Economic Modelling 32 (2013) 429–439

Contents lists available at SciVerse ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

Dynamic general equilibrium model with uncertainty: Uncertainty regarding the future path of the economy

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ARTICLE INFO

Article history:
Accepted 20 February 2013

JEL classification:
C68
C63

Keywords:
Computable general equilibrium model
Uncertainty
Risk
Tourism

ABSTRACT

This paper develops a new method for incorporating uncertainty within a computable general equilibrium (CGE) model. The method involves incorporating uncertainty into the model by formulating different states of the world or paths that the economy may take. The risk then is that on one or more of the paths, there may be an external demand shock, for example, an exogenous shock in tourism demand. The multi-sector forward-looking CGE model with risk shows the impact of uncertainty on the economy and how households and industry respond to the presence of uncertainty. The results show that, where there is an asymmetric shock, the possibility of a future tourism demand shock creates a welfare loss. The welfare gains along the non-shocked path are a result of household's risk aversion and their substituting resources away from the shocked path. The difference in the monetary values of the welfare on the different paths can be interpreted as the 'price' of the risk. It is the price households would pay to remove the possibility of the tourism shock. Therefore, this research was able to quantify the monetary value of the risk. This method can be used in scenario modelling for other adverse contingent events, such as the uncertainty of climate change impacts, and agriculture production risks.

1. Introduction

The concept of risk has been examined from many different disciplines: from an economic perspective (Anscombe & Aumann, 1963; Arrow, 1965; Kahneman & Tversky, 1979; Pratt, 1964; Rothschild & Stiglitz, 1970, 1971; von Neumann & Morgenstern, 1944), from a sociological perspective (Finucane & Holup, 2005; Slovic, 1986, 1987; Slovic et al., 1985), from a financial perspective (Bluhm et al., 2002) and from a technical perspective (Kammen & Hassenzahl, 1962). Risk is a complex construct. Risk has been defined in many different ways. One frequently cited definition of risk is that of Knight (1921). He defines risk as "measurable uncertainty". Denenberg et al. (1974) simply define risk as "uncertainty of loss". There can be many types of losses as well. Denenberg et al. take a very narrow view of risk defining loss as the loss of wealth or profit. Loss could be a loss of satisfaction/happiness or utility as in the economic meaning of utility. Thus, a loss of utility could involve a financial loss or may involve dissatisfaction or simply just the loss of happiness. This can be measured as a loss in economic welfare.

The CGE class of models is empirically estimated by Arrow and Debreu (1954) using general equilibrium models with empirical data. CGE models were developed in the early 1960s to solve for both market prices and quantities simultaneously, thus simulating the working of a competitive market economy. A CGE model attempts to model the whole economy and the relationships between the economic agents in it. The model solves for a set of prices, including production prices, factor prices, and exchange rate and levels of production that clear all markets. The result is that, following the neoclassical assumption, producers maximise profits, which are the difference between revenue earned and the cost of factors and intermediate inputs. Commodity market demands depend on all prices and satisfy Walras's law. That is, at any set of prices, the total value of consumer expenditures equals consumer incomes. Technology is described by constant returns to scale production functions. Producers maximise profits. The zero homogeneity of demand functions and the linear homogeneity of profits in prices (i.e. doubling all prices double money profits) imply that only relative prices are of any significance in such a model. The absolute price level has no impact on the equilibrium outcome (Rutherford & Paltsev, 1999).

In conventional forward-looking dynamic CGE models, economic agents are endowed with perfect foresight, so both consumers and firms anticipate any exogenous shocks and adjust their maximising behaviour from the first time period onwards. Perfect foresight then would appear to negate any uncertain response to a shock. Taking a

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http://dx.doi.org/10.1016/j.econmod.2013.02.034

simple model with Ramsey economic growth dynamics, this paper illustrates a frame work that incorporates uncertainty by allowing alternative future time paths resulting in uncertainty in the model. When an adverse shock occurs on one of the paths, this uncertainty is realised as a risk.

The next section outlines the way risk is treated in standard CGE model, whether they are comparative static modes, or dynamic model (both dynamic recursive or forward-looking). Section 3 assesses previous research that has attempted to incorporate risk and uncertainty into CGE models. Section 4 in this paper conceptually describes the explicit treatment of risk in a CGE model involving the creation of multiple future paths for the model, where agents are able to predict each path and make decisions, given an element of risk aversion, in the presence of this uncertainty. Section 5 takes the conceptualisation of the uncertainty explained in Section 4 and applies it to a stylised benchmark economy to show the impact of the uncertainty on the economy. The implications the uncertainty has for the behaviour of the different economic agents (households, tourists, government, and industry) are highlighted. Section 6 concludes and suggests areas for further research using this uncertainty framework.

2. Risk in standard CGE models: behaviour of microeconomic agents

The section outlines the basic characteristics of the different types of CGE models: the static model, the dynamic recursive model, the single sector dynamic forward-looking model and the multi-sector dynamic forward-looking model. For each type of model, the implicit assumptions of risk are outlined.

2.1. Risk in a comparative static CGE model

The comparative static (within period) CGE model follows the interactions and relationships of a market economy and solves for a set of prices including production prices, factor prices and exchange rate and levels of production that clear all markets. Equilibrium in this model is characterised by a set of prices and levels of production in each industry such that the market demand equals supply for all commodities. Since producers are assumed to maximise profits, and production exhibits constant returns to scale, this implies that no activity (or cost-minimising technique for production functions) does any better than break even at the equilibrium prices. Demand for and supply of goods and services readjust until all excess demands and excess supplies are eliminated through changes in prices. The production function is specified into terms of labour and capital and the amount of each type of these inputs employed by a producer in a particular sector is based on the sector specific production technology and input prices. Perfectly competitive markets operate to determine these equilibrium prices. Additionally, in equilibrium, no sector earns above-normal profits, markets clear for all factors and products, and, in an open economy, the value of imports for intermediate use and final demand equals the value of export earnings. The microeconomic underpinnings of economic agents in a CGE framework follow the traditional neoclassical approach. Agents have rational preferences among outcomes that can be identified and associated with a value. Individuals exhibit maximising behaviour and act independently on the basis of full and relevant information.

In terms of implicit risk, the return on capital captures all the inherent risk associated with the investment and owners of capital are paid an appropriate return, given the level of risk. Elasticities capture the trade-off between the choice of various products and of the inherent risk associated with the curvature of the utility functions. In such models, risk or uncertainty is not explicitly factored into the model.

2.2. Risk in a dynamic recursive CGE model

A dynamic recursive model is backward-looking by nature: what happens in future periods does not affect the current year's equilibrium. The model is solved year by year without having to solve the whole study period at once. Agents in these models exhibit myopic behaviour. These sequential dynamic models are basically a series of static CGE models that are linked between periods by behavioural equations for endogenous variables and by updating procedures for exogenous variables. Capital stock is updated endogenously with a capital accumulation equation, whereas exogenous variables such as total labour supply are updated between periods. This process can be seen in Fig. 2. The intra-temporal model is represented by the circular flow diagram within the black ovals in Fig. 1. The updating of the exogenous variables flow chronologically from left to right, that is, the with-in period model solves and then advances to the next time period.

The models are linked together by the savings/investment rule. However, other research has shown that the savings/investment rule can determine to a large extent, the results of the model. The concept of risk in the dynamic recursive model is the same as the treatment of risk in a static model. The 'new' elements in the dynamic recursive model are deterministic in nature and again, the risk is implicitly modelled through the interest rate and in the elasticities.

2.3. Risk in a single-sector dynamic forward-looking CGE model

The dynamic forward-looking computable general equilibrium model assumes that consumers' and producers' behaviour is derived from both intra- and intertemporal optimization. These models incorporate some form of life-cycle behaviour. The household maximises an additive separable time-invariant intertemporal utility function, while the producer's optimal behaviour is determined by the maximisation of the market value of the firm or by the maximisation of the present discounted value of net cash flows. The market value of the firm is usually represented as the present discounted value of the future steam of dividends. The model is based upon the perfect foresight hypothesis and describes the transition path to the new equilibrium point. Households and firms make optimal choices given their intertemporal budget constraints. Households maximise the present value of their lifetime utility and firms maximise the value of their profits. In every period, prices adjust to guarantee equilibrium in the model so that demand equals supply. These types of model were first developed by Ramsey (1928), Cass (1965) and Koopmans (1965) (see Barro and Sala-i-Martin, 1995).

As with the comparative static model, demand for and supply of goods and services re-adjust until all excess demands and excess supplies are eliminated through changes in prices. Perfectly competitive markets operate to determine these equilibrium prices. Additionally, in equilibrium, no sector earns above-normal profits, markets clear for all factors and products. Equilibrium is met for each product in each time period by allowing prices to clear markets. The CPI is often adopted as the numeraire, as in this study. Hence all price changes mentioned in the Results section should be interpreted as changes relative to the price of consumer goods (Dixon et al., 2005).

In contrast to the dynamic recursive model, the dynamic forward-looking model does not have a rule that links one time period to the next but capital is accumulated in each future time period (represented by the orange links between the intra-temporal models in Fig. 3). Further, firms maximise the net present value of their profits and consumers maximise their net present value of their utility. They have model-consistent rational expectations about future time periods. Decisions made in period, t (and subsequent time periods) take into consideration events that occur in future time periods. Economic agents can adjust to shocks before they occur. As represented in Fig. 3, the expectations are made for each time period considering what has happened before and what will happen after the current time period so in period $t = 2$, the representative consumer optimises