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Southern Africa – Towards Inclusive Economic Development

Using economy-wide modelling for South African policy analysis

An introduction

Rob Davies and Dirk van Seventer

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Southern Africa –Towards Inclusive Economic Development (SA-TIED)

SA-TIED is a unique collaboration between local and international research institutes and the government of South Africa. Its primary goal is to improve the interface between research and policy by producing cutting-edge research for inclusive growth and economic transformation in the southern African region. It is hoped that the SA-TIED programme will lead to greater institutional and individual capacities, improve database management and data analysis, and provide research outputs that assist in the formulation of evidence-based economic policy.

The collaboration is between the United Nations University World Institute for Development Economics Research (UNU-WIDER), the National Treasury of South Africa, the International Food Policy Research Institute (IFPRI), the Department of Monitoring, Planning, and Evaluation, the Department of Trade and Industry, South African Revenue Services, Trade and Industrial Policy Strategies, and other universities and institutes. It is funded by the National Treasury of South Africa, the Department of Trade and Industry of South Africa, the Delegation of the European Union to South Africa,IFPRI, and UNU-WIDER through the Institute's contributions from Finland, Sweden, and the United Kingdom to its research programme.

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Towards Inclusive Economic Development in Southern Africa

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ABSTRACT

This paper introduces a framework of advisory basic principles to be employed by users of economy-wide models such as those used in policy analysis in South Africa and in SA-TIED papers.

JEL classification: C 30, C 68

1 INTRODUCTION

One of the attractions of building models on computers is that we know when the models 'work' in a purely technical sense: the equations solve, producing numbers that apparently give specific answers to questions. However, this attraction can also be a disadvantage, especially for beginner modellers. They often rush to the technical aspects, focussing on getting the model to 'work', rather than thinking about the economics of what they are trying to do. Most effort is focussed on computer programming, on finding neat ways to get the computer to provide an 'answer', rather than thinking about the economics of what is being done, why they get the 'answers' they do, and whether the lessons learned are applicable and useful outside the model.[1]

This paper provides a background for those implementing and interpreting economy-wide models, particularly computable general equilibrium (CGE) models. Such economy-wide modelling is not a purely technical exercise. Model-building is a tool that helps us think more clearly about aspects of the economic problem at hand and, in order to be effective, modellers' advice to policy makers needs to be presented in ways that can be understood. For understandable reasons political leaders might respond to the advice with scepticism, saying 'that may be fine in theory but not in the real world'. Such scepticism is based, however, on a misunderstanding of models and their role in the policy process.

This paper is a brief introduction designed to enable both modellers and policy-makers in South Africa understand the nature of models, the positive role they can play in policy-making and their limitations. Mary Morgan (Morgan, 2012) and many works referred to there explore similar issues in greater depth. This paper is intended as a complement to the several papers published by SA-TIED that use economy-wide models to develop policy insights for South Africa.

2 WHAT ARE MODELS?

Models are abstractions from reality

Economics and economists are often criticized for using models.[2] However, ordinary people use models on a daily basis. Reality is complex and does not explain itself. It is clearly impossible to describe reality in every detail. It is also not very useful, particularly if we want to understand it. When trying to explain something or to make an argument, not only in economics but also in everyday life, we all leave out irrelevant details. The quote from Paul Krugman in Box 1 applies not only to economics. We construct models all the time, even if only implicitly: a model is an abstraction from reality, based on a set of assumptions, focussing on the key aspects of the issue at hand while leaving out those features of reality that are judged irrelevant.

> *Any time you make any kind of causal statement about economics, you are at least implicitly using a model of how the economy works. And when you refuse to be explicit about that model, you almost always end up – whether you know it or not – de facto using models that are much more simplistic than the crossing curves or whatever your intellectual opponents are using.*
>
> Paul Krugman, Blog, October 9, 2014

1 Of course this problem is not confined to CGE modelling, but also affects econometric or any other economic modelling.

2 This criticism is often made by economists themselves. See for example Axel Leijonhuvhud, Life among the econ', *Western Economic Journal*, September 1973.

Theorists commonly encounter critics who claim to be 'practical' and to let the facts speak for themselves. But 'facts' do not speak. They are mental constructs which only take on meaning and relevance when embedded in some theory or world view. What is a relevant fact in one context may be irrelevant in another.[3] Knowing what to include and what to leave out is part of the modelling craft.

Models are like maps

Models are similar to maps. All maps leave out some detail but are nevertheless useful for finding our way. There is not one map that suits all purposes: the road map of a country is not very helpful in finding a street address in a city.[4] Nor is a street map useful to find the way from one city to another 600 miles away. Modellers sometimes cite Borges' short story 'Del rigor en la ciencia' (On rigour in science) in which cartographers construct a map of an empire that is so accurate it is the same size as the empire. No one can use it and it is left discarded in the desert.

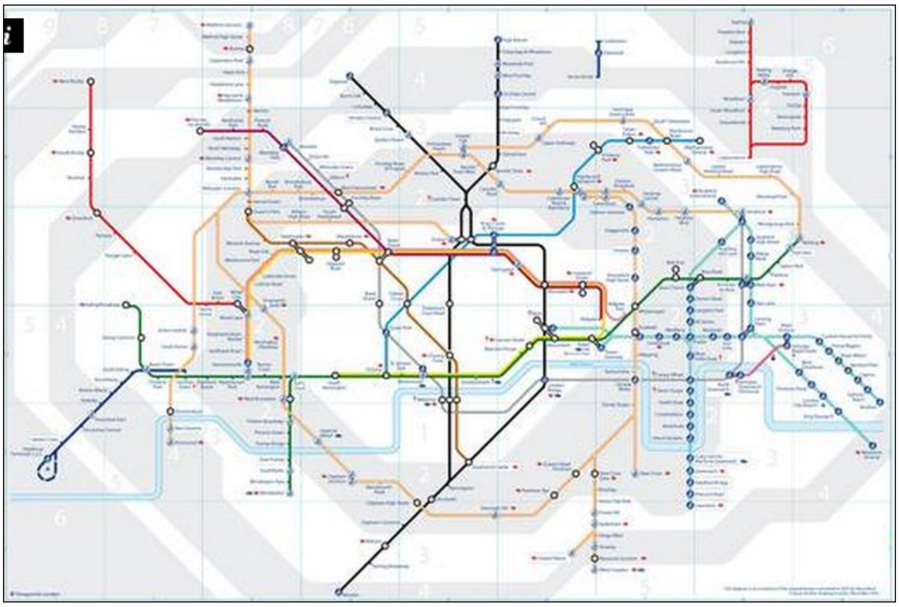

Figure 1: A Map of the London Underground
Source: http://www.reactivegraphics.co.uk/web-design-london-inspiration/

But maps not only reflect our view of the world they also influence it. Take for example the map of the London Underground. It is one of the cleverest and easiest to use maps ever constructed.[5] It helps

3 One of the present authors likes to recount a colleague who was asked for his opinion of a paper on alcoholism in Soweto. Having read the paper, he commented that he found it hard to discern the author's theoretical model. 'Oh,' replied the author, 'I went in with an open mind and wrote about what I observed.' 'But you do not mention street lights.' 'Street lights?' 'You must have seen street lights.' 'Yes, but what have they got to do with alcoholism?' 'Oh, so you did have a theory – one that excluded street lights.' (Note that we can easily construct theories as to why street lighting or its absence might influence alcoholism.)

4 Possibly Google Maps undermines this standard analogy.

5 According to [http://www.reactivegraphics.co.uk/web-design-london-inspiration/:](http://www.reactivegraphics.co.uk/web-design-london-inspiration/) The design of the London Underground map that we utilize across print and digital platforms of the London Underground map is an evolution of a design conceived by Harry Beck way back in 1913. The somewhat radical schematic transit map of London's public transit systems were cleverly drawn up by Beck under the premise that passengers riding the underground were not too bothered about geographical accuracy, but were more interested in how to get from one station to another…. [T]he map was refused on several occasions due to its geographical inaccuracy (despite design brilliance!) as stations were plotted like an electricity circuit diagram where distances are not as important as order.

even first-time visitors get around London very easily. But those who use only the Underground get a deeply embedded picture of its geographical reality: Kennington is directly north-east of Morden, Ealing Broadway directly due west of St Paul's. Even less 'realistic' than the directions are the distances. The stations along many of the lines appear equidistant; if you try walking them, you will find this is not so. The same is true for modellers and policy-makers using South Africa's Gautrain. The simplification that makes the system map easily usable for train passengers indicates relative distances between stations that are quite different from those shown on a scale map of the network's terrain (see Figure 2).

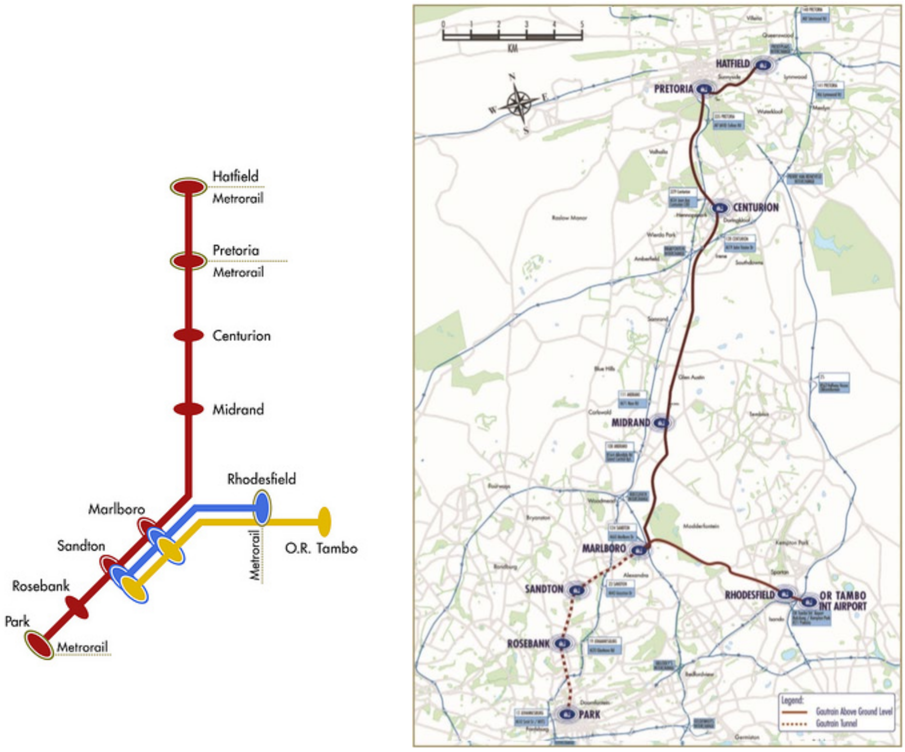

Figure 2: Maps of the Gautrain system
Source: https://www.gautrain.co.za/pdf/Gautrain_User_Guide_FA.pdf

And so it is with models. It is very easy for modellers to believe that their model *is* reality, at least in the domain it covers, especially when they have invested time and mental effort into constructing it. It may be useful in a particular setting to assume markets are perfectly competitive, or that there is full employment. We should be careful not to assume that these model constructs are a description of reality.

But economic models are not just pictures

The analogy with maps may give the wrong impression that models are just simplified representations of reality. Economists build a model not because they want to simplify a complex reality, but because they want to do things with it. They want to introduce some change – a policy innovation such as a carbon tax in South Africa, say[6] – and see what the ramifications are. They want the model to do some work for them. The analogy with maps breaks down in this respect. Adding a road to a map changes its depiction of reality, but nothing else happens. We want to build models where, if we change a tax, households' savings rates, a price, or the size of an industry, it sets off other changes. The model is a

6 Alton, T., Arndt, C., Davies, R., Hartley, F., Makrelov, K., Thurlow, J., & Ubogu, D. (2014). Introducing carbon taxes in South Africa. *Applied Energy*, 116, 344-354.

tool, not simply a set of instructions. We want to build it, change something in it, trace how it responds and then think about whether that response is likely to be the same in the 'real' world.

Simpler is better

Beginning modellers often want to construct 'the' model of a country, holding the view that the model should capture as much of that country's 'reality' as possible. However, given that models are tools to clarify our thinking, smaller and simpler models tend to be better. If a model becomes too complex – contains too many assumptions and details – it does not serve its purpose of helping us understand. This can be a problem when dealing with policy-makers, who often seem to want a 'model of everything'. This is understandable. The ways economists 'simplify' are often confusing to non-economists. Civilians can grasp sectors such as 'textiles' or 'mining', and therefore cope with the idea of a model that has tens or hundreds of such sectors. Economists may simplify things by combining these into 'tradable' and 'non-tradable' sectors. How can we add mining to textiles? This is a problem that policy modellers must confront: how can we construct models that are simple enough to give us answers we can understand but still explain the results in terms that our policy masters understand?

How simple should we aim to be? Abraham Lincoln, a tall and gangling man, is reputed to have been asked by a journalist trying to embarrass him, 'Mr President, how long do you think a man's legs should be?' His response – 'Long enough to reach the ground.' – could be applied to models. A model should be just complex enough to enable it to answer the question for which it was designed. Often the problem we are trying to unravel is so complex that a complicated model is unavoidable. When we have two models addressing the same problem, we might apply a version of Occam's razor: the simpler one is the better one.[7]

Note that there are two completely different ways in which models can be complex or big. Firstly, the behaviour built into them, the inter-relations, the functional forms – basically the model's structure – can be very complicated. Secondly, a model might be highly disaggregated. It may have hundreds of producers using dozens of factors to produce hundreds of products for thousands of households. In both cases we want to be sure that the features of the model are necessary for what we want to do with them; unnecessary complexity detracts from the model. But it is the complexity of the first type that we should seek to avoid. So many things are going on in them that it is hard to unravel any clear story. On the other hand, while the second type of model is definitely big, it may not be complicated. The functional form representing production might be the same for all producers, that representing demand the same for all households. We could reduce the size of the model easily by aggregating the data. We can grasp the fundamental structure easily. Of course, the bigness makes it hard to explain results, since there are so many channels through which effects can potentially work. But the underlying story is (relatively) simple.

The issue of bigness and complexity versus smallness and simplicity should be seen in the context in which the modelling is undertaken. In an academic environment, we are often interested in complex models but not generally in big ones. A 1000 x 1000 model that behaves the same way as a 3 x 3 one is uninteresting to the academic modeller: it imparts no new information. Indeed, it may obscure what we already know.[8] In a policy environment, however, bigness might be a virtue. Policy-makers are often interested in impacts on narrowly defined sectors; they *want* the empirical detail.

7 Occam's (or Ockham's) razor is a principle attributed to the 14th century logician and Franciscan friar William of Ockham, 1287–1347.

8 We can all sympathize with Lance Taylor's lament 'How one can understand what is going on with a million variables is a mystery to me, but perhaps the large teams now working on the models can do so' (Taylor, 2010).

Let a thousand models bloom

A consequence of searching for simplicity is that we need different models to answer different questions, just as we use different maps for different journeys. We might have a model that addresses one set of questions well. Then we get asked to address another set. Rather than trying to complicate our initial model, carrying along a lot of detail that is unnecessary for the current problem, we might construct a different, purpose-built one. So, the aim of modellers is not to construct a model of everything, but rather to construct a suite of models that can be used as appropriate, i.e., horses for courses.

All models are wrong, but some are useful

Since models are abstractions from reality, no model can be right in the sense that it has a complete correspondence with reality. As the statistician George Box has said, 'Essentially, all models are wrong, some are useful' (Box and Draper, 1987). Note that 'wrong' here refers to the model's correspondence with reality: models that are internally inconsistent are also wrong, but in an unacceptable and unuseful way.

Models and reality

Since models by definition do not completely correspond to reality, there is the question of how closely they have to do so to be useful. This is complicated and has been and will continue to be widely debated, not only by economists. It cannot be resolved here, but some observations are in order. At the risk of being regarded as naïve, a beginning could be the observation that usefulness is in the mind of the user. If a model clarifies some problem for you, it is useful. But clarifying problems for ourselves is generally not the final objective of our model building. We want to use the clarification to persuade and influence others. Our ability to do so will depend on many things, including not only how amenable the others are to being persuaded but also their perception of how 'realistic' our model is. So, it is desirable to have a more widely accepted method for assessing realism.

Of course, economics has a variety of methods for assessing a model's conformability to reality, econometrics being the main one. But there are many examples in economics of the failure of economists to agree on the relevance of a model, despite very sophisticated empirical methods being brought to bear on it. The art of persuasion requires one to understand one's audience; since economy-wide modelling in South Africa is directly or indirectly related to policy issues, the modeller needs to be able to address policy-makers. Often the more sophisticated the method, the less its power to convince policy-makers. They want something that 'makes sense'. This imposes a difficult burden on the analyst. It is often not the results of the model but the way in which the story is told that makes the results plausible in the eye of the (policy) master.

Once we view matters from this perspective, the question 'How realistic is the model? 'should really be 'How appropriate is the model for the problem at hand?'.

There is a large volume of writing on this, generally centring around whether models that have obviously unrealistic assumptions can be useful. One such assumption that is often focussed upon is that of 'perfect competition'. 'Full employment' is another. Many models incorporate both these assumptions, and such assumptions can be useful for certain analyses. But the important thing is to think about which assumptions are crucial in driving results and how sensitive results are to changing these assumptions. If the model results are particularly sensitive to some key assumptions, and those assumptions are patently false *in the context in which the model is being used*, that is not useful

3 EXPLICIT VERSUS IMPLICIT MODELS

Economists tend to make their models explicit, often writing them down formally in mathematical terms. This often opens them to criticism, not only from other modellers, but also from those who react against the formalization – people who fall into the second group of people referred to by Paul Krugman in the quote in Box 2. Often these criticisms question the very use of models. However, as was pointed out earlier, since everyone uses models – even people who do not realise they are using them – this seems to be a spurious argument. It is fundamentally a criticism of explicit models by someone whose model is implicit. This is different from focussed criticisms of specific methods of modelling or of the usefulness of a specific model. The paper assumes that the case for making models explicit is obvious, but nonetheless offers a few observations.

There are a variety of ways in which models can be made explicit. As already indicated, economists (and other disciplines) overwhelmingly use mathematics, but a model does not have to be mathematical. However, there have been only a few economists smart enough to be able to think through an economic problem correctly without the assistance of mathematics. Most of us must use algebra to help us think carefully and consistently, particularly when there are many components to the argument.

> *'Too many economists have the wrong attitude toward models. They're not Truth; they're intuition pumps, gadgets you use to clarify your story. You go badly wrong when you take them too seriously, and either forget that they're just models or reject them because the world isn't that simple.'*
>
> Paul Krugman, Blog September 11, 2014

Even when we use mathematics as our primary language of analysis, we will also use verbal language to provide at least an intuitive idea of the model. Some early economists tried to present their models entirely verbally.[9] However, we should differentiate between verbal presentations and using verbal methods of enquiry. It is the latter that is extraordinary difficult to get right

Apart from verbal and mathematical models in economics, the standard economists' toolbox includes the following:

- Econometric models which, using stochastic time series, cross-section or panel data as statistical measures of variables specified in theory, estimate the coefficients of stochastic models. In South African policy-making, the South African Reserve Bank's CORE model is a key macro-econometric model of that type.[10]
- CGE modellers, using computers, build and solve CGE models numerically to generate simulations of the effects of policy 'shocks' or other innovations. These are fundamentally mathematical, not statistical, models, giving deterministic solutions without stochastic error terms. Their non-stochastic character is the key simplification that makes them tractable compared to the random character of our real-world observations. But CGE models acquire relevance to actual economies by incorporating independently estimated coefficients into their equations and calibrating against observational data.
- Dynamic stochastic general equilibrium (DSGE) models generate long-run equilibrium solutions for the main macroeconomic variables included in the model, and hence simulations of the effect of policy changes or other shocks, such as technological innovation. Adopted by central

9 Alfred Marshall famously said that he went by the following rules: '(1) Use mathematics as a short-hand language, rather than as an engine of inquiry. (2) Keep to them till you have done. (3) Translate into English. (4) Then illustrate by examples that are important in real life. (5) Burn the mathematics. (6) If you can't succeed in 4, burn 3. This last I did often' (Marshall, 1906).

10 https://www.resbank.co.za/Lists/News%20and%20Publications/Attachments/8057/05Comparing%20the%20SARB's%20Quarterly%20Projection%20Model%20to%20the%20'Core'%20macro-econometric%20model%20–%20September%202017.pdf.

banks throughout the world, policy decisions may be responses to 'gaps' between actual measured variables (such as output or unemployment) and their long-run equilibrium values. Many DSGE models have a high degree of complexity. Simpler quarterly projection models (QPMs), such as the South African Reserve Bank's QPM,[11] are based on a DSGE but focus directly on the key 'gaps' between current economic variables and their long run equilibrium values. QPMs are now increasingly used by central banks as key tools in deciding on monetary policy actions.

Why make models explicit?

As argued above, the question confronting us is not whether we should use a model, but whether it should be explicit. There are many reasons why stating our model as explicitly as we can is essential, apart from the primary reason for building the model in the first place. We emphasize *transparency*: everything the model does is because of what is in it, so an explicit formulation in principle permits us to examine the exact drivers of any results in the model. Things do not happen because of extraneous changes. Food prices do not rise because of droughts – unless droughts are built into the model; unemployment is not caused by wage rigidity unless we have built wage rigidity into the model.

More will be said about transparency below, but before doing so, other advantages arising from building explicit models can be pointed out. Often we learn by doing so. This is probably particularly true of economy-wide model building, where we try not only to be explicit about the behaviour of different agents and markets in the economy but also about how they fit together. Trying to fit together the pieces of the jigsaw puzzle often shows us that pieces are missing, that there are gaps in our model. These gaps in the model often reflect gaps in our knowledge. Completing the model requires us to find out more about these aspects or to develop theories about them. Doing so can lead to new knowledge.

An example of this in economics was the development of the Phillips curve. Phillips built a mechanical model of the economy essentially representing the circular flow of income (http://www.rbnzmuseum.govt.nz/activities/moniac/TheRealMoniac.aspx). To complete the model, he postulated a link between wage inflation and unemployment. Subsequent econometrics showed there was indeed such a link and this debate led to concepts such as the natural rate of unemployment or the NAIRU, which is a key element of all modern macroeconomic models. Perhaps more profoundly, outside economics, James Watson and Francis Crick used a physical model – cut-out metal shapes and clamps – to help them imagine what the structure of DNA might be. In his autobiography, Maurice Wilkins, who shared the Nobel prize with them, laments that he dismissed their modelling as playing with toys: 'If I had attempted to construct such a model, I might have realized much earlier what the structure had to be.'[12]

This learning process applies not simply to discovery of new, previously unknown ideas. By trying to build models that use conventional theory, we often gain better understanding of that theory. 'Learning by modelling' is a strong argument in favour of policy analysts building and working with models themselves, rather than bringing in experts to do it for them. Such expert advice may provide strong policy recommendations quickly, but it generally does not bring the learning and understanding that comes with hands-on model-building. This learning comes in part because building an explicit

11 https://www.resbank.co.za/Lists/News%20and%20Publications/Attachments/8057/05Comparing%20the%20SARB's%20Quarterly%20Projection%20Model%20to%20the%20'Core'%20macro-econometric%20model%20–%20September%202017.pdf.

12 A more recent example is the modelling work on colliding galaxies that is being used to calibrate the Large Synoptic Survey Telescope in Chile. (*New Scientist,* Multiverses-in-a-box let us simulate the cosmos before we see it, 30 September 2015)

model requires paying careful attention to how the different parts work and interact. It is very easy to wave one's hands at various points in everyday argument rather than be precise; this allows us to skate over details, leaving them vague, saying, 'you know what I mean'. But computers do not know what we intend or mean, unless we give them precise instructions.[13] Explicit model-building generally requires us to state what we mean more precisely than we must in a more implicit argument. The care needed to make the model explicit requires us to think more clearly about what we are doing.[14]

In *Mostly harmless econometrics*, Joshua Angrist and Jörn-Steffen Pischke advise applied econometricians to begin by imagining an ideal experiment they could design to answer their question were they not constrained by time, ethics and money. 'If you can't devise an experiment that answers your question in a world where anything goes, then the odds of generating useful results with a modest budget and non-experimental survey data seem pretty slim.' (Angrist & Pischke, 2008: 5) Perhaps similar advice could be given to policy modellers: if you cannot write down how you think something works in a highly simplified version of the world, you probably will not understand it in reality.

These three things – transparency, learning and care – are related. They come as a package. If we are learning new things, we need to subject them to public scrutiny – to be transparent. We also need to take care that the new insights are genuine and not spuriously created by our careless modelling. But transparency and openness lie at the base of all of them.

Modelling and transparency

Transparency is one of the powerful contributions modelling can make to policy debates. The rules for what happens in any model must be fully specified in the computer code. Nothing happens in the model except what we have told the computer. When our results are criticized, our response should be: 'Don't tell us you disagree with our results, show us where we have made a mistake. Here are our instructions. Which would you do differently?' So, our aim should be to be as transparent as possible.

Transparency is, however, a two-way street. It requires effort on the part of both the modeller and the person she is advising. Of course, this may be too much to expect. The recipient of advice does not want to engage with the modeller about the details of the model. That is why she hired the modelling expert in the first place. In our experience, the advisee simply wants an answer that is broadly consistent with what he thought in the first place. Should he be criticized for the policy he initiates based on that answer, he will simply say that is what the expert told him. This is unfortunate, but unavoidable. However, it does not relieve the policy modeller from the need to be transparent. Often the modelling debate is undertaken at the level below the principals: 'our modellers will debate your modellers'. And for that we need to be prepared to put our model out in the open.

For the present authors, keeping your model hidden – releasing the results but not letting people see how they were derived –undermines any scientific pretensions modellers might have. In effect the 'modeller' says: 'Trust me. I will not show you how I get this result, but I promise you I know what I am doing.' The authority and legitimacy of the results derives not from the quality of the model but from the perceived status of the modeller. And even famous people, or loud people, can make mistakes. It is this 'black box modelling' that gives modelling – and economics – a bad name.

Threats to transparency come from different sources. Firstly, because information is power, some modellers like to keep their models 'secret' because it gives them power (and earns them income or, in economic terms, rents). Similarly, some policy-makers like to keep models private (even when they

13 Even fuzzy logic has to be precisely coded.

14 It is unfortunate that much undergraduate economics teaching focusses on what could be called 'describing theory' rather than 'theorizing'. Students are asked to learn what assumptions lie behind particular theorems rather than to explain carefully what role each of those assumptions play in the theorem. Unless one learns the latter, many assumptions seem stupid and unrealistic.

have not built them!) because it helps them in turf wars both within their own institutions and across institutions; indeed, some governments like to keep models secret because they do not want to engage in debates with their citizens. Modellers can try to avoid these tendencies in themselves, but it is difficult to prevent them in others. One should keep arguing that transparency strengthens modelling.

Secondly, some modellers seem to shun transparency out of insecurity. Making your model easily accessible opens you to criticism; you cannot keep your weaknesses private. But modellers (and scientists) should embrace criticism, not hide from it. Where the criticism is right, it helps us improve; where it is wrong, we need pay no attention. But this is difficult for all of us.

Thirdly, the models themselves may be opaque even to experienced modellers. It is time-consuming to work through someone else's equations, especially for a large and complex model. Asking people to explain what is wrong with your model can be a ploy for evading criticism when you know that the critic has no chance of understanding the model. As modellers we should be aware of this and try to make our models as accessible as possible.

A good practice is to build what is often called a 'toy model', which captures the essential features of your model but is applied to a much smaller database. Readers can find their way through this, before you whack them with the big model. This is a good strategy not only in the policy sphere, but even for academic papers. We should also try to give good intuitive explanations of what is going on in the model.

To summarize. Models are abstractions from reality that are designed to capture the essentials of the issue under debate. They are tools to help clarify thinking about complex situations. Simple is better. Different models are appropriate for different purposes. Selection of an appropriate model is a craft, not a purely technical matter.

4 ECONOMY-WIDE AND OTHER MODELS

The foregoing discussion is relevant for all economic analysis, for any type of model. This paper is concerned with empirical models of a certain type. However, there are many different types of models that are useful for policy analysts. It may be instructive to contrast briefly the models with which we are concerned with to those with which the reader is probably more familiar. Most economics courses introduce students to the following types of models and methods:

Partial equilibrium models

These focus on a part of the economy – an agent, market or sector – without worrying about interactions with other parts. The method of partial equilibrium analysis was one of the powerful methods that Alfred Marshall introduced. It allowed economists to do sensible analysis without being bogged down by the reality that 'everything depends on everything else'. It remains a powerful tool.

General equilibrium models

These examine how multiple producers and consumers – viewed in isolation under partial equilibrium – interact to determine outcomes in the economy as a whole. Most students are introduced to general equilibrium models in a highly theoretical way, drawing on the work of Walras, Arrow and Debreu. The potential number of goods and consumers is so high that we can only approach full general equilibrium analysis in an abstract way. It is not entirely clear what impact they have had on policy analysis in this form. The CGE models we deal with are only loosely connected with the Arrow-Debreu general equilibrium theory (Taylor, 2011).

Macroeconomic models

These focus on the movement of the economy as a whole. They are general equilibrium models, but they cut through the problems of the disaggregated Walrasian General Equilibrium models. In their simplest form they do this by aggregation. The first macroeconomic model most economists encounter deal with a single good – national product – that has many uses: consumption, investment, exports, etc. Again, it is a powerful method that allows the economist to eliminate many complexities.

Static and dynamic models

All the above modelling approaches can be used to develop static or dynamic models. Dynamic models have a time dimension, while static models do not. The solution of a static model depends only on values in a given period. In a dynamic model it depends on past or future values. For a long time, economic methods were dominated by statics: the method of Marshall was comparative statics. Set up a model, shock it, and compare the solution after everything has worked itself out. The interest was in the two endpoints, the start and the finish, with little attention being paid to the path by which the economy moved from one to the other. Marshall (and subsequent economists) dealt with time largely by expanding the period over which the static model was defined. In static models some variables are fixed. In the very short period, very little can change but as we extend the period, more and more is allowed to change until in the very long run everything can change.

Dynamic models are generally concerned with the path the economy takes when it responds to a shock. They have become much more common as economists' mathematical tools have expanded. So, these days, macroeconomics – at least in academia –is dominated by DSGE models. These are generally kept tractable by keeping them relatively small in terms of variables. Dynamic models are generally distinguished by whether they use inter-temporal optimization or are recursive. With inter-temporal optimization, agents make choices in the current period taking into account what they expect the future holds, generally taking a long view of what optimal choices are. Recursive models operate by solving a static model for an initial period and then using the results to update the starting point for the next period, and so on for T periods. They are thus a linked sequence of static models.

There are many dynamic CGE models available, including recursive dynamic versions of the IFPRI standard model. Although it seems appealing to be able to say your results come from a dynamic model, it is important to first understand fully what is going on inside the static part. Confusion in a recursive dynamic model equals confusion in a static model x T.

Agent-based models

The rise of computing power has facilitated several newer modelling approaches. These cannot be gone into here, but modellers should be aware of them, since they are likely to gain more prominence and dominance in the field. Agent-based models have rapidly become a tool for modellers and are beginning to generate interesting results. Richiardi (2015) provides a useful introduction and history.

Theoretical versus empirical models

Many models are taught in purely theoretical terms. Often they can be solved analytically, deriving general results. For many applications, however – particularly for policy-modelling – we want to use the models for empirical analysis. Many economists would hold that a theoretical model can only be validated by confronting it with data. It is not enough that models are internally consistent and logical. Economics deals with real phenomena, and we can only tell whether our theory is useful by seeing whether it conforms to the actual phenomena it purports to explain. In policy analysis this need for empirical conformity goes further. Many of our theoretical models will show us that outcomes depend on the value of a parameter. When a commodity tax is raised, revenue will rise or fall depending on the elasticity of demand. We need to know that elasticity in any situation to be able to advise policy makers.

Most empirical applications in economics are based on econometrics. Models are applied using more or less sophisticated econometrics. Often this is done in the spirit of testing the model, but not always.

In much modern economics, econometrics dominates theory. Econometrics is the method of applied economics. However, there are circumstance in which econometrics cannot help.

If we are to do econometrics properly, we generally need many data points. Where sufficient data are not available, we very quickly run into problems of insufficient degrees of freedom. This problem is sometimes resolved by using calibration rather than estimation. Calibration has long been used in economics (see Kaldor's stylized facts) but came to the fore in mainstream economics with real business cycles (see Dawkins, et al, 2001). We assign plausible initial values to parameters and then adjust them to ensure that the behaviour of the overall model conforms to some real-world data. Our plausible values draw on intuition and a mix of evidence – from other countries and other times.

5 WHAT ARE COMPUTABLE GENERAL EQUILIBRIUM MODELS?

All the approaches listed above can make an important contribution to policy analysis, and good policy economists should be comfortable using all of them. This paper, however, sets out some broad features of CGE models. The CGE models being developed are economy-wide, disaggregated, calibrated and static simulation models. By *economy-wide,* it is meant that the models attempt to cover the whole economy, like macroeconomics. However, unlike macroeconomics present interest is in *disaggregated* elements and how they connect to each other, like microeconomics. Structure matters, including the linkages between sectors, how they impact on factor markets and how that connects with income distribution and household demands. Furthermore, decisions and choices made by households and producers also matter. CGE models incorporate these essentially microeconomic elements. However, at the same time they also recognize macroeconomic constraints are important. For example, investment and savings must balance; the government may or may not run a budget deficit (in principle, subject to a long-run budget constraint); the current account of the balance of payments may be in deficit, surplus, or balance subject to the constraints imposed by national income accounting principles, and so on. Adjustment at the microeconomic level might be constrained in different ways by these macroeconomic considerations. Macroeconomists are fond of emphasizing the microeconomic foundations of macroeconomics; CGE models can be thought of as showing the macroeconomic foundations of microeconomics.

As will be discussed in the next section, the national accounting framework serves as the typical benchmark in economic analysis in general. GDP growth, for better or for worse, remains the key benchmark for economic performance, growth in income and the economy. GDP is measured as part of the national accounts, so it makes sense for an economy-wide modelling framework to be consistent with the national accounts if it is to serve the purpose of public sector policy makers. This ensures, at the very least, that everyone involved in the discussion is singing off the same song sheet.

CGE models are sometimes referred to as second-generation economy-wide models. First-generation models grew out of the input-output analysis founded by Wassily Leontief. Leontief's insight was that we can depict the economy as an inter-connected network of flows between different industries producing outputs to satisfy both industry and final demand. This network can be set up in the form of a matrix, which, based on some simple assumptions, we can manipulate using matrix algebra to examine the direct and indirect consequences for production of changes in final demand. Input output analysis was extended in the 1970s to social accounting matrices, which went beyond the interindustry flows of input-output tables to incorporate commodities and flows of income generated in to income distribution and thus to expenditure and final demand. The matrix algebra techniques remained much the same.

Two of the fundamental assumptions of these first-generation economy-wide models were that the economy operated with fixed proportions – there was no substitution in either production or final demand – and that either prices or production capacity were fixed. While various neat ways of relaxing some of these assumptions were developed, users were essentially faced with a choice of assuming fixed prices and examining quantity adjustments to external shocks, or fixed capacity and examining price adjustments.

Building on the powerful economy-wide focus of these first-generation models, CGE models introduced the possibility of substitution in both production and consumption spending and the possibility of both prices and quantities adjusting at the same time to external shocks. This allowed the modelled economies to respond more flexibly to various shocks.[15]

Although CGE models do not have to be large, they often are. While it is possible to solve small models analytically using standard algebraic methods, it is not easy to do so for large models. We therefore tend to use numerical algorithms to solve them. The numbers in our models thus do not simply represent some features of the economy we are modelling. It is also important to have numerical representations so that we can solve them.

The numerical nature of the models creates a natural predisposition of modellers to focus on the numerical solutions. You will often come across CGE based reports that simply report the numerical results. But it is important to keep in mind that these numerical results are often the only way we can figure out how the model works. They are the immediate or superficial manifestations of the deeper working of the model. Reporting the numbers is surely the first step in explaining how the model gives us insight into the consequences of a policy. The story behind the numbers is in many ways more important than the numbers themselves.

6 WHY USE ECONOMY-WIDE MODELS FOR POLICY ANALYSIS?

But why should these policy makers be concerned with disaggregation of an economy-wide modelling framework? When their concern is with high level performance of the economy – growth, employment, inflation – they can use standard macroeconomic models. And when they are concerned with very specific parts of the economy – growth in the motor industry, the increase of a grant to poor households – they can draw on an array of well-tested microeconomic models. Why do they need economy-wide models?

We can answer this from two different perspectives. Firstly, think about a policy which essentially has an economy-wide focus, such as a national minimum wage, a youth wage subsidy, a reduction in corporate tax rates, or a generalized investment incentive. We could analyse the impact using an aggregated macro model. But we know that the impacts of these measures will vary from sector to sector, depending on their exact nature. The overall effect may differ from economy to economy, depending on their structures. These differences could be significant particularly when assessing the impact on subsidiary targets.

Secondly, consider a 'sector-focussed' policy, such as raising a tariff on a good, or a government transfer to a particular income group. Or perhaps we are interested in the impact of a rise in the world price of a significant commodity export. We have the microeconomic tools to assess the direct impacts of such interventions and shocks. But there may be indirect effects that are not easily analysed using those tools. The tariff may stimulate production in the targeted sector. This may lead to higher demand for raw materials and other intermediate inputs. These indirect knock-on effects might be ignored in a narrow sector focussed study, even though they may significantly add to the impact of the policy. Indeed, if the shock is large enough, it is possible that the knock-on effects generate effects that feed-back to the original targeted sector. The tariff stimulates the targeted sector, which stimulates production in other sectors. There is an increase in income which raises demand. If these feedback effects are large enough, it would mean that the sector-focussed approach not only overlooks some

15 It is agreed that the first CGE model was built by Leif Johansen in 1960. A nice account of his intentions in developing this is given in Halsmayer (2017).

effect operating through other sectors but in fact mis-estimates the impact on the targeted sector itself. A sector-focussed study might be wrong.

Obviously, whether or not the additional effects through these channels are significant will depend on the size of the stimuli and the economic structure of the network. Economists have tended to ignore them in the past, not because they were unaware of them but because the tools for such detailed analysis did not exist. Or, to put it in more economic terms, given the available empirical tools, the marginal costs of tracing these effects were much greater than the marginal benefits: much better – and probably accurate to a first approximation – to ignore them. Computers and data availability have changed that calculation.

Economy-wide policy-modelling can also give political economy insights that can be useful for policy-makers. Often the direct effects and the primary beneficiaries of an intervention are quite obvious. However, indirect effects may be less clear and there may be unanticipated consequences for other groups that are not as well represented as those that benefit more directly from the intervention. One example could be the call for higher tariffs on imports of clothing. This may benefit workers and enterprises in the country's clothing industry, but a typical indirect effect is an increase in the domestic import price of clothing. This may have a negative impact on low-income households, which spend a higher than average proportion of their budgets on these items. While unions and enterprises may be able to lobby for the higher tariffs, it is not clear who may have the interest of low-income households at heart. Policy-makers would like to consider winners as well as losers, possibly with the aim of somehow compensating the losers through some or other redistribution measure. It is those indirect effects that require a disaggregated economy-wide framework.

7 ASKING THE RIGHT QUESTIONS

Economy-wide models are useful tools if asked the right question. They cannot tell us how firms will respond to a carbon tax, since that knowledge is required to build the model. But if we know how individual firms respond, these models might be able to tell us what the economy-wide implications of such a tax might be. We can use an analogy of a jigsaw puzzle. We have many puzzle pieces that we fit together to see what overall picture they make. We need the pieces to build the picture. In the same way, in an economy-wide model we use knowledge of individual components taken in isolation to construct a bigger picture.

Economy-wide models can help us understand channels through which policies work, even if the data are not accurate. However, much of the structure of the economy is in the data and we therefore need to pay attention to data and improvement thereof. Economy-wide models are based primarily on data captured in social accounting matrices and national accounts

Asking the right question can be thought of also from the policy makers' point of view. What policy questions might they ask? They may have a policy in mind and want an assessment of its impact. Or they may have a particular outcome in mind and want to know the 'best' way of achieving it. This second is the preferable question for the policy analyst, but typically policy-makers not only have an aim in mind but have some preferred policy instrument for achieving it. The policy or instrument might have a primary target in mind, but often its assessment will be based not simply on how well it achieves that objective but also on a range of other impacts. For example, many developing country governments have overarching concerns with employment, income inequality, and poverty. The specific policy – reducing a tariff, raising a tax rate and so on – might not be aimed at any of these general concerns, but the policy-maker will often expect a report on the likely impact on each of them.

The precise question being asked might also vary. While the analyst might be asked what the impact of the policy might be, the meaning of 'impact' is often left vague. Policy-makers might be interested in what the economy will look like in a year's time if the policy is implemented. However, many things will be impacting on the economy over the period and many other aspects of the economy will be changing. This question is therefore too broad. We need to narrow it so that we at least keep our attention on the impact of the policy, not on everything else that is going on. It would be more appropriate to ask how the introduction of the policy change will impact the economy. Answering this allows us to ignore the myriad of other influences that will be changing and causing change and focus only on those that happen because of the policy.

Models and forecasting

We can also distinguish models by the purpose they are intended for. An important distinction to make is between forecasting and other uses. Many people, particularly but not only outside economics, seem to think that economic models are only used for forecasting. Even models that are constructed to help understand some phenomenon should be tested by seeing whether they make some correct prediction. This might be true, but prediction is not the same as forecasting. We make a conditional forecast. If the following are true, then action x will lead to outcome y. We think of a forecast as saying that if we do x now then in period t the world will look like y.

This is a fundamental methodological problem in economics. Often policy-advisors are expected to make a forecast about what the rate of growth of GDP will be this year, or the rate of inflation, or what the value of the dollar will be in a year's time. But all such forecasts, because they are based on models implicitly or explicitly, are actually conditional predictions. If, in the real economy, the things that control the rate of growth *in my model* move in the way I have made them move *in my model* then the rate of growth will be x%.

Economists have tried to avoid this problem of conditionality by making projections. If the rate of growth follows the trend it has been on, then we expect it to be x% one year forward. We qualify the projection by putting some statistically estimated confidence bounds on it. This is essentially the Eeyore view of the world: 'It was raining yesterday, it is raining today, it will probably be raining tomorrow.' It is a valid method for dealing with complexity, but it does assume that everything continues as before – it is ergodic. Not only might there be some massive exogenous shock that throws the economy off its normal path but, as economists are increasingly coming to understand and finding methods of dealing with, there may be emergent properties of the economy so that there are chaotic jumps that arise from the normal functioning of the model.

The question of forecasting has become much more problematic for economists since the 2008 financial crash, which economists are famously criticized for not having forecast. This has put a greater burden on modellers. What is the point of models – your model did not forecast the crash? Models are useless. In fact, the crash was 'forecast' by a number of economists—in the sense of expected. Many economists warned that the fundamental changes in banking regulation and structure that had been taking place since the 1980s were setting the financial system up for a fall. They did not forecast the date on which that fall would happen (Eaton and Taylor 1999). That lack of precise timing is seen to be a failing. But the same critics do not change doctors when the latter suggest that their lifestyle will cause them to have a heart attack but cannot say when it will happen.

The question of forecasting has been dwelt on rather lengthily in order to emphasize what the type of models we are dealing with can and cannot do. We can use them for making conditional predictions. But the models are more useful than that. They allow us to explore consequences of actions or events while controlling everything else that might, in the real world, be changing as well. In this sense, models allow us to do some kinds of controlled experiment. In the chemistry laboratory, when we want to find out the effect of some chemical on another, we take care to ensure that our experiment is not contaminated by the introduction of extraneous matter. We probably go further to control for temperature, for pressure and a host of other environmental factors that could influence the results. In medicine, checking the effectiveness of a drug, we might undertake controlled field trials. We try to see what the influence of the drug is by having one group take the drug and one not and seeing what the difference is. Such randomized control trials have become the favoured method of many economists. We select our two groups so that they are alike in every respect except for the taking of the drug. That often requires large numbers and sophisticated econometric techniques. Big Data seems to take this approach.

But for many problems in which we are interested, we cannot do such controlled trials. What is the effect of some policy on inflation? Economy-wide problems are limited by the fact that we cannot legitimately do experiments on economies. We at best must rely on natural experiments. This is what the sub-industry of cross-country econometric studies relies on. Countries have followed different policies at different times. We can therefore construct a panel of countries in which we are able to distinguish the influence of policies on outcomes from other influences.

A different approach, which harks back to earlier days of economics, is to do a thought experiment. Can we think through logically what the likely impact of the policy will be?

Economy-wide models and data consistency

The other benefit of an economy-wide approach is that it allows us to investigate inaccuracies and consistency of data that are often drawn from quite disparate sources. This kind of analysis shows us where there are gaps in our knowledge. Moreover, with the national accounts as the unifying benchmark, this serves as a reality check on the plausibility of policies. Often the effects of policies are seen, particularly by policy-makers, as adding to whatever is already going on: a large infrastructure investment project will, we are told, add to total investment in the economy. In practice, they may substitute for current activity: if cement supply is limited, the large project curtails other projects. The net investment increase in the economy is less than investment in the project. Economy-wide thinking is needed to pick up these important substitution effects. In this way, economy-wide modelling results in better economic thinking.

As mentioned before, a distinction can be made between macroeconomic and multisector economy-wide modelling. Macroeconomic models are usually econometrically estimated but offer limited structure, they are macro rather than micro. The class of dynamic stochastic general equilibrium (DSGE) models does offer some disaggregation but there tends to be limited data to support doing this in any great detail. Multisector economy-wide general equilibrium modelling identifies, as the name suggest, more detail in terms of sectors. Their calibration on a limited number of benchmark years allows the use of input-output tables (IOTs), supply and use tables (SUTs) or social accounting matrices (SAMs). These data bases are typically compiled at a multiyear frequency and therefore do not lend themselves easily to econometric analysis, also because their construction is not always consistent over time. Economy-wide models based on these data bases can be of linear or non-linear nature.

Linear multiplier models based on IOTs highlight the interactions amongst industries producing homogenous commodities, while those based on SUTs distinguish between industries and the commodities they produce, so that an industry can produce more than a single commodity. SAM-based models add factors of production, income distribution and expenditure, thereby creating a full picture of the circular flow of income that also underlies the national accounts. All these models are characterized by simple linear behaviour. They are strongly proportional (although some variations can be made) and therefore rather simplistic in adjustment. These models are often referred to as multiplier models, as a positive intervention will always result in a positive overall impact.

While such behaviour may be a reasonable representation for interventions and exogenous shock that are sufficiently small, these models become less attractive when considering larger scale impacts. CGE models try to overcome this simplification while maintaining the same linkages of IOTs, SUTs and SAM-based models. Behavioural responses based on more generally accepted theory typically using non-linear relationship are added, which makes CGEs more complex to solve. Results could go either way:

a positive intervention may well end up with negative impacts for some entities identified in the model. Such complexity also requires the use of specialized software.

Yet another concern is that it is thought that successful development is often the outcome when there are sectors with high productivity growth which have strong linkages to the rest of the economy. Multisector economy-wide models may be useful in this regard since they capture these linkages in the structure of the underlying IOT, SUT or SAM data bases. Linkage analysis goes back to the 1950s when Hirschman (1958) introduced forward and backward linkage measures (and a combination of these two). This analysis lost some of its popularity in the 1970s as the paradigm of the trickle down of industrialization made way for more active social interventions, which gave rise to SAMs and models build on them. However, more recent literature now goes back to these notions of linkages in a more contemporary context that focusses on (national, regional and international) value chains (Wang & Powers, 2009), the concept of trade in value added / the value added of trade (Stehrer, 2012), and analysis that focusses on networks which suggests that higher variability in linkages across industries may result in higher vulnerability to shocks of the relevant economy (Jones, 2008 ; Acemoglu *et al*, 2010).

8 EVIDENCE-BASED POLICY

How can we know what the impact of a policy intervention will be before it has been implemented or of an exogenous shock before it has happened? Typically, economists will draw on economic theory to guide their expectations. Governments (particularly in developing countries) often like to draw on the experience of other countries. Both are valid and useful approaches. But they both face the same problem: how do we know that the theory or the other country experience is relevant for our country in our circumstances? In their book on evidence-based policy (EBP), Cartwright and Hardie (2012) see the primary problem of EBP as being how to move from evidence that 'this policy worked there' to 'this policy will work here'. Even when we agree on which are the best comparator countries, we cannot be sure that the context and conditioning factors that operated there obtain here.[16]

We can also draw on theory about how an economy works to figure out potential impacts. But this is the same as constructing an analytical model. If so, the question can still be raised whether a generic theory applies to the current policy context.

Applied models are based on theory but they bring empirical evidence into the model to make the model specific to the context. As applied policy analysts, the present authors agree with the call for policy decisions to be based on evidence. However, a small flag of protest must be raised against the recent rise in popularity of EBP. It seems to imply that in the past policies were not evidence-based, something policy-makers of bygone years would object to. They would claim to have weighed up the facts before deciding what to do. Furthermore, it is not obvious that 'evidence' is clear cut. What evidence is admissible? Often those calling for EBP seem to mean only quantitative evidence, or indeed, only quantitative evidence gathered through randomized controlled trials, but there are a host of other types of evidence that can and should be brought to bear on policy decisions.

It was earlier suggested that policy-advising is about persuasion. Evidence that persuades one policy-maker might not persuade another, even though that evidence is not 'wrong'. Often, it seems, the call for evidence-based policies is in fact an attempt to lend spurious rigour or scientism to preferred policies.[17]

16 It is perhaps interesting to consider just how much selection bias there is in typical studies drawing on other countries. Governments tend to send fact-finding teams to countries in which the preferred policy 'worked'; very little effort is put into studying 'failures'.

17 It could be argued that policy-makers sometimes actually want 'policy-based evidence' rather than 'evidence-based policies'.

9 POLICY ANALYSIS AND POLITICS

Considerations such as these raise questions about the whole nature of the policy endeavour. As economists we might wish for a world reigned by rational policy making aimed at the public good. But such a world does not exist nor could it. The world comprises different and often conflicting interests; there is little consensus on what the public good is, let alone what best serves it.

An earlier generation of economists tried to develop a distinction between matters of efficiency and those of distribution. Economists, they said, could advise on the former, since that can be determined by positive science. But they should refrain from the latter, since distributional outcomes could only be judged on by normative – and therefore subjective and non-scientific – standards. Thinking has come a long way since then. Modern political economy acknowledges that policy is generally driven by competing interests. Modern game theory provides some tools for analysing outcomes in these circumstances.

Approaches to economic policy making have evolved over the past century. Initially, the idea was that the politicians would set a goal. Economists would then advise how to design policy to achieve it. We would then have a process as in Figure 2. This view has evolved over the years into something more complex. Most political economists recognize that economic policies are both driven by and—through their impact on distribution—affect interests. So, the picture is much more complex, possibly as shown in Figure 3. The economic impact of the policy affects the distribution of economic power. And that distribution not only affects the setting of goals and the choice of instruments, but also the political economy within which policy is determined and even the 'rules of the game' – the constitution and governance structures that determine what policy makers can and cannot do.[18]

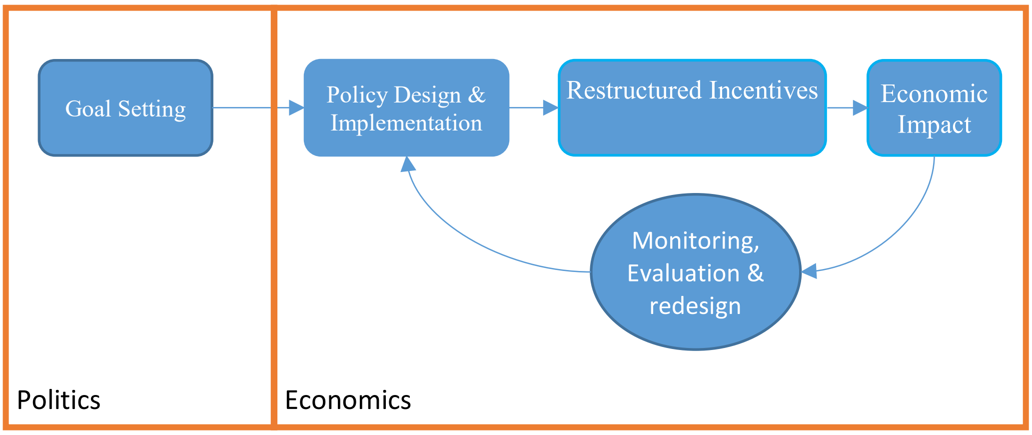

Figure 2: An old-fashioned view of economic policy-making

18 This exposition is influenced by, but does not do justice to, Rausser and Roland (2008).

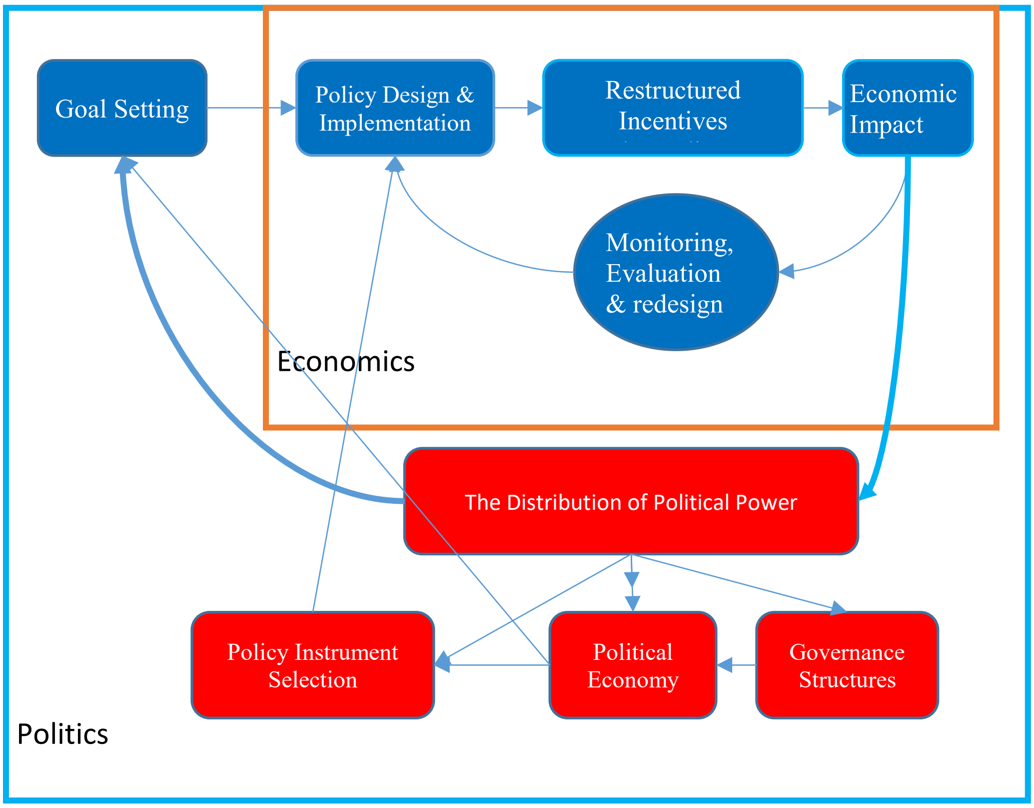

Figure 3: A more modern view of economic policy-making

These views are raised here in part because we have sometimes been asked – generally by students from countries in which governance structures are weak – why they should bother with systematic evidence-based policy analysis. 'Everything is driven by politics. What role is there for 'sensible' economic analysis?' There is no doubt that this can be a problem. However, there is still a role for policy analysis. To the extent that politicians' power depends at all on performance of the economy, even the most self-interested politician will be concerned to know what the impact of a policy will be. Does it really serve her interests or those of the people she represents? And proper economic analysis is of course an element that feeds into the political economy. Sustained public and transparent policy analysis in the face of overwhelming politics is part of the process of evolution towards not only better policy-making but also better politics.

In some countries this is institutionalized: in the Netherlands, the CPB runs the economic proposals of parties through their models prior to an election and reports on their plausibility. This is not a legislated requirement, but the institution has established a reputation for sober and impartial analysis, so that any party that refuses to submit is treated with suspicion.

10 CONCLUSIONS

There remains a large challenge in moving from model lessons to policy formulation. Model-based analysis is only part of policy analysis. Policy design requires adapting model recommendations to fit the context. However, this is still better than pretending that we use no theory or model.

To conclude, this paper offers a broad idea of what CGE models are about, and of some the jargon we may slip into using. Basically, a CGE model consists of a bunch of variables embedded in a system of equations. We typically differentiate between endogenous and exogenous variables. The values of the former are determined by the model as solutions to the equations. The values of the latter are given from outside the model. We sometimes slip into using 'fixed' as a synonym for 'exogenous'. This should not be taken as implying that their values are fixed for all time. It simply means that things in the model will not cause them to change. In addition to endogenous and exogenous variables, models will have a number of parameters. Mathematically these are like exogenous variables – their values are not changed by things happening in the model. But as economists we think of them differently. Typically, they are values that go into the equations to capture underlying behaviour, such as elasticities.

The equations can take on a variety of functional forms. Some may be complex non-linear relationships, trying to capture behaviour of different agents. Others might be simple linear relationships, often expressing essentially accounting relationships (or identities) that we know must apply, such as the definitional rules governing national accounts systems.

We next bring data into the model. The essential process is to collect data on all our variables (exogenous and endogenous), populate the model with our parameter estimates and the data on exogenous variables and see if it generates the values of the endogenous variables in the database. We call this 'replicating the base'; if we believe we have built a model of how our economy works, and we have a consistent set of data that has been generated by that economy, it seems reasonable that our model should be required to do a reasonable job replicating it. If it does not, we must do further work improving our parameter estimates, changing the functional forms, possibly even changing our thinking that underlies the model. This process is calibration.

Once we have our model working (in the sense that the various parts are consistent with each other and the model produces a solution value for each endogenous variable), we use it by changing the value of an exogenous variable and seeing what the impact on endogenous variables is. Often we call this process 'shocking the model' and refer to the change as a shock. The shock might be a policy intervention such as raising a tax rate or it could be some other change from outside the model, such as a fall in a world price that we assume is exogenous.

Note that we can only shock exogenous variables. If we change an endogenous variable, the model will solve by going back to its original value. A little reflection on this demonstrates why we need many models. We might think for example that a large gold-producing country influences the world gold price and therefore that we should make that price endogenous. But if we want to explore the implications of a rise in the price of gold, we need to make it exogenous. We might have a model that has the exchange rate endogenously determined, which we think is a reasonable representation of our economy. But then we get asked to explore the impact of a strong currency. We need to manipulate the exchange rate in our model, so we must make it exogenous.

These examples demonstrate how we use models and they illustrate why we might use a model that has a 'wrong' assumption. We are using the model as a laboratory in which we can do controlled experiments. They are thought experiments.

In this respect, it is interesting that many economists regard applied general equilibrium modelling as too difficult for policy analysts. In fact, policy-makers tend to think in economy-wide terms. The assumption of *ceteris paribus* is difficult for them to understand: how can we assume 'other things equal' in an interconnected and ever-changing world? On being told why some policy will have some outcome, and given the basis for that view, many policy-makers respond: 'But what about x or y or z?' They want to bring more and more features into the underlying model. Although economists will often add complications to their models, typically they want to simplify them as much as possible.

An often-raised concern is not to be too self-critical about your model. Know its limitations but do not be too apologetic. One of the authors of this paper once presented something in which he explained carefully the limitations of the model. A member of the audience said 'Don't keep telling us what your model does not do, tell us what it does. We know it cannot do everything.' In a sense, it is the surprises in the model results that often yield most insight and understanding – if you get results that surprise you, you can learn a lot.

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