

CENTRE of

POLICY

STUDIES and

the IMPACT

PROJECT

Eleventh Floor
Menzies Building
Monash University Wellington Road
CLAYTON Vic 3168 AUSTRALIA

Telephone:
(03) 905 2398, (03) 905 5112

from overseas:
61 3 905 2398 or
61 3 905 5112

Fax numbers:
(03) 905 2426, (03)905 5486

from overseas:
61 3 905 2426 or 61 3 905 5486

e-mail

impact@vaxc.cc.monash.edu.au

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Integrating Econometric and Environmetric Modelling

by

Alan A. POWELL

Monash University

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ABSTRACT

This paper is organized around brief accounts of two modelling initiatives, one with an Australian and the other with a global focus, which have contributed to the policy debate about greenhouse gas abatement. The Australian study involved the combined use of an energy technology programming model, MENSA/MARKAL, with an applied general equilibrium model of the Australian economy, ORANI-F. This interfaced suite of models was used to inform the Australian government's consultations on environmentally sustainable development. The second study involves the *Global 2100* model, which also uses a mathematical programming model of energy technology, but couples it to a macro, rather than an applied general equilibrium model. The latter study is one of several, each based on a different model, used as an input to OECD deliberations on greenhouse.

After giving brief accounts of the interfaces between the econometric and economic component modules of ORANI-F\MENSA/MARKAL and of *Global 2100* and a synopsis of what insights into global warming have come out of these models, I set out my ideas about how better interfaces between econometric and econometric models can be achieved. These suggestions relate more to the 'culture' of modelling than to technicalities. It seems that the technical (often model-specific) problems encountered at the interfaces will be more tractable if everyone involved adopts the same computer modelling language and standards of documentation. Modellers from both sides will have to discipline themselves to keep their component models down to a size that allows the interfaced system to be solved using computer resources that are routinely available.

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INTEGRATING ECONOMETRIC AND ENVIRONMETRIC MODELLING

Alan A. Powell

Monash University

1. INTRODUCTION

In this paper 'econometric' will be used in its generic sense, thus embracing *all* quantitative approaches to economic argument (rather than just those that contain a statistical inferential element). A similarly catholic interpretation will be used for 'environmetric'.

The discussion below is organized around brief accounts of two modelling initiatives, one with an Australian and the other with a global focus, which have contributed to the policy debate about greenhouse gas abatement. Whilst the focus is thus quite specific, the studies are, I think, representative of what is currently afoot in attempts to put together insights from environmental science and from economics.

The paper is organized as follows. Section 2 contains preliminary remarks about what economics has to offer to environmental analysis. As seems well known, economists so far have been better at working out the costs, rather than the benefits, of environmental programs. Attention is drawn to recent progress on the economic measurement of benefits.

Section 3 contains brief accounts of the interfaces between the environmetric and economic component modules of an Australian model used to inform debate during the Australian government's consultations on environmentally sustainable development, and of the *Global 2100* model. The latter is one of several models used by the OECD to examine the impact on the world economy of cutting CO₂ emissions.

Section 4 contains highlights from the findings of the studies made with the two models. Because some of the insights are difficult to obtain without formal economic logic, they may at first seem surprising to environmental scientists without a background in economics.

Section 5 contains my ideas about how better interfaces between econometric and environmetric models can be achieved. These suggestions relate more to the 'culture' of modelling than to technicalities.

Concluding remarks are offered in Section 6.

2. WHAT ECONOMETRIC MODELS OFFER

Most environmental applications to date of econometric models have concentrated on the *costs* of achieving given environmental targets. Examples include Jorgenson and Wilcoxon's assessment [11] of the impact of environmental protection legislation upon US economic growth in the 'seventies and 'eighties, the estimation [2] by Adams, Dixon and Parmenter of the probable effects through 2002 on the Australian economy of reducing CO₂ emissions so as to meet Australia's commitments to the Toronto targets, and the recent OECD-sponsored comparative study [17] of the global economic impacts of CO₂ abatement.

The last-mentioned compares simulations from six multiregional global models: this succeeds in pinpointing many areas where uncertainty about model parameters has major impact on the results. One such key parameter is the likely future rate of autonomous improvement in the efficiency of energy use: "a difference of 0.5 per cent per annum ... can lead to an outcome [i.e., CO₂ emissions] in 2100 which is as much as 20 billion tons different (corresponding to over three times the emission level in 1990)" (Dean and Hoeller in [6], p. 13). Other parameters critically affecting the results are those characterizing the degree of substitutability among commodities (especially raw energy forms) in production and consumption.

Economic studies attempting to quantify the *benefits* of environmental policies have been much rarer than those dealing with costs. I don't think the reason has anything to do with the prejudices of economists as a group. The plain truth is that the benefits are more difficult to characterize economically than the costs. From this it does not follow that they are less significant, nor deemed to be so, by economists! While an appropriate methodology for the measurement of benefits remains a controversial matter (see, for example, the recent volume on the contingent valuation method [9]), some progress does seem imminent — Bergman's *environmentally adjusted net national product (ENP)* [3] is particularly promising because it is easily related to well understood and accepted modes of economic analysis. Briefly, the method consists of defining an environmental quality index that enters directly into calculations of economic welfare. Although estimation of the parameters of this index inevitably is far from clear cut, Bergman did succeed in calibrating his index (at least in an exploratory way) to Swedish data. The trick was to assume that existing taxes on pollutants gave useable guidance about the public's willingness to pay for environmental quality — presumably, if the taxes had exceeded this willingness, the Swedes would have changed their government at the first opportunity!

The key feature of the studies [2], [3] and [11] cited above, as well as much of the work reported in [17] — and indeed the bulk of quantitative economic work on the environment — is the visualization of the economy as a *system*. Thus unlike the Club of Rome's first consciousness-raising study of the *Limits to Growth* [15], most economic modellers have attempted to capture the homeostatic mechanisms at work in the economies they studied. Such mechanisms usually involve increasing relative prices as signals of accelerating

scarcity, with consequent feedbacks upon the rate at which the scarce entity is utilized, together with the increasing use, where available, of substitutes. This is why empirical estimation of substitution elasticities is so important for the quantitative results produced by economic models.

This use of a systems approach *by economists*, however, does tend to be restricted to the *economy*. To do environmental problems justice we need a similar way of viewing the *bio-*, *geo-* and *atmospheres* (or more properly, the global environmental system) and the *polity* (the national and international political/social systems). And in an ideal world, we would know how to integrate all of them into a single system. But for reasons touched upon below in Section 5, such holism is likely to remain a dream in the foreseeable future.

3. EXAMPLES OF INTERFACES BETWEEN ENVIRONMETRIC AND ECONOMETRIC MODELS

Most economists are aware of environmetric modelling *at the macro level*, but scarcely at all at the micro level. The form in which they expect to receive inputs from environmentally focussed disciplines is as a set of schedules (or better, models) detailing how economic activity (production, investment, consumption) affects the environment. Different technologies will produce different pollutants in different intensities. Under the assumption (made by virtually all economists) that producers seek to minimize costs, any given pollution abatement target will imply a choice of technology.

3.1 An Australian model of CO₂ abatement

The process of interfacing an energy model with environmental content with a large-scale model of a national economy (Australia) is illustrated in Figure 1. The MENSA/MARKAL model has been described by Adams, Dixon and Jones [1] in the following terms:

'MENSA is a model of Australia's production and use of energy. It was originally developed as a variant of MARKAL which is a general, non-country-specific framework. MARKAL was built under the sponsorship of the International Energy Agency and was first used in Australia in the early 1980s (see Musgrove *et al.* [16]). In later Australian work, MARKAL was extended by the addition of a regional dimension (Stocks and Musgrove [21]). The resulting ... model is presently maintained by Intelligent Energy Systems in Sydney. The Australian Bureau of Agricultural and Resource Economics (ABARE) also runs [it].'

MENSA/MARKAL is a large dynamic linear programming model which chooses technologies and activities in a detailed representation of the energy sector so as to minimize 'system cost'. ORANI-F (Horridge *et al.* [10]) is the forecasting version of ORANI (Dixon *et al.* [7]) which is a large multisectoral model of the Australian economy consisting of many thousands of non-linear equations. ORANI is frequently used for policy analysis (Powell and Snape [19]).

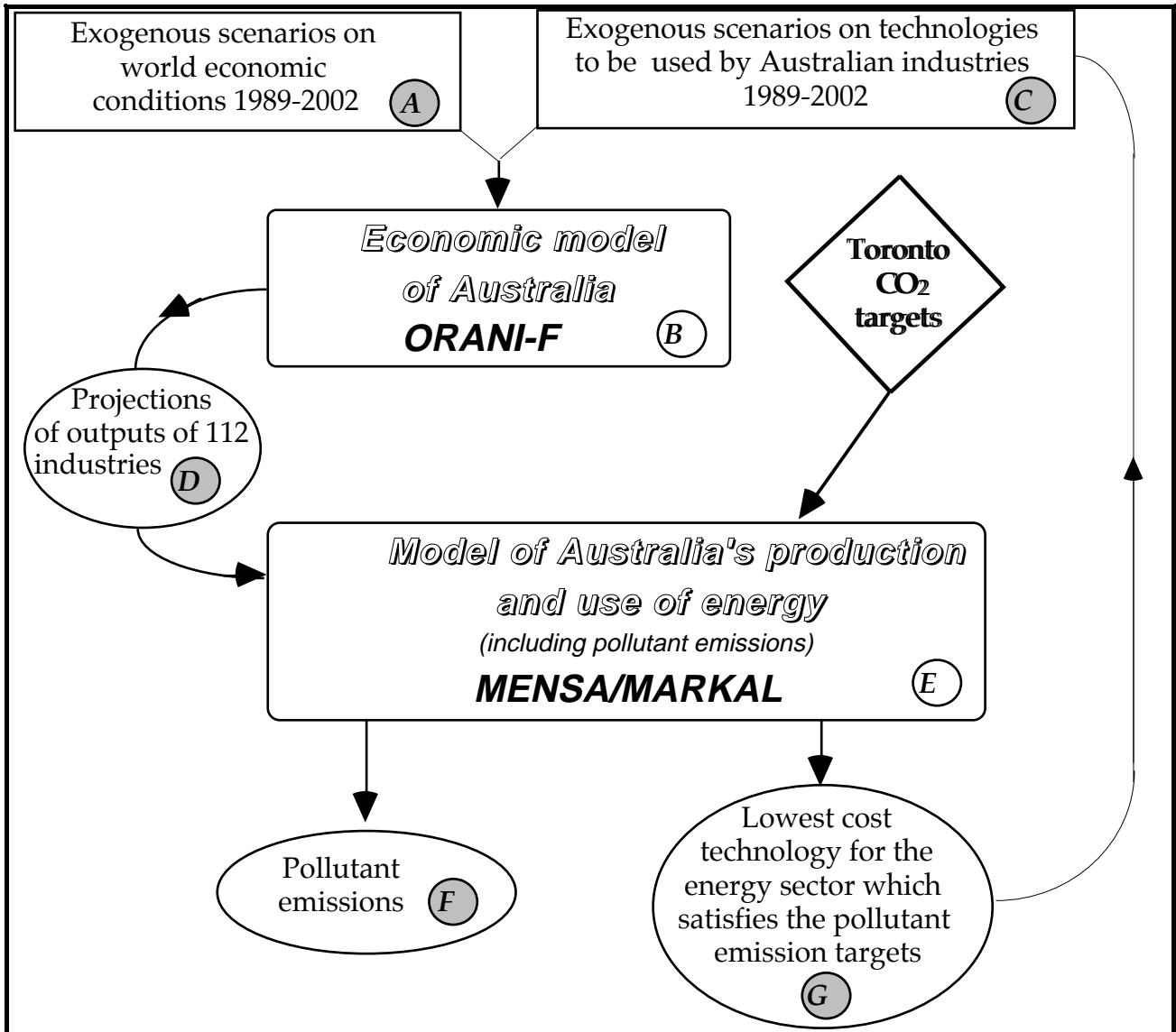


Figure 1 Flow chart for the interface of ORANI-F with MENSA/ MARKAL. The simplest interface has computation terminating at *F* and *G* after one pass through; in the most comprehensive (fully simultaneous) interface, computation would cycle back to *C* and iterate to solution. Note that MENSA/MARKAL solves for the technologies in the energy sector that will minimize overall costs subject to meeting the Toronto emission standards.

Reference [2] reports the results of a study using ORANI-F\MENSA/MARKAL as part of the Australian government's consultations on environmentally sustainable development. The focus of this study was the abatement of CO₂ emissions. The exercise commences with the writing of scenarios on the multitude of variables which are exogenous to the Australian economy as modelled by ORANI-F. With very few exceptions,

Australia is a small enough player on the world scene to allow one to ignore feedbacks from the local economy onto these scenarios. ORANI-F then produces a fairly detailed picture of outputs by industries.

In the next step these output levels are fed to the MENSA/MARKAL model, together with CO₂ emission limits based on the Toronto targets. MENSA/MARKAL then searches for the least-overall-cost set of technologies, and activity levels at which to operate them, which deliver n the outputs previously determined by ORANI-F, whilst staying within the Toronto limits.

At this stage, an inconsistency has arisen. The original technological scenarios on which the ORANI-F industry output projections were based will differ from those identified by MENSA/ MARKAL (see panels G and C of Figure 1). ORANI-F can be resolved under the new technological scenarios, yielding a new set of industry projections; and so on, until a full simultaneous solution of the interfaced system is found.

3.2 A global model of CO₂ abatement

Manne's study [13] uses a similar set-up within each of five linked regional models — one each for the USA, the other OECD (OOECD) countries, the former USSR, China and the rest of the world (ROW). The model (built by Manne and Richels [12]) is geopolitically comprehensive — a must for global analysis of environmental issues. Its environmetric components are generically known as ETA, Energy Technology Assessment models, while its econometric models go under the generic label of MACRO. Figure 2 depicts one of the five ETA \MACRO interfaces.

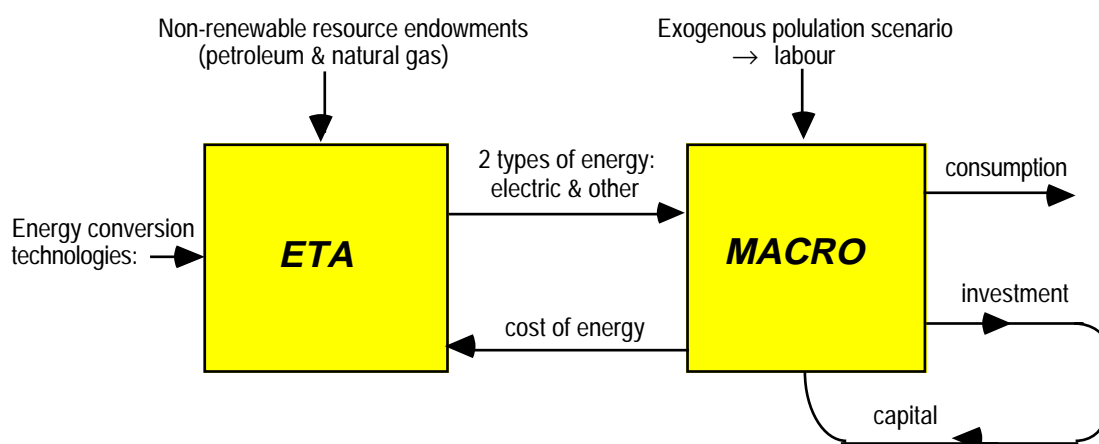


Figure 2 Flow chart for the interfaces of the energy technology assessment (ETA) modules with the economic modules (MACRO) within regions of Manne's *Global 2100* model (after Manne [13]).

The MACRO models are *much* less detailed than ORANI-F. Thus relative to the Australian study, Manne's global study may miss changes in the energy (and pollutant)

intensity of GDP that are brought about by *compositional* changes in the economy (say favouring energy-efficient industries under the imposition of a carbon tax). This, of course, could be fixed *ex post* by changing the values of certain macro coefficients within *Global 2100* (the name of the complete model obtained by linking the five ETA\MACRO regional models) to reflect the changed composition of GDP. But for guidance on this issue, separate recourse to more detailed national models would be necessary. Nevertheless, the (relatively) compact size of *Global 2100* does have advantages, as will be seen below.

In practice, in the Australian study [2], the iterative procedure depicted in Figure 1 was terminated after one recycling from G to C. The reasons for this curtailment tell us something about the practicality of building interfaces between large models, especially ones with disparate parentage. On the other hand, in Manne's study [13], the full simultaneous interface was implemented. Before further discussing the interfacing issue, a brief survey of the simulation results from the two studies is given in Section 4.

4. SYNOPSES OF THE RESULTS OF AN AUSTRALIAN AND A GLOBAL CO₂ ABATEMENT STUDY

4.1 The Australian study

Not surprisingly, the impact of CO₂ abatement policies is felt most directly in the energy sector. Achievement of the targets, according to MENSA/MARKAL, results in significant increases in the costs of electricity generation as natural gas is substituted for coal. According to ORANI-F, this results in reduced real GDP and wages. Because existing coal-burning equipment must be scrapped early, and because the cleaner replacement technologies are more expensive, additional capital needed in the electricity generating sector leads to increased levels of investment which crowd out consumption.

The implications for the coal industry depend on what is happening in the rest of the world. If world demand for coal stays strong (which suggests that globally the Toronto targets are *not* being met), then the coal that would have been used by Australian industries (especially by producers of electricity) is simply exported — along with its pollution potential. If reduced overseas demand prevents such exportation, then the local coal mining industry contracts substantially.

The issues canvassed in the preceding paragraph raise the prospect which has seriously worried policy makers in the OECD countries: would a rigorous unilateral enforcement of the Toronto targets by its member countries just lead to the relocation of polluting industries in the Third World? Is it possible, likely even, that global emissions of greenhouse gases would *not* decline? Some of the global studies reported in [17] shed light on these questions.

4.2 Manne's global study

Growth of population and of the economies of less developed regions features prominently in the simulations reported in the OECD comparative models study [17]; Manne's study is no exception. The common exogenous population scenario used by all six models entailed a rise in population

'from 5.3 billion in 1990 to 9.5 billion in 2050 and to 10.4 billion by 2100, by which time it is hardly growing at all (World Bank projections); nearly all of the growth is in China and other developing countries ...' (Dean and Hoeller, [6], p.14).

In the common base-line (business-as-usual) scenario, the rate of growth of real GDP was projected to slow down to 1 per cent per annum by the year 2100 in the OECD, and to fall from 4 to 3 per cent per annum for developing countries. In this scenario, oil prices are projected to rise in real terms by six 1990 US dollars per barrel per decade, reaching 50 (1990) US dollars in 2030, and remaining unchanged after that date. The three CO₂ abatement scenarios have emissions growing in *all* regions by 1, 2 and 3 percentage points per annum *less* than in the business-as-usual scenario. These abatement scenarios were chosen to standardize the simulations across the six models in the OECD study; they have no policy significance.

The 2 per cent abatement scenario 'would require absolute cuts [in CO₂ emissions, relative to 1990] in the OECD and in the former Soviet Union and allow some continued, albeit very low growth elsewhere' (Dean and Hoeller [6], p.14). In Manne's *Global 2100* simulations, the 2 per cent scenario produces a fall in total carbon emissions from about 6 billion tons in 1990 to about $4\frac{1}{2}$ billion tons in 2100 ([13], p. 58).

The issue of relocation of polluting activities is addressed head-on in *Global 2100*.

'...it is assumed that carbon emissions are imposed in such a way as to have minimum impact on economic growth. For a market economy, this could be accomplished by auctioning off carbon emission rights.' (Manne [13], p. 59).

Making such rights internationally tradeable allows the abatement targets to be reached at considerably lower cost than could be achieved otherwise. The former USSR has vast reserves of natural gas which it would not be able to exploit under the 2 per cent scenario (since to do so would involve exceeding its allowable emissions). Natural gas is a cheaper energy form than the 'back-stop' technologies that have to be adopted in the OECD countries by the middle of the next century. World demand for energy-intensive products can be satisfied at a lower cost if the OECD is allowed to sell some of its emission quotas to the former USSR. If international trade in emission rights is allowed, the former USSR becomes a substantial purchaser of emission rights, importing the right to emit 0.3 billion tons annually of carbon from each of the US and the OOECD in 2100.

The significance for China and other developing countries of the *Global 2100* simulations is made explicit by Manne in the following quotation:

'As of 1990, the industrialized countries (USA, OECD and [former] USSR) generated about 2/3 of the global emissions total. According to *Global 2100*, their emissions continue to grow during the 21st century, but those from China and the ROW will increase at a much more rapid rate. The overall result is that the share of the USA, OECD and USSR drops to only 30 per cent by the year 2100. Clearly, if there is to be a meaningful global agreement, the currently industrialized countries cannot be the only participants. China and the ROW will also have to bear a portion of the burden.' ([13], p. 57)

What sorts of sacrifices are involved in reducing CO₂ emissions? Under the 2 per cent abatement scenario, *Global 2100* puts the costs in 2100, as a percentage deviation below base-line GDP, at the following values:

| | | | | | | | | | |
|----|-----|------|-----|----------------|-----|-------|-----|-----|-----|
| US | 3.1 | OECD | 1.9 | former USSR | 5.6 | CHINA | 5.0 | ROW | 5.6 |
|----|-----|------|-----|----------------|-----|-------|-----|-----|-----|

Source: Manne [13], p.61

All of the results quoted above, of course, come with *caveats*. And there are substantial differences between the *Global 2100* results and those obtained with other models. But all things considered, a good measure of agreement seems to be emerging, at least between Manne's work and that encapsulated in the OECD's GREEN model (see Oliveira Martins *et al.* [17] and Manne [14]).

5. SCOPE FOR BETTER INTEGRATED MODELS

What scope exists for better integration of environmetric and econometric models? And what pay-offs can be expected from better integration?

In the case of the two models discussed above, a serious attempt at integration was made. It was not completely successful, however, in the case of the Australian model. This was in part due to tight deadlines for the completion of the study but also due to more fundamental factors. Both MENSA/MARKAL and ORANI-F are large models, and at least in the case of (the successor to) ORANI-F, still growing. In stand-alone mode their solution requires access to superior hard- and software. Mounting both models on the same computer platform under a single controlling program would put the enterprise at the frontier of computing technology. We will not be seeing such large models integrated as a routine matter, at least for some time to come.

Compared to ORANI-F, *Global 2100* has a regional dimension to cope with, as well as detailed temporal disaggregation. (The successor to ORANI-F, the MONASH model currently under construction, will have detailed temporal disaggregation.) On the other hand, the dimensionality of the economic models in *Global 2100* is tiny by comparison with ORANI-F. This simplification allows the former model to be solved with a fully simultaneous interface (admittedly, with access to superlative computation resources — human and otherwise).

Questions of size aside, the existence of strong *discipline-based imperatives* also limits scope for integration. As the availability of hard- and software improves, there is always a backlog of enhancements that the modellers in each camp are just itching to implement. As the horizon of possibilities expands, what we tend to get is bigger and better environmetric and bigger and better econometric models, rather than a better integration of the two.

Communication between disciplines is rarely easy. Chances are that the econometric and environmetric models to be interfaced will involve modellers from different disciplines. If they are to communicate, a *sine qua non* is comprehensive documentation of the models — not only their mathematics and their computer systems, but also plain language descriptions of their principal mechanisms. To this must be added complete documentation of data and parameter files, with their provenance noted.

As formidable as the obstacles mentioned above may be, environmental scientists and economists *will* make the effort where the pay-offs seem substantial to both. Given that the environment now is permanently on the political agenda, many instances are sure to arise in which the incentives to co-operate are strong. If global warming proceeds in the manner predicted by many climatologists, the pressure to develop integrated models will become irresistible. Given the useful insights coming out of models with relatively primitive interfaces, however, one should not become obsessed with the idea of integration for its own sake. On occasions it will suffice to 'man-handle' the interchange of information between the models.

How can better interfaces be built? Because the larger models are already at the limits of routine computation, prototypes of interfaced models must be developed in exactly the same way that prototypes are developed for *any* large model: all non-essential dimensionality must be shed. In the case of models in the ORANI family the number N of industries is routinely aggregated from over 100 to about a dozen during the exploration of new developments; with solution times approximately proportional to N^3 , this reduction in size makes it possible to turn around developmental runs many times during the course of a day. Similar condensations of environmetric prototypes must be feasible.

After prototype development, the size of operational version of the interfaced model will necessarily increase. Given the difficulties experienced with manipulating and solving very large models, this process of allowing the model to 'fill out' should be circumspect. An extension of Occam's razor will be helpful here. We should be asking ourselves: is the additional complexity really necessary to achieve the purposes of the model? Or would a simpler structure supplemented by sensitivity analysis achieve the same ends?

With dimensionality reduced to manageable proportions, the question remains as to how to implement the interface. There should be no problem in identifying a natural division of 'labour': each of the component models should be used to endogenize the variables with respect to which that model is stronger. In the examples above, the strength of the environmetric models was in technological choice, and in quantifying the pollutant

emissions flowing from the use of each technology. The strength of the economic models was in assessing how changing cost conditions led to changed production, consumption, international trading patterns, and living standards.

Finally, as has been stressed above, computation is a non-trivial issue. Clearly, the choice of hard- and software would best be made jointly. There exist powerful modelling languages ([4], [5], [8]) commonly used by economic modellers which almost certainly are also suitable vehicles for the implementation of environmetric models. Quite likely there are computer packages familiar to environmental scientists (but not to me) which economic modellers would find useful. Ideally the econometric and the environmetric modules of the combined model would be written in the same computer modelling language and have access to the same battery of solvers (solution algorithms). If the modelling language used is transparent (i.e., close to ordinary algebra), then provided ample comments are retained, the computer implementable version of the model provides definitive documentation and allows easy transfer between professionals and computer installations — at least this has been the experience of the community of economic modellers using the GEMPACK [5], [8] and GAMS [4] modelling languages.

6. CONCLUDING REMARKS

The perception of a global environmental crisis (greenhouse) arose just as economic modellers had mastered the art of simulating the impacts of diverse shocks on fairly detailed computer representations of economies (the technique is known as computable or applied general equilibrium analysis). The subsequent large research investment by national and international organizations into abatement of greenhouse gases (especially CO₂) created the necessity of interfacing models built by scientists, engineers and operations researchers with models built by economists. Results to date are promising. However it seems that the technical (often model-specific) problems encountered at the interfaces will be more tractable if everyone involved adopts the same computer modelling language and standards of documentation. Modellers from both sides will have to discipline themselves to keep their component models down to a size that allows the interfaced system to be solved using computer resources that are routinely available.

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REFERENCES

- [1] Adams, Philip D., Peter B. Dixon and Barry Jones, The MENSA model: an exposition. Centre of Policy Studies, Monash University, Discussion Paper D155, July 1992.
- [2] Adams, Philip D., Peter B. Dixon and Brian R. Parmenter, Prospects for the Australian economy 1989-90 to 2001-02: ORANI-F projections for the ecologically sustainable development working groups. Chapter 6 in Hargreaves, C. (ed.), *Macroeconomic modelling of the long run* pp. 119-157. Edward Elgar, Aldershot (U.K.), 1992.
- [3] Bergman, Lars, General equilibrium costs and benefits of environmental policies: some preliminary results based on Swedish data. Paper presented at the Fondazione ENI Enrico Mattei conference, 'Modelling Environment Economy Linkages', Milan, December 1992; and at the Fourth CGE Modeling Conference, University of Waterloo, Ontario, October 1993.
- [4] Brooke, Anthony, David Kendrick and Alexander Meeraus, *GAMS: a user's guide*, Scientific Press, Redwood City, 1988.
- [5] Codsì, G. and K. R. Pearson GEMPACK: General-purpose software for applied general equilibrium and other economic modellers, *Computer Science in Economics and Management*. 1 189-207, 1988.
- [6] Dean, Andrew and Peter Hoeller, Costs of reducing CO₂ emissions: evidence from six global models. In OECD [17], pp. 13-36.
- [7] Dixon, P. B., B. R. Parmenter, J. Sutton and D. P. Vincent (1982) *ORANI: a multisectoral model of the Australian economy*. North-Holland, Amsterdam, 1982.
- [8] Harrison, W. Jill and K.R. Pearson An introduction to GEMPACK, Monash University, Clayton, Vic., Australia, Impact Project, GEMPACK document GPD-1, First edn, April 1993.
- [9] Hausman, J. A. (ed.), *Contingent valuation – a critical assessment*. North-Holland, Amsterdam, 1993.
- [10] Horridge, J. M., B. R. Parmenter and K. R. Pearson, ORANI-F: a general equilibrium model of the Australian Economy. *Economic and Financial Computing* 3(2) 71-140, 1993.
- [11] Jorgenson, Dale W. and Peter J. Wilcoxon, Environmental regulation and U.S. economic growth. *Rand Journal of Economics* 21(2) 314-340, 1990.
- [12] Manne, A. S. and R. Richels, *Buying greenhouse insurance – the economic costs of CO₂ emission limits*. MIT Press, Cambridge, Massachusetts, 1992.

- [13] Manne, Alan S., Global 2100: alternative scenarios for reducing carbon emissions. In OECD [17], pp. 55-65.
- [14] Manne, Alan S., International trade — the impact of unilateral carbon emission limits. Paper presented at the International Conference on the Economics of Climate, OECD/IEA, Paris, June 1993; and at the Fourth CGE Modeling Conference, University of Waterloo, Ontario, October 1993.
- [15] Meadows, Donella H. *et al.* *The limits to growth: a report to the Club of Rome's project on the predicament of mankind.* Earth Island Ltd, London, 1972.
- [16] Musgrove, A. R. deL., K. J. Stocks, P. Essam, D. Le, J. V. Hoetzel, Exploring some Australian energy alternatives using MARKAL. CSIRO, Division of Energy Technology, Lucas Heights Research Laboratories, NSW, Technical Report TR2, 1983.
- [17] OECD, *The costs of cutting carbon emissions: results from global models.* OECD Documents, Paris, 1993.
- [18] Oliveira Martins, Joaquim, Jean-Marc Burniaux, John P. Martin and Giuseppe Nicoletti, The costs of reducing CO₂ emissions: a comparison of carbon tax curves with GREEN. In OECD [17], pp. 67-94.
- [19] Powell, Alan A. and Richard H. Snape, The contribution of applied general equilibrium analysis to policy reform in Australia. *Journal of Policy Modeling* 15(4) 393-414, 1993.
- [20] Rutherford, T.F., General equilibrium modelling with MPS/GE. Department of Economics, University of Western Ontario, London, Ontario, 1989.
- [21] Stocks, K. J. and A. R. deL. Musgrove, MENSA — a regionalized version of MARKAL, the IEA linear programming model for energy systems analysis. *Energy Systems and Policy* 8(4) 313-348, 1984.