Single Country and Global Recursive Dynamic Computable General Equilibrium (CGE) Modelling

"The only function of economic forecasting is to make astrology look respectable."
(J K Galbraith)

Introduction

This is a course on recursive dynamic (RDYN) single-country or global computable general equilibrium (CGE) modelling using the General Algebraic Modelling System (GAMS) software. The course is designed for individuals who have a well-developed background in economics and single-country or global CGE modelling, who wish to develop the technical skills needed to implement recursive dynamic single-country or global CGE models. The course emphasises the development of the skills required to develop systematic policy experiments and the interpretation of the results from those experiments. The course also develops the participants understanding of the calibration of RDYN CGE models, the behavioural relationships that control the updating of the model parameters, while enhancing GAMS coding skills. The course uses a mix of video presentations (lectures), videos, practical computer exercises and policy analyses exercises.

The course presumes that users are proficient users of comparative static CGE models with appreciable experience implementing and interpreting comparative static policy scenarios. The course includes no guidance on the core comparative static models. Users should also be experienced GAMS coders.

The course emphasises an understanding of the theories of growth and general equilibrium (GE), CGE databases, GAMS coding skills, CGE model coding skills, the formulation of appropriate policy experiments and the interpretation of the results from simulation models.

The course is offered with two pathways/variants. The first is a single-country course that builds on the 'Single Country CGE modelling course' and uses the STAGE_t model. The

second a global course that builds on the 'Global CGE modelling course' and uses the ANARRES_t model.

The course is delivered via a website – http://www.cgemod.org.uk/rdyn_cge.html . The materials are organised in two streams of 6 modules each of which is scheduled to take some 20 to 40 hours of study, i.e., 150 to 250 hours. The course runs all year. Participants should plan to allocate up to 20 hours per week to complete the course; little and often has produced better outcomes.

The course uses a mix of video presentations (lectures and 'how to' videos), practical computer exercises and policy analyses exercises. The core software for the course is GAMS (www.gams.com), its editor GAMS Studio, and various GAMS utilities; you will need a GAMS license: visit the website https://www.gams.com/download/ or contact sales@gams.com . You will need MS Excel and MS Word, or another word processing package, an ability to play MP4 video files, and a reader for PDF files. The GAMS computer codes are platform independent for Windows, Mac OS and LINUX. The course codes were developed using Windows and some testing with Mac OS has been undertaken. Interfacing GAMS with Excel was developed using Windows and some testing with Mac OS has been undertaken; but we cannot guarantee that all the Excel techniques used are available with Mac OS. We do not use LINUX and have not tested the materials using LINUX.

User of this course need well developed CGE and GAMS skills. A minimum expectation is the completion of the 'Single Country Computable General Equilibrium (CGE) Modelling course' (see www.cgemod.org.uk/single_cge.html for details) or the 'Global Computable General Equilibrium (CGE) Modelling course' (see www.cgemod.org.uk/global_cge.html for details), plus practical experience. Without these skills and experience users are unlikely to benefit from this course.

The course is offered **without** tutor support: so users to rely on the course documentation, solution code examples, sample answers for policy analyses.

Course Description

Recursive dynamic (RDYN) CGE models are essentially series of comparative static (CS) solutions – the 'model' phase - interspersed with code that updates model parameters – the 'update' phase. The defining feature of this class of CGE models is that decisions for the next period are based on the outcomes of previous periods, i.e., expectations are backward looking. The approach in this course adopts the KISS principle[1] by solving the comparative static CGE model in a series of LOOPs (at least two with one for 'time' and one for experiments) and between each 'time' LOOP running a 'model' that updates key parameters, e.g., factor supplies by institutions. The code structure can be made more complex, e.g., by indexing all parameters, variables and equations on 'time', but it is suggested that more complex variants serve more to confuse that help.

CGE models can be defined as 'theory with numbers' hence this course starts with a review of theories of growth. Interestingly theories of economic growth go in and out of fashion.[2] It is argued that if CS CGE models should be based on microeconomic theory, then RDYN CGE models should be firmly based on theories of economic growth. Since the production systems in CS CGE models are based on standard production theory it is arguably reasonable that the growth theories adopted are based on the same theories of production. Accordingly, the approach to growth taken in this course is based on the growth theories of the 1950s, mainly the Solow model[3], new growth theories[4], and the growth accounting[5] and

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1 KISS – Keep It Simple (or be) Stupid.

2 Much of classical economic thought (Smith, Ricardo, etc.,) was concerned with growth. From the late 19th century, the focus shifted more to demand and supply with the development of neoclassical microeconomics. Following the depression of the 1930s growth returned to the agenda with the development of the Harrod and Domar models but then lapse again until the mid-1950s with the neoclassical growth models, e.g., the Solow and Swan models and the Cass model. It then lapsed again until the emergence of the new growth theories New (endogenous) growth theory that emphasizes technology and knowledge as the primary drivers of long-run economic growth, e.g., the Romer and Lucas models. It again seems out of fashion.

3 Solow, R. (1956) 'A Contribution to the theory of Economic Growth', *Quarterly Journal of Economics* 70, 65-94.

4 Romer, P. (1990) 'Endogenous Technological Change', *Journal of Political Economy*, 98. 71-102. Lucas, R.E. (1988) 'On the Mechanics of Economic Development', *Journal of Monetary Economics* 22, 3-42

5 Jorgenson and Griliches (1967), 'The Explanation of Productivity Change', *Review of Economic Studies*, 34 (99), 249–80.

structural change literature[1]. Some of the relevant considerations are explored in the first module (D1).

This module touches on the deeply misleading designation of the results from RDYN models as forecasts and introduces perpetual inventories that are an important tool. The reasons are simple. The behavioural relationships in standard CGE models have virtually no macroeconomic content and do not include money or a financial sector. Moreover, CGE models are commonly used to examine step changes in policies, e.g., new trade agreements, and/or exogenous events, e.g., climate change, which means they operate in circumstances where economic forecasts are most fragile.

The second module (D2) uses the smod_t.gms model to introduces the basics of RDYN models. The decision to use a simpler model reflects the facts that the focus is on the mechanics of the 'update' phases, which are essential independent of the precise behavioural relationships in the 'model' phase, and that knowledge of smod_t.gms should be common to those taking either the single country or global streams. This module explores the concept of 'time' in RDYN models and the mechanics of capital accumulation. A key consideration is the development of a 'reference' scenario and the related calibration of RDYN models. We depart from the practice of defining a 'Business-as-Usual' (BaU) baseline since the terminology implies a degree of precision that does not exist[2], while failing to recognise that 'reference' scenario (and BaU) is simply an experiment based on selected parameter value.

After the first two modules the course splits into Single Country (SD) and Global (GD) streams. The single-country course that builds on the 'Single Country CGE modelling course' and uses the STAGE_t model and the global course that builds on the 'Global CGE modelling course' and uses the ANARRES_t model. While much of the material is broadly similar for both streams the emphasis is different, which reflects the differences in the CS models. In both streams an important theme is the distinction between crude factor

1 Leontief, W.W., (1951). *The Structure of American Economy, 1919–1939: An Empirical Application of Equilibrium Analysis* (2d ed). New York: Oxford University Press. Domar, E. D. (1961). 'On the measurement of technological change'. *The Economic Journal* 71(284), 709–729.

2 It is also suggestive of forecasting.

accumulation – 'piling wooden ploughs on top of wooden ploughs' – and factor accumulation and exogenous vv endogenous factor quality changes.

The Single Country stream starts with an introduction about the STAGE_t model and then sets up the mechanics for running a 'reference' scenario and the processing of the results for later use as benchmarks for analysing the results from experiments; for this module the parameterisation of the 'reference' scenario is exogenous. The next module generalises simple capital accumulation to allow for putty-putty (capital is mobile before and after it is installed) or putty-clay (capital is mobile before installed but is fixed to an activity after installation) options through the closure rules. The remaining components focus on technology changes and factor quality changes. It starts by considering the implications of exogenously determined technology changes that implicitly presume equiproportionate increases in factor efficiencies. These efficiency gains are implicitly treated as 'manna from heaven', whereas economic growth theories argue that efficiency gains are, to a greater or lesser extent, driven by investment in R&D (for capital goods) and education and training (for labour). These issues are explored in components SD3:5 and SD3:6. The final component is a project that involves running a trade policy shock and analysing the results.

The next module extends the depth of analyses. The first component addresses the process for generating the baseline parameters for 'reference' scenarios: what factors should or should not be included, e.g., what is the role for macroeconomic forecasts, how should ongoing investments in increasing factor quality be accounted for, etc. The remaining components explore topics relevant to single country studies that are facilitated by the ease with which the details in an independent SAM can be augmented. Components SD4:3, SD4:4, SD4:5 and SD4:6 consider the interactions between public sector enterprises and government 'savings', and the impact of lags between expenditures on R&D and education and training on endogenously driven factor quality changes, some implications of FDI and associated returns, and funding borrowing. The module finishes with another project.

The single country stream ends with a project that seeks to bring together various strands of course.

The Global stream starts with an introduction about the ANARRES_t model and then sets up the mechanics for running a 'reference' scenario and the processing of the results for

later use as benchmarks for analysing the results from experiments; for this component the parameterisation of the 'reference' scenario is exogenous. The next component generalises simple capital accumulation to allow for putty-putty (capital is mobile before and after it is installed) or putty-clay (capital is mobile before installed but is fixed to an activity after installation) options through the closure rules. The remaining components focus on technology changes and factor quality changes. It starts by considering the implications of exogenously determined technology changes that implicitly presume equiproportionate increases in factor efficiencies (GD3:4) and then generalises to the case where there are different exogenously determined technology changes by region. These efficiency gains are implicitly treated as 'manna from heaven', whereas economic growth theories argue that efficiency gains are, to a greater or lesser extent, driven by investment in R&D (for capital goods) and education and training (for labour). These issues are explored in components GD3:6 and GD3:7. The final component is a project that involves running a trade policy shock and analysing the results.

The next module extends the depth of analyses. The first component addresses the complex issue of the valuation of capital. The valuation of capital depends on assumptions about the 'rate of interest'/return to capital with a common assumption being that the rate of 'interest' is common across all countries. This presumption is atheoretical and not consistent with the theory of production in CGE models. The next component examines the process for generating the baseline parameters for 'reference' scenarios: what factors should or should not be included, e.g., what is the role for macroeconomic forecasts, how should ongoing investments in increasing factor quality be accounted for, etc. The remaining components explore topics relevant to global studies that are constrained by the difficulties with augmenting the global SAM. Components GD4:4, GD4:5, GD4:6 and GD4:7 consider the impact of lags between expenditures on R&D and education and training on endogenously driven factor quality changes, some implications of remittances and foreign aid, and the funding borrowing. The module finishes with another project.

The global stream ends with a project that seeks to bring together various strands of course.

Course Aims and Objectives

Course Aims

To develop the CGE modelling skills of participants (using GAMS) so they

i) understand the behavioural relationships used in RDYN CGE models;
ii) understand the impact of different behavioural relationships used to update model parameters in RDYN CGE models;
iii) understand the calibration of the model parameters in RDYN CGE models;
iv) can formulate appropriate RDYN CGE policy experiments; and
v) can interpret the results generated by RDYN CGE models.

Course Objectives

On completion of the course the participants will be able:

i) formulate and code appropriate policy experiments;
ii) identify and understand the strengths and limitations of RDYN CGE models;
iii) modify behavioural relationships that control the updating of model parameters;
iv) interpret the results from RDYN CGE models; and
v) identify, and present, the policy implications of simulations using RDYN CGE models.

Software

This course does NOT use a GUI (Graphical User Interface) to access GAMS. Experience has demonstrated, to our satisfaction, that the use of GUI's by participants on training programmes typically limits the development of the skills needed to be a good CGE modeller or user of CGE models, while encouraging the belief that CGE models are 'black boxes'. All course materials were developed using GAMS Studio, which is platform independent for Windows, MacOS and Linux. We work in Windows, so we cannot guarantee that all the techniques are available with Mac OS or LINUX. We do not use LINUX and have not tested the materials using LINUX, but some testing has been done for MacOS.

A full licence for GAMS with the PATH solver is required (see www.GAMS.com). Contact sales@gams.com to arrange and/or purchase a license.

STAGE & ANARRES Models

This course uses the STAGE_t or ANARRES_t CGE models, which are developments of the open source STAGE_1 model (www.cgemod.org.uk/stage.html) and the ANARRES_1 model (www.cgemod.org.uk/globe.html). STAGE_t and ANARRES_t models are state-of-the-art CGE models designed for the analyses of a wide range of real-world policy issues and advanced basis for the further (academic) model development.

Programme
Module D1: Growth and Recursive Dynamic CGE Models

	Topic	Tasks	Exercises
D1:1	Introduction to Recursive Dynamics	Review the principles and theory for a RDYN model	None
D1:2	Economics of Growth	Review economics of growth	None
D1:3	Forecasting & RDYN	Understanding the limitations of RDYN CGE models	None
D1:4	Factor productivity'	Economics of Factor Productivity (FP) and the 'Residual'	FP and the 'Residual' **Project D1.1**
D1:5	Perpetual inventories	Accounting for factor growth	A simple perpetual inventory
D1:6	Measuring Factor Quantities	Pragmatic solutions to 'the' measurement problem	

Module D2: The Basics of a Recursive Dynamic (smod_t) CGE Model

	Topic	Tasks	Exercises
D2:1	Introduction to smod_t	Review smod_t.gms	None
D2:2	Model and Directory Structure	Nested sub-directories; Review data	Testing the model; using SETGLOBAL; reference files and searching
D2:3	Time & RDYN	The meaning of 'time' in RDYN models	Coding the time sets
D2:4	Simple Factor Accumulation	Factor growth; Saving; Gross & Net Investment; Depreciation	Exogenous factor growth; Putty-putty capital accumulation
D2:5	'Reference' Scenario	Defining a baseline; Model closure & market clearing	Running & evaluating a 'reference' scenario
D2:6	Calibration in RDYN Models	Calibration of functional forms in CGE models	Coding time period specific parameters
D2:7	A First RDYN Experiment	Adding a policy shock to an RDYN model	Tariff reform in an RDYN model
D2:8	Putty-Clay Capital Accumulation	Mobile vv immobile capital	Coding putty-clay capital accumulation **Project D2**

Module SD3: Recursive Dynamic Single Country (stg_t) CGE Model

	Topic	Tasks	Exercises
SD:1	Introduction to stg_t.gms	Review smod_t.gms; Nested sub-directories; Review data	Using SETGLOBAL; reference files and searching
SD3:2	Dynamics in STAGE_t	Review the 'reference' scenario	Running and analysing the 'reference' scenario
SD3:3	Basic Dynamics stg_t	Closure changes	Putty-Clay vw Putty-Putty
SD3:4	Technology Changes in the Baseline	Technology shocks and production function	Technology shocks to production and to value added
SD3:5	Factor Quality Changes in RDYN Models	'Qualities' of labour and capital with existing investments	'Exogenous' labour quality change; 'Exogenous' capital quality change
SD3:6	R&D and Training and Factor 'Quality'	Investments in Education and R&D and factor quality; perpetual inventories	Education and R&D investments and the changing quantities of factor services
SD3:7	A Second RDYN Experiment	Modify factor accumulation and analyse trade policy shock	

Module SD4: Extensions to Recursive Dynamic Single CountryCGE Model

	Topic	Tasks	Exercises
SD4:1	Introduction	Review extensions	None
SD4:2	An Estimated 'Reference' scenario	Closure setting for estimated baseline	Calibrating a 'reference' baseline from estimated macro aggregates
SD4:3	Public Enterprises	Government current & capital accounts	Modifying investible funds accounts
SD4:4	Investments in R&D and Training with Lags	Marginal changes in R&D and training	Policy induced endogenous factor quality changes
SD4:5	Foreign Investment	Foreign ownership of assets and returns	Changes in the pattern of factor ownership
SD4:6	Borrowing and Debt	Foreign and Domestic Debts	Debt repayments by government
SD4:7	A Third RDYN Experiment	Policy analysis	Policy shock **Project** SD4.1

Module SD5: Recursive Dynamic Single Country CGE Model: Project

The objectives of the project are to develop your ability to (i) set up and implement policy experiments in a RDYN CGE model. There are five elements to the project: calibration, dynamics, policy experiments and interpretation, sensitivity analyses and project report.

It is assumed you will use the course materials with your own model as part of preplanned research project. Thus, the materials for this module are designed to help you develop your own vision of a recursive dynamic model. Hence, the policy simulations, closure assumptions and sensitivity analysis conducted are not prescribed.

	Topic	Tasks	Exercises
SD5:1	stg_t RDYN project	The project aims are 1. set up and implement policy experiments in the stg_t CGE model; & 2. interpret the results of your policy experiments.	There are six elements to the project, 1. choose country and write-up the 'backstory, 2. run the comparative static model with your country data and check, 3. setup the 'reference' scenario for the project, 4. program the policy experiments, 5. run policy experiments and interpret the results, 6. write the project report (**Project SD5.1**).

Module GD3: Recursive Dynamic Global (anar_t) CGE Model

	Topic	Tasks	Exercises
GD3:1	Introduction to ANARRES_t	Review anar_t.gms; Nested sub-directories; Review data	Using SETGLOBAL; reference files and searching
GD3:2	Dynamics in anar_t	Review the 'reference' scenario	Running a 'reference' scenario
GD3:3	Basic Dynamics	Closure changes	Putty-Clay vv. Putty-Putty via closures
GD3:4	Technology Changes in the Baseline	Technology shocks and production function	Technology shocks to production and to value added
GD3:5	Different Region Factor Productivity rates	Vary TFP by region	Different region TFP rates
GD3:6	Factor Quantity Changes	'Quality' of factors with existing 'investments'	'Exogenous' factor quantity change
GD3:7	R&D and Training and Factor 'Quality'	Investments and factor quality; perpetual inventories	Education and R&D investments and the changing quantities of factor services
GD3:8	A Second RDYN Experiment	Modify factor accumulation and analyse trade policy shock	**Project GD3 – Trade policy shock**

Module GD4: Recursive Dynamic Global (anar_t) CGE Model

	Topic	Tasks	Exercises
GD4:1	Introduction to Extensions	Review extensions to the recursive dynamic model	Setting up and testing the model
GD4:2	Depreciation & Interest rates anar_t	Change depreciation rate and return on investment by region	Capital by region with different depreciation and interest ratesg Putty-Putty closure
GD4:3	An Estimated 'Reference' scenario	Closure setting for estimated baseline	Calibrating a 'reference' baseline from estimated macro aggregates
GD4:4	Capital 'Quality'	Investment and capital quality	R&D and capital services
GD4:5	Labour 'Quality'	Investment and labour quality	Training and labour services
GD4:6	Remittances and Foreign Aid	Change remittances and foreign aid	Changes in the volume of remittances and bilateral and multilateral aid
GD4:7	Borrowing and Debt	Foreign and Domestic Debts	Debt repayments by government
GD4:8	A third RDYN Experiment	Factor accumulation and remittances and/or aid shock	**Project GD4.1–Remittances and/or aid policy shock**

Module GD5: Recursive Dynamic Global (anar_t) CGE Model Project

The objectives of the project are to develop your ability to (i) set up and implement policy experiments in a RDYN CGE model. There are five elements to the project: calibration, dynamics, policy experiments and interpretation, sensitivity analyses and project report.

It is assumed you will use the course materials with your own model as part of preplanned research project. Thus, the materials for this module are designed to help you develop your own vision of a recursive dynamic model. Hence, the policy simulations, closure assumptions and sensitivity analysis conducted are not prescribed.

	Topic	Tasks	Exercises
GD5:1	anar_t RDYN project	The project aims are 3. Develop a project proposal, 4. set up and implement policy experiments in the anar_t CGE model. 5. interpret the results of your policy experiments.	There are six elements to the project, 7. choose aggregation and write-up the 'backstory 8. Aggregate the database consistent with your policy question 9. run the comparative static model with your country data and check, 10. setup the 'reference' scenario for the project, 11. program the policy experiments, 12. run policy experiments and interpret the results, 13. write the project report (**Project SD5.1**).