial composition of activity shifts towards industries whose capital is structure-intensive and vice versa.

Throughout his book Johansen provided thoughtful commentary on the theoretical limitations of his model, but was not apologetic. He had a strong, immediate and practical purpose.

> *"The model presented in this study is in many respects unsatisfactory when judged from a purely theoretical point of view. It is, however, constructed with an eye to the possibility of it being implemented by existing statistics. Without this possibility the model would hardly be very interesting." [Johansen 1960, p. 1.]*
>
> *"I do believe that the numerical results also give a rough description of some important economic relationships in the Norwegian reality." [Johansen 1960, p. 3.]*

He argued that people who merely use the data to illustrate the working of a model are giving themselves an excuse for not using the data seriously. He thought that underestimating the value of the data is as serious a sin as drawing conclusions that are too strong.

Fifty years on, the exact specification of Johansen's model is of only historical importance. It was revolutionary at its time and even today, it would be respectable. However, there are two aspects of the model that remain of immediate relevance to today's CGE community and which are the defining features of what we will refer to as Johansen-style CGE modelling.

- The first is the way in which Johansen presented his model as a rectangular system of linear equations in change and percentage-change variables and solved it by matrix inversion.
- The second, and related aspect, is how he used the linear representation and the linear solution method: to clarify properties of the model; to elucidate real world issues; and to check the validity of the model.

2.1. Johansen's solution method

The computational form of Johansen's model is a linear system of 86 equations and 132 variables. He expressed it as:

$$B * \xi = L * \eta \qquad (2.1)$$

[4] Net exports (exports less imports) are exogenous for all commodities except non-competitive imports which are endogenously determined as Leontief inputs to production and as a commodity in the household utility function.

where

B and L are matrices of dimensions 86 by 86 and 86 by 46; and

ξ and η are column vectors, dimension 86 and 46, of changes or percentage changes in the model's 86 endogenous variables and 46 exogenous variables.

Johansen derived most of the equations in (2.1) from underlying levels forms. For example, in (2.1) he represents the Cobb-Douglas relationship:

$$X_j = A_j * N_j^{\gamma_j} * K_j^{\beta_j} * \exp^{\varepsilon_j * t} \tag{2.2}$$

between the output in industry j (X_j), labour and capital inputs (N_j and K_j) and the rate of technical progress (ε_j) as

$$x_j = \gamma_j * n_j + \beta_j * k_j + \varepsilon_j \tag{2.3}$$

where x_j, n_j and k_j are percentage rates of change in X_j, N_j and K_j. For consumer demands, Johansen specified a percentage change form directly without giving an underlying levels form. A slightly simplified version of what he wrote is:

$$c_i - v = \sum_j \eta_{i,j} * p_j + E_i * (y - v) \tag{2.4}$$

where

c_i, p_j, y and v are percentage rates of change in consumption of good i, the price of good j, total household expenditure and the number of households, and

$\eta_{i,j}$ and E_i are parameters representing the elasticity of demand for i with respect to the price of j and the elasticity of demand for i with respect to total household expenditure.

From (2.1), Johansen solved his model as

$$\xi = T * \eta \tag{2.5}$$

where T is the 86 by 46 matrix given by $B^{-1}*L$.

Solution (2.5) is simple and was computationally feasible in the late 1950s. However, as recognised by Johansen, it gives only an approximate solution; it is subject to linearization error. In the 1973 addendum to his 1960 book, Johansen (1974) reports experience with a method implemented in the late 1960s by Spurkland (1970) for calculating accurate solutions. Spurkland's method used (2.5) to obtain an approximate solution and then moved to an accurate solution via a general non-linear-equation method such as Newton's algorithm. In section 4.5, we describe a multi-step Johansen method. This is a more obvious and straightforward way of extending Johansen's technique to produce accurate solutions and is now in common use around the world.

2.2 The T matrix: clarifying properties of the model; elucidating real world issues; and checking the validity of the model

Johansen was fascinated by the T matrix in (2.5). He devoted most of chapters 7 and 8 of his book to discussing it and also displayed the entire matrix as a foldout table. His focus on the T matrix explains much about the way in which he was able to understand his model and assess it against reality. In this section we describe how Johansen used the T matrix and some of the things he found out.

The T matrix shows the sensitivity (usually an elasticity) of every endogenous variable with respect to every exogenous variable. Johansen regarded the 3,956 entries in the T matrix as his basic set of results and he looked at every one of them. How could he cope with this volume of results? As many current CGE modellers find, it is easy to become overwhelmed and confused when confronted with a huge number of results. Johansen's management strategy was to use a one-sector back-of-the-envelope (BOTE) model as a guide. He set this up in chapter 2. The BOTE told him what to look for and what to expect in his full-scale model for the effects of exogenous changes in aggregate capital, aggregate employment, the number of households, technologies, exogenous demands and the price of non-competitive imports. The effective use of BOTE models to organize, understand and explain results is a skilful art: the BOTE model must strike a balance between being readily accessible and being descriptive of the main model. Johansen was the first master BOTE builder (a well known Norwegian specialty) in CGE modelling. Perhaps because of the degree of difficulty, he has not had many peers in this area.

Johansen's examination of the T matrix starts with a discussion of the elasticities of industry prices and outputs with respect to aggregate capital (K) and employment (N): entries in the price and output rows of the k and n columns. On the basis of the BOTE model, he explained why the full model shows negative entries in the price rows of the k-column and positive entries in the price rows of the n-column. An increase in K raises the marginal product of labour requiring an increase in the real wage rate. With the overall nominal wage rate set exogenously, this must be brought about by a decrease in the price level. An increase in N lowers the marginal product of labour requiring an decrease in the real wage rate, brought about by an increase in the price level.

For the output rows, Johansen's BOTE model suggests that the entries in the k- and n-columns should lie in the (0,1) interval: this follows from a macro version of equation (2.3)[5]. With one exception, this expectation is fulfilled: the T matrix shows a negative entry for the elasticity of equipment output with respect to an increase in aggregate employment. Following up and explaining exceptions is an important part of the BOTE methodology. In this way we can locate result-explaining mechanisms in the full model that are not present in the BOTE model. In other words, we can figure out what the full model knows that the BOTE model doesn't know. In the case of the equipment-output/employment elasticity, the explanation of the negative result is that an increase in aggregate employment changes the composition of the economy's capital stock in favour of structures and against equipment.[6] This morphing of the capital stock reduces maintenance demand for equipment, thereby reducing the output of the equipment industry. How does an increase in employment lead to a decrease in the equipment-intensity of the economy's capital stock? The answer is that it leads to a reallocation of the economy's capital towards housing, a highly structure-intensive form of capital. With aggregate capital fixed, there is a consequent reduction in the economy's stock of equipment capital. What explains the reallocation of the economy's capital towards housing? An increase in employment stimulates consumption of all goods including housing services. Whereas the increases in the outputs of labour-intensive consumption goods are accommodated

---

[5] That is $x = \gamma * n + \beta * k + \varepsilon$ where γ and β are parameters with values between 0 and 1.

[6] Johansen (1960, p. 120) gets this far in the explanation, then appears to go off the track. We provide the rest of the explanation.

with increased labour input and reduced capital input, increased output of housing services can be achieved only by increases in the housing stock.

One of the most interesting parts of T is the 22 by 22 sub-matrix, T(x,z), relating movements in industry outputs (x) to movements in exogenous demands (z). At the time when Johansen was writing, Leontief's input-output model, with its emphasis on input-output multipliers, was the dominant tool for quantitative multi-sectoral analysis. In Leontief's model, if an extra unit of output from industry j is required by final users, then production in j must increase by at least one unit and production in other industries will increase to provide intermediate inputs to production in j. Further rounds of this process can be visualized with suppliers to j requiring extra intermediate inputs. Thus, in Leontief's picture of the economy, industries are in a complementary relationship, with good news for any one industry spilling over to every other industry. Johansen challenged this orthodoxy. His T(x,z) sub-matrix implies diagonal derivatives ($\partial x_j/\partial z_j$) that in most cases are less than one and off-diagonal derivatives and are predominantly negative. Rather than emphasising complementary relationships between industries, Johansen emphasised competitive relationships. In Johansen's model, expansion of output in one industry drags primary factors away from other industries. Only where there are particularly strong input-output links does Johansen find that stimulation of one industry (e.g. food) benefits another industry (e.g. agriculture).

In chapter 8, Johansen used the T matrix to decompose movements in industry outputs, prices and primary factor inputs into parts attributable to observed changes in six sets of exogenous variables: aggregate employment; aggregate capital; population; Hicks-neutral primary factor technical change in each industry; exogenous demand for each commodity; and the price of non-competing imports. In making his calculations, he applied shocks to all 46 exogenous variables. These shocks represent average annual growth rates for the period around 1950. Johansen computed the effects[$\xi(j)$] on the 86 endogenous variables of movements in the j^{th} set of exogenous variables as

$$\xi(j) = T(j) * \eta(j) \quad , \ j = 1, \ldots, 6 \qquad (2.6)$$

where

$\eta(j)$ is the vector of shocks applied to the j^{th} set of exogenous variables; and

T(j) is the sub-matrix of T formed by the columns corresponding to the j^{th} set of exogenous variables.

In discussing the $\xi(j)$s, Johansen paid particular attention to the behaviour of agricultural employment. This was a contentious issue among economists in 1960. On the one hand, diminishing returns to scale suggested that relative agricultural employment would grow with population and perhaps even with income despite low expenditure elasticities for agricultural products. On the other hand, agriculture was experiencing rapid technical progress, suggesting that employment in agriculture might not only fall as a share of total employment but might even fall in absolute terms. Johansen was able to separate and quantify these conflicting forces. The $\xi(j)$s for capital, employment and population growth showed relatively strong increases in agricultural employment, consistent with diminishing returns to scale interacting with increased consumption of food. However, the dominant effect on agricultural employment was technical change. This was strongly negative, leaving agricultural with net declining employment.

Another aspect of the decomposition results that interested Johansen was the role of rapid capital accumulation. The results indicated that this was the major source of real wage growth. He worried that increases in the capital/labour ratio were reducing rates of return, raising questions about the sustainability of capital growth and therefore of real wage growth. In the 1973 addendum to his book, Johansen continued to worry about these issues and wondered whether long-run movements in rates of return can be described adequately in a model with Cobb-Douglas production functions and Hicks-neutral technical change.

Having completed his examination of the individual $\xi(j)$ vectors, Johansen compared the aggregate effects $[\sum_j \xi(j)]$ of the six sets of exogenous shocks with reality for 1948 to 1953. He assessed this validity test as follows:

> *"A first glance at the figures confirms that some general tendencies are roughly the same in the computed and in the observed figures. Some interesting differences are, however, also revealed." [Johansen 1960, p. 152]*

Johansen used these differences to pinpoint weaknesses in his model and to organize a discussion of real-world developments. For agriculture he found that the computed growth rate in output closely matched reality but that the computed growth rate in employment was too high while that in capital was too low. This led to a discussion of reasons, not accounted for in the model, for exodus of rural workers to the cities. For communication & transport and for forestry, the computed growth rates for output and primary-factor inputs were too high. In the case of communication & transport, Johansen wondered whether this reflected unsatisfied demand for these government supplied services. For forestry, Johansen thought that he may have set the income elasticity of demand for forestry products too high and also that there may have been a taste change, not included in his model, against the use of forestry products as fuel. By going through his results in this way, Johansen developed an agenda for model improvement (ch. 9).

In the 1973 addendum to his book, Johansen (1974, ch. 10) reported implementation of some of the items on this agenda. He also reported further applications of the model including a validation test in which projections for 1950 to 1963 covering output, capital, labour and prices by industry are compared with reality. However, at the theoretical level, rather little change took place in the model during the 1960s.[7] In particular the treatment of trade remained unchanged and underdeveloped. This was surprising considering that exports and imports each represented about 40 percent of Norwegian GDP. It appeared that Johansen did not have a solution to the flip-flop problem. This refers to unrealistic and unstable levels of industrial specialization. It occurs in long-run simulations with models in which import/domestic price ratios are allowed to play a role in import/domestic choice and imported and domestically produced units of commodity i are treated as perfect substitutes. It is also a problem when export prices are taken as given and long-run supply curves are flat. Johansen discussed flip-flop in the addendum in connection with the model of Taylor and Black (1974). He recognized that Taylor and Black avoided extreme flip-flop by adopting a short-run closure (fixed capital in each industry) thereby giving supply curves a positive slope. With his focus on long-run

[7] Development of the model accelerated in the late 1970s and 80s with an emphasis on capital-labour-energy-material substitution, see Longva *et al.* (1985).

tendencies, Johansen could not adopt the Taylor and Black approach. Instead he continued to treat exports and competitive imports exogenously.[8]

3. Other starting points for CGE modelling

While Johansen was the first to plant a seed in what has now become the CGE forest, it was not the only seed. Largely independently of Johansen's work, CGE modelling had several other starting points. In 1991, when Herbert Scarf was awarded a distinguished fellowship of the American Economic Association, the citation read in part:

> *"Scarf's path-breaking technique for the computation of equilibrium prices has resulted in a new subdiscipline of economics: the study of applied general equilibrium models … Scarf was the catalyst behind the creation of this subfield of the profession and in the transformation of the general equilibrium model from a purely theoretical construct to a useful tool for policy analysis." [American Economic Review, 82(4), September 1992]*

Scarf's work was published in the late 1960s and early 1970s without reference to Johansen.[9] It led to a flaring in the 1970s of interest in CGE modelling in prestigious journals, with the major contributors being Scarf's students, John Whalley and John Shoven.[10]

Another independent CGE seed was the work of Jorgenson and his associates in the 1970s focusing on energy.[11] They solved what can be clearly recognised as CGE models by iterative methods mimicking a Walrasian search for an equilibrium price vector. As with Scarf, there is nothing to suggest a debt to Johansen.

A third post-Johansen but independent CGE seed was the work of Irma Adelman, Sherman Robinson and their associates at the World Bank. This group was clearly aware of Johansen. For example, Adelman and Robinson in their 1978 book mention Johansen on page 3:

> *"We took our inspiration from the early work on price-endogenous planning models by L. Johansen. His first model (Johansen 1960) was "linearized" and solved by simple inversion for rates of change of prices and production. Our model is highly non-linear and expressed in terms of levels."*

However, this is the only mention. It is clear that their style of CGE modelling owed little to Johansen. Equations are presented and discussed in non-linear levels form; no use is made of the T-matrix of elasticities of endogenous variables with respect to exogenous variables; little emphasis is given to explaining results via a BOTE model; and no attempt is made to match structural results against observed outcomes over a time horizon of more than two years from the base period[12]. By contrast, Taylor and

---

8 This was also the approach of Hudson and Jorgenson (1974) for the U.S. Adelman and Robinson (1978) in their study of Korea set exports of some commodities exogenously and fixed the share of exports in domestic output for other commodities. For most imports, Adelman and Robinson fixed the import share in domestic demand. Taylor *et al.* (1980, ch. 7) in their study of Brazil exogenized exports and related imports to industry outputs and final demands via exogenous coefficients.

9 See Scarf (1967a & b and 1973).

10 See, for example, Shoven and Whalley (1972, 1973, 1974 and 1984).

11 See for example, Hudson and Jorgenson (1974).

12 Adelman and Robinson (1978, pp. 62-76) showed that when their model was fed base-period values for the exogenous variables then it closely reproduced base-period values for the endogenous variables. This indicates that they successfully calibrated their model but it does not test the predictive or explanatory power of the model.

his associates, also at the World Bank[13], drew more heavily on Johansen. In their 1980 book, they solved their model by a non-linear method similar to that used by Spurkland (1970) to solve later versions of Johansen's model, see section 2.1. Echoing Johansen, Taylor *et al*. emphasised the performance of their model in reproducing industry growth rates for an historical period (1959-71) and set out a linear-percentage-change BOTE model to assist in the explanation of results.

What became of these seedlings?

Scarf did not make a contribution to the economic content of CGE modelling, he provided a solution algorithm. His technique was never the most effective method of solving CGE models. Even those CGE modellers who embraced Scarf's method in the 1970s had by the 1980s largely abandoned it in favour of much simpler methods.

Jorgenson and his associates continue to make path-breaking contributions to the economic content of CGE modelling. Reflecting Jorgenson's research over many decades, they have introduced theoretical and econometric innovations in the specification in CGE models of production, investment and consumption. Hudson and Jorgenson (1974) were the first to include in a CGE model flexible functional forms for production (econometrically estimated translog functions). Jorgenson and Yun (1986a & b) embedded Jorgenson's well known theory of investment (Jorgenson 1963) into a CGE study of U.S. tax policy. The models of Jorgenson and Wilcoxen (1993) and Ho and Jorgenson (1994) included econometrically estimated consumer demand functions based on Jorgenson, Lau and Stocker's (1980, 1981 & 1982) work on exact aggregation. A model incorporating many of Jorgenson's innovations is described in Goettle *et al.* (2007).

The World Bank seedling, particularly through the efforts of Sherman Robinson, has grown and spread. Johansen's own seedling has also grown and spread, but not as we will see directly from Norway: it grew first in Australia and then spread to the rest of the world from there. In both cases special purpose software played a key role: GAMS for the World Bank and GEMPACK for the Johansen-style models from Australia.

GAMS was developed starting in the mid-1970s by Alex Meeraus and Jan Bisschop working at the World Bank. Its focus was the solution of large-scale, non-linear optimization problems.[14] The adaption of GAMS to CGE modelling took place at the World Bank in the mid-1980s. The first GAMS-based CGE model was by Condon *et al.* (1987).

GEMPACK was developed starting about 1980 by Ken Pearson, specifically to solve Johansen-style models. The first version of GEMPACK was used for teaching in 1984, and shortly after that was adopted by Australian CGE modellers. The first GEMPACK manuals were published in 1986 (see Codsi and Pearson, 1986). Early journal descriptions of GEMPACK are Pearson (1988) and Codsi and Pearson (1988).

---

[13] The 1970s must have been a controversial time for CGE modelling at the Bank. As mentioned by Jack Duloy in his introduction to their 1980 book, Taylor *et al.* reached conclusions on the role of public policy in influencing income distribution that were sharply at odds with those of Adelman and Robinson (1978).

[14] The early history of GAMS is described in Kallrath (2004, pp. 20-21). The first published technical descriptions of GAMS appeared in Bisschop and Meeraus (1982) and Meeraus (1983).

Both GAMS and GEMPACK allowed economists to specify their models in the computer in a form that is close to ordinary algebra and then call upon standard equation solvers to produce solutions. From the point of view of economists wishing to enter the CGE field, GAMS and GEMPACK dramatically reduced the required level of knowledge of numerical methods and computing, and also reduced the time required in writing and checking computer programs. Both software systems facilitated communication by allowing models to be transferred conveniently between users and between sites.

4. Johansen in Australia

Johansen's approach to CGE modelling was not pursued outside Norway in a sustained way for well over a decade after the publication of his seminal work in 1960.[15] There were some important one-off flurries using his technique in the mid-1970s (see for example, Taylor and Black, 1974, Staelin, 1976, Bergman, 1978 and Keller, 1980), but the place where Johansen-style modelling really took root outside Norway was Australia.

In 1975, the Australian Government set up the IMPACT Project under the direction of Alan A. Powell, who was at that time Australia's foremost applied econometrician. The task set for IMPACT was to build a modular policy framework embracing the macro economy, demography and industries. Powell hired Peter Dixon to build the industry module with an emphasis on quantifying the effects of trade policy.

4.1. Armington, Leontief and the ORANI model

Dixon brought two influences to this assignment: Armington[16] and Leontief[17]. Armington (1969 & 1970) had built a 15-country trade model in which each country produced just one good but consumed all 15 goods, treating the goods from different countries as imperfect substitutes. He specified and solved his model as a linear system in percentage changes of the variables. Armington's imperfect substitution specification was an effective way of overcoming the flip-flop problem that had beset earlier trade models. However, Armington's model lacked an industry dimension. To create a industry model with a satisfactory treatment of trade, Dixon integrated Armington's specification with Leontief's input-output model. The result was the ORANI model (Dixon *et al.* 1977 &1982).

---

[15] Bergman (1985, p.142) offers three possible explanations: lack of interest in structural issues in the 1960s, a period of stable economic growth; computational difficulties; and focus by modellers on linear programming techniques. By the mid-1970s the time was right for the growth of CGE modelling: the oil crises had moved structural issues to centre stage; computational difficulties had eased; and the short-comings of linear programming techniques were being recognised. Dixon (2008) argues that it took until the 1970s for it to be widely recognised that the theoretical underpinnings of economy-wide time-series econometric models (popular in the 1960s) were insufficient to allow them to generate useful insights on the likely effects of unprecedented events.

[16] Dixon overlapped with Armington at the IMF in 1973-4. While at the IMF, Dixon studied MERM (the IMF's Multilateral Exchange Rate Model, Artus and Rhomberg, 1973) which was based on Armington's work and was important in negotiations following the breakdown of the Bretton Woods arrangements in 1971-2. His paper assessing and explaining MERM was eventually published as Dixon (1976).

[17] Dixon's 1972 thesis (Dixon, 1975) was supervised by Leontief at the Harvard Economic Research Project. At the Project Dixon studied, among other things, the path-breaking 1968 thesis on Australian protectionism by H. David Evans (Evans, 1972), also a student of Leontief. From this thesis Dixon became aware of the difficulties in modelling trade issues in a purely input-output/linear-programming framework, see Dixon and Butlin (1977).

The Armington elasticities[18] in ORANI were econometrically estimated for about 50 commodities by Alaouze *et al.* (1977) and Alaouze (1977) using a quarterly database assembled for this purpose on import and domestic prices and quantities for the period 1968(2) to 1975(2). This work is summarized in Dixon *et al.* (1982, pp. 181-9). With its Armington specification, the ORANI model avoided flip-flop on the import side and produced results in which imports responded in a realistic manner to changes in the relative prices of imported and domestic goods. This was critical for a model concerned with quantifying the effects of trade policy. Following ORANI, the Armington specification has been adopted almost universally in CGE models, although there is some dissatisfaction with this approach.[19] On the export side, ORANI avoided flip-flop by the introduction of downward-sloping export demand curves (see Dixon *et al.* 1982, pp. 195-6).

ORANI not only introduced the Armington specification to CGE modelling[20], but also contained a number of other innovations including: flexible closures; multi-product industries and multi-industry products; CRESH substitution possibilities between primary factors in all industries; CRETH[21] transformation possibilities between products in farm industries; specification of technical change and indirect taxes associated with every input-output flow; explicit modelling of transport, wholesale and retail margins; and a regional dimension. The model was implemented at the 100-industry level, well beyond anything that had been attempted in CGE modelling up to that time. The model contained about 600 thousand equations and about 1.2 million variables and was solved without linearization errors.

What made the implementation of all this possible was the adoption and extension of Johansen strategies for computing and for organizing and understanding results. In their overview of the IMPACT Project's first ten years of operation, Powell and Lawson (1990, pp. 265-6) identify the decision to use Johansen strategies as a key ingredient in the Project's success.

4.2. Coping with large dimensions in the Johansen computational framework

ORANI was presented in the same way as Johansen's model. However, the dimensions of the B matrix in (2.1) were far too large to allow direct solution via (2.5). This dimensionality problem was overcome by a process of condensation in which high dimensional variables were substituted out of the computational form of

---

18 In a one-country model such as ORANI, Armington elasticities are substitution elasticities between domestically produced and imported varieties of the same commodity. These elasticities were referred to as "Armington" elasticities in Dixon *et al.* (1982).

19 In multi-country models, the Armington specification with domestic/import elasticity values in the empirically relevant range (say 2 to 10) leads to negative terms-of-trade effects that outweigh efficiency gains for countries undertaking unilateral tariff cuts even from quite high levels (e.g. 30 per cent), see Brown (1987). This is worrying to people who believe that low tariffs are always better than high tariffs. For a discussion of the relevant issues see Dixon and Rimmer (2010b). While no alternative to Armington for practical CGE modelling has emerged, incorporation of ideas from Melitz (2003) seems promising, see Fan (2008). The Melitz specification introduces productivity differences between firms within industries. Efficiency effects of tariff cuts are increased by allowing for elimination of low-productivity firms. However, potentially large terms-of-trade effects remain.

20 Petri (1976) and Baker (1976) used Armington specifications in input-output frameworks. Both introduced an inconsistency by employing input-output commodity balance equations of the form X= AX +Y-M (implying perfect import/domestic substitutability) despite their assumption that imports and domestic supplies are not perfect substitutes.

21 CRESH production functions were introduced as a generalization of CES by Hannoch (1971). CRETH is the analogous generalization of CET transformation functions and was introduced by Vincent *et al.* (1980).

the model. For example, consider the variable x(i,s,j,k,m) which represents the percentage change in the use of margin commodity m (e.g. road transport) to facilitate the flow of commodity i from source s (domestic or imported) to industry j for purpose k (current production or capital creation). In a model with 100 commodities/industries and 10 margin commodities this variable has 400,000 components. These were explained in ORANI by 400,000 Johansen-style linear percentage change equations:

$$x(i,s,j,k,m) = x(i,s,j,k) + a(i,s,j,k,m) \tag{4.1}$$

where

x(i,s,j,k) is the percentage change in flow (i,s,j,k); and

a(i,s,j,k,m) is the percentage change in the use of margin m per unit of flow (i,s,j,k). In many ORANI simulations variables such as a(i,s,j,k,m) were interpreted as changes in technology.

To reduce the computational dimensions of ORANI, equation (4.1) was used to substitute out x(i,s,j,k,m): that is (4.1) was deleted and x(i,s,j,k,m) was replaced by the righthand side of (4.1) wherever it appeared in the rest of the model. By this process, the dimensions of the matrix to be inverted in (2.5) were reduced to a manageable size: about 200 by 200 in the 1977 version of ORANI and about 400 by 400 in the 1982 version.[22]

While variables and equations disappear from a model during condensation, no information is lost. Results for eliminated variables can be recovered by backsolving using the eliminated equations. One implication of this is that eliminated variables are necessarily endogenous.

Through condensation in a Johansen linear framework, problems of dimensionality were largely removed. This gave two advantages. First, the full dimensionality of available input-output tables could be used. Second, computational-theoretical compromises were reduced. For example, in ORANI there was no inhibition on computational grounds about including a high dimensional equation such as (4.1) if this was considered the theoretically appropriate specification.

4.3. Flexible closures in the Johansen framework

Johansen used just one closure. On the supply side, he exogenized aggregate employment, aggregate capital and technology thereby largely determining GDP. On the demand side he linked replacement investment to capital stocks and exogenized aggregate expansion investment, net exports and government consumption, while leaving aggregate consumption to be determined endogenously as a residual in the equation GDP = C + I + G +(X - M).

Johansen's framework was readily extended to encompass closure flexibility. This was done in ORANI by leaving the allocation of variables between ξ (endogenous) and η (exogenous) in Johansen's equation (2.1) as a user choice. This imparted an important degree of flexibility.

If, for example, the focus was on the short-run effects of a tariff cut, then capital in each industry was treated exogenously, unaffected in the short-run. At the

[22] The condensations of the two versions are described in Sutton (1976) and Dixon *et al.* (1982, pp.207-29).

same time, rates of return were treated endogenously, with the model typically showing reductions in rates of return for import-competing industries and increases for export industries. Simulations conducted under this closure were thought to reveal effects of the tariff cut that would emerge after about two years.[23] If a long-run focus were required, then the closure was reversed. It was assumed that deviations in rates of return from levels reflecting interest rates and perceptions of risk (factors determined independently of tariff cuts) would be temporary. Thus in long-run simulations, rates of return were exogenous while capital stocks adjusted endogenously to allow rates of return to be maintained at their initial levels. Typically the model showed long-run decreases in capital stocks in import-competing industries and increases in export industries. Other pairs of variables that were often swapped between the endogenous and exogenous categories were: the average real wage rate and aggregate employment; the balance of trade and either public or private consumption; export volumes and export subsidies; and the exchange rate and the rate of inflation.

An early ORANI study that took advantage of closure flexibility was that by Dixon *et al.* (1979). This was commissioned by the Crawford Group, set up by the Australian Government in 1977 to report on macro and industry policies to achieve a broad-based industry and regional recovery from what was then a deeply recessed situation. To widen the appeal of the ORANI results and defuse criticism, simulations were conducted under two closures. In both closures real wages were treated exogenously, reflecting their determination in what was at the time a legalistic, centralized system that could produce outcomes with little resemblance to those that would be expected from market forces. The closures differed with respect to capital utilization and exports.

In what was referred to as a neoclassical closure, capital used in each industry was set exogenously to fully employ the capital available to the industry. Rental rates adjusted endogenously to ensure compatibility between demand for capital and the exogenously given levels of capital usage. Exports in the neoclassical closure were determined by the interaction of production costs in Australia and price-elastic foreign demands.

In what was referred to as a neo-Keynesian closure[24], the rental rate on capital was treated as a profit mark-up and linked exogenously in each industry to variable costs per unit of production. Capital in use was treated endogenously. Exports were assumed rigid and to make this computationally possible, a phantom export subsidy was endogenized for each commodity.

Despite these seemingly radical differences in closure, the policy implications of the two sets of simulations were the same: a combination of reduction in the real costs of employing labour and an expansion in demand offered the best prospect for a broad-based recovery.[25] Real cost reduction would stimulate trade-exposed industries

[23] This was worked out by Cooper and McLaren (1983) who compared ORANI comparative-static short-run results with those produced by a continuous-time macro model. See also Breece *et al.* (1984) and Dixon (1987).

[24] The terms neoclassical and neo-Keynesian have been used by a number of authors, but never in quite the same way. For a discussion of closure possibilities in early CGE models with associated nomenclature see Rattso (1982) and Robinson (2006).

[25] ORANI was used to find the increase in aggregate demand and the reduction in real wage rates that would produce a 5 per cent increase in employment with no deterioration in the balance of trade. In ORANI, a given percentage increase in demand in the neoclassical (neo-Keynesian) closure produced

and regions while demand expansion would stimulate the rest of the economy. Naturally, the question arose as to what policies could reduce labour costs in an acceptable way while expanding demand. One answer, illustrated by ORANI simulations in Corden and Dixon (1980), was a wage-tax bargain under which workers forego wage increases in return for tax cuts or improvements in social capital. Such bargains were an important part of Australian economic policy in the 1980s.

In the 1990s, the idea of flexible closures was extended in the MONASH model of Australia, the dynamic successor of ORANI (Dixon and Rimmer, 2002). In MONASH and subsequent Johansen-style dynamic models[26] created by the Centre of Policy Studies (the successor organization to IMPACT) there are four basic closures:

- the *historical* closure in which the exogenous variables are chosen so that historical observations on movements in consumption, investment, government spending, exports, imports, employment, capital stocks and many other variables can be introduced to the model as shocks. Computations with this closure produce detailed estimates of movements in technology and preference variables and also generate up-to-date input-output tables that incorporate available statistics for years since the last published input-output table. For example, historical simulations can be used to generate input-output tables for Australia for 2009 incorporating data for years beyond 2006, the year of Australia's latest detailed input-output table.
- the *decomposition* closure in which technology and preference variables are exogenous so that they can be shocked with the movements estimated for them in an historical simulation. Computations with this closure can be used to identify the roles in the growth of industry outputs and other naturally endogenous variables of changes in technology, changes in preferences, and changes in other naturally exogenous variables.[27] Decomposition simulations are valuable in policy work because they counteract exaggerated claims about the importance of policy changes in determining outcomes for industries. For example, representatives of Australia's motor vehicle industry may claim that cuts in tariffs explain their industry's rather poor growth performance over an historical period and that further cuts would be disastrous. A decomposition simulation can show the role of tariff cuts in the past and allow it to be compared with the roles of changes in other relevant variables such as c.i.f. import prices, technologies and consumer tastes.

---

a weak (strong) increase in employment and a strong (weak) deterioration in the trade balance. A given percentage decrease in the real wage rate in the neoclassical (neo-Keynesian) closure produced a strong (weak) increase in employment and a strong (weak) improvement in the trade balance. Thinking of the policies as being introduced in a sequence, a given increase in demand under the neoclassical (neo-Keynesian) closure does little (a lot) towards achieving the employment target and leaves the trade balance strongly (weakly) deteriorated. To complete the movement to a 5 per cent employment increase and to rectify the damage to the trade balance requires similar wage reductions under the two closures: under the neoclassical (neo-Keynesian) closure the wage reduction has a lot of (a little) work to do but is a strong (weak) instrument with respect to both targets.

[26] Some of these models are described in section 5.

[27] MONASH decomposition analysis is similar to Johansen's decomposition analysis described in section 2.2, equation (2.6). However, MONASH simulations produce a complete decomposition of historical movements in outputs, prices, etc., that is, a decomposition without a gap between computed and actual movements (see Dixon *et al.*, 2000 and Harrison *et al.*, 2000). Unlike Johansen's decomposition, a MONASH decomposition does not provide a validity check. Validation is discussed in section 6.

- the *forecast* closure which is used in simulations designed to produce a believable business-as-usual or basecase picture of the future evolution of the economy. The underlying philosophy of this closure is quite similar to that of the historical closure. In both closures, we exogenize variables for which we have information, with no regard to causation. Rather than exogenizing variables for which we have historical observations, in the forecast closure we exogenize variables for which we have forecasts. This might include macro variables, exports by commodity and demographic variables for which forecasts are provided by official organizations. Technological and preference variables in forecast closures are largely exogenous and are given shocks that are informed by trends derived from historical simulations.
- the *policy* closure which is used in simulations designed to quantify the effects of changes in policies or other exogenous shocks to the economy. The underlying philosophy of this closure is quite similar to that of the decomposition closure. In both policy and decomposition closures, we are concerned with causation, with how tariff changes, for example, cause changes in the real exchange rate and thereby cause changes in employment and so on. Thus in policy closures, as in decomposition closures, naturally exogenous variables are exogenous and naturally endogenous variables are endogenous. In policy simulations, nearly all of the exogenous variables adopt the values that they had, either endogenously or exogenously, in the forecast simulation. The only exceptions are the policy variables of focus. For example, if we are interested in the effects of a tariff change, then the relevant tariff variable is moved away from its basecase forecast path. The effects of the tariff change on macro variables, exports by commodity and other endogenous variables are calculated by comparing their paths in the policy simulation with their paths in the forecast simulation. Policy simulations conducted in this way give policy effects as deviations away from realistic pictures of the economy of the future. By contrast, policy simulations conducted in comparative static models or models without realistic basecase forecasts generate policy results as deviations from the economy of the present or past. This can be misleading. The effects of policies imposed on economies with structures likely to be relevant in the future are often different from the effects of these policies imposed on economies with the structures of the present or past.

In their analysis of the Australian motor vehicle industry, Dixon and Rimmer (2002, ch. 2), show how simulations run under each of the four closures can contribute to a single policy study. They used an historical simulation to trace out the technological performance of the industry and to quantify shifts in consumer preferences towards imported cars. They used a decomposition simulation to quantify the damage to the industry caused by preference shifts and compared this with damage caused by tariff cuts. They used a forecast simulation to assess prospects for the industry and a policy simulation to estimate how these prospects would be affected by proposed further tariff cuts.

4.4. Complex functional forms in the Johansen framework

Early CGE modellers outside the Johansen school worried that the use of the Johansen linear percentage-change format was limiting with respect to model specification. For example, Dervis *et al.* (1982, p. 137) comment that:

"Johansen linearized the general equilibrium model (in logarithms) and so was able to solve it by simple matrix inversion … Since then there have been advances in solution methods that permit CGE models to be solved directly for the levels of all endogenous variables and so permit model specifications that cannot easily be put into log-linear forms."

Far from being limiting, the Johansen framework simplified the introduction into CGE modelling of the advanced functional forms that were being developed in this period. For example, consider the CRESH cost minimizing problem:

choose X_i, i = 1, …, n

to minimize $\sum_{i=1}^{n} P_i * X_i$ (4.2)

subject to $\sum_{i=1}^{n} \left(\frac{X_i}{Z}\right)^{h_i} * \frac{Q_i}{h_i} = \alpha$ (4.3)

where

Z is output;

the P_is and X_is are input prices and quantities; and

the Q_is, h_is and α are parameters with the Q_is being positive and summing to one and the h_is being less than one but not precisely zero.

On the basis of problem (4.2) - (4.3) it is difficult to obtain an intuitive understanding of the input-demand functions: they have no closed form levels representation. Given values for the h_is, values for the Q_is and α can be determined on the basis of input-output data, but this is technically awkward. By contrast, the Johansen-style percentage change representation of the input-demand functions is readily interpretable and easily calibrated:

$x_i = z - \sigma_i * (p_i - p)$, i = 1, …, n (4.4)

where

x_i, z and p_i are percentage changes in the variables represented by the corresponding uppercase symbols;

σ_i is a positive substitution parameter defined by $\sigma_i = 1/(1-h_i)$; and

p is a weighted average of the percentage changes in all input prices defined by

$$p = \sum_{k=1}^{n} S_k^{\#} * p_k \quad . \tag{4.5}$$

The weights $S_k^{\#}$ are modified cost shares of the form

$$S_k^{\#} = \frac{S_k * \sigma_k}{\sum_{i=1}^{n} S_i * \sigma_i} \quad . \tag{4.6}$$

where S_k is the share of k in costs.

The interpretation of (4.4) is straightforward. Reflecting constant returns to scale, it implies that a 1 per cent increase in output, holding input prices constant, causes a one percent increase in demand for all inputs. An increase in the price of i relative to the average price of all inputs causes substitution away from i and towards other inputs. The sensitivity of demand for i with respect to its relative price is controlled by the parameter σ_i. If this parameter has the same value for all i, then (4.4) takes the familiar CES form. However, if we wish to introduce differences between inputs in their price sensitivity then this can be done by adopting different values for the σ_is. Once values have been assigned for the σ_is, calibration can be completed on the basis of cost shares (S_k) from the input-output data.

More generally, all differentiable input demand functions and output supply functions can be represented in a Johansen format.[28] Usually the Johansen representation is more transparent than the levels representation.[29] Perhaps reflecting this, rapid progress was made in the adoption of sophisticated functional forms in the ORANI model.

4.5. Computing solutions without linearization errors in the Johansen framework

Johansen's T-matrix gives exact values for the derivatives or elasticities of endogenous variables with respect to exogenous variables evaluated at the initial solution of the model, that is the solution reflected in the initial database. However, as mentioned in section 2.1, when the effects on endogenous variables of finite changes in exogenous variables are evaluated in (2.5), the results are subject to linearization error. This is because the computation does not take into account changes in the derivatives or elasticities as we move a way from the initial values of the variables.

The nature of the linearization errors is easily understood through an example:

$$x_i = \sum_{j=1}^{n} B_{i,j} * x_{i,j} \quad . \tag{4.7}$$

This is a typical Johansen-style equation. It equates the percentage change in the total demand for good i to a weighted average of the percentage changes in demands, $x_{i,j}$, by each of the agents j (e.g. industries, households, etc). The weights are sales shares: $B_{i,j}$ is the share of the total sales of i that is absorbed by j. In the Johansen presentation in (2.1), x_i and the $x_{i,j}$s are variables (part of the ξ and η vectors) and the $B_{i,j}$s are coefficients and enter the B or L matrices. The linearization errors arise because in computation (2.5), the $B_{i,j}$s are treated as constants: changes in sales shares caused by, for example, growth in demand by agent 1 relative to that by agent 2 are ignored. Similarly, changes in cost shares in equations such as (4.5) are ignored.

A conceptually simple way to avoid linearization errors while retaining the simplicity and interpretability of the Johansen method is to allow sales and cost shares to move. If we are concerned with the effects of a 50 per cent increase in tariffs, then linearization errors can be reduced by applying a 2-step procedure. First we use (2.5) to compute the effects of a 25 per cent increase. This computation shows movements

[28] In its initial formulation, the Johansen approach was not suitable for models in which complementarity conditions and other non-differentiabilities are important. However, in practical CGE models of the 1970s and 80s, non-differentiabilities were not important. Since then Harrison *et al.* (2004) have shown how complementarity conditions can be handled in a Johansen framework by closure changes (switches between exogenous and endogenous states of complementary pairs of variables) within a multi-step Johansen solution.

[29] Dixon *et al.* (1992, pp. 124-148) give derivations of Johansen-style demand and supply equations for a variety of optimizing problems based on CES, CET, Translog, CRESH and CRETH functions.

in prices and quantities away from their initial levels and allows us to evaluate sales and cost shares in the new situation with the 25 per cent tariff increase in place, leading to a new T-matrix giving updated derivatives and elasticities. Using this new T-matrix, we can calculate the effects of another 25 per cent increase in tariffs. The total effects of a 50 per cent increase can then be evaluated from the results from the two 25 per cent increases. Further accuracy can be obtained by increasing the number of steps, that is dividing the 50 per cent increase into a greater number of parts.

Dixon *et al.* (1982, ch. 5) set out the formal mathematics of the multi-step Johansen procedure and demonstrated that as the number of steps approaches infinity, linearization errors approach zero. This would not be of practical significance if a large number of steps were required to generate acceptably accurate solutions or if computing new T-matrices were difficult. Fortunately, it was found that a small number of steps supplemented by a simple extrapolation is usually adequate and that updating the T-matrix is elementary.

With the ORANI model, as few as two steps was typically required. This was also the experience of Bovenberg and Keller (1984) for Keller's (1980) model of tax incidence in the Netherlands. Figure 1 gives some insight into why accurate solutions can be generated in few steps. The figure illustrates the multi-step Johansen procedure for a two-variable one-equation model in which the true relationship between the endogenous variable V_1 and the exogenous variable V_2 is given by

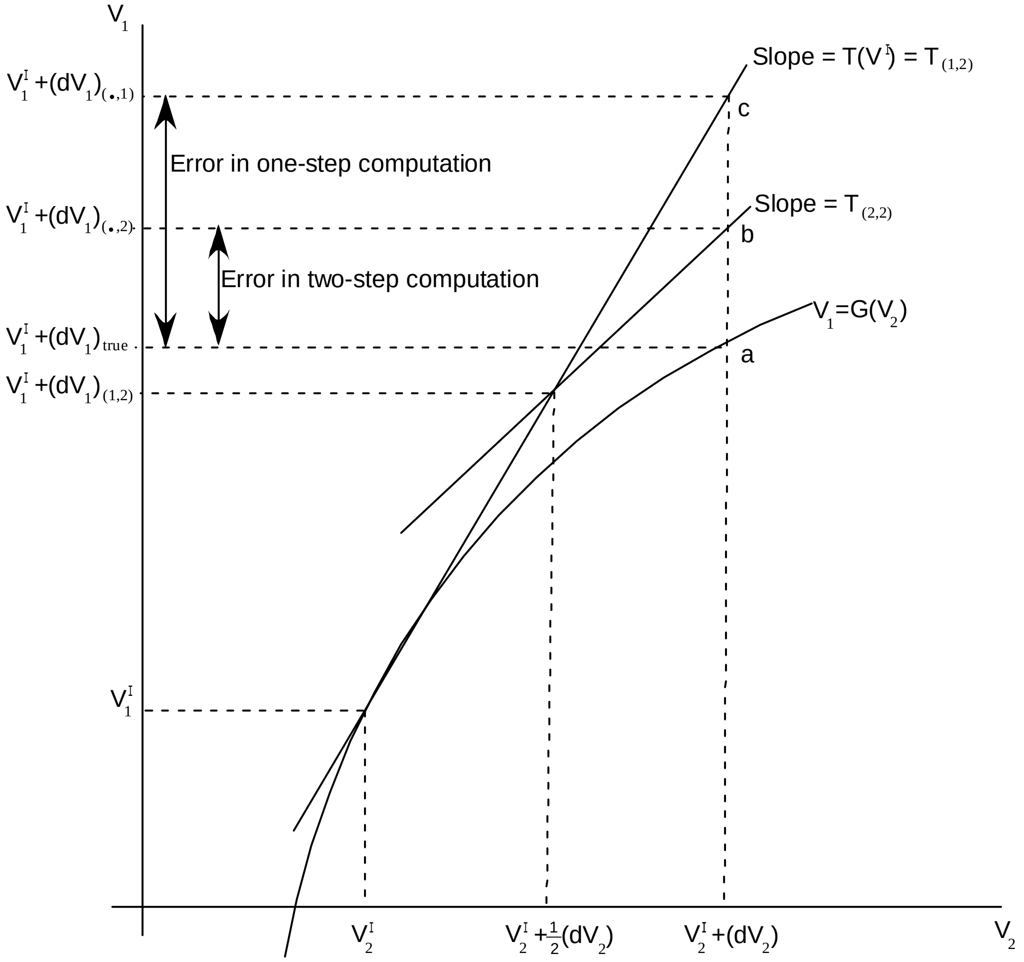
$$V_1 = G\left(V_2\right) \ , \tag{4.8}$$

and the initial solution is at (V_1^I, V_2^I). In the figure, the subscripts (.,1) and (.,2) indicate the situations at the end of 1-step and 2-step computations, while (1,2) indicates the situation after one step in a 2-step computation. In a Johansen computation (1-step), the movement of V_2 from V_2^I to $V_2^I + d\left(V_2\right)$ generates a new solution at c, implying an increase in V_1 of $d(V_1)_{(\cdot,1)}$. The linearization error is ca, that is $d(V_1)_{(\cdot,1)} - d(V_1)_{true}$. In a 2-step computation, the linearization error is ba, that is $d(V_1)_{(\cdot,2)} - d(V_1)_{true}$. This 2-step error still looks substantial. However, as can be seen from the figure, it is approximately half the 1-step error. The rule that doubling the steps halves the error was found to apply generally in ORANI computations and also in Bovenberg and Keller's computations for Keller's tax model. As explained in Dixon *et al.* (1982, pp. 206-7), the rule applies almost exactly if the G function in (4.8) is quadratic. While the form of the G-functions in detailed CGE model cannot be known explicitly, it appears that they are well approximated as quadratics for most CGE models. By exploiting the doubling-halving rule, we can deduce a highly accurate solution on the basis of 1-step and 2-step solutions from the extrapolation formula

$$d(V_1)_{1,2,extrap} = d(V_1)_{(.,2)} - \left[d(V_1)_{(.,1)} - d(V_1)_{(.,2)} \right] \ . \tag{4.9}$$

This formula turns out to be the simplest example of a Richardson extrapolation (see for example, Dahlquist *et al.* 1974, p. 270). More elaborate versions can be used to deduce accurate solutions from results from low-step computations even if G is highly non-linear. For example, if G is cubic, then a Richardson extrapolation using results from three low-step computations (e.g. 1-step, 2-step and 4-step) will produce close to exact solutions.

Figure 1. Effects on V_1 of moving V_2 computed via 1- and 2-step Johansen procedures



While the number of steps is not a problem there is still the issue of updating the derivatives, that is forming a new T-matrix at each step. This is largely a matter of updating the model's social accounting matrix according to the formula:

$$FLOW\left(n,j\right)_q = FLOW\left(n,j\right)_{q-1} * \left(1 + 0.01 * x(n,j)_q + 0.01 * p(n,j)_q\right), \; q=1,\ldots,N-1. \qquad (4.10)$$

where

$FLOW(n,j)_{q-1}$ is the value in the $(n,j)^{th}$ component of the social accounting matrix in the data input to the q^{th} step [$FLOW(n,j)_0$ is the data matrix];

$x(n,j)_q$ and $p(n,j)_q$ are the percentage changes in the q^{th} step in the quantity and price that underlie the flow; and

N is the number of steps.

Implementing (4.10) is computationally trivial. The T-matrix for the q^{th} step is then formed by repeating the procedures (e.g. calculations of cost and sales shares) that produced the initial T-matrix but applying them to the social accounting matrix composed of $FLOW(n,j)_{q-1}$ for all n and j.

In the mid-1980s, the multi-step Johansen computational method, pioneered in the ORANI model, was made available to the CGE community through the GEMPACK software (described in section 3). Since then, Ken Pearson, George Codsi, Mark Horridge, Jill Harrison and Michael Jerie have developed an ever-increasing set of wonderfully useful GEMPACK features for facilitating Johansen-style modelling. For example, AnalyseGE allows GEMPACK users to see the value of any coefficient (that is, any function of database items) or any variable in a particular solution via point-and-click applied to the algebraic representation of the model. ViewSOL allows GEMPACK users to see a series of simulation results in a variety of styles (e.g. year-on-year growth, cumulative growth from an initial year or cumulative difference between two series of results) and a variety of formats (graphs or numbers). These aids greatly enhance the user's ability to undertake Johansen-style modelling: that is to use the linear representation of a model to clarify its properties; to elucidate real world issues; and to check model validity.

Honouring the intellectual ancestry of the GEMPACK computational approach, users of the software see a photograph of Johansen and are given the opportunity to read some biographical material.

4.6. Realizing the Johansen potential

The previous four subsections show how Johansen gave us the potential for creating and solving high-dimensional, flexible CGE models incorporating advanced functional forms, and how this potential was realized in Australia's ORANI model. However, there is considerable doubt amongst economists about the value of large-scale CGE models. As Rauscher (1999, p. F799) put it:

> *"To many economists, computable general equilibrium (CGE) models are a bit dubious. They are huge, they are complex, and they appear to be large black boxes that produce results that cannot be traced to an accessibly small set of simple assumptions or axioms."*

Perhaps reflecting sensitivity to the black-box criticism, some CGE modelers adopt a small-is-beautiful strategy and build a series of small models each focusing on a particular aspect of economic behaviour. Thus, it is reasonable to ask whether realizing Johansen's potential, as interpreted in Australia, was worthwhile.

The most convincing way to answer this question is to look at ORANI applications. Within 10 years of the first account of ORANI, there were 202 published applications. These covered a wide range of topics and were undertaken by or for many different organizations. Powell and Lawson (1990) list these publications in a matrix form, see Table 1.[30] The rows show topics: protection; exchange rate policy; terms-of-trade shocks; other aspects of international trade; supply shocks including mineral discoveries, technical change and drought; macroeconomic policy; employment and wage issues; immigration; indirect taxes and other government fiscal policies; and studies focusing on a particular industries. The columns show the organizations: the IMPACT Project where ORANI was built; the Industries

[30] An earlier matrix listing of ORANI applications is in Parmenter and Meagher (1985).

Table 1. Published applications of the ORANI model: 1977-1987 [*]

	IMPACT	IAC	Other federal agencies	State & regional authorities	Academics	Private sector	Total
Protection	16	6	3	10	8	4	47
Exchange rates	5	1	0	1	1	2	10
Terms of trade	3	2	0	0	1	2	8
Other international	1	1	1	0	2	1	6
Supply shocks	8	1	2	6	1	3	21
Macro policy	3	3	0	1	5	1	13
Employment, wages	4	0	0	2	4	1	11
Immigration	0	0	1	0	3	0	4
Taxes, fiscal policy	5	3	1	8	11	1	29
Specific industries	7	21	8	8	5	4	53
Total	52	38	16	36	41	19	202

[*] Citations for each application counted in this table are in Powell and Lawson (1990).

Assistance Commission (a Federal government agency); other Federal government agencies; State government agencies; Academics; and Private sector organizations. Of the 202 applications, two thirds were conducted by people who were not involved with the construction of the ORANI model.

Why did the Johansen-style ORANI model achieve such broad-based acceptance and application? It is impossible to give precise reasons but two factors were certainly important. The first was a favourable policy and institutional environment. The second was the model's Johansen formulation which gave it: (a) the capacity to carry credibility-enhancing detail; (b) flexibility in application; (c) transferability; and (d) interpretability.

Favourable policy and institutional environment

This factor is independent of ORANI's Johansen lineage and has been discussed fully in Powell and Snape (1993) and Dixon (2008), so here we can be brief. Since the 1920s, Australia's manufacturing industries had been heavily protected by tariffs and import quotas. By the 1960s, the protectionist consensus was being challenged by leading economists such as Max Corden (see for example Corden 1958). By the 1970s, there was demand from policy institutions, particularly the Industries Assistance Commission, for a quantitative tool for analysing protection. Thus the time was right for a model such as ORANI that emphasised inter-industry resource reallocation in response to changes in relative prices. Under the leadership of an inspired public servant, Alf Rattigan, the Commission set up the IMPACT Project. The arrangements for the Project maximized the probability of a successful outcome: the appointment of an outstanding academic leader (Alan Powell) as director coupled with an open environment at arms length from the policy making bureaucracy.

Credibility-enhancing detail

Practical policy makers and politicians want to see detail. They want to see results for identifiable industries (e.g. motor vehicle parts), not vague aggregates (e.g. manufacturing). They want results for regions, not just the nation. Consequently, ORANI was designed from its outset to encompass considerable detail. The first version had 113 industries (Dixon *et al.* 1977). Within a few months the model was endowed with a facility for generating results for Australia's 8 states/territories (Dixon *et al.*1978a).[31] Later this facility was extended to 56 sub-state regions, Fallon (1982). The imperative of providing results that were persuasive in policy circles meant that ORANI was equipped not only with industry and regional detail but also with detail in other areas that were normally ignored by academics. For example, from its outset ORANI had a detailed specification of margin costs (road transport, rail transport, air transport, water transport, wholesale trade and retail trade). Recognition of margin costs is important in translating the effects of tariff changes (that impact basic prices) into implications for purchasers prices (that influence demand responses). Attention to such details was important in providing results that could be believed by policy makers.

Detail expands dimensionality. As explained in section 4.2, with the adoption of Johansen computing strategies huge dimensions can be handled.

Flexibility in application

Carefully worked out and empirically supported detail not only increases credibility in policy circles, but it also increases a model's flexibility in application by providing appropriate variables to be shocked. Many of the early ORANI applications involved shocks to variables that are available only in a highly disaggregated model, for example, shocks to technology variables in particular activities such as logging.

However, even a highly disaggregated model is often missing the detail relevant for a particular application. David Vincent (1990), a senior official at the Industries Assistance Commission, emphasized the importance of having flexibility to modify a model by adding new data and equations. He described modifications to standard ORANI to facilitate Commission inquiries into various industries including Dairying, Chemicals and Agriculture. In each case, the Commission disaggregated the ORANI database to introduce relevant details. For its inquiry into the Dairy

---

[31] The 1978 regional facility was an adaptation to CGE modeling of the regional extension designed by Leontief *et al.* (1965) for input-output models. It was top-down, that is, it generated regional results from national results without any feedback from the regional level to the national level. Top-down modeling is not suitable for shocks in which the essence is changes in relative costs across regions. A hybrid regional method for the ORANI model that retained the simplicity of top-down but allowed for changes in relative costs across regions by introducing regional industries (e.g. Tasmanian forestry) in the national model was devised by Higgs *et al.* (1983 & 1988). Liew (1981 & 1984) implemented a Johansen-style bottom-up regional model identifying Australia's 6 States as separate trading economies. This was followed by further bottom-up Johansen-style models for Australia including FEDERAL (Madden, 1990 & 1996), MMR (Naqvi and Peter, 1993), MMRF (Adams *et al.* 2000), FEDERAL-F (Giesecke, 2002) and TERM (Wittwer and Horridge, 2010). MMRF and TERM have become the workhorse models for contract work by CoPS in Australia.

industry, for example, the Commission created ORANI-milk in which the ORANI industry Milk cattle was disaggregated into six industries defined by region (Farm milk – NSW, Farm milk –Victoria, etc) and the ORANI commodity Milk products was disaggregated into seven commodities (Butter, Cheese, Skim milk, etc). With this data setup, and with additional equations describing the intricacies of the regional subsidy schemes applying to dairy farmers and the protection regimes applying to different milk products, the Commission was able to provide the government with convincing advice on the costs and benefits of policy reform in the sector (Industries Assistance Commission, 1983). While disaggregating industries and commodities is always challenging from the point of view of data assembly, in the Johansen framework of the ORANI model it presented no computational difficulties at a time when CGE modellers outside that framework rarely dealt with more than 30 broad sectors.

Another aspect of flexibility in the Johansen framework valued by Vincent (1990) is closure flexibility. This has already been discussed in section 4.3. Vincent saw closure flexibility as particularly attractive in allowing the Commission to use ORANI to quantify both short- and long-run effects of proposed changes in industry policies. As he points out, short-run effects are important for assessing adjustment costs, while long-run effects are important in calculations of welfare implications.

Transferability

Starting soon after the first version of ORANI was operational, the IMPACT Project made strenuous efforts to transfer the model, first to the Industries Assistance Commission and then more generally. Within a few years, versions were being operated, applied and developed in several organizations outside IMPACT. The transfers of the model were supported by documentation of the theory and database (Dixon *et al.*, 1977) and of the computer code (Sutton, 1977). IMPACT also provided training. By 1981, the training program had evolved into the provision of periodic, residential, one- and two-week intensive courses attended mainly by economists from government agencies and universities.

With the model presented and computed in Johansen's linear framework, successful transfers were made to people with limited backgrounds in mathematics and computing. Mathematically complex equations became transparent when expressed in Johansen's linear percentage change form (section 4.4) and computing was explained as a sequence of straightforward matrix operations.

Interpretability

Users of the ORANI model were initially faced with skeptical audiences of policy advisers who, while trained in economics, had little interest in economic modelling. In this environment, a key ingredient in ORANI's early survival and eventual success was the emphasis at the IMPACT Project on interpretation of results. In this task, the ORANI team had a particular connection with Johansen. His influence on their efforts to interpret results in a way that was convincing to non-modelling economists was more psychological and attitudinal than technical, although there was an important technical element. As discussed in section 2, results mattered to Johansen. He thought they were worth interpreting and devoted a major part of his 1960 book to working out what insights his results provided for understanding past and future growth and structural change in Norway. Being reminded of Johansen's attitude to results was of relevance (and still is) to practical modelers working in a profession in which complexity and theoretical novelty are often put on a pedestal while real-world significance is downplayed. At a technical level, Johansen left a couple of valuable hints for analyzing results: (a) use back-of-the-envelope models; and (b) look at the reduced-form elasticity matrix (Johansen's T matrix) to understand simulation results in terms of contributions from individual exogenous shocks.

To be effective, people presenting ORANI results had to tell their story without referring to modelling technicalities. Sometimes a qualitative story was sufficient to persuade policy advisers that there might be some truth in what seemed to be a counterintuitive result. For example, Johnson (1985) used an ORANI simulation to assist government officials in their negotiations with forestry workers who were campaigning against proposed restrictions on clear felling in old-growth native forests. The workers feared that the restrictions would destroy forestry jobs. Johnson's simulations demonstrated that the proposed regulations would in fact increase forestry employment. His non-technical but effective explanation of this result had three elements. First, restrictions on clear felling would increase labour required per log taken from existing forests. Second, restrictions would increase investment in plantation forestry, an activity that provided jobs for forestry workers. Third, there would be a reduction in output of forestry products, reflecting higher prices, but the reduction would be small because the elasticity of demand for forestry products is low. Johnson found that the first two positive effects on forestry employment would easily outweigh the third negative effect.

Another example of a counterintuitive result that had a plausible explanation was that of Adams and Parmenter (1993 and 1995). They were commissioned by the Bureau of Tourism Research to simulate the effects on the State economies in Australia of a general increase in inbound tourism. Their ORANI simulation suggested that Queensland (Australia's main destination for foreign tourists) would be a small loser. In explaining this result, they pointed at data showing that international tourists spend a lot of time in Queensland but not a commensurate amount of money. Tourists do their shopping and pay for their within-Australia travel in Sydney (in New South Wales). So the upside for Queensland from a general stimulation of inbound tourism is not as strong as might be imagined. At the same time, Adams and Parmenter identified a significant downside. Queensland is a major exporting state for mining and agriculture. These industries would be hurt by tourism-induced real appreciation.

For the ORANI modelers (and some discerning clients), merely qualitative explanations of results were not sufficient. Before the modelers could present confidently, they needed to be sure their results were "right". They needed to understand why the model implied that an x per cent increase in a tariff would increase output in the protected industry by y per cent and not 2y per cent. Following Johansen's lead (see section 2), they developed BOTE models for justifying and explaining results, but they took the BOTE idea further than Johansen and provided *quantitative*, not just qualitative, justifications.[32] They saw three roles for BOTE calculations:

[32] The ORANI team could be much more ambitious about BOTE calculations than Johansen. They had powerful calculators. Johansen (1960, p.138) mentions a calculation he did by slide rule!

"First, there is a purely practical point. With a model as large as ORANI, the onus is on the model builders to provide convincing evidence that the computations have been performed correctly, i.e., that the results do in fact follow from the theoretical structure and database. Second [BOTE calculations are] the only way: to 'understand' the model; to isolate those assumptions which 'cause' particular results; and to assess the plausibility of particular results by seeing which real-world phenomena have been considered and which have been ignored. Third, … by modifying and extending [BOTE] calculations … the reader will be able to obtain a reasonably accurate idea of how some of the projections would respond to various changes in the underlying assumptions and data." [Dixon et al. 1977, pp. 194-5]

The BOTE models constructed to explain ORANI results were small, often having just one domestically produced good which was consumed domestically and exported, one imported good, one type of labour and one type of capital. However, the exact nature of the BOTE models varied from application to application. For an ORANI simulation of the effects of an increase in oil prices, the corresponding BOTE model included the price of oil and the share of oil in the economy's production costs (see Dixon *et al*. 1984). For an ORANI simulation of the effects of a tariff increase, the corresponding BOTE model included a tariff rate (see Dixon *et al*. 1977, pp. 214-22). As demonstrated in many papers, BOTE calculations reproduced ORANI results with considerable precision. This led some economists to wonder why we needed ORANI. The answer is that in most cases it would not have been possible to think of the BOTE model without first having the results from the main model. In any case, critical ingredients of the BOTE models were supplied from the database of the main model.

An important BOTE-related idea is that CGE results are usually best explained in a top-down fashion: macro to micro rather than micro to macro. Consider, for example, the short-run effects on employment of an increase in tariffs under the assumptions of: fixed real wages; slack labour markets; and a fixed nominal exchange rate. Given the task of explaining why a CGE model such as ORANI shows a decrease in aggregate employment, beginning students in CGE modelling typically adopt a micro-to-macro strategy, starting with industry results. These show reductions in employment in export-related industries. Students argue correctly that higher tariffs raise costs by increasing intermediate input prices and nominal wage rates: imported input prices rise directly; domestic input prices rise in response to reduced competitive pressure from imports; and nominal wage rates rise to maintain real wage rates by offsetting tariff-induced increases in consumer prices. Students recognize that export industries face high demand elasticities and are hurt because they are poorly placed to pass cost increases into higher prices. But what about employment in tariff-protected import-competing industries? For these industries higher tariffs generate increased employment by inducing favourable demand switches towards their products and away from imported substitutes. Thus the micro-to-macro approach leaves students with the correct but inadequate conclusion that aggregate employment decreases because the losses in export-oriented industries outweigh the gains in import-competing industries.

A good starting point for developing an adequate explanation of the *net* employment result is a model in which the economy produces and exports one good (grain) and imports another good (vehicles). Grain production is via a constant-returns-to-scale production function of capital and labour inputs. The cost of a unit of consumption is a Cobb-Douglas function of the consumer prices of grain and vehicles. Finally, we assume that the cost per hour of employing labour equals the value to the employer of labour's marginal product. Under these assumptions we have:

$$W = P_g * A * F_\ell\left(\frac{K}{L}\right) \tag{4.10}$$

and

$$P_c = P_g^{\alpha_g} * \left(P_v * T_v\right)^{\alpha_v} \quad , \tag{4.11}$$

leading to

$$\frac{W}{P_c} = \left(\frac{P_g}{P_v}\right)^{\alpha_v} * \left(\frac{1}{T_v}\right)^{\alpha_v} * A * F_\ell\left(\frac{K}{L}\right) . \tag{4.12}$$

where

- W is the nominal wage rate;
- P_g and P_v are the basic prices of grain and vehicles;
- T_v is the power of the tariff (1+rate) on vehicles;
- P_c is the price of a unit of consumption;
- α_g and α_v are positive parameters summing to one;
- K and L are capital and labour inputs;
- A is the technology variable in the production function relating grain output to factor inputs, that is grain output = A*F(K,L); and
- F_ℓ is the derivative of F with respect to L and, on the assumption of constant returns to scale, is an increasing function of K/L.

For the tariff simulation, (4.12) immediately puts us on the right track for explaining the reduction in aggregate employment. Under fixed real wages, the tariff increase has no effect on the left hand side of (4.12). On the right hand side, there is a reduction in $1/T_v$. We can also anticipate that our full-scale CGE model will behave as if there is a reduction in A: tariff increases cause inefficiencies in the allocation of capital and labour between import-competing and export industries. Against these two effects, we can expect an increase in P_g/P_v. This is because tariff increases generate an improvement in the terms of trade by restricting the supply of exports (thereby increasing their foreign-currency price) and restricting the demand for imports (thereby reducing their foreign currency price). If the reductions in $1/T_v$ and A outweigh the increase in P_g/P_v, then (4.12) implies that F_ℓ must increase. In the short run, K is fixed and so L must fall. Provided that terms-of-trade effects are weak, reflecting the adoption of high export-demand and import-supply elasticities, we can understand why the full-scale model implies that an increase in tariffs reduces aggregate employment in the short run.

Our macro-based BOTE explanation can be tested in various ways. If the BOTE explanation is really capturing what is going on, then a repeat of the simulation in the full-scale model with lower export-demand and import-supply elasticities would show a smaller reduction in employment. The BOTE model can also be extended to explain other results. For example, the BOTE model set out in Dixon and Rimmer (2002, pp. 88-9) includes investment. This facilitates the explanation of investment, consumption and balance of trade results in a tariff simulation conducted with the MONASH model of Australia. Finally, the BOTE model can be made numeric by giving F_{ℓ} a specific form and plugging in stylized values from the database for parameters and cost shares.

Once the behaviour of macro variables such as aggregate employment, consumption, investment and the trade balance are understood via a BOTE model, then it is usually comparatively straightforward to explain results for micro variables. For example, if we can understand why a simulation shows a reduction in aggregate investment, then we can understand why it shows a reduction output and employment in the construction industry.

Top-down explanations of micro results can often be deepened by regression analysis. Consider, for example, the results in Figure 2 obtained by Dixon *et al.* (2007a) from the USAGE model[33] for the effects on employment by state in the U.S. of removal of major import restraints (tariffs and quotas). The worst affected states are Idaho and North Carolina which lose 0.498 and 0.477 per cent of their jobs, while the most favoured state, Washington, obtains a 0.214 per cent increase in jobs. Idaho suffers from over-representation in its employment of highly protected Sugar crops, Sugar products and Dairy products while North Carolina suffers from over-representation of highly protected Textiles. Washington benefits from over-representation of export-oriented commodities such as Aircraft and Aircraft equipment. Do state employment shares and percentage changes in commodity outputs at the national level explain all of the regional employment results? To answer this question Dixon *et al.* regressed state employment results from USAGE against a national index worked out for region r as:

$$\text{NatIndex}(r) = \Sigma_j \text{Sh}(j,r) \times \text{Nat\_emp}(j) \tag{4.13}$$

where

Sh(j,r) is the share of employment in region r accounted for by production of good j; and
Nat_emp(j) is the percentage change in employment at the national level in the production of commodity j.

The outcome of the regression was:

$$\text{Reg\_emp}(r) = -0.023 + 2.755 * \text{NatIndex}(r)\,,\ \text{R-sq} = 0.73 \tag{4.14}$$

where

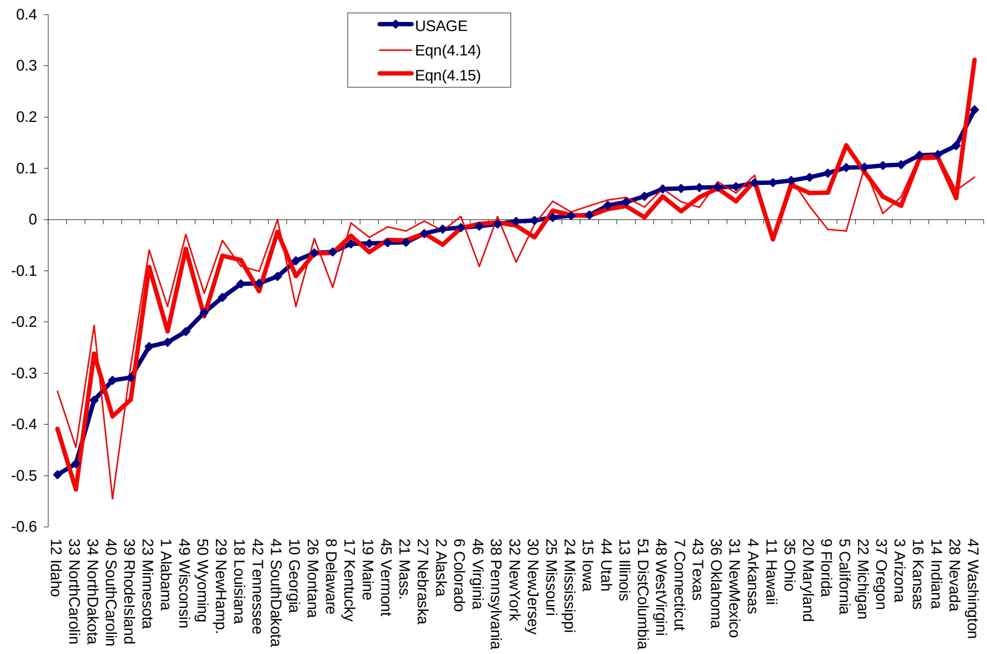
Reg_emp(r) is the USAGE percentage change result for employment in state r.

On studying Figure 2, Dixon *et al.* (2007a) saw that regression equation (4.14) strongly under-predicts the USAGE employment results for Washington, California and South Carolina. A factor that these three states have in common is major ports. In the USAGE simulation, a state benefits from having a major port via the trade-expanding effects of the removal of import restraints. On this basis Dixon *et al.* decided to add a port index to their regression explanation of the USAGE results. The index chosen was a ratio of two shares: the state's share of U.S. trade going through its ports and the state's share of national employment. With the port index included, the regression equation became:

---

33 USAGE is a large scale Johansen-style model of the U.S., see section 5.2.

Figure 2. State employment effects (%) of removing major U.S. tariffs and quotas explained by regression equations



$$Reg\_emp(r) = -0.050 + 3.164*NatIndex(r) + 0.056*PortIndex(r), \quad R\text{-}sq = 0.88 \qquad (4.15)$$

The port index enters the regression with the expected sign and raises R-squared to 0.88. Nevertheless, Figure 2 still shows some large gaps between the USAGE results and those explained by the regression.

By investigating these gaps, Dixon *et al.* uncovered further mechanisms in USAGE that were relevant for their simulation. They noted that regression equation (4.15) strongly under predicts the USAGE employment results for Hawaii, Nevada and Arizona. By adding a state tourism-related variable to the regression equation they demonstrated that under-prediction for these states is related to tourism effects specified in USAGE but not captured by either NatIndex or PortIndex.

5. Taking Johansen from Australia to the rest of the World

5.1. Early exports of Johansen-style modelling from Australia

From the early 1980s, insights gained from Australia's Johansen-style ORANI model began to be exported to other countries. The first export was associated with the appointment of David Vincent (one of the authors of the 1982 ORANI book) to a research fellowship at the Kiel Institute in the early 1980s. Out of his collaboration with colleagues at Kiel came ORANI models of Chile, West Germany, Korea, Colombia, Ivory Coast and Kenya.[34] Following Vincent's appointment, Philippa Dee (a long-time IMPACT associate) spent a period at Kiel and contributed a Johansen-ORANI model of Korea with an extension covering financial markets.[35] On his return to Australia in the mid-1980s, Vincent was influential in introducing staff and foreign students at the Australian National University to Johansen-style CGE modelling and

---

[34] These models are described in Dicke *et al.* (1983, 1984 & 1989) and Vincent (1982 & 1985) .
[35] See Dee (1986).

GEMPACK software.[36] Many of these people built and applied ORANI models for developing countries. At the same time, Powell, Dixon, Parmenter and others associated with the IMPACT Project trained foreign students at Melbourne, Monash and La Trobe Universities.

5.2. Export activity at the Centre of Policy Studies

In 1991 the core group of researchers associated with the IMPACT Project relocated to the Centre of Policy Studies (CoPS) at Monash University. From there they undertook major model development and application tasks for organizations in South Africa and Thailand.[37] In their description of these early international projects, Parmenter and Horridge (1994) emphasize the role of generic models and GEMPACK software:

> *"Our ability to export our modelling techniques to other environments was greatly enhanced by our construction of a generic ORANI-style model which can easily be implemented on personal computers via GEMPACK …The generic model is documented by Horridge, Parmenter and Pearson (1993) in a style designed to take the reader through all the steps required for implementation of such a model, including its computer representation."*

Over the last twenty years, CoPS has continued to undertake international modelling assignments. Usually these involve short exchanges of personnel between CoPS and foreign clients. However, in some cases, there have been extended visits. For example, the current director of CoPS, Philip Adams, spent several months in 2000 at the Danish Institute of Agricultural and Fisheries Economics. This visit produced a Johansen-MONASH model of Denmark with an emphasis on agriculture (Adams, 2000; and Adams *et al.* 2001). As shown on its website, CoPS has now completed modelling projects for about 20 countries and is currently engaged in ongoing projects in Vietnam, Malaysia, Finland, the Netherlands, China and the U.S.

In all of these projects, Johansen-style models implemented in GEMPACK software have been constructed and applied, often in collaboration with officials in policy-making government departments. For example, in China, CoPS researchers have been working over the last three years with a team from the State Information Centre (Beijing) on the construction of SIC-GE, a 137-sector dynamic model of China. The model is being applied by the CoPS/SIC team to the analysis of several urgent policy issues. One of the most interesting is reform of social security arrangements for rural workers migrating to cities. Using SIC-GE, Zhao Kun (2010) shows that proposed reforms impose considerable costs on employers of rural-urban workers. In these circumstances, for employment of such workers to be maintained they must be willing to supply their labour at a lower post-tax wage. This will depend on the perceived attractiveness to rural-urban workers of the proposed arrangements. Zhao Kun's analysis suggests that the reforms will be embraced by employers and workers only if workers see good prospects of eventually receiving substantial retirement benefits. Zhao Kun emphasizes that because jobs for rural-urban workers are often short-term, they will find the proposed social security arrangements

---

[36] In the late 1980s Vincent worked as an adjunct Ph.D. advisor in Helen Hughes' National Centre for Development Studies at the Aistralian National University in Canberra. Among the staff and Ph.D. graduates from the Centre at that time who have subsequently made distinguished careers in CGE modelling were Rod Tyers, Peter Warr and YinHua Mai.

[37] The South Africa and Thailand projects are described in Horridge *et al.* (1995) and Arunsmith (1998).

attractive only if they are confident that their entitlements will be transferred easily between jobs. Other applications of SIC-GE are concerned with greenhouse policy, transportation, carbon tariffs on China's exports, and the pricing of gasoline. All of these applications were delivered at a recent conference in Beijing.[38]

CoPS' most elaborate venture in exporting Johansen-style modelling services is its collaboration with departments of the U.S. government. Starting in 2000 with the MONASH model of Australia as a template, CoPS worked on the construction of USAGE (U.S. Applied General Equilibrium), a policy-oriented model of the U.S. economy. Bob Koopman, Director of the Office of Economics at the U.S. International Trade Commission, saw potential in the USAGE project from an early stage. Under his leadership, the USITC has been supporting the project financially and intellectually since 2002. For the last five years they have maintained a seconded officer from CoPS in Washington DC and have hosted an annual USAGE training course.

After 10 years work at CoPS and contributions by economists at the USITC, USAGE has become the most detailed CGE model to have been constructed anywhere in the world. Exploiting the computational simplicity of the extended Johansen method and the data handling convenience of the GEMPACK software, USAGE can accommodate 500 U.S. industries, 51 regions (50 states plus the District of Columbia), 700 occupations and 23 sources for U.S. imports and destinations for U.S. exports. The model is dynamic and integrates microeconomic detail with a fully articulated macro specification covering taxes, tariffs, public expenditures, public debt, the balance of payments, foreign assets and foreign liabilities. It has been used to track economic performance from 1992 and produces detailed baseline projections and policy simulations to 2020.

USAGE is now widely recognized in Washington DC. It has been applied not only on trade issues for the USITC[39], but also on other topics for the U.S. Departments of Agriculture, Commerce and Homeland Security. These topics include

- partial replacement of imported crude petroleum by domestically produced biofuels (see Dixon *et al.*, 2007b; Osborne, 2007; and Gehlhar *et al.*, 2010);
- a security-related closure of U.S. ports (see Dixon *et al.* 2010a);
- a serious H1N1 epidemic (see Dixon *et al.* 2010b);
- the implications for industries and regions of the 2009-10 U.S. recession and the likely effects of the Obama stimulus package (see Dixon and Rimmer, 2010a); and
- different approaches to the problem in the U.S. of illegal immigration (see Dixon and Rimmer 2009; and Dixon *et al.*, 2010c).

Many of these applications have produced results that are plausible, policy-relevant and could not have been obtained in a less detailed model. An example is the occupation-mix effect identified in USAGE simulations concerned with low-skilled illegal immigrants. With effective restriction of these immigrants, the U.S. economy would be smaller with fewer jobs in all occupations. USAGE simulations show that new legal entrants to the workforce would find reduced employment opportunities in skilled occupations (smaller economy) and increased opportunities in low-skilled

[38] See State Information Centre and China-Australia Governance Program (2010).

[39] The USITC uses USAGE in several ways: in its flagship publications on import restraints (USITC, 2004, 2007 & 2009); in analyses conducted for the U.S. Trade Representative in the Executive Office of the President; and in one-off research projects, see for example, Fox *et al.* (2008).

occupations (vacancies created by reduction in low-skilled immigrants). In this way the occupational-mix of legal employment would be slanted towards low-skilled, low-paid jobs with a consequent negative effect on the welfare of legal residents.

5.3. The Global Trade Analysis Project

A final conduit of Johansen-style modelling from Australia to the rest of the world is the Global Trade Analysis Project (GTAP) founded in 1992 by Tom Hertel at Purdue University (see Hertel, 1997). Hertel visited the IMPACT Project for the academic year 1990-91. During his visit, he was exposed to the ORANI model and the GEMPACK software. He was particularly impressed by the SALTER model, a Johansen-style multi-country model being constructed at the Industries Assistance Commission in Canberra (IMPACT's main sponsoring agency) using ORANI as the theoretical starting point and GEMPACK software for computations. Hertel took SALTER back to Purdue and this formed the basis for the first version of the GTAP model of the global economy.[40]

GTAP is an extraordinarily successful project. As well as the GTAP model, the Project provides: a database of input-output tables and trade flows for about sixty commodities and one hundred countries; training courses attended by people from around the world; an annual conference at which about 200 papers are delivered mainly on trade issues using the GTAP data and model; and a website on which several thousand participants from nearly every country exchange data and ideas on CGE modelling. The factors underlying the success of GTAP are much the same as those underlying the success of ORANI: a favourable policy environment, suitable institutional arrangements and a Johansen-style modelling framework.

The policy issues that made the time right for GTAP were the proliferation in the 1980s and 1990s of bi-lateral and multi-lateral trade negotiations. The most important initial applications of the GTAP model were concerned with the Uruguay round (see, for example, MacLaren, 1997, Yang *et al.* 1997 and Martin and Winters, 1997). Later, the range of GTAP applications expanded to include other global issues such as: greenhouse gases (see Hertel *et al*., 2009); international labour movements (see Walmsley *et al.*, 2005); and poverty (see Hertel and Winters, 2006).

On institutional arrangements, Hertel (1994) in a paper entitled "Taking IMPACT Abroad: the Global Trade Analysis Project", explains that GTAP "was established … on the institutional principals of the IMPACT project …". Reflecting Alan Powell's approach at IMPACT, Hertel emphasized transferability of data and model code, replicability of results and openness supported by training courses and documentation. Hertel's financing strategy consisted initially of forming a consortium of agencies with interests in evidence-based analysis of world trade issues. In 1993, the consortium had five members: two from Australia, two from the U.S. and the World Bank. In 1997 this number had risen to 16 and reached 25 in 2007. Each of the consortium organizations make a small financial contribution.[41] Other sources of funds include revenue from courses, conferences and the supply of data. However, the GTAP budget has remained modest and supports a research group at Purdue of

[40] Anderson (2005, p. 16) discusses the relationship between ORANI, SALTER and GTAP. For a history of GTAP see Powell (2007). A set of working papers on SALTER written in the period 1991 to 1995 is available at http://www.pc.gov.au/ic/research/models/saltermodel . After 1995 SALTER seems to disappear, perhaps completely overtaken by GTAP.

[41] According to Powell (2007), the Consortium membership fee in 2007 was $US18,200.

only about seven people.[42] Hertel's particular forte has been to organize major inputs in-kind to GTAP from participating researchers and organizations. For example, Powell (2007) mentions contributions to the GTAP data on tariffs by Bradley McDonald of the U.S. Department of Agriculture, Will Martin and Jerzy Rozanski of the World Bank, Hiroaki Kuwahara of UNCTAD and David Laborde, Sebastien Jean, Lionel Fontagné and Antoine Bouët of CEPII (the *Centre d'Etudes Prospectives et d'Information Internationales*). Other examples of a major in-kind contributions are software developments and teaching support provided by Ken Pearson and Mark Horridge of CoPS and Tom Rutherford during his period at the University of Colorado. Input-output data and trade matrices compatible with GTAP requirements have been compiled and supplied free of charge by researchers in many countries.

With regard to the model, GTAP has retained a large scale but relatively simple Johansen-style model as its core analytical and teaching device.[43] The model is implemented in GEMPACK[44] and takes full advantage of developments in this software as they occur. Via GTAP and the GEMPACK software, thousands of economists from every part of the world are undertaking Johansen-style modelling: they are using the linear representation of a CGE model to clarify its properties; to elucidate real world issues; and to check model validity.

6. Concluding remarks

Since its inception in 1960 with the publication of Johansen's book, CGE modelling has proved a remarkably fruitful technique for combining data with economic theory to project implications for macro, industry, regional, occupational, environmental and distributional variables of a wide range of policy changes and other shocks to the economy. In this paper, we have mentioned many CGE applications and results and we could have mentioned hundreds of others.

Johansen was first in the CGE field and provided a particular style of CGE modelling based on a linear representation of the theory and a linear solution method. The main objection to his methods, especially in North America, was that Johansen solutions were only approximations. This objection was overcome in Australia by 1980 through a simple and effective multi-step Johansen procedure that eliminated linearization errors. By adopting the Johansen-style, Australian CGE modellers were able to make rapid progress. In the 1970s they created CGE models with:

- price-sensitive treatments of international trade;
- policy-relevant levels of detail such as the modelling of gaps between basic and purchasers prices, the inclusion of technology and tax terms associated with every input-output flow and facilities for generating results at regional and occupational levels;

---

[42] GTAP maintains a close connection with Australia, with two of its key long-term staff members (Rob McDougall and Terrie Walmsley) being former members of CoPS.

[43] Some researchers, e.g. Fan (2008), use GTAP data with different theory from the Armington specification embedded in the core GTAP model.

[44] There are now versions of the GTAP model in GAMS. However, as Rutherford (2006) explains, it was necessary to simplify the GTAP model for GAMS implementation. It appears that outside the Johansen framework, advanced functional forms such as CDE expenditure functions (used in standard GTAP) cause difficulties.

- flexible closures allowing for generation of short-run results, long-run results and results under different price-setting assumptions (neoclassical versus neo-Keynesian); and
- the ability to handle complex functional forms for production and consumption.

Facilitated by Johansen's linear representation, Australia's ORANI model was taught, transferred and interpreted. By the 1980s, Johansen-style modelling had been widely adopted by government departments and consulting firms[45] in Australia and was being used in public debates on almost every important economic issue. From Australia Johansen-style modelling spread to the rest of the world through the activities of members and former members of IMPACT and the Centre of Policy Studies and through the GTAP Project. The use of Johansen-style CGE modelling throughout the world has been immeasurably facilitated by the creation at IMPACT/CoPS of the GEMPACK software by Ken Pearson and his colleagues.

For us, the major challenge now is validation. CGE models have produced many results, but how should they be assessed? How do we know they are right? This is a key concern of consumers of CGE results. One of the first questions we are always asked at presentations in policy circles is: "What reliance can I place on your results?".

6.1. Forms of validation

Checking the code

There are several forms of validation. The first is checking for coding and data handling errors. One effective way to do this is to run simulations for which the answers are known *a priori*. For example, in a model with no nominal rigidities, a 10 per cent shock to the numeraire should make all nominal variables increase by 10 per cent while leaving all real variables unchanged.[46] Another check is provided by including in the model GDP calculated from the income side as well as the expenditure side. The results from the two sides should be identical in both real and nominal terms.[47]

Plausibility and BOTE calculations

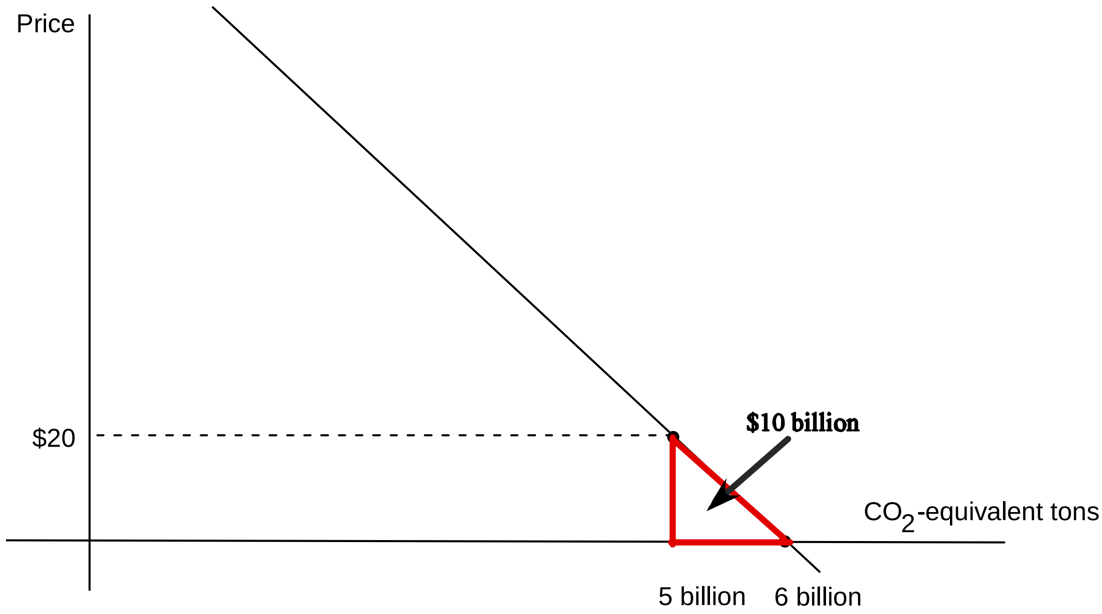
A second form of validation, of which Johansen was a master, is plausibility checks on results. This is largely a matter of using back-of-the-envelope calculations. For example, assume that we are simulating the effects of a tax of $US20 per ton on CO_2-equivalent emissions in the U.S. Assume that our results show a reduction in emissions from 6 billion to 5 billion tons. These are the sort of figures that were being discussed in Washington DC at the end of 2009 in the run up to the UN Climate Change Conference held in Copenhagen. What should we expect our model to say

[45] The pioneer in the application of CGE modelling by private consulting firms was Vince FitzGerald of the Allen Consulting Group. Other groups, including the Centre for International Economics, Access Economics, Acil Tasman, PricewaterhouseCoopers, Deloittes and Frontier Economics, followed. By the 1990s, CGE modelling had almost completely replaced input-output modelling as the analytical tool for economy-wide analysis by contract researchers in Australia.

[46] Dixon *et al*. (1992, pp. 246-51) describes five test simulations.

[47] See Dixon *et al.* (1992, pp. 252-76).

Figure 3. Demand for the right to emit CO_2



about long-run economic welfare? A simple diagram (Figure 3) showing a demand curve for the right to emit CO_2 against the price of such emissions suggests that the welfare loss should be about $US10 billion. If our model shows a distinctly different number then we must adopt more elaborate back-of-the-envelope calculations in a search for the mechanisms and data items that explain the result. Unless these can be located, the result should not be trusted. In any case, without a plausible explanation the result is unlikely to be influential.

Fitting history

A third type of validation for a model is a check on its consistency with history. Such checks can take various forms. For Jorgenson's models (see particularly Jorgenson, 1984) consistency with the past means that parameters (e.g. substitution elasticities) are estimated by econometric techniques applied mainly with time-series data. For the ORANI model there were also considerable efforts to estimate parameters from time-series. With the MONASH series of models, including the USAGE model of the U.S., we have adopted the technique of historical simulation under which we force models to track observed movements in outputs, inputs and final demands and allow them to generate implied changes in technologies, consumer preferences, world trading condition and other naturally exogenous but unobservable variables. The plausibility of these generated changes can be assessed, perhaps informally, against other information. For example, a USAGE historical simulation from 1992 to 1998 (Dixon and Rimmer, 2004) plausibly quantified preference shifts indicating increasing interest by U.S. households in health and lifestyle issues: with preference shifts towards Boats, Luggage, Travel trailers, Sporting clubs and Cable TV and against Cigarettes, Malt beverages, Wine and spirits and Distilled liquors. Fashion changes were also evident: with preference shifts away from Bowling centres and Newspapers. Among the technology changes revealed by the historical simulation were shifts by industries in favour of the use of Computer equipment, Computer services, Personnel supply services, Job training and Management services. In capital creation, there were shifts against Glass, Sawmill products and Brick and clay tiles and towards Ready-mix concrete . It appears that between 1992 and 1998, U.S. building methods became more basic and less artistic.

Less plausibly, our initial historical simulations showed preference shifts against nearly all food products. This alerted us to the possibility that the expenditure elasticities of demand for food products (deduced from an econometric study) were too high, so that income growth was generating too much growth in food consumption, thus requiring negative preference changes to allow USAGE to reproduce observed growth. When lower elasticities were adopted the problem of preference shifts against food disappeared. In this way, results from historical simulations are used to refine parameter estimates.

Forecasting performance

As mentioned in section 4.3, Johansen-style models built at CoPS since about 1990 can be used to generate forecasts.[48] These incorporate trends in technologies, consumer preferences, world trading condition and other naturally exogenous variables derived at a detailed level (e.g. 500 industries/commodities in the case of USAGE) from historical simulations. They also incorporate macro forecasts and specialist sectoral forecasts provided by government and business organizations. For example, in USAGE we use macro forecasts from the Congressional Budget Office and forecasts for numerous energy variables from the U.S. Energy Information Administration.

There are several reasons for providing CGE forecasts. First, private- and public-sector consumers of CGE analyses want projections not only of the effects of particular shocks, but also of the evolution of the economy without the shock. Second, answers to "what if" questions can be improved by generating them as deviations around a realistic forecast. For example, in their USAGE-based study of the effects of import restraints on the U.S. economy, the U.S. International Trade Commission (2007) recognised via their a baseline forecast that import-competing industries such as Textiles, Apparel and Sugar are likely to suffer rapid decline even in the absence of further cuts in protection, that is, output and employment in these industries is likely to be considerably smaller in 2012, for instance, than it was in 2007. By taking this into account, the Commission avoided exaggerating the likely loss of jobs in these industries that would occur in 2012 as a result of tariff cuts. Third, forecasts are necessary in studies of adjustment costs. For example, in considering the adjustment costs following from a tariff cut, it makes all the difference whether the reductions in employment in adversely affected industries are accommodated by an increase in the rate of firing or a reduction in the rate of hiring, but to know which applies we cannot avoid forecasting.[49]

A fourth reason for CGE forecasts, and the one that has been the focus of our interest in recent years, is that forecasting offers a vehicle for testing the validity of

---

[48] Our first published CGE-generated set of forecasts is Dixon (1986).

[49] A quantitative analysis of adjustment costs requires a model not only with forecasting capability but with three additional characteristics: detail (adjustment costs are about spray painters in the motor vehicle industry in Kentucky); dynamics (adjustment costs are about the rate at which industries change their demands for labour); and an economy-wide perspective (adjustment costs can only be assessed comprehensively if account is taken of changes in employment opportunities in all industries, not jut those that are directly affected by the policy under investigation). Dixon *et al.* (1997) and Dixon and Rimmer (2002, pp. 289-99) provide a measure of adjustment costs for use in conjunction with CGE simulations. For an application of this measure in a policy context see Productivity Commission (2000).

CGE models. This was recognised by Johansen. As described in section 2.2, he analysed the ability of his 22-sector model to "forecast" changes in the 1950s in the industrial composition of Norwegian economic activity and checked these forecasts against outcomes. Johansen's lead was followed by several early contributors to CGE literature[50] but little work on validating CGE models has been undertaken since the 1980s. Perhaps this reflects the predominantly *comparative* static/dynamic nature of modern CGE studies, concerned with the effects of one or a small group of exogenous shocks. Because at any time the economy is affected by a myriad of exogenous shocks, isolating the real-world impact of any particular shock has proved very difficult. Thus, it is hard to find an empirical basis for validating most modern CGE results.[51] By contrast, baseline forecasts that purport to account for the myriad of shocks can be checked against outcomes, reasons for discrepancies can be investigated and avenues for modelling improvements can then be found.

We are following this agenda with the USAGE model (see Dixon and Rimmer, 2010c). Using trends for technology, preference and trade variables derived from an historical simulation for 1992 to 1998 together with expert macro and energy forecasts available in 1998, we have generated USAGE forecasts for growth in U.S. outputs of 500 commodities/industries between 1998 and 2005. We found that these USAGE forecasts are 42 per cent better that those that could be derived by simply extrapolating output trends from the period 1992 to 1998 (that is, the average percentage error for the USAGE forecasts is 42 per cent less than that for the non-model-based trend forecasts).

Having made a pure forecast for 1998 to 2005 (that is, one using only information available up to 1998) we then conducted a series of forecast simulations in which we successively introduce the 'truth' for the movements in different groups of exogenous variables. This exercise indicates that major reductions in forecasting errors would be made with better forecasts for exogenous variables associated with trade (e.g. the positions of foreign demand curves for U.S. products). With this in mind, we examined annual trade data from 1992 to 2005. For many commodities, these data are highly volatile. To improve USAGE forecasting performance it is apparent that the underlying causes of volatile trade behaviour must be understood so that informed opinions can be built into the forecasts concerning future movements.

This suggests an approach in which preliminary forecasts are made and then tested in discussions with industry experts. The U.S. International Trade Commission and the Departments of Commerce and Agriculture, three of the agencies that use USAGE, are well placed to provide feedback on institutional and technological factors that should be taken into account in creating forecasts at a detailed level. We hope that our forecasts and modelling can be improved by a process similar to that

---

50 In section 3 we mention validation work by Taylor *et al.* (1980) on their 25-sector Brazilian model. Other early validation studies include: Cook (1980) who tested the performance of year-on-year projections from a 22-sector ORANI model of Norway for 1949 to 1961; and Dixon *et al.* (1978b) who tested the performance of a 109-sector model of Australia (the SNAPSHOT model) in reproducing movements in outputs, imports and employment by occupation for the period 1963 to 1972.

51 This point was not adequately addressed in the often-cited validation exercise by Kehoe (2005). In that exercise, Kehoe assesses the performance of various models in predicting the effects of NAFTA. He notes that the model of Brown, Deardorff and Stern predicted that NAFTA would increase Mexican exports by 50.8%. Over the period 1988 to 1999, Mexican exports went up by 140.6 per cent. Kehoe invites us to draw the conclusion that Brown *et al*. strongly underestimated the effects of NAFTA. However, what about all the other factors that affected Mexican trade volumes over these 10 years?

described by Johansen in connection with projections made with his model in 1969 by the Norwegian Ministry of Finance for the period 1963 to 1990:

> *"The projections described above aroused great interest in wide circles. … Several institutions, enterprises and persons approached the Ministry of Finance to get more details or suggest alternative assumptions. There was a clear need to continue the explorations and the Ministry invited interested persons to take part in an informal working group. Some 30 persons representing organisations, research institutes, private firms and other ministries participated. This group met regularly with members of staff of the Ministry in 1970. Several aspects and possible uses of the projections were discussed and many alternatives were tried. … Among alternatives tried were some with variations in the expansion of ocean transport (a very important element on the Norwegian balance of payment), some with variations in the rate of growth of total labour force and alternatives with lower overall growth generated by lower investment proportions and slower technological progress." [Johansen, 1974, pp. 225-6].*

This leaves us with the thought that understanding the economy is a huge task. Key issues vary from industry to industry. In these circumstances we should, like Johansen, welcome opportunities to present our work to and learn from people with practical experience in business and government.

References

Adams, P.D. (2000), "Dynamic-AAGE: A dynamic CGE model of the Danish Economy Developed from the AAGE and Monash Models", *Report No. 115*, Danish Institute of Agricultural and Fisheries Economics, pp. 135.

Adams, P.D. and B.R. Parmenter (1993), "The medium-term significance of international tourism for the State economies", Report commissioned and published by the Bureau of Tourism Research, Canberra: Australian Government Publishing Service.

Adams, P.D. and B.R. Parmenter (1995), "An applied general equilibrium analysis of the economic effects of tourism in a quite small, quite open economy", *Applied Economics*, Vol. 27, pp. 985-94.

Adams, P.D., J.M. Horridge and B.R. Parmenter (2000), "Forecasts for Australian Regions Using the MMRF-Green Model", *The Australasian Journal of Regional Studies*, Vol. 6(3), pp. 293-323.

Adams, P.D., L. Andersen and L-B. Jacobsen (2001), "Does Timing and announcement matter? Restricting the production of pigs within a dynamic CGE model", *The Danish Institute of Agricultural and Fisheries Economics Working Paper, No. 18*/2001.

American Economic Review (1992), "Herbert E. Scarf: Distinguished Fellow", *American Economic Review*, Vol. 82(4), September.

Adelman, I. and S. Robinson (1978), *Income Distribution Policy in Developing Countries: A Case Study of Korea*, Oxford University Press, New York.

Alaouze, C.M. (1977), "Estimates of the Elasticity of Substitution between Imported and Domestically Produced Goods Classified at the Input-Output Level of Aggregation", *IMPACT Working Paper , No. O-13*, pp. 32, available at http://www.monash.edu.au/policy/elecpapr/O-13.htm .

Alaouze, C.M., J.S. Marsden and J. Zeitsch (1977), "Estimates of the Elasticity of Substitution Between Imported and Domestically Produced Commodities at the

Four Digit ASIC Level”, *IMPACT Working Paper , No. O-11*, pp. 66, available at http://www.monash.edu.au/policy/elecpapr/o-11.htm .

Anderson, K. (2005), “Setting the Trade Policy Agenda: what roles for economists” *World Bank Policy Research Working Paper WPS3560*, pp. 33, available at http://wwwds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2005/04/14/000012009_20050414131144/Rendered/PDF/wps3560.pdf .

Armington, P.S. (1969), “The geographic pattern of trade and the effects of price changes”, *IMF Staff Papers*, XVI, pp. 176-199.

Armington, P.S. (1970), “Adjustment of trade balances: some experiments with a model of trade among many countries”, *IMF Staff Papers*, XVII, pp. 488-523.

Artus, J.R. and R.R. Rhomberg (1973), “A Multilateral Exchange Rate Model”, *Staff Papers*, International Monetary Fund, Vol. 20(2), pp. 591-611.

Arunsmith, K (1998), “Thailand in economic crisis: a multisectoral forecasting simulation (1997-1999) derived from a CGE model (CAMGEM), *Chulalongkorn Journal of Economics*, Vol. 10(1), pp. 15-42.

Barker, T.S. (1976), “Projecting alternative structures of the British Economy”, pp. 3-25 in S. Polenske (editor), *Advances in Input-Output Analysis*, Ballinger Publishing Company, Mass.

Bergman, L. (1978), “Energy policy in a small open economy: the case of Sweden”, RR-78-16, International Institute for Applied Systems Analysis, Laxenberg, Austria, available at http://www.iiasa.ac.at/Admin/PUB/Documents/RR-78-016.pdf

Bergman, L. (1985), “Extensions and applications of the MSG-Model: a brief survey”, pp. 127-161 in F.R. Forsund, M. Hoel and S. Longva (editors), *Production, Multi-Sectoral Growth and Planning*, Contributions to Economic Analysis 154, North-Holland Publishing Company, pp. xvi+337.

Bisschop J. and A. Meeraus (1982), “On the development of a general algebraic modeling system in a strategic planning environment”, *Mathematical Programming Study*, Vol. 20, pp. 1-19.

Bjerkholt, O. and S. Tveitereid (1985), “The use of the MSG model in preparing a ‘perspective analysis 1980-2000’ for the Norwegian economy”, pp. 271-87 in F.R. Forsund, M. Hoel and S. Longva (editors), *Production, Multi-Sectoral Growth and Planning*, Contributions to Economic Analysis 154, North-Holland Publishing Company, pp. xvi+337.

Bovenberg, A.L. and W.J. Keller (1984), “Non-linearities in applied general equilibrium models”, *Economic Letters*, Vol. 14, pp. 53-59.

Breece, J.H., K.R. McLaren, C.W. Murphy and A.A. Powell (1994), “Using the Murphy Model to Provide Short-run Macroeconomic Closure for ORANI”, *Economic Record*, Vol. 70, September, pp.292-314.

Brown, D.K. (1987), Tariffs, the terms of trade, and national product differentiation”, *Journal of Policy Modeling*, Vol. 9(3), pp. 503-26.

Codsi, G and K.R. Pearson (1986), “GEMPACK documents numbers 2, 3, 5-8 and ll-18”, Impact Project, Melbourne.

Codsi, G. and K.R. Pearson (1988), “GEMPACK: General-purpose Software for Applied General Equilibrium and Other Economic Modellers”, *Computer Science in Economics and Management*, Vol. 1, pp. 189-207.

Condon, T., H. Dahl and S. Devarajan (1987) , "Implementing a computable general equilibrium model on GAMS : the Cameroon model", Report number DRD290, World Bank, Washington DC.

Cook, L.H. (1980), *Validation of a Johansen-type multi-sectoral model: Norway, 1949-1961*, PhD thesis, Department of Economics, Monash University, Australia.

Cooper, R.J. and K.R. McLaren (1983), "The ORANI-MACRO Interface: an Illustrative Exposition", *Economic Record,* Vol. 59, June, pp. 166-79.

Corden, W.M. (1958), "Import restrictions and tariffs: a new look at Australian policy"¸ *Economic Record,* Vol. 34(69), December, pp. 331-46.

Corden, W.M. and P.B. Dixon (1980), "A Tax-Wage Bargain in Australia: Is a Free Lunch Possible?", *The Economic Record,* Vol. 56, September 1980, pp. 209-21.

Dahlquist, G., A Bjorck and N. Anderson (translator) (1974), *Numerical Methods*, Prentice-Hall, New Jersey.

Dee, P.S. (1986), Financial markets and economic development: the economics and politics of Korean reform, *Kiel Institute Study 198,* J.C.B. Mohr (Paul Siebeck) Tubingen.

Dervis, K., J. de Melo and S. Robinson (1982), *General Equilibrium Models for Development Policy,* Cambridge University Press, Cambridge, U.K.

Dicke, H., S. Gupta, T. Mayer and D. Vincent (1983), "The short-run impact of fluctuating primary commodity prices on three developing countries Colombia, Ivory Coast, Kenya", *World Development*, Vol. 11, pp. 405-16.

Dicke, H., D. Gerken, T. Mayer and D. Vincent (1984), "Stabilization strategies in primary commodity exporting countries: a case study of Chile, ", *Journal of Development Economics,* Vol. 15, pp. 47-75.

Dicke, H., J.B. Donges, E. Gerken and G. Kirkpatrick (1989), "Effects of agricultural trade liberalization on West Germany's economy", Chapter 4, pp. 125-49 in A.B. Stoeckel, D. Vincent and S. Cuthbertson (editors), *Macroeconomic Consequences of farm support policies*, Duke University Press, Durham and London.

Dixon, P.B. (1975), *The Theory of Joint Maximization,* Contributions to Economic Analysis 91, North-Holland Publishing Company, pp. xii + 212.

Dixon, P.B. (1976), "Effective Exchange Rates and the International Monetary Fund's Multilateral Exchange Rate Model : A Review", *Australian Economic Papers*, Vol. 15(26), June, pp.59-75.

Dixon, P.B. (1986), "Prospects for Australian Industries and Occupations, 1985 to 1990", *Australian Economic Review,* 1st Quarter, pp. 3-28.

Dixon, P.B. (1987), "On Using Applied General Equilibrium Models for Analysing Structural Change", pp. 149-158 in L. Pasinetti and P.J. Lloyd (editors), *Structural Change, Economic Interdependence and World Development,* Vol. 3 of *Structural Change and Adjustment in the World Economy,* Macmillan Press for the International Economic Association, London.

Dixon, P.B. (2008), "Trade Policy in Australia and the development of computable general equilibrium modelling", *Journal of Economic Integration,* Vol. 23(3), September, pp. 605-30.

Dixon, P.B. and M.W. Butlin (1977), "Notes on the Evans Model of Protection", *The Economic Record*, Vol. 53(143), September, pp.337-349.

Dixon, P.B. and B.R. Parmenter (1996), "Computable General Equilibrium Modelling for Policy Analysis and Forecasting", Chapter 1, pp.3-85 in H.M. Amman, D.A. Kendrick and J. Rust (editors), *Handbook in Computational Economics*, Vol. 1, Elsevier, Amsterdam.

Dixon, P.B. and M.T. Rimmer (2002), *Dynamic General Equilibrium Modelling for Forecasting and Policy: a Practical Guide and Documentation of MONASH*, Contributions to Economic Analysis 256, North-Holland Publishing Company, pp. xiv+338.

Dixon, P.B. and M.T. Rimmer (2004), "The US economy from 1992 to 1998: results from a detailed CGE model", *Economic Record*, Vol. 80(Special Issue), September, pp.S13-S23.

Dixon, P.B. and M.T. Rimmer (2009) "Restriction or Legalization? Measuring the economic benefits of immigration reform", Trade Policy Analysis paper no. 40, Cato Institute, Washington DC, August, pp.24, available at http://www.freetrade.org/node/949 .

Dixon, P.B. and M.T. Rimmer (2010a), "Simulating the U.S. Recession with and without the Obama package: the role of excess capacity", *CoPS/IMPACT Working Paper G-193*, pp. 41, available at http://www.monash.edu.au/policy/ftp/workpapr/g-193.pdf .

Dixon, P.B. and M.T. Rimmer (2010b) "Optimal tariffs: should Australia cut automotive tariffs unilaterally?", *Economic Record*, forthcoming June.

Dixon, P.B. and M.T. Rimmer (2010c), "Validating a detailed, dynamic CGE model of the U.S.", *Economic Record*, forthcoming.

Dixon, P.B., B.R. Parmenter, G.J. Ryland and J. Sutton (1977), *ORANI, A General Equilibrium Model of the Australian Economy: Current Specification and Illustrations of Use for Policy Analysis*, Vol. 2 of the First Progress Report of the IMPACT Project, Australian Government Publishing Service, Canberra, pp. xii + 297.

Dixon, P.B., B.R. Parmenter and J. Sutton (1978a), "Spatial Disaggregation of ORANI Results: A Preliminary Analysis of the Impact of Protection at the State Level", *Economic Analysis and Policy*, Vol. 8(1), March, pp.35-86.

Dixon, P.B., J.D. Harrower and D.P. Vincent (1978b), "Validation of the SNAPSHOT model", *Preliminary Working Paper No. SP-12*, IMPACT Project, Melbourne, pp. 65.

Dixon, P.B., A.A. Powell and B.R. Parmenter (1979), *Structural Adaptation in an Ailing Macroeconomy*, Melbourne University Press, pp.xvii + 88.

Dixon, P.B., B.R. Parmenter, John Sutton and D.P. Vincent (1982), *ORANI: A Multisectoral Model of the Australian Economy*, Contributions to Economic Analysis 142, North-Holland Publishing Company, pp. xviii + 372.

Dixon, P.B., B.R. Parmenter and A.A. Powell (1984), "The role of miniatures in computable general equilibrium modelling: experience from ORANI", *Economic Modelling*, Vol. 1(4), October, pp. 421-28.

Dixon, P.B., B. R. Parmenter, A.A. Powell and P.J. Wilcoxen (1992), *Notes and Problems in Applied General Equilibrium Economics*, North-Holland Publishing Company, pp. xvi + 392.

Dixon, P.B., B.R. Parmenter and M.T. Rimmer (1997), *The Australian Textiles, Clothing and Footwear Sector from 1986-87 to 2013-14: Analysis using the*

MONASH Model, paper presented at the 26th Conference of Economists, Hobart, September, pp. 108, available from the Centre of Policy Studies, Monash University.

Dixon, P.B., J. Menon and M.T. Rimmer (2000), "Changes in technology and preferences: a general equilibrium explanation of rapid growth in trade", *Australian Economic Papers*, Vol. 39(1), March, pp.33 – 55.

Dixon, P.B., M.T. Rimmer and M.E. Tsigas (2007a), "Regionalising results from a detailed CGE model: macro, industry and state effects in the U.S. of removing major tariffs and quotas", *Papers in Regional Science*, Vol. 86(1), March, pp. 31-55.

Dixon, P.B., Stefan Osborne and Maureen T. Rimmer (2007b) "The economy-wide effects in the United States of replacing crude petroleum with biomass", *Energy and Environment*, 18(6), pp. 709-722.

Dixon, P.B., J. Giesecke, M.T. Rimmer and A.Z. Rose (2010a), "The Economic Costs to the U.S. of closing its borders: a computable general equilibrium analysis", *Defence and Peace Economics*, forthcoming.

Dixon, P.B., B. Lee, T. Muehlenbeck, M.T. Rimmer, A.Z. Rose and G. Verikios (2010b) "Effects on the U.S. of an H1N1 epidemic: analysis with a quarterly CGE model", paper presented at the Fourth Annual DHS University Network Summit, held at the Renaissance Hotel, Washington DC, March 10-12.

Dixon, P.B., M. Johnson and M.T. Rimmer (2010c) "Economy-wide effects of reducing illegal immigrants in U.S. employment" *Contemporary Economic Policy*, forthcoming.

Evans, H.D. (1972), *A General Equilibrium Analysis of Protection: the effects of protection in Australia*, Contributions to Economic Analysis 76, North-Holland Publishing Company, Amsterdam.

Fallon, J. (1982), "Disaggregation of the ORANI employment projections to statistical divisions – Theory", *ORANI Research Memorandum*, archive No. OA0160, April, pp. 5.

Fan, Z. (2008), "Armington meets Melitz: introducing firm heterogeneity in a global CGE model of trade", *Journal of Economic Integration*, Vol. 23(3), September, 2008, pp. 575-604.

Fox, A., W. Powers and A. Winston (2008) , "Textile and Apparel Barriers and Rules of Origin: What's Left To Gain after the Agreement on Textiles and Clothing?", *Journal of Economic Integration*, Vol. 23(3), pp. 656-84..

Frisch, R. (1959), "A Complete Scheme for Computing All Direct and Cross Elasticities in a Model with Many Sectors", *Econometrica*, Vol. 27, April, pp. 177-196.

Gehlhar, M., A. Somwaru, P.B. Dixon, M.T. Rimmer and R.A. Winston (2010), "Economywide Implications from US Bioenergy Expansion", *American Economic Review: Papers & Proceedings 100*, May.

Giesecke, J.A. (2002), "Explaining regional economic performance: an historical application of a dynamic multi-regional CGE model". *Papers in Regional Science*, Vol. 81(2), April, pp. 247-78.

Goettle, R.J., M.S. Ho, D.W. Jorgenson, D.T. Slesnick and P.J. Wilcoxen (2007), 'IGEM, an Inter-Temporal General Equilibrium Model of the U.S. Economy with Emphasis on Growth, Energy, and the Environment," paper prepared for the U.S. Environment Protection Agency, July, pp. 68, available at http://www.economics.harvard.edu/faculty/jorgenson/files/IGEM%20Documentation.pdf

Hanoch, Giora (1971) "CRESH Production Functions", *Econometrica*, Vol. 39, September, pp. 695-712.

Harrison, W.J., J.M. Horridge and K.R. Pearson (2000), "Decomposing simulation results with respect to exogenous shocks", *Computational Economics*, Vol. 15(3), June, pp. 227-49.

Harrison, W.J., J.M. Horridge, K.R. Pearson and G. Wittwer (2004), "A Practical Method for Explicitly Modeling Quotas and Other Complementarities", *Computational Economics*, Vol. 23(4), June, pp.325-41.

Hertel, T. (1994), "Taking IMPACT Abroad: the Global Trade Analysis Project", paper presented at the IFAC Meetings on Computational Methods in Economics and Finance, Amsterdam, June 8, pp. 26, available as technical document PPAP0077 on http://www.monash.edu.au/policy/archivep.htm .

Hertel, T.W. editor (1997), *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, Cambridge, U.K.

Hertel, T.W. and L.A. Winters, editors (2006), *Poverty and the WTO: Impacts of the Doha Development Agenda*, New York, Palgrave MacMillan.

Hertel, T.W., S.K. Rose, R.S.J. Tol, editors (2009), *Economic Analysis of Land Use in Global Climate Change Policy*, Routledge, pp. 348.

Higgs, P.J., B.R. Parmenter and R.J. Rimmer (1983), "Modelling the Effects of Economy-Wide Shocks on a State Economy in a Federal System", *Working Paper No. OP-37*, IMPACT Project, Melbourne, pp. 40.

Higgs, P.J., B.R. Parmenter and R.J. Rimmer (1988), "A Hybrid Top-Down, Bottom-Up Regional Computable General Equilibrium Model", *International Regional Science Review*, Vol. 11(3), pp. 317-28.

Ho, M.S. and D.W. Jorgenson (1994), "Trade Policies and U.S. Economic Growth", *Journal of Policy Modeling*, Vol. 16(2), pp. 119-46.

Horridge, J.M., B.R. Parmenter and K.R. Pearson (1993), " ORANI-F: a general equilibrium model of the Australian economy", *Economic and Financial Computing*, Vol. 3(2), pp. 71-140.

Horridge, J.M., B.R. Parmenter, , M. Cameron, R. Jourbert, A. Suleman and D. de Jongh (1995), "The macroeconomic, industrial, distributional and regional effects of government spending programs in South Africa", *CoPS/IMPACT Working Paper G-109*, pp. 43, available at http://www.monash.edu.au/policy/ftp/workpapr/g-109.pdf .

Hudson, E.A. and D.W. Jorgenson (1974), "U.S. Energy Policy and Economic Growth, 1975-2000", *Bell Journal of Economics and Management Science*, Vol. 5(2), Autumn, pp. 461-514.

Industries Assistance Commission (1983), *The Dairy Industry*, Report No. 333, Australian Government Publishing Service, Canberra.

Johansen, L. (1960), *A Multisectoral Study of Economic Growth*, Contributions to Economic Analysis 21, North-Holland Publishing Company, pp. x+177.

Johansen, L. (1974), *A Multisectoral Study of Economic Growth, second enlarged edition*, Contributions to Economic Analysis 21', North-Holland Publishing Company, pp. x+274.

Johnson, D. (1985), “The short-term economic effects of environmental constraints on forest industries”, *Review of Marketing and Agricultural Economics*, Vol. 53(3), pp. 149-56.

Jorgenson, D.W. (1963), “Capital Theory and Investment Behavior” *The American Economic Review*, Vol. 53(2), Papers and Proceedings of the Seventy-Fifth Annual Meeting of the American Economic Association, May, pp. 247-259.

Jorgenson, D.W. (1984), “Econometric methods for applied general equilibrium analysis” pp. 139-203 in H.E. Scarf and J.B. Shoven (editors), *Applied General Equilibrium Analysis*, Cambridge University Press, New York.

Jorgenson, D.W. and K-Y Yun (1986a), “The efficiency of capital allocation”, *Scandinavian Journal of Economics*, Vol. 88(1), pp. 85-107.

Jorgenson, D.W. and K-Y Yun (1986b), “Tax policy and capital allocation”, *Scandinavian Journal of Economics*, Vol. 88(2), pp. 355-77.

Jorgenson, D.W. and P.J. Wilcoxen (1993), “Energy, the Environment and Economic Growth”, pp. 1267-1349 in A.V. Kneese and J.L. Sweeney, editors, *Handbook of Natural Resource and Energy Economics*, Vol. III, North-Holland, Amsterdam.

Jorgenson, D.W., L.J. Lau and T.M. Stoker (1980), “Welfare comparison under exact aggregation”, *American Economic Review*, Vol. 70, pp. 268-72.

Jorgenson, D.W., L.J. Lau and T.M. Stoker (1981), “Aggregate consumer behavior and individual welfare”, in D. Currie, R. Nobay and D. Peel (editors) *Macroeconomic Analysis*, Groom-Helm, London.

Jorgenson, D.W., L.J. Lau and T.M. Stoker (1982), “The transcendental logarithmic model of aggregate consumer behavior”, in R.L. Bassmann and G.F. Rhodes Jr (editors) *Advances in Econometrics*, Vol. 1, JAI Press, Greenwich.

Kallrath, J. (2004), *Modeling Languages in Mathematical Optimization*, Kluwer Academic Publishers, Mass.

Kehoe, T.J. (2005) ‘An Evaluation of the Performance of Applied General Equilibrium Models of the Impact of NAFTA,’ in Timothy J. Kehoe, T.N. Srinivasan, and John Whalley, editors, *Frontiers in Applied General Equilibrium Modeling: Essays in Honor of Herbert Scarf*, Cambridge University Press, 341–77.

Keller, W.J. (1980), *Tax incidence: a General Equilibrium Approach*, Contributions to Economic Analysis 134, North-Holland Publishing Company, pp. xv+348.

Leontief, W.W. (1936), “Quantitative Input-Output Relations in the Economic System of the United States”, *The Review of Economics and Statistics*, Vol. 18(3), August, pp. 105-125.

Leontief, W.W. (1941), *The Structure of the American Economy 1919-1929*, Harvard University Press, Mass.

Leontief, W., A. Morgan, K. Polenske, D. Simpson and E. Tower (1965), “The economic impact – industrial and regional – of an arms cut”, *Review of Economics and Statistics*, Vol. XLVII, pp. 217-241.

Liew, L.H. (1981), *A multi-regional, multi-sectoral computable general equilibrium model of the Australian economy*, Ph. D. thesis, Monash University, Melbourne.

Liew, L.H. (1984), “Tops-down versus bottoms-up approaches to regional modelling”, *Journal of Policy Modeling*, Vol. 6(3), Auguest, pp. 351-67.

Longva, S., L. Lorentsen and O. Olsen (1985), "The multi-sectoral growth model MSG-4: formal structure and empirical characteristics", pp. 187-240 in F.R. Forsund, M. Hoel and S. Longva (editors), *Production, Multi-Sectoral Growth and Planning*, Contributions to Economic Analysis 154, North-Holland Publishing Company, pp. xvi+337.

MacLaren, D. (1997), "An evaluation of the Cairns Group strategies for agriculture in the Uruguay round" in T.W. Hertel (editor), *Global Trade Analysis: Modeling and Applications,* Cambridge University Press, Cambridge, U.K.

Madden, J.R. (1990), "FEDERAL: A two-region multi-sectoral fiscal model of the Australian economy", *PhD Thesis*, University of Tasmania, Hobart, Australia.

Madden, J.R. (1996), "FEDERAL: A Two-Region Multisectoral Fiscal Model of the Australian Economy", pp. 347-52 in L. Vlacic, T. Nguyen, andD. Cecez-Kecmanovic (editors) *Modelling and Control of National and Regional Economies: Proceedings*, Pergamon, Oxford.

Manne, A.S. (1963), "Key sectors of the Mexican economy 1960-1970", pp. 379-400 in A.S. Manne and H.M. Markowitz, editors, *Studies in process analysis*, New York, Wiley.

Martin, W. and L.A. Winters, editors (1997), *The Uruguay Round and the Developing Countries,* Cambridge University Press, Cambridge UK.

Meeraus A. (1983), An algebraic approach to modeling", *Journal of Economic Dynamics and Control*, Vol. 5(1), pp. 81-108.

Melitz, M.J. (2003), "The impact of trade on intra-industry reallocations and aggregate industry productivity", *Econometrica*, Vol. 71(6), pp. 1695-1725.

Naqvi, F. and M.W. Peter (1996), "A Multiregional, Multisectoral Model of the Australian Economy with an Illustrative Application", *Australian Economic Papers*, Vol. 35(66), pp. 94-113.

Osborne, S. (2007), "Energy in 2020: assessing the economic effects of Commercialization of cellulosic ethanol", *U.S. Department of Commerce, International Trade Administration*, pp. 20, available at www.trade.gov/media/publications/pdf/cellulosic2007.pdf .

Parmenter B.R. and J. M. Horridge (1994), "Exporting Economic Models: CoPS' Experience in South Africa and Asia", *CoPS/IMPACT Working Paper G-199*, pp. 22, available at http://www.monash.edu.au/policy/ftp/workpapr/g-199.pdf .

Parmenter B.R. and G.A. Meagher (1985), "Policy analysis using a computable general equilibrium model: a review of experience at the IMPACT Project", *Australian Economic Review*, Vol. 1'85, pp. 3-15.

Pearson, K.R. (1988), "Automating the Computation of Solutions of Large Economic Models", *Economic Modelling*, Vol. 5(4), pp. 385-395.

Petri, P.A. (1976), "A multilateral model of Japanese-American trade", pp. 481-98 in S. Polenske (editor), *Advances in Input-Output Analysis*, Ballinger Publishing Company, Mass.

Powell, A.A. (2007), "Why, how and when did GTAP happen? What has it achieved? Where is it heading?" *CoPS/IMPACT Working Paper G-167*, pp. 23, available at http://www.monash.edu.au/policy/ftp/workpapr/g-167.pdf .

Powell A.A. and Tony Lawson (1990), "A decade of applied general equilibrium modelling for policy work", pp. 241-290 in L. Bergman, D. Jorgenson and E.

Zalai (editors). *General Equilibrium Modeling and Economic Policy Analysis*, Basil Blackwell, Massachusetts.

Powell A.A. and R.H. Snape (1993), "The contribution of applied general equilibrium analysis to policy reform in Australia", *Journal of Policy Modeling,* Vol. 15(4), pp. 393-414.

Productivity Commission (2000), *Review of Australia's General Tariff Arrangements: Inquiry Report*, Australian Government, Canberra, available at http://www.pc.gov.au/projects/inquiry/tariff/docs/finalreport .

Rattso, J. (1982), "Different macro closures of the original Johansen model and their impact on policy evaluation", *Journal of Policy Modelling*, Vol. 4(1), March, pp. 85-97.

Rauscher, M. (1999), Review of: T.W. Hertel (editor), Global Trade Analysis: modeling and Applications, *Economic Journal*, Vol. 109(459), November, pp. F799-800.

Robinson, S. (2006), "Macro Model and Multipliers: Leontief, Stone, Keynes, and CGE Models", Chap. 11, pp.205-32, in A. de Janvry and R. Kanbur (editors), *Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke*, Springer, New York.

Rutherford, T. (2006), "GTAP6inGAMS", available at http://www.mpsge.org/gtap6/ .

Sandee, J. (1960), *A long-term planning model for India*, New York, Asia Publishing House and Calcutta, Statistical Publishing Company.

Scarf, H.E. (1967a), "The approximation of fixed points of a continuous mapping", *SIAM Journal of Applied Mathematics*, Vol. 15(5), pp. 328-343.

Scarf, H.E. (1967b), "On the computation of equilibrium prices", in W. Fellner, editor, *Ten essays in honor of Irving Fisher*, New York, Wiley.

Scarf, H.E. (1973), *The computation of economic equilibria*, New Haven/London, Yale University Press, pp. x + 249.

Schreiner, P. and K.A. Larsen (1985), "On the introduction and application of the MSG model in the Norwegian planning system", pp. 241-69 in F.R. Forsund, M. Hoel and S. Longva (editors), *Production, Multi-Sectoral Growth and Planning*, Contributions to Economic Analysis 154, North-Holland Publishing Company, pp. xvi+337.

Shoven, J.B. and J. Whalley (1972), "A general equilibrium calculation of the effects of differential taxation of income from capital in the U.S.", *Journal of Public Economics*, Vol. 1, pp. 281-321.

Shoven, J.B. and J. Whalley (1973), "General equilibrium with taxes: A computational procedure and an existence proof", *Review of Economic Studies*, Vol. 40, pp. 475-489.

Shoven, J.B. and J. Whalley (1974), "On the computation of competitive equilibrium in international markets with tariffs", *Journal of International Economics*, Vol. 4, pp. 341-354.

Shoven, J.B. and J. Whalley (1984), "Applied General-Equilibrium Models of Taxation and International Trade: An Introduction and Survey", *Journal of Economic Literature*, Vol. 22, September, pp. 1007-51.

Spurkland, S. (1970), "MSG – A tool in long-term planning" report prepared for the *First Seminar on Mathematical Methods and Computer Techniques*, organized by the United Nations Economic Commission for Europe, Varna.

Staelin, C.P. (1976), "A general equilibrium model of tariffs in a non-competitive economy", *Journal of International Economics*, Vol. 6(1), pp. 39-63.

State Information Centre and China-Australia Governance Program (2010), *International Conference on the SIC-GE Model and Policy Simulations*, Proceedings of a conference held on 15-16 April 2010 at the Beijing GuoHong Hotel. These proceedings will be formally published by the Chinese Academy of the Social Sciences.

Sutton, J. (1976) "The solution method for the ORANI module", *Preliminary Working Paper No. OP-03*, IMPACT Project, Melbourne, pp. 52.

Sutton, J. (1977) "Computing manual for the ORANI model", *IMPACT Computing Document C1-01*, IMPACT Project, Melbourne, pp. 59.

Taylor, L. and S.L. Black (1974), "Practical general equilibrium estimation of resource pulls under trade liberalization", *Journal of International Economic*, Vol. 4(1), pp. 35-58.

Taylor, L., E.L. Bacha, E.A. Cardoso and F.J. Lysy (1980), *Models of growth and distribution for Brazil*, Oxford University Press for the World Bank, New York.

United States International Trade Commission (2004, 2007 & 2009), *The Economic Effects of Significant U.S. Import Restraints: Fourth, Fifth and Sixth Updates*, Investigation No. 332-325, Publications 3701, 3906 and 4904.

Vincent, D.P. (1982), "Effects of higher oil prices on resource allocation and living standard: The case of Korea", *The Developing Economies*, Vol. XX, pp. 279-300.

Vincent, D.P. (1985), "Exchange rate, devaluation, monetary policy and wages: a general equilibrium analysis for Chile", *Economic Modelling*, Vol. 2, pp. 17-32.

Vincent, D.P. (1990), "Applied general equilibrium modelling in the Australian Industries Assistance Commission: perspectives of a policy analyst" pp. 291-347 in L. Bergman, D. Jorgenson and E. Zalai (editors). *General Equilibrium Modeling and Economic Policy Analysis*, Basil Blackwell, Massachusetts.

Vincent, D.P., P.B. Dixon and A.A. Powell (1980), "The Estimation of Supply Response in Australian Agriculture: the CRESH/CRETH Production System", *International Economic Review*, Vol. 21(1), pp.221-242.

Walmsley, T., L.A. Winters, S.A. Ahmed and C.R. Parsons (2005), "Measuring the Impact of the Movement of Labour Using a Model of Bilateral Migration Flows", GTAP resource 1921 available at https://www.gtap.agecon.purdue.edu/resources/download/2398.pdf .

Wittwer, G. and J.M. Horridge (2010), "Bringing regional detail to a CGE model using census data", *Spatial Economic Analysis*, Vol. 5(2), June, pp. 229-55.

Yang, Y., W. Martin and K. Yanagishima (1997), "Evaluating the benefits of abolishinh the MFA in the Uruguay Round package" in T.W. Hertel (editor), *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, Cambridge, U.K.

Zhao, K. (2010), "Modelling the effect of the new social security scheme for rural-urban migrant workers", pp. 14 (in Chinese), in State Information Centre and China-Australia Governance Program, *International Conference on the SIC-GE Model and Policy Simulations*, Proceedings of a conference held on 15-16 April 2010 at the Beijing GuoHong Hotel. These proceedings will be formally published by the Chinese Academy of the Social Sciences.