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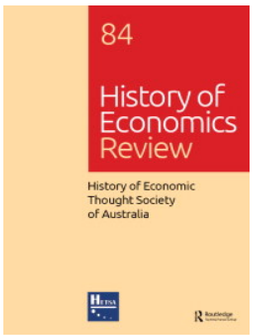

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H. David Evans, 1941–2022: Progenitor of Computable General Equilibrium Modelling in Australia

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ABSTRACT

David Evans was an Australian who completed a path-breaking PhD thesis at Harvard in 1968 under the supervision of Wassily Leontief. The thesis set out Australia's first computable general equilibrium (CGE) model, with an application to an analysis of Australia's then policy of high tariffs. David returned to Australia in 1968 but left in 1973 and spent the rest of his career in the UK. Despite his relatively brief time working in Australia, David was a major contributor to Australian economics. In this paper, I start with a few personal reminiscences about David. Then I explain how the Evans model worked, and its limitations. This is followed by a description of what happened in Australian CGE research in the 1970s, post-Evans. Since then, Australia has become well known in this field. The international reach of Australian CGE modelling is described briefly in the final part of the paper.

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David Evans; CGE modelling; linear programming; protection policy; IMPACT project

1. Introduction

David Evans was brought up in Perth and graduated in 1963 from the University of Western Australia with a first-class honours degree in economics. He credited his undergraduate teacher Professor Ian Bowen for kindling his interest in economic planning models. As an undergraduate he wrote seeking research advice from Wassily Leontief at Harvard. Later, he was admitted to Harvard where in 1968 he completed a path-breaking PhD thesis under Leontief's supervision. The thesis set out Australia's first computable general equilibrium (CGE) model, with an application to an analysis of what was then Australia's policy of shielding industries from import competition by imposing high tariffs and other protective devices.

David returned to Australia in 1968 but left in 1973 and spent the rest of his career in the Institute of Development Studies at the University of Sussex. He died in April 2022, surrounded by family. He was 81.

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Despite his relatively brief time working in Australia, David was a major contributor to Australian economics. He was also my friend and a person I respected. He influenced my early career choices.

In this paper, I start with a few personal reminiscences about David. Then I explain how the Evans CGE model worked, and its limitations. This is followed by a description of what happened in Australian CGE research in the 1970s, post-Evans. Since then, Australia has become well known in this field. The international reach of Australian CGE modelling is described briefly in the final part of the paper.

2. Impressions

Big, powerful and handsome, that was our first impression of David when he met my wife Orani and me at Boston's Logan airport late on a September night in 1968. It was our first time in the US. We had been travelling from Melbourne for 36 hours. I was enrolled for a PhD in economics at Harvard and our plan was for Orani to get a job to keep us afloat financially. We were excited, nervous and unsure.

David had been in the Harvard economics program for four years and was about to finish his PhD. Within half an hour we had our second impression. We knew that he was kind, generous and thoughtful. He took us in his tiny VW Beetle to a friend's apartment where there was a spare bed for the rest of the night. The next day he helped us find somewhere to live, gave us furniture, including a bed that he had built himself, and got us started on the practical business of living cheaply in the US. Still in that first week, he introduced Orani to Karen Polenske who gave her a research assistant job at the Harvard Economic Research Project. For me, he provided sound advice on what courses to take and how to handle a daunting first year assignment of writing two 10,000-word economic history essays.

Why did he do all this? Perhaps it was simply that he had old-fashioned Australian virtues which include helping out Australian mates in situations where you can make a difference, even if they are complete strangers.

My third impression of David came a couple of years later, long after he had left Harvard and taken an appointment at Monash University in Melbourne. By studying his PhD thesis, I came to understand that David had outstanding intellectual abilities. He had built a 35-industry general equilibrium model of the Australian economy. The thesis was an eye-opener. It showed me the power of the general equilibrium method in getting beyond the first-round effects of policy changes and exposing the ultimate effects. The Evans model was technically innovative and the thesis was meticulously written. It strongly influenced my own choice of thesis topic and future research direction.

A revised version of the thesis (Evans 1972) was published by North-Holland in their prestigious series, *Contributions to Economic Analysis*. In a postscript, David revealed characteristics that are unusual for a young, technically sophisticated economist. He was modest and uncertain about the value of his contribution. Now, more than 50 years later, there can be no doubt that what David did was highly significant.

3. David's Thesis and Protection in Australia

In the 1960s when David was writing his thesis, protection of manufacturing against competition from imports was a major economic and political issue in Australia. Protectionist policies dated from federation of the Australian states in 1901, and intensified during the 1930s. By 1969, effective rates of protection on Australian manufacturing industries averaged 46%.[1] Economists in Australia understood that tariffs and import quotas were reducing Australia's standard of living.[2] But the problem was how to transition from high protection to low protection. The unresolved question was: what would happen to people employed in protected industries such as footwear, textiles, clothing and motor vehicles?

In his thesis, David tackled this question with the emerging technique of CGE modelling.[3] These models are built around input-output tables, an invention for which Leontief received the 1973 Nobel Prize in Economics. An input-output table is a two-dimensional array of numbers showing for a year all of the transactions in the economy. The rows of an input-output table identify commodities and primary factors of production (labour, capital and land). The columns identify economic agents (industries, households, government, capital creators and foreigners). Looking along a row we see the sales pattern of a commodity or primary factor. Looking down a column we see purchases made by an agent.

An input-output table is a static representation of the economy, a snapshot. CGE modelling introduces equations that describe how each cell of the input-output table responds to a change in economic policies and other aspects of the economic environment. In David's development and application of CGE modelling, the Australian input-output table responded to hypothetical reductions in tariffs and relaxations of import quotas. David's model showed that lowering protection would reduce the value of the Australian dollar in terms of other currencies thereby benefiting exporting activity in mining, agriculture and internationally competitive parts of manufacturing. At the same time, Australian households would benefit from lower-priced, higher-quality consumer goods. While not dismissing transition problems, David's modelling indicated that reductions in protection would open up new employment opportunities for workers displaced by increased imports.

Before the advent of CGE modelling (and for quite a long time afterwards) calculations of effective rates were used to give answers to questions such as: to what extent did the tariff system allow the Australian motor vehicle industry to be larger (use more labour and capital) than would have been the case in the absence of tariffs? For each industry, effective rate of protection calculations took account of two factors. The first was the tariff applying to imports of the product that competed with that produced by the industry. The second was the tariffs applying to imports of products that were used by the industry as intermediate inputs. For the Australian motor vehicle industry, the effective rate was increased by the tariff on imported cars and reduced by the tariffs on steel and other intermediate inputs used in making cars. It was known that other factors may also be important in determining the inter-industry resource allocation effects of a tariff system. Corden (1966) discussed in qualitative terms adjustments to effective-rate calculations to take account of exchange rate

movements and the tradability of an industry's product. However, quantification remained elusive.

David's model quantified the importance of exchange rate effects and export orientation. His results predicted inter-industry resource allocation effects from reductions in tariffs that are only weakly correlated with effective rates of protection – see Evans (1971 and 1972, ch. 5).

4. The Evans Model

The Evans model was formulated and solved as a linear programming (LP) problem.[4] In the LP problem, the Australian economy maximized the level of consumption (a combination of private and public) in a *snapshot* year, usually 10 years after an initial or database year in which an assumed policy reform takes place. In the main publication on the model, Evans (1972), the initial year was 1958 and the final year was 1968.

Consumption in the snapshot year was limited by various constraints including:

- consumption of each commodity must be no more than output *plus* imports *minus* exports *minus* the use of the commodity as an input to current production and capital creation (investment) *minus* government purchases of the commodity using tariff revenue and revenue from other indirect taxes;[5]
- output in an industry must be no more than is allowed by the capital available to the industry;
- capital available to an industry is the industry's capital in the initial year *plus* net capital installed between the initial year and the snapshot year;
- capital creation in each industry in the snapshot year must maintain the rate of growth in the industry's capital stock implied by the model for the period from the initial to the snapshot year;
- employment added across industries must not exceed the exogenously given level for aggregate labour supply in the snapshot year;
- the total value of imports must be no greater than the total value of exports *plus* an exogenously given value for the trade deficit; and
- total revenue from tariffs and other indirect taxes must be at least as great as the sum across commodities of the relevant rates and quantities.

In addition to labour supply, the exogenous variables for the snapshot year in the Evans model are fob export prices, cif import prices, tariff and subsidy rates, and technology coefficients such as labour and capital requirements per unit of output in each industry and intermediate-input requirements per unit of output and per unit of capital creation in each industry. Economic growth between the initial year and the snapshot year was dictated by the exogenously specified movements between the two years in aggregate employment and technology variables.

The solution to the LP problem together with its dual[6] revealed an equilibrium in which: households maximize utility subject to their budget constraint; markets for primary factors and commodities clear; pure profits in all production and trade

activities are zero; and rates of return on investment in each industry are equalized. By comparing solutions of the model for the snapshot year computed with different values for the tariff and subsidy rates, David was able to project the long-run effects (effects after 10 years) of movements to free trade.

Post-PhD, David continued at Monash University working on a more elaborate version of his model. He was the central researcher on the Monash Project financed by a grant from the Australian Research Grants Commission and directed by Professor Alan Powell. David expanded the industry dimension of his model from 35 to about 100 and did an enormous amount of work on the data underlying the technology coefficients, particularly those concerned with capital and investment. He worked hard to represent in his model not only tariffs but also home-price support schemes, export subsidies and other aspects of Australia's trade policies. However, despite his best efforts at Monash, David was not able to progress his modelling much beyond his PhD thesis. In my view, he was severely hamstrung by the LP method. Perhaps the difficulties he was experiencing played a role in the rather pessimistic postscript to his North-Holland book and in his decision to leave Australia in 1973 and to pursue different lines of research in England.

5. Limitations of the LP Method

This method was a natural generalization of Leontief's input-output model. Whereas final demands are exogenous in the input-output model, in the LP formulation they become endogenous, determined by optimization. LP ideas were prominent in Leontief's group at the Harvard Economic Research Project (HERP) where David was a research student and at Harvard's Centre for International Affairs (Hollis Chenery's group) where David had friends who were building LP planning models for developing countries. So it is unsurprising that David went down the LP path.

As became increasingly apparent in the decade after David's PhD thesis, LP is a clumsy framework for handling price-induced substitution effects such as substitution between capital and labour in production, substitution between commodities in household consumption, and substitution between domestic and imported commodities in satisfying demands. In the LP framework, most substitution elasticities are implicitly either zero or infinity. For example, in the Evans model each industry used capital and labour in fixed proportions (zero elasticity of substitution) while users of commodities were indifferent between domestic and imported varieties (infinite elasticity of substitution). This latter assumption is particularly problematic in a model concerned with trade. Under this assumption, small changes in domestic/import price ratios can lead to extreme and unrealistic movements in the shares of domestic and imported goods in satisfying demands by consumers and industries for cars, apparel, machinery and other importable commodities. Extreme specialization in the commodity composition of exports was another problem in LP models in which fob export prices are unresponsive to volumes of exports (no terms-of-trade effects). To prevent extreme results for trade variables, it was necessary to include in the Evans model rather arbitrary devices such as lower bounds on industry outputs and maximum and minimum bounds on the exports of some commodities.

Indifference curves for consumers and isoquants for producers with shapes between right-angles (zero substitution elasticity) and straight lines (infinite substitution elasticity) can be specified in LP models. This is done by approximating conventionally shaped curves by curves composed of linear pieces.[7] But the process is tortuous, error-prone and sapping of research energy. I suspect that for David to make satisfactory progress along those lines was too difficult in a large model with policy-relevant detail.

6. The Next Generation of CGE Modelling for Australia

I was fortunate in following David at HERP and in having Leontief as a supervisor. In my thesis I used input-output data and linear programming, just as David did, but not for Australia and not with David's intense policy focus. My first job after completing my PhD in 1972 was at the IMF. The induction program included a lecture on the IMF's multi-lateral exchange rate model (MERM).[8] At that time, MERM was a 15-country model in which each country produced one commodity (called GDP) and consumed 15 commodities (its own commodity and the 14 commodities from the other countries). Having studied David's work and having been supervised by Leontief, I was incensed (I was young and easily incensed) by the absence in MERM of industry and input-output detail.[9] However, two features of MERM resonated with me. First, was the use of what became known as the Armington assumption[10] through which the 15 products consumed in each country were treated as imperfect substitutes. This overcame the LP weakness of extreme sensitivity of import shares. Second, was the solution method. MERM was specified as a system of easily-solved linear equations in which the variables were percentage changes away from the base-period situation. For example, rather than equating the supply of country j's commodity to the sum over all countries in their demands for this commodity, in MERM the *percentage change* in the supply of j's commodity was equated to a weighted average of *percentage changes* in demands, where the weights were the shares of the purchasing countries in j's total sales.

In a percentage-change system, the introduction of price effects was straightforward. Household demand equations, for example, could be written as linear equations in which:

> the percentage change in the demand for commodity i equals the percentage change in the household budget multiplied by the expenditure elasticity of demand for commodity i *plus* the percentage change in the price of each commodity j multiplied by the price elasticity of demand for i with respect to changes in the price of j.

There was one drawback: linearization errors. Sales shares, cost shares and expenditure and price elasticities were treated as parameters, when theory suggests that they are affected by prices and incomes. The linear percentage-change system gives truly accurate results only for the effects of infinitesimally small shocks (changes in policies, technologies, etc.). For shocks of practical interest, the solution from the linear percentage-change system is only approximate. To me, obtaining an approximate solution to a model incorporating realistic price-sensitive behaviour[11] seemed

preferable to obtaining an exact solution to an LP model in which most price sensitivities are assumed away while others are exaggerated.

In between the rather light duties of a junior officer of the IMF, I thought about what I had learned from studying David's thesis and what I was learning from analysing MERM. Together with Subhash Thakur, also a junior IMF officer, I tried to build the ideal price-sensitive Evans-MERM model for Korea. For technical reasons, that I subsequently understood, our effort failed.

In 1975, there was another opportunity to build the ideal model. This came to me through the IMPACT Project which was set up by agencies in the Australian government to model the relationships between the macro economy, demographic change and industry development. The driving force behind the creation of IMPACT was Alf Rattigan,[12] the legendary chairman of the Industries Assistance Commission (IAC). The IAC's role was to advise the government on industry matters, particularly the use of tariffs and other devices designed to protect industries from import competition. Rattigan and his second-in-command, Bill Carmichael, were aware of the Monash Project and the Evans model. They appreciated the potential that CGE modelling offered for quantifying the implications of protection policy not only for protected industries but also for other industries such as those relying on export markets. Rattigan appointed Alan Powell as director of the IMPACT Project. Powell's strategy was to create a macro team, a demography team and an industry team.[13] He hired me to lead the industry team. In preparation for this task I recreated the Evans model and computed LP solutions, see Dixon and Butlin (1977). This was a valuable exercise for the work ahead.

Under inspiring leadership and management by Powell, my IMPACT colleagues, Brian Parmenter, John Sutton, David Vincent, George Ryland and I produced the ORANI model. This combined the best of MERM and Evans. Like MERM, the initial version of ORANI was a linear percentage-change system with imported and domestic products treated as imperfect substitutes.[14] A major effort was made to estimate the import/domestic substitution elasticities.[15] Like the Evans model, ORANI was policy-oriented with over 100 industries.

In addition to the standard input-output linkages, the model specified the demand for margin services (transport and wholesale and retail trade) required to facilitate flows from producers (or ports of entry for imports) to users (or ports of exit for exports). Along with the role of margin services, the model included the distinction between purchaser prices (which motive demands) and producer prices (which motivate supplies).

In common with MERM, the 1977 version of ORANI suffered from linearization errors which reduce the reliability of results for the effects of large shocks. By 1982, we were able to refine the solution method so that it produced exact solutions for ORANI even for large shocks.[16] This was done by solving the model in steps. For example, if we were interested in the effects of a 20% tariff cut, then in the first step we might use the linearized equations to compute the effects on all prices and quantities of a 10% cut. Our program then updated the input-output database so that it showed the situation in which tariffs were 10% lower. With the updated database the program revaluated all the sales shares, cost shares, price and income elasticities and other coefficients in the linearized system. Using this updated system, the program

then computed the effects of another cut in tariffs sufficient to complete the required 20% cut. If two steps did not give sufficient accuracy then it was a simple matter to undertake more steps.

Starting in the mid-1980s, Ken Pearson and colleagues at the IMPACT Project created GEMPACK (the General Equilibrium Modelling PACKage), a modelling platform that enabled CGE modellers throughout the world to solve their own models using the multi-step solution method.[17]

7. From Australia to the Rest of the World

The Australian style of CGE modelling with a focus on trade and with equations expressed in linear percentage-change form and solved in GEMPACK is now prominent in many parts of the world. The Centre of Policy Studies (CoPS) which evolved from IMPACT sells GEMPACK licences to about 700 modelling organizations in about 95 countries. CoPS currently undertakes about 50 contracts a year for the supply of model development and application services in Australia, the US, Canada, China, Indonesia, Netherlands, Finland, South Africa, India, Brazil and many other countries. In these contracts, CGE modelling is used to elucidate economic aspects of trade, environment, taxation, immigration, micro-economic reform, infrastructure provision, labour markets, epidemics, natural disasters and terrorism events.

The formation of the Global Trade Analysis Project (GTAP) at Purdue University in the 1990s arose from its founder, Tom Hertel, spending a sabbatical year at the IMPACT Project in 1990–91. The GTAP network now has a membership of 20,000 researchers from about 150 countries. Many of these people use the GTAP global model which is easily recognizable as a multi-country generalization of the ORANI model. The Australian role in GTAP is acknowledged by the naming of its major annual award in honour of Alan Powell.

David's work was an important first step in this Australian research success story.

Notes

1. See Tariff Board (1971, 30). An effective rate of 46% means that the protected industry is able to compete with imports in the home country even though its use of capital and labour per unit of output is 46% higher than would be competitive in the absence of tariffs or other protective measures.
2. See for example Corden (1957).
3. The 1960s predate the adoption of the name CGE for this class of models. The expression CGE seems to have come into general use after the publication of Adelman and Robinson (1978).
4. Routine computer programs for solving moderately large LP problems were available in the 1960s, based on Dantzig's algorithm developed at the Pentagon during the 1940s: see Dantzig (1951). Using these programs was highly inconvenient by modern standards, requiring modellers of David's generation to cope with thousands of punch cards, days of delay at the computer centre and copious reams of computer printout.
5. In the Evans model, revenue from tariffs and other indirect taxes is used by the government to purchase units of the private/public consumption composite. These units are not included in the LP maximand but are included in welfare calculations. In this way, the Evans model correctly captures the distorting effects of tariffs and indirect taxes.

6. In the dual problem, prices of primary factors and commodities are determined by calculating the increases in consumption that would be made possible by unit increases in factor and commodity supplies. The relationship between a general equilibrium and the solution to an LP problem and its dual was well understood in the 1960s: see Dorfman, Samuelson, and Solow (1958, ch. 13).
7. The method is explained by Hadley (1964, ch. 4). For an application to general equilibrium modelling, see Dixon (1978).
8. See Artus and Rhomberg (1973).
9. My critical review of MERM was published after I left the IMF: see Dixon (1976).
10. See Armington (1969, 1970).
11. Johansen (1960) used a linear percentage-change system to give approximate solutions of his model of Norway, now recognized as the first CGE model. Outside Norway, Johansen's solution technique was largely overlooked for about 15 years. As explained in the text, I became aware of the technique via MERM, published without reference to Johansen in 1973. Johansen used his percentage-change system to handle price-induced substitution between capital and labour, and between commodities in household consumption. However, without the Armington specification of import-domestic substitution he did not achieve a satisfactory treatment of trade.
12. Rattigan (1986, ch. 13) gives a fascinating account of how the IMPACT Project was created and how it was saved in its early infancy in 1976 from the 'Razor gang' set up by the newly elected government of Malcom Fraser.
13. See Powell (1977).
14. See Dixon et al. (1977).
15. See Dixon et al. (1977), Alaouze (1976) and Alaouze, Marsden, and Zeitsch (1977).
16. See Dixon et al. (1982, chs 2 and 5).
17. See Codsi and Pearson (1988), Harrison and Pearson (1996) and Horridge et al. (2013).

Disclosure statement

No potential conflict of interest was reported by the author.

Notes on contributor

Peter Dixon is a professor in the Centre of Policy Studies at Victoria University Melbourne. His main research contributions have been in the development and application of computable general equilibrium models.

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