Let's Get Physical: Creating a Stocks and Flows View of the Australian Economy

G.M. Turner and **F. Poldy**

Resource Futures Group, CSIRO Sustainable Ecosystems, Canberra ACT (Graham.Turner@csiro.au)

Abstract: Physical functions and structure underpin the operation of a nation's socio-economic system, including the provision of services. For every dollar that is exchanged in Australia's gross domestic product, there is a chain of physical actions that brings that final good or service to the consumer's basket. The Australian Stocks and Flows Framework (ASFF)—designed and implemented using whatIf® simulation software from ROBBERT Associates—is a set of linked calculators covering the major sectors of Australia's physical economy, all grounded with 50–60 years of historical data. In the framework, population demographics drive direct needs such as buildings, transport and other infrastructure, which are supplied by the processing and primary industries that draw on the nation's basic resources. The search for sustainable and possibly radical pathways uses the concepts of age and inertia, recognising the slow moving nature of long-term issues. Our approach uses scenarios (effectively collective sensitivity analysis) where policy analysts can design or foresee future physical economies by making assumptions about key parameters. Because scenarios are not constrained to establish equilibrium positions, transition pathways can be tested for physical feasibility and ultimately conservation of mass and energy. Importantly, we explicitly separate analysis of the physical economy from the policy or decision-making space. ASFF complements traditional economic approaches; it does not model behavioural effects such as response to prices, but takes these as inputs. Through the ASFF interface these assumptions are made transparent—a critical element since an understanding of the physical issues involved is a vital precursor to acceptance of any radical re-designs of the socio-economy. This relatively novel approach is gaining application in a range of policy debates, such as energy and greenhouse gas, and oil depletion and transport systems. Current use of the modelling framework is focused on long-term population policy, land and water futures, and fisheries management.

Keywords: National Policy; Stocks and Flows; Physical Economy Scenarios

1. INTRODUCTION

The long-term future of modern industrial economies, like that of Australia, is strongly dependant on both national policy for the future and the pathway taken in the past. Slowly changing drivers such as population, economic growth and lifestyle have profound effects on our economy, resources and environment over the long-term. Increases in the national gross domestic product (GDP) are strongly correlated with increases in energy use (Figure 1)—even as our economy moves toward a more service oriented structure—and energy use is correlated with increases in environmental degradation [Cocks et. al., in preparation]. However, due to their slowly changing nature and the increasing complexity of our modern economy, the changes and consequences are generally difficult to perceive and therefore to incorporate into policy making.

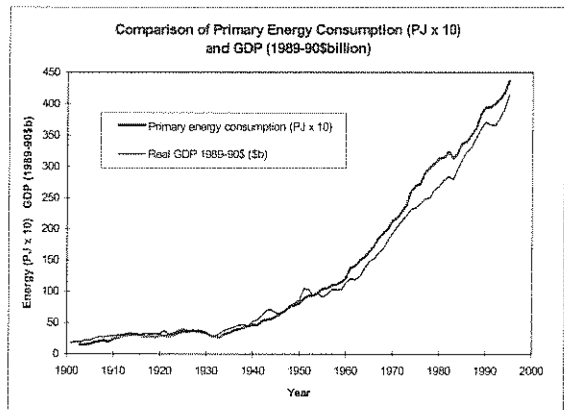

Figure 1. The growth in Australian GDP and energy use.

In order to examine the long-term consequences of many policy interactions, the Resource Futures Group at CSIRO Sustainable Ecosystems have developed the *Australian Stocks and Flows Framework* (ASFF). ASFF consists of a quantitative model and an integrated historical database over 1940–2000. The framework permits design and testing of different functions and structures for the physical economy. The term 'physical economy' is coined for the vast array of physical transactions that underpin the economy. For every dollar that is exchanged in Australia's gross domestic product, there is a chain of physical actions that bring that final good or service to the consumer's basket. The processes that run the physical economy in Australia require that over 170 tonnes of material are moved per person per year to supply our essentials, our lifestyle and the exports needed to pay for our imports. By contrast, Japan and the USA move around 40 and 80 tonnes per person respectively.

We adopt a design approach [Gault et. al., 1987] using scenario modelling to implement ASFF in support of policy- and decision-making. A fundamental concept to achieve this is that the quantitative analysis of the physical economy should remain separate in analytic terms from the ideology of the policy analyst or decision-maker. Ideally qualitative scenarios are formulated by the policy analyst making assumptions about the key physical parameters (including any time dependence), which are open to scrutiny and debate. We are typically involved in the examination and debate of these assumptions and resulting scenario outcomes, seeking evidence from other sources for support and collaboration of the ASFF output. The quantitative framework that tests the summation of effects of these assumptions uses physical equations, life cycle analysis and the laws of thermodynamics to ensure that the scenarios do not depart from physical reality. The deliberate omission of feedback loops in the framework explicitly puts the onus on the analyst to solve any mis-matches (tensions) between broadly the demand for goods and services and the supply of these to the population.

This design approach is an implicit element of the **whatIf®** suite of software applications developed by ROBBERT Associates [Hoffman et. al., 2001]. This software and the design approach promotes several important features, in particular acceptance of uncertainty as an implicit element of planning for the future, analysis of the implications of uncertainty, and an increased understanding by the policy analyst or decision maker as part of the decision-making process.

This paper will describe first the ASFF and then the underlying software applications we use to implement the framework; each section includes a discussion of the associated aspects that support decision-making. Application of ASFF to Australia's fisheries and agricultural sectors are described in separate papers [Dunlop et. al., 2001; Lowe et. al., 2001].

2. THE AUSTRALIAN STOCKS AND FLOWS FRAMEWORK

2.1. Stocks and Flows

ASFF is a highly disaggregate simulation that keeps track of all physically significant stocks and flows in the Australian socio-economic system [Poldy et. al., 2000]. Stocks are the quantities of physical items, such as land, livestock, people, buildings, etc., and are expressed in numbers or their appropriate SI units. Flows represent the rates of change of stocks resulting from physical processes, such as the (net) additions of agricultural land, immigration and birth rates, etc.

Relative to stocks, flows can be changed dramatically (even being switched from on to off states or vice versa). Therefore, flows tend to be used as policy levers, with attention focused on these measures. In contrast, changes to stocks take place slowly and therefore are difficult to perceive especially by the market place or in a short-term policy environment. This difference derives from the age-structure implicit in stocks. To substantially increase or decrease the number of young (say 25-30 year old) males in the population within a time-step of the order of years would take radical/unrealistic policy initiatives (using flows such as immigration or death rates). The age-structure of stocks is a key feature of ASFF.

2.2. Scale and Scope of the Framework

ASFF covers the complete economy, including service aspects, but incorporates only the physically significant elements of each sector. At the centre of the framework is an input-output model for the transformation of basic materials and energy types. Elsewhere, there are physical accounting relationships that represent the key processes, such as converting the requirement for transport of goods into the size of the freight transport fleet and the fuel requirement. The result is that all the variables representing physical stocks and flows obey the thermodynamic constraints of conservation of mass and energy.

Geographically, ASFF covers continental Australia. Within specific sectors of the framework different geographic resolutions are used, e.g., in agriculture we operate at the statistical division level. The processes modelled at these levels are necessarily ones mostly representing accounting or physical identities. Differences between the outputs from ASFF and more sophisticated models dealing with specific sectors and operating at higher resolutions are (arguably) marginal and therefore not of concern to the long-term, national picture. Additionally, data is rarely available to support high resolutions models across the continent.

The temporal extent of ASFF is long-term: scenarios over the future are calculated to 2100, and the model is also run over an historical period of 1940–2000. In some sectors such as agriculture it is necessary to provide data for earlier than 1940 due to the lengthy life-time of important agricultural land stocks, e.g., of different quality. The time step used is 5 years, coinciding with Australian Bureau of Statistics census years.

2.3. Structure and Information Flow

The major structural elements of ASFF and the flow of information within the framework are shown schematically in Figure 2. The design of the processes within each of the major sectors in ASFF was informed through a series of sixteen workshops involving a range of people from industry, government and other areas with expertise in the specific sectors [Conroy et. al., 2000].

All sectors have control variables that can be adjusted to suite different policies or explore the effect of technological factors in various scenarios. Some sectors, however, do not receive input from any other sectors (see the top of Figure 2).

For the purposes of explanation, some sectors have also been separated into requirements (i.e., physical requirements necessary for economic activity of the particular scenario) and provision sectors—left and right respectively in Figure 2. Broadly, population numbers drive the requirements for services like transport, infrastructure such as buildings and roads, and consumable goods. Houses require bricks, timber, glass, etc, etc. Food implies crops, animals, tractors, etc, etc. Independently, materials from the primary sectors on the provision side are transformed and processed into the goods and infrastructure for both the domestic and international markets. Information from many of the sectors (calculators) on the impacts to land, air and water resources is collated separately.

Without any feedback loops coded into the model there are values for the control variables (particularly those in the primary sectors) that lead to a mis-match (which we call a tension) between the requirement for goods or infrastructure and the provision of these. (In principle, tensions can appear anywhere in the framework.) In Figure 2, this generally means tensions are in the lower boxes representing the sectors with information flow from the requirement and provision sides of the framework.

Optional and obligatory tensions require different responses from the user. Tensions in which the provision is greater than the requirement represent inefficiency (in the same way that unemployment is not a 100% efficient use of the labour force), and the user can choose whether or not to address these. In ASFF many of the possible over-supply tensions are absorbed as exports in the International Trade sector.

The obligatory type of tension in which the provision is less than the requirement represents a physical inconsistency in the scenario since the specified activity of the economy can only take place if there is sufficient supply of goods, materials, resources and/or energy. Such tensions must be dealt with explicitly by the user by

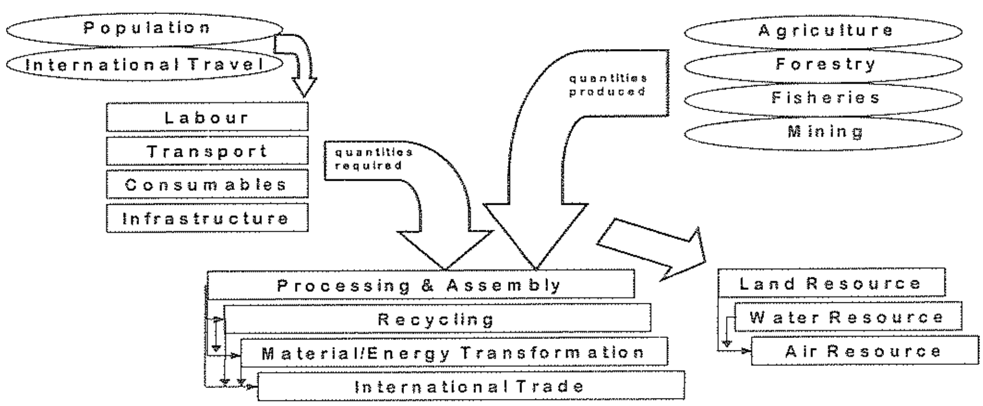

Figure 2. The major structural elements of the Australian Stocks and Flows Framework and the flow of information within the framework. Exogenously specified sectors are shown by ellipses.

adjusting appropriate control variables—choices may include lowering economic activity, increasing supply or increasing parameters representing technological efficiency.

2.4. Complete and Consistent Historical Database

ASFF is the first attempt to provide an integrated context for physical data of the Australian socio-economic system. Data have been collected from a wide range of sources, drawing heavily on the Australian Bureau of Statistics. Through a calibration process, every variable (some 800 multi-dimensional objects) in the framework is assigned data over all dimensions for the entire period from 1940 to 2000, making the database complete and consistent (see section 3.1).

2.5. Scenarios

A base case or starting position scenario has been created using insights from the historical database and advice from stakeholders involved in the sixteen design workshops. This scenario generally captures specific industry expectations of continued growth with no surprising changes in current trends. The base case scenario, like all other scenarios, is not a prediction, but a physically plausible future pathway. It provides a reference or benchmark, and a basis for creating other scenarios.

2.6. Support to Decision Making Associated with the Framework

There are a range of organisations for which ASFF is well suited, in both the public and private sectors. The framework is ideal for policy making at the Federal Government level given the long-term, national economic scope and degree of aggregation in the framework. For example, three population scenarios were examined for the Department of Immigration and Multicultural Affairs to explore the infrastructure, resource and environmental consequences of different immigration rates [Foran and Poldy, 2001]. Although Federal government departments may have their own modelling/analysis capabilities, ASFF compliments these by providing an integrated picture of the whole economy. State governments and regional organisations benefit from examining their policy directions within a national context.

Industry associations and commercial entities can use ASFF to gain domestic and international competitive advantages. Strategic gaming and business plans—epitomised by Royal Dutch Shell's positioning in relation to the 1970's oil crisis—can be informed by quantified, physically realistic scenarios. Competition for resources or markets can be identified. ASFF provides the ability to plan for major investment humps.

Several specific features of ASFF that support national level policy- and decision-making are as follows. The framework complements economic theories and it provides physical reality checks on future development paths. Trade-offs across the whole economy can be examined and critical time periods for introduction or roll-over of infrastructure can be identified and finally, the historical database provides a quantitative basis for creation and comparison of scenarios.

3. IMPLEMENTATION OF THE FRAMEWORK WITH whatIf? SOFTWARE

The front-end of the suite of whatIf? applications incorporates a Scenario And Model Manager (SAMM) and a model design tool called Documenter. SAMM is used as the interface between the operational model and the user, allowing control parameters to be changed, scenarios to be defined and stored (as the collective settings of all control parameters), and rapid evaluation and display of the resulting model outputs. At the beginning of the process, Documenter is primarily used to design the model using a graphical depiction of model structure, the model variables and the relationships between them.

Both SAMM and Documenter employ the Tool Object Oriented Language (TOOL) to provide the programming construct for handling the large multi-dimensional variables. Therefore all observed and constructed data can be represented and simulated in all its complexity. Display of these variables is provided through propriety Graph and Table (spreadsheet) applications, with options to export to common spreadsheet packages.

3.1. Three Stages to the Design Approach for Decision Support

There are three key stages to the process of developing a decision support model, such as ASFF, using the whatIf applications:

- designing models or frameworks;
- data integration (calibration); and
- scenario creation and comparison.

The first step involves designing the model using the Documenter application, resulting in a graphical representation of the model (see Figure 3). This conceptual step consists of identifying the processes to be represented in the framework, and defining the variables and the relationships among them. An important element of design is the designation of the critical uncertainties or tensions that will be the subject of exploratory simulation. It is important that the design not be constrained by the unavailability of data, although model development should be cognisant of the data sources identified. The model design step is best accomplished by the interaction between policy analysts, planners, interest groups and science/technology experts in workshops with the model developer. The programming of TOOL code to capture the variable relationships in terms of mathematical statements completes the design step.

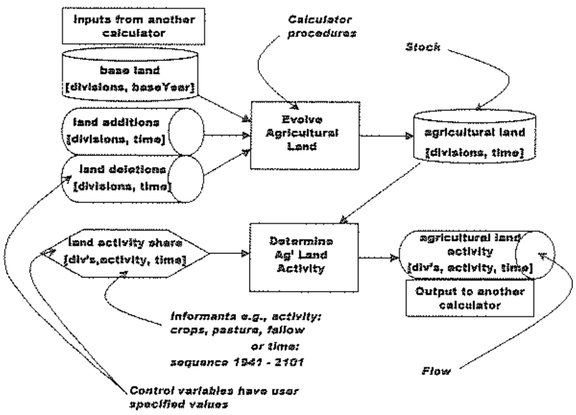

Figure 3. An example of part of the model displayed in Documenter.

The next step involves the calibration of the model over historical time to ensure that the model outputs are entirely consistent with the observed data. Calibration (or data reconciliation) involves assembly and formatting of all relevant data sets, estimation of missing data, correction of erroneous data, and estimation of parameters and variables that do not have any observed data. The estimation of values for some variables may be comparatively free or in other cases completely constrained depending on the relationships described in the model and the observed data that is available. Either way, the result is a *complete and consistent database* in the sense that all variables have data over all their dimensions (completeness), and the observed data is reproduced when the model is run over the historical period (consistency). This is a necessary but not sufficient requirement for a valid model.

The third step to the design approach involves the creation and comparison of scenarios. Scenarios are plausible pathways into the future, plausible in that they are internally consistent (within the framework) and anchored in the present (values of variables at the start of the scenario period are derived from the values at the end of the historical period). Changes to the values of any number of the independent (control) variables are made in the SAMM application. The resulting model outputs and the control variables can be saved as a scenario and used as the basis for other scenarios.

3.2. Aspects of Support to Decision Making

There are direct and indirect aspects to supporting policy and decision making that are implicit in the approach and software we use to implement ASFF.

The most direct and arguably most important decision making support is achieved in the final stage of creating and comparing scenarios, providing an environment for effectively educating the user and influencing the decision-making process. Ideally the policy analyst or decision maker suggests adjustments to chosen control variables and observes the model results, including any tensions in output variables. Since there are no feedback loops these tensions can only be resolved by further adjustment of the control variables. This means the user must explore the simulation to identify the driving factors, if not understood already, and must then consciously decide on an appropriate course of action. Even in the cases where tensions are absent or of a 'behavioural' nature (i.e., physically possible), the user learns from observing the effect of making trade-offs. In many cases it has been necessary for the model analysts to undertake this scenario development role, and follow on with promoting the comparison of scenarios and associated implications. We have identified collaborative evidence from other intellectual sources (literature reviews, national media, and other quantitative analysis) for supporting arguments.

In a similar fashion, at the beginning of the design process the stakeholders are ideally involved in designing the model or framework. The stakeholders can direct the model development facilitated using graphical symbols and descriptive language in the Documenter application. In effect, the model itself becomes its own documentation. The TOOL coding underlying the mathematical relationships is left to the model developer. Nevertheless, the philosophy is that the key model assumptions and operations can be interpreted from the Documenter diagram. This is an important element for increasing the shelf-life of the model.

There are several subtle features in the Documenter application that enable this philosophy. At a high level of abstraction, the structure of the major modules or calculators of the model is displayed. This is an active navigational aid through the model and provides a reminder of the conceptual links and information flow between calculators.

Within a calculator, variables and the operations on these are explicitly described (see Figure 3). Shapes of variables indicate their nature as either stocks, flows or parameters (drawn as barrels, pipes and hexagons, respectively). Further detailed information is provided in the list of dimensions or "informants" for each variable. The presence of an informant in a variable indicates a dependence of the variable on that dimension—the functional dependence is contained in the data values of the variable. Most variables have a time dependence which is usually the right most informant. The simplicity of descriptively explaining the operations or processes of the model rather than using a symbol for each mathematical operation greatly enhances the interpretation of the diagram.

From our experience in real applications and that of ROBBERT Associates we observe that the advantage of this approach comes from:

- the flexibility which allows user/model developers to capture quickly the essence of conceptual relationships without committing to lengthy coding, and
- the ability of human cognitive processes to abstract concepts well but relatively limited ability to keep track of even a small number of operations—most people understand the conceptual elements of chess but few can manage to plan more than a couple of moves ahead.

The process of calibration provides policy- and decision-makers with greater confidence in the supporting historical data. The accuracy of historical data is enhanced since discrepancies between alternative data sources are highlighted and must be resolved by either identifying data errors (or mis-interpretation) or by re-design of the model. Where (as is the attempt in ASFF) the model represents accounting identities or strict physical relationships, then conflicting data must be scrutinised closely.

Calibration also results in a data meta model that is transparent (through the associated Documenter diagrams) and robust. Original data sets can be traced back through the Documenter diagram.

Finally, the framework provides a context in which to identify important data that should be collected (but currently isn't), with the potential to improve future decision-making.

4. CONCLUSIONS

Both the Australian Stocks and Flows Framework and the whatIf applications in which ASFF is implemented support policy- and decision-making. ASFF provides, inter alia, the physical reality check on long-term scenarios for appropriate consideration of slow-moving but important stocks (such as natural resources, infrastructure and pollution levels). This is implemented using a design approach—ideally involving the policy analyst or decision-maker to resolve tensions that arise in the model, and providing a learning environment for the policy analyst or decision-maker.

5. ACKNOWLEDGEMENTS

The authors wish to express their appreciation for insightful discussions with Bert McInnis and Robert Hoffman of ROBBERT Associates, and their support for implementing the Australian Stocks and Flows Framework.

6. REFERENCES

Cocks, K.D., F. Poldy, and B.D. Foran, A Comprehensive Simulation Model of Material and Energy Transformations and Transfers in the Australian Economy, in preparation.

Conroy, J., B.D. Foran, F. Poldy, and T. Quinnell, CSIRO Sustainable Ecosystems, Future Options to 2050: DIMA Workshops Report, Working Paper Series 00/03, 2000.

Dunlop, M., B.D. Foran, and F. Poldy, Exploring Solutions to Australia's Long-term Land and Water Problems Using Scenario Modelling at MODSIM 2001 Congress proceedings, Canberra, ACT, Australia, 2001.

Foran, B.D. and F. Poldy, Future Dilemmas: Options to 2050 for Australia's Population, Technology and Environment, Report to DIMA, Working Paper Series 01/06, 2001.

Gault, F.D., K.E. Hamilton, R.B. Hoffman, and B.C. McInnis, The Design Approach to Socio-economic Modelling, *Futures*, 3-25, 1987.

Hoffman, R.B., B.C. McInnis, and M. Hoffman, ROBBERT Associates, ROBBERT Associates, www.robbert.ca, July 2001.

Lowe, D.B., F. Poldy, B.D. Foran, and R.E. Kearney, Exploring Options for the Long Term Future of Australia's Fisheries Using a Scenario Modelling Approach at MODSIM 2001 Congress proceedings, Canberra, ACT, Australia, 2001.

Poldy, F., B. Foran, and J. Conroy, CSIRO Sustainable Ecosystems, Future Options to 2050: Australian Stocks and Flows Framework, Working Paper 00/04, 2000.