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Modelling

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1. MODELLING: A BRIEF DESCRIPTION

A model is a verbal, graphic or mathematical depiction of social or economic relationships. Models provide a simplified framework by focusing on the key relationships of interest and ignoring factors considered to be more marginal. In the words of the economist Joan Robinson, "A model which took account of all the variegation of reality would be no more use than a map at the scale of one to one."[1]

A theory of change (see Brief No. 2, Theory of Change) is an example of a model. 'Modelling' as an approach to impact evaluation is usually restricted to mathematical models in economics or epidemiology, however.

Mathematical models describe social and economic relationships in algebraic notation. The simplest models are single-equation models. For example, the health production function in economics expresses a health outcome, for example, infant mortality rate, as a function of income, female education, immunization, nutritional inputs and so on.

Single-equation models have unidirectional causality from intervention to outcome, which is sometimes referred to as a 'linear approach'. Linearity also has a different meaning, as the functional form of the relationship between an outcome and its determinants, and single-equation models can capture non-linearity of this sort. For example, in many countries the relationship between infant mortality and mother's age at the infant's birth is an inverted-U relationship, with mortality higher among children born to younger and to older mothers than among children born to mothers in their twenties or early thirties. Single-equation models are just a form of shorthand notation.

Dependent variable = *f* (independent variables, parameters) or

$$y = \beta_0 + \beta_1 X_1 + \varepsilon$$

In the equation above, *y* is the dependent variable and is a function of the independent x variable. The intercept is β_0 while β_1 is the slope and X_1 the independent variable, with ε the error term.

The real value of modelling lies in models with more than one equation, since these allow for both direct and indirect effects and also two-way relationships to be captured. For example, raising income directly affects child health if households can afford more and better food and health care when needed, and a higher income can also affect child health indirectly if the higher income results in higher tax revenues for government, some of which are spent on health services. An example of a simultaneous relationship is the one between fertility and mortality. Fertility depends on child mortality (since households may decide to have more children if it is likely that some of them will die), but mortality also depends on fertility (children in larger families are more likely to die). The two-equation model that captures this two-way relationship shows how an exogenous change that reduces mortality (or fertility) not only has a one-off direct effect but also an indirect effect, as it sets off a virtuous circle in which both decline by more than the original decline caused by the exogenous change.

Systems dynamic modelling emphasizes the importance of feedback loops and of including both stocks and flows in models. For example, in epidemiological models it is the stock of people who have been immunized which matters for the spread of the disease, but that stock depends on the rate of new immunizations (and death rates of both immunized and non-immunized populations).

Vector auto-regressive models may be used if time series data are available. In this type of model, an equation is written for every variable in which that variable is a function of all other variables. The parameters in this model are then estimated statistically. The resulting model can be used to introduce exogenous changes that capture the impact of the programme or policy.

[1] Robinson, Joan, *Essays in the theory of economic growth*, Macmillan, London, 1962.

Models are used to examine the impact of a programme or policy (rarely a project) by introducing the programme or policy as an exogenous change in some of the variables, parameters or equations, as illustrated in the following examples:

- **Changing variables** – Introducing a cash transfer scheme is an exogenous increase in the income of the recipient households.
- **Changing parameters** – Of course, the transfer has to be paid for either by aid or by government revenues. If government raises taxes on wealthier individuals and uses that money to pay for the cash transfer scheme, the increase in the tax rate is introduced into the model by changing parameters in the tax function.
- **Changing equations** – Economic reforms can change the way the economy functions and thus require the equations that capture how the economy functions to be changed. For example, the introduction of a cash transfer scheme changes (1) the income equation for recipient households; (2) the education expenditure function of recipient households; and (3) the government expenditure equations.

Finally, models also make arguments 'by omission'. This approach has been used in examining the causes of climate change, in which all known determinants of climate change are included, but leave a large, unexplained component, which must be attributable to human causes of climate change.

Models may also be qualitative. A theory of change flow diagram is an example of a qualitative model, in which the links from one stage to another, and the underlying assumptions, may be tested using qualitative data.

Main points

1. Modelling is an approach to impact evaluation, which uses mathematical models to describe social and economic relationships and to infer causality from intervention to outcome and/or between an outcome and its determinants.
2. Models with more than one equation are most valuable, as they allow for both direct and indirect effects and also two-way relationships to be captured.
3. Models can be used to examine the impact of a programme or policy (rarely a project) by introducing the programme or policy as an exogenous change in some of the variables, parameters or equations.

2. WHEN IS IT APPROPRIATE TO USE THIS METHOD?

Models can be used for ex-ante and ex-post evaluations. Ex-ante modelling is carried out to predict what the impact of a programme or policy will be, whereas ex-post modelling estimates what the impact has actually been. Ex-ante modelling will require assumptions to be made as to the value of all exogenous variables. Ex-post modelling can use the actual values of these variables taken from either administrative or survey data. Ex-ante modelling and ex-post modelling serve different purposes – the former enables the appraisal of whether a particular programme or policy is worthwhile, the latter is done for evaluation purposes.

Three situations in which models are used for ex-post evaluations:

1. When the outcomes of interest cannot be directly measured by the evaluation, because they are far in the future or because they are infrequent events (such as mortality, especially maternal mortality). Early child development and schooling interventions aim to improve the participants' life chances, as

reflected in indicators such as lifetime earnings. Clearly it's unfeasible to wait 50 years to measure this outcome, however, so instead outcomes such as completed years of schooling and learning outcomes are looked at. It's then possible to calculate the impact on lifetime earnings by drawing on extensive research showing age-earnings profiles for people with different levels of educational attainment. All models require assumptions – in this example, the assumption made is that past performance is a reliable guide to future outcomes, but this won't be the case if there are marked changes in the job market, whether because job opportunities change or the supply of qualified people increases more rapidly than employment opportunities.

2. For national programmes or policies of the type for which it is difficult to have a comparison group, the counterfactual is constructed using a model. This may be just a single-equation model or it may be a complex model with hundreds or even thousands of equations. Computable general equilibrium (CGE) models were widely used in the 1990s to analyse the effects of economic reform policies on poverty and social outcomes, for example, in David Sahn et al.'s *Structural Adjustment Reconsidered.*[2]

3. To capture general equilibrium effects. This approach should be used either when (1) indirect effects are thought to be important, or (2) the programme operates on a sufficiently large scale to have 'macro' effects (though possibly only in the local economy). For example, many projects in developing countries support women's groups to engage in small enterprises such as poultry farming or goat herding. The presence of new producers will reduce the market price for eggs and goat meat, however, especially if access to external markets is limited. On the other hand, the additional income that these individuals will earn is likely to be spent locally, increasing the income of other villagers. The village-level CGE model would capture all of these factors.

The first of these reasons is often used in epidemiology. Maternal mortality is a rare event, for example, so it is difficult to obtain sufficient power in an impact evaluation to use this as an outcome variable. Hence, a proxy outcome may be used such as take-up of antenatal services, from which an estimate of the impact of maternal mortality is then extrapolated. This approach requires some confidence in the parameters used for the extrapolation, which should come from quality research in similar settings.

Modelling can also be seen as a specific type of causal chain analysis, in which the different causal mechanisms are quantified.

Models are also used for ex-ante analysis (i.e., before programme/policy implementation) to:

- estimate the expected effects of a new or planned programme or policy
- estimate the effects of expanding a programme or policy beyond its current reach.

For ex-ante analysis, parameter estimates are taken from existing models and similar programmes/policies elsewhere.

3. HOW TO CONDUCT MODELLING

Models can play an important role in influencing policy decisions by making predictions about and estimating the impact of programmes and policies. There are many different types of models – both quantitative and qualitative – and this section provides a short description of some of these. It begins with economic models, which may be either 'partial equilibrium' or 'general equilibrium'. The brief then discusses approaches that may be linked to models: microsimulations, benefit incidence analysis and cost-benefit analysis.

[2] Sahn, David, et al., *Structural Adjustment Reconsidered: Economic Policy in Africa*, Cambridge University Press, Cambridge, 1999.

Economic models

In economics, partial equilibrium analysis considers the direct effects of an intervention but not the impacts caused through changes in supply and demand. For example, a poultry project for poor women will increase the supply of eggs, thus reducing their price, which will adversely affect existing producers. Most impact evaluations estimate partial equilibrium (direct) effects. These are sometimes called 'first order' effects, indicating that they are more important than 'second order' effects', which are indirect.

General equilibrium analysis takes into account the economy-wide effects caused by an intervention. Such models are usually at the national level but can be constructed for a smaller geographical unit such as a region or even a village. A CGE model is computable as numeric values are given to the model parameters, so the model can be used to calculate the outcomes with and without a particular programme or policy.

CGE models are used to perform 'policy experiments', either ex ante or ex post. The logic is the same in both cases: the model is estimated with the programme or policy and then without it, with the difference in key outcomes defining the impact of the programme or policy (predicted impact for ex-ante studies and estimated impact in the case of ex-post studies).

A CGE model is usually based on a social accounting matrix (SAM), which is a matrix-based presentation of the national accounts. A SAM captures the national accounting identities, notably that each and every expenditure is someone else's income. The production accounts in a SAM are the input-output matrix showing how the outputs of one industry are used as inputs by another industry. Households are usually disaggregated by a functional classification such as waged employees, informal sector workers and subsistence farmers, although they may also be disaggregated by income (poor and non-poor, or by quintile). Social indicators such as enrolment and mortality may augment a SAM.

A SAM contains numbers. A CGE model is produced by writing the equations that generate those numbers. Some of the equations that make up the CGE model could be identities (such as total income equals total expenditures, and total imports equal total exports plus net capital inflows and the change in reserves) and others could be behavioural relationships. Economic behavioural relationships in a typical CGE model are those between expenditure and income (the consumption function) and between inputs and outputs (the production function). An augmented SAM will include additional relationships, for example, how infant mortality is related to health expenditure and food consumption.

Constructing a CGE model thus requires three steps: (1) constructing the SAM (or using one that has already been constructed); (2) writing the equations for the CGE model; and (3) calibrating the CGE model. Calibration involves assigning numerical values to the parameters in the behavioural equations and checking that key outcome variables correspond to their historically observed values in the year to which the SAM relates. Findings from impact evaluations may inform some of these parameters. For example, CGE analysis has been conducted of the economy-wide effects of Mexico's Progresa/Oportunidades conditional cash transfer (CCT) programme[3], which draws on impact evaluation evidence around how much of the cash transfer is consumed and on what.

Calibration can involve key stakeholders, which can both strengthen the model and generate understanding of and buy-in for the model's insights. The International Food Policy Research Institute (IFPRI) has been responsible for producing many SAMs for developing countries. Part of the preparation process involves a 'SAM walk' in which a large version of a matrix is laid out on the floor or a large table and country experts are invited to be quizzed on aspects of the data. Policymakers can be asked to comment on different model simulations that offer insights to how the model is working, and to provide feedback on the model equations and parameters.

[3] See Secretaría de Desarrollo Social (SEDESOL), Oportunidades, www.oportunidades.gob.mx.

This participatory approach to model development is explicitly included in systems dynamic modelling. Such engagement is most likely to be successful in small models[4] in which causal pathways can be clearly identified. Large CGE models generate outcomes under different policy scenarios, but the causal pathways in large models may be too complex to unravel.

The UNICEF study of the impact of fuel subsidies in Ghana (see example under section 6, below) and the offsetting effect of transfers uses a partial equilibrium model, which examines how the change in prices affects the level and composition of expenditure for different income groups. The Ghana model is an example of an ex-ante simulation (although the subsidies had been removed, pre-reform data were used for the analysis).

Microsimulation is an increasingly popular modelling approach. Microsimulations are large, complex models in which the behaviour of each unit (individual or household) is modelled, capturing the interaction between all of the units in the model. Microsimulation models have been used in demography, economics and health sciences.

The results from modelling may inform other types of analysis. One example is benefit incidence analysis, which examines who benefits from public expenditure by combining data on access to services with the unit costs for providing those services. For example, data can be used on primary, secondary and tertiary enrolments by income quintile, together with the unit costs for each level of education (preferably regionally disaggregated). The data can be shown in a Lorenz curve, plotting the share of cumulative government expenditure against the cumulative share of the population.

Cost-benefit analysis quantifies all of the costs and benefits of an intervention, thus calculating the rate of return on the expenditure. Impact evaluations, including modelling, generally quantify the benefits stream and so are inputs into cost-benefit analysis.

4. ETHICAL ISSUES AND PRACTICAL LIMITATIONS

Ethical issues

The main ethical issues surrounding models relate to their intended use. Where the intended use of a model is to inform harmful, exploitative or unethical activities, for example, to increase profits from an illegal activity,[5] the research itself is unethical and should not be conducted. The purpose of modelling should be clear, ethical and, in the UNICEF context, intended to advance the rights of children.

Practical limitations

A major limitation of models is that they are assumption dependent. The more complex the model, the more assumptions are required, and the more sensitive are the findings to these assumptions. So it is important to undertake sensitivity analysis.

Traditional sensitivity analysis varies key parameters to see how the model outcomes are affected. A Monte Carlo simulation assigns a probability distribution to each of the model parameters and uses these distributions to run thousands of simulations, thus generating a probability distribution of the outcomes of interest. Whilst it may sound messy, a Monte Carlo simulation does emphasize the fact that point estimates are misleading: estimates are best reported as a range of likely outcome values.

[4] Ghaffarzadegan, Navid, et al., 'How small system dynamics models can help the public policy process', *System Dynamics Review*, 27, 2011, pp. 22–44.

[5] Kleijnen, J.P.C., 'Ethical issues in modeling: Some reflections', *European Journal of Operational Research*, 130, 2001, pp. 223–230.

More fundamentally, models may not capture the most important variables or relationships. Good modelling is well grounded, though, and so should avoid this limitation.

5. WHICH OTHER METHODS WORK WELL WITH THIS ONE?

Modelling combines impact estimates with a broader range of economic or epidemiological relationships. A knowledge of context should inform model specification; this can come from policymakers and/or other stakeholders. These stakeholders may have key insights into causal pathways, which the researchers do not themselves possess. The outputs of participatory data collection, for example, mapping and oral life histories, may also provide insights for modelling.

6. EXAMPLES OF MODELS

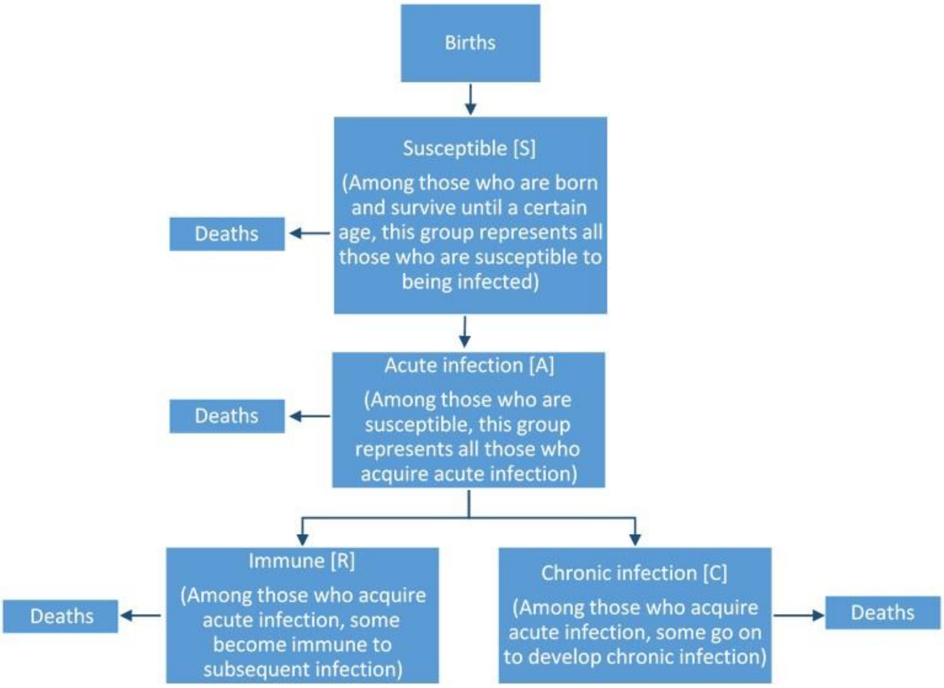
An epidemiological model

Figure 1 below shows a framework for the epidemiology of an infectious disease model (in this case, hepatitis B), which can be translated into a mathematical model.

The figure shows that susceptible individuals are more likely to acquire acute infections. Some among this group become immune after being exposed to the acute infection while others go on to develop chronic infection. Additionally, there are certain inflows and outflows from each state (represented by births and deaths).

A mathematical model of this framework specifies an equation for each of the arrows to estimate how many individuals would be present in each state as well as the rate of flow of infection.

Figure 1. Framework for the epidemiology of an infectious disease model



Source: Adapted from Garnett, G.P., et al., ‘Mathematical models in the evaluation of health programmes’, The Lancet, 378, 2011, pp. 515–525.

A partial equilibrium example

A UNICEF evaluation used a modelling approach to examine the impact of the abolition of fuel subsidies in Ghana and how a cash transfer programme (in this case, the Livelihood Empowerment Against Poverty programme) may be used to cushion the poor from this impact[6]. Although the fuel subsidy reform had already been introduced, this was an ex-ante study since it used data from some years previous to estimate the impact of the reform. The impact of removing subsidies was captured through both a direct effect, in which real household expenditure falls as more must be spent on fuel products, and indirect effects, as the fuel price rise affects the cost of other items. The study is a partial equilibrium analysis as it does not capture how the change in real income reduces demand and therefore lowers incomes for other firms and workers, etc.

The analysis revealed that the fuel subsidy had been very regressive, with the richest 20 per cent of the population capturing 78 per cent of the subsidy and the poorest quintile receiving just 3 per cent of the benefit. Nonetheless, the poor would experience a 2.1 per cent reduction in their consumption as a result of the increase in fuel prices, and the poverty headcount would increase by 1.5 per cent. Expanding the Livelihood Empowerment Against Poverty cash transfer programme to at least 150,000 households, however, would offset the effect of the price rises on poverty – and at a fraction of the cost of the money saved by scrapping the subsidy.

The model is relatively simple, but nevertheless requires many assumptions. The example shows, however, that writing a model allows for the quantification of effects and so helps to inform policy in a very specific manner. Specifically, the analysis revealed the regressive nature of the subsidy, countering arguments that removing subsidies will mainly hurt the poor. And the numbers were able to show the cost of compensating the poor for the loss they did suffer.

Strengths and weaknesses of modelling

Good models make clear their assumptions, and test the sensitivity of the key results to these assumptions. A bad model would do the opposite: presenting a finding based on a specific set of assumptions that is not explicit and that remains unclear, and where the results are fragile to varying those assumptions.

Another disadvantage of modelling is its inherently technical nature, which means that only a technical audience can understand it.

7. KEY READINGS AND LINKS

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GLOSSARY

Comparison group	*In a quasi-experimental research design, this is the group of research subjects/participants that, for the sake of comparison, does not receive the treatment/intervention given to the treatment/intervention group. Comparison group subjects are typically not randomly assigned to their condition, as would be true of control group subjects in an experimental design study.*
Counterfactual	*The situation or condition which hypothetically may prevail for subjects (individuals, organizations, etc.) if there was no intervention.*
Dependent variable	*A variable that receives stimulus and is measured for the effect the independent variable (e.g. intervention/treatment) has had upon it. See: independent variable. See: independent variable.*
Ex-ante evaluation	*An evaluation performed before the implementation of an intervention (i.e. programme or policy).*
Ex-post evaluation	*An evaluation of an intervention (policy or programme) conducted after the implementation of the intervention.*
Exogenous	*Something that has an external origin or cause.*
Impact	*Positive and negative, primary and secondary long-term effects produced by a development intervention, directly or indirectly, intended or unintended. (OECD-DAC definition, 2010)*
Independent variable	*The variable that has been identified (from theory or elsewhere) as the possible cause of the phenomenon being researched. The level or strength of the independent variable is manipulated or changed by the researcher to identify whether the intervention had an expected effect. See: dependent variable.*
Lorenz curve	*A graph on which the cumulative percentage of total national income (or another variable) is plotted against the cumulative percentage of the corresponding population (ranked in increasing size of share). The extent to which the curve slumps below a straight diagonal line indicates the degree of inequality of distribution. (Oxford dictionary definition)*
Theory of change	*Explains how activities are understood to produce a series of results that contribute to achieving the final intended impacts. It can be developed for any level of intervention – an event, a project, a programme, a policy, a strategy or an organization.*
Time series data	*Well-defined data items collected through repeated measurements over time.*
Vector auto-regressive model	*An econometric model used for the analysis of multivariate time series. It is useful for describing the dynamic behaviour of economic and financial time series and for forecasting, and can also be used for structural inference and policy analysis.*