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Economic modelling and forecasting

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Policy simulation and forecasting of rational-expectations models in EViews

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Models with explicit expectations terms

- Some special modelling problems arise when a (non-linear) model includes forward-looking variables and/or explicit expectations terms and when we wish to use the model for policy simulation or forecasting
- In particular, standard solution techniques for backward-looking models will have to be extended to allow for rational or model-consistent expectations…
- …as the introduction of such terms raises both **conceptual** and **practical** problems

Models with explicit expectations terms…and EViews

- Manipulating, solving, simulating and forecasting (non-linear) models with forward-looking variables and/or explicit expectations terms has recently become much easier following the release of simulation programmes for EViews by the Federal Reserve (http://www.federalreserve.gov/econresdata/frbus/us-models-package.htm)
- In particular, the Federal Reserve provides a rational expectations (RE) solver package for EViews called `mce_solve` that solves linear and non-linear models under model-consistent expectations

A small-scale new Keynesian model for India (1)

- We will simulate and forecast the preferred specification of Patra and Kapur's (2010) **augmented** three-equation new Keynesian (NK) model for India, which consists of:
  - an estimated backward-looking aggregate demand or dynamic IS curve (equation (4) in their paper);
  - an estimated backward-looking aggregate supply or Phillips curve (equation (2) in their paper); and
  - an estimated forward-looking monetary policy reaction function or Taylor rule (equation (6) in their paper)
- The estimated coefficients of the equations for `ygapsa`, `infgdp` and `effective3` can be found in Table 1 (column 4), Table 3 (column 4) and Table 4 (column 3) in the original paper respectively

A small-scale new Keynesian model for India (2)

- We will use the estimated model for policy analysis and forecasting
- Specifically, we will:
  - assess model dynamics in response to anticipated as well as unanticipated shocks to both endogenous and some exogenous model variables;
  - assess the statistical fit of the three-equation NK model, highlighting the important role of exogenous variables in tracking the actual data; and
  - use the model to (conditionally) forecast the three endogenous variables in the model

A small-scale new Keynesian model for India (3)

- The six model equations we will be working with are:

ygapsa = 0.38 – 0.15*rpr(-3) + 0.28*ygapsa(-1) + 0.21*ygapagrsa
+ 0.12*wexprgapsa – 0.06*reer36gapsa(-2) (1)

infgdp = 0.99 + 0.20*ygapsa(-4) + 0.68*infgdp(-1) + 0.07*infglobal
+ 3.11*dum1998q3q4 + 0.05*dlexcha (2)

effective3 = 1.49 + 0.24*infgdpdev(+2) + 0.24*ygapsa(+2)
+ 0.77*effective3(-1) + 0.02*dlexch4(-1) (3)

A small-scale new Keynesian model for India (4)

- The six model equations we will be working with are:

ygapsa = 0.38 – 0.15*rpr(-3) + 0.28*ygapsa(-1) + 0.21*ygapagrsa + 0.12*wexprgapsa – 0.06*reer36gapsa(-2) (1)

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effective3 = 1.49 + 0.24*infgdpdev(+2) + 0.24*ygapsa(+2) + 0.77*effective3(-1) + 0.02*dlexch4(-1) (3)

infgdpdev = infgdp – 5 (4)

rpr = effective3 – infgdp (5)

dlexcha = (dlexch4 + dlexch4(-1) + dlexch4(-2) + dlexch4(-3))/4 (6)

A small-scale new Keynesian model for India (5)

- Where does this model come from?
- As extensively explained in the paper, the foundation is the canonical three-equation NK model (Clarida *et al.* (1999), Galí (2008))…
- …making the final model an **augmented** version of the canonical three-equation NK model
- The three equations (a dynamic IS curve, a new Keynesian Phillips curve and a monetary policy reaction function) are meant to capture the main channels of the monetary transmission mechanism

A small-scale new Keynesian model for India (6)

- The six model equations we will be working with are:

$$y_t = E_t y_{t+1} - \sigma^{-1}(i_t - E_t \pi_{t+1}) + \eta_t$$

ygapsa = 0.38 – 0.15*rpr(-3) + 0.28*ygapsa(-1) + 0.21*ygapagrsa + 0.12*wexprgapsa – 0.06*reer36gapsa(-2)

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + z_t$$

infgdp = 0.99 + 0.20*ygapsa(-4) + 0.68*infgdp(-1) + 0.07*infglobal + 3.11*dum1998q3q4 + 0.05*dlexcha

$$i_t = \gamma i_{t-1} + (1 - \gamma)(\theta_\pi \pi_{t+k} + \theta_y y_t) + v_t$$

effective3 = 1.49 + 0.24*infgdpdev(+2) + 0.24*ygapsa(+2) + 0.77*effective3(-1) + 0.02*dlexch4(-1)

Economic models and expectations

- How do agents in the economy form expectations?
- How can we measure agents’ expectations?
  - direct measures of agents’ expectations from surveys or indirect measures from prices of traded financial instruments;
  - expectations can be parameterised by explicit rules or models for expectations formation, such that future expected endogenous (and exogenous) variables are substituted out of the model by some auxiliary expectations-generating model – this is associated with a loss of estimation efficiency and is prone to the Lucas critique (1976); and
  - in the absence of knowledge about how expectations are actually formed, practitioners often invoke model-consistent or rational expectations

Modelling expectations (1)

- The predominant paradigm for modelling expectations is the **rational expectations** (RE) hypothesis
- In its strong form, the RE hypothesis assumes that agents act ‘as if’ they know the true structure of the model of the economy (up to a set of white-noise errors)…
- …which some may find a little implausible
- As Friedman (1979) clearly points out, the **information exploitation** assumption of RE, namely that agents use efficiently whatever information is available, is largely uncontentious
- It is the **information availability** assumption that many economists find objectionable

Modelling expectations (2)

- For agents that are rational, their predictions are equal to the conditional mathematical expectation of the (true) model (Muth (1960))…
- …and hence their (one-step-ahead) forecast errors are independent of any information available at the time the forecast is made – the latter is the error-orthogonality property of RE
- The advantage of the RE approach is that it can cope with regime changes and other structural shifts automatically

Modelling expectations (3)

- We define expectations using the notation:

$$x^e_{t+k|t-1} = \mathrm{E}[x_{t+k}|\Omega_{t-1}] \quad (10)$$

where $x^e_{t+k|t-1}$ is the expected value of variable x_{t+k} formed at the end of period t – 1 and based on information available at that time, represented by the information set Ω_{t-1}

- The **rational expectations** hypothesis of Muth (1960, 1961) asserts that expectations should satisfy:

$$x_{t+k} = x^e_{t+k|t-1} + \eta_{t+k} \quad (11)$$

where $\mathrm{E}[\eta_{t+k}] = 0$

Modelling expectations (4)

- Most model solutions methods set η_{t+k} to its expected value of zero and adopt the stronger assumption of **model-consistent expectations**, namely:

$$x_{t+k} = x^{e}_{t+k|t\text{-}1} \qquad (12)$$

Linear models with forward expectations (1)

- We should all be familiar with the lag operator, L
- When applied to any variable z_t at time t, the application of the lag operator, L^j ($j \geq 0$), results in the following manipulation of the original series:

$$L^j z_t = z_{t-j} \qquad (13)$$

- What would the lag operator, L^j, with $j < 0$ do?
- Assuming $j = -1$, we obtain:

$$L^j z_t = L^{-1} z_t = z_{t-(-1)} = z_{t+1} \qquad (14)$$

- This is frequently re-written using the forward expectations operator, F ($= L^{-1}$), where:

$$F^j z_t = (L^{-1})^j z_t = L^{-j} z_t = z^e_{t+j|t} \qquad (15)$$

Linear models with forward expectations (2)

- Defining the forward expectations operator $F^j z_t$ as:

$$F^j z_t = z^e_{t+j|t-1} \quad (16)$$

a general linear model including forward expectations of the endogenous variables, y_t, can be written as:

$$B(L)y_t + D(F)y_t = C(L)x_t + u_t \quad (17)$$

where:

$$B(L) = B_0 + B_1L + B_2L^2 + \ldots + B_pL^p \quad (18)$$

with $B_0 = \mathrm{I}_n$ and:

$$C(L) = C_0 + C_1L + C_2L^2 + C_qL^q \quad (19)$$

and:

$$D(F) = D_1F + D_2F^2 + \ldots + D_kF^k \quad (20)$$

is a matrix polynomial of order k with $D_0 = 0$

A small-scale new Keynesian model for India (7)

- In the form of equation (17), the left-hand side of the model is:

$$\underbrace{\begin{pmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{pmatrix}}_{B_0}\underbrace{\begin{pmatrix} ygapsa \\ \inf gdp \\ effective3\end{pmatrix}}_{y_t}+\underbrace{\begin{pmatrix}-0.28 & 0 & 0\\ 0 & -0.68 & 0\\ 0 & 0 & -0.77\end{pmatrix}}_{B_1}\underbrace{\begin{pmatrix} ygapsa(-1) \\ \inf gdp(-1) \\ effective3(-1)\end{pmatrix}}_{y_{t-1}}+\underbrace{\begin{pmatrix}0 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{pmatrix}}_{B_2}\underbrace{\begin{pmatrix} ygapsa(-2) \\ \inf gdp(-2) \\ effective3(-2)\end{pmatrix}}_{y_{t-2}}$$

$$+\underbrace{\begin{pmatrix}0 & 0.15 & -0.15\\ 0 & 0 & 0\\ 0 & 0 & 0\end{pmatrix}}_{B_3}\underbrace{\begin{pmatrix} ygapsa(-3) \\ \inf gdp(-3) \\ effective3(-3)\end{pmatrix}}_{y_{t-3}}+\underbrace{\begin{pmatrix}0 & 0 & 0\\ -0.20 & 0 & 0\\ 0 & 0 & 0\end{pmatrix}}_{B_4}\underbrace{\begin{pmatrix} ygapsa(-4) \\ \inf gdp(-4) \\ effective3(-4)\end{pmatrix}}_{y_{t-4}}$$

$$+\underbrace{\begin{pmatrix}0 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{pmatrix}}_{D_1}\underbrace{\begin{pmatrix} ygapsa(+1) \\ \inf gdp(+1) \\ effective3(+1)\end{pmatrix}}_{y_{t+1}}+\underbrace{\begin{pmatrix}0 & 0 & 0\\ 0 & 0 & 0\\ -0.24 & -0.24 & 0\end{pmatrix}}_{D_2}\underbrace{\begin{pmatrix} ygapsa(+2) \\ \inf gdp(+2) \\ effective3(+2)\end{pmatrix}}_{y_{t+2}} \qquad (21)$$

A small-scale new Keynesian model for India (8)

- In the form of equation (17), the right-hand side of the model is:

$$\underbrace{\begin{pmatrix} 0.38 & 0.21 & 0.12 & 0 & 0 & 0 & 0 \\ 0.99 & 0 & 0 & 0 & 0.07 & 3.11 & 0.0125 \\ 0.29 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}}_{C_0} \underbrace{\begin{pmatrix} 1 \\ ygapagrsa \\ w\exp rgapsa \\ reer36gapsa \\ \inf global \\ dum1998q3q4 \\ dlexch4 \end{pmatrix}}_{x_t} + \underbrace{\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.0125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.02 \end{pmatrix}}_{C_1} \underbrace{\begin{pmatrix} 1 \\ ygapagrsa(-1) \\ w\exp rgapsa(-1) \\ reer36gapsa(-1) \\ \inf global(-1) \\ dum1998q3q4(-1) \\ dlexch4(-1) \end{pmatrix}}_{x_{t-1}}$$

$$+ \underbrace{\begin{pmatrix} 0 & 0 & 0 & -0.06 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.0125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}}_{C_2} \underbrace{\begin{pmatrix} 1 \\ ygapagrsa(-2) \\ w\exp rgapsa(-2) \\ reer36gapsa(-2) \\ \inf global(-2) \\ dum1998q3q4(-2) \\ dlexch4(-2) \end{pmatrix}}_{x_{t-2}} + \underbrace{\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.0125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}}_{C_3} \underbrace{\begin{pmatrix} 1 \\ ygapagrsa(-3) \\ w\exp rgapsa(-3) \\ reer36gapsa(-3) \\ \inf global(-3) \\ dum1998q3q4(-3) \\ dlexch4(-3) \end{pmatrix}}_{x_{t-3}} \qquad (22)$$

Linear models with forward expectations (3)

- Assumption (9) that expectations are model consistent implies that $F = L^{-1}$, so that (14) can be rewritten as:

$$B(L)y_t + D(L^{-1})y_t = C(L)x_t + u_t$$

$$(B(L) + D(L^{-1}))y_t = C(L)x_t + u_t$$

$$\Phi(L, L^{-1})y_t = C(L)x_t + u_t \qquad (23)$$

where:

$$\Phi(L, L^{-1}) = B_0 + B_1L + B_2L^2 + \ldots + B_pL^p + D_1L^{-1} + \ldots + D_kL^{-k} \qquad (24)$$

is a polynomial of order $(p + k)$ with $n(p + k)$ roots

- Assume that we want to solve model (23) over a fixed time period, given by $t = 1, \ldots, T$, subject to suitable **initial** and **terminal** conditions

Linear models with forward expectations (4)

- It is worth actually writing out the left-hand side of (23) in full:

$$\begin{bmatrix} \varphi & \varphi(L^{-1}) & \varphi(L^{-2}) & & & & \varphi(L^{-(T-1)}) \\ \varphi(L) & \varphi & \varphi(L^{-1}) & & & & \\ \varphi(L^{2}) & \varphi(L) & \varphi & & & & \\ \varphi(L^{3}) & \varphi(L^{2}) & \varphi(L) & \varphi & & & \\ \varphi(L^{4}) & \varphi(L^{3}) & \varphi(L^{2}) & \varphi(L) & \varphi & & \\ \vdots & & & & & \ddots & \\ \varphi(L^{(T-1)}) & & & & & & \varphi \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ \\ y_T \end{bmatrix} \qquad (25)$$

Linear models with forward expectations (5)

- If the full Φ matrix is upper triangular, that is, it only has zeroes above the leading diagonal, the model contains no model-consistent expectations terms and it may be solved in the usual way, which is one period at a time:
  - while the model (23) includes current and lagged values of the endogenous variables, at each point in time *t*, the lagged values of the endogenous variables, y_t, are predetermined and can be treated as fixed; meaning that
  - the solution can thus proceed sequentially for each time period $t = 1, \ldots, T$

Linear models with forward expectations (6)

- When the upper triangle is **not** empty, the model is no longer recursive over time, meaning that the solution of the model can no longer proceed one period at a time
- In fact, one of the special approaches to be discussed below must be used
- The reason is quite simply that in model-consistent methods, current values depend on expectations of future values as well, which in principle involves an infinite progression into the future

Terminal conditions (1)

- Note that a RE solution of a model over a finite time horizon $t = 1, \ldots, T$ generally requires values of the variables $y_{T+1}, \ldots, y_{T+k}$, which are outside the solution period
- Before one can solve a model which involves future expectations to yield a model-consistent solution, a suitable set of **terminal conditions** must therefore be supplied

Terminal conditions (2)

- There have basically been three approaches to the choice of terminal conditions:
  - terminal values are set to fixed exogenous values or according to an automatic rule such as a constant level, $y_{T+j} = y_T$, $j = 1, \ldots, k$ or a constant growth rate, $y_{T+j} = y_T^{j+1} y_{T-1}^{-j}$, $j = 1, \ldots, k$;
  - following Minford *et al.* (1979), it is also possible to choose terminal conditions to reflect the equilibrium properties of the model; and
  - Fair and Taylor (1983) suggested that any arbitrary condition could be used as long as it was far enough into the future so as not to affect the early period of interest (the extended solution path)
- To some extent, terminal conditions are arbitrary and it is important to know how sensitive the model solution is to them

Shocks

- By their very nature, models are **stochastic** simply because no description of the world can ever be so complete that the models fit the data perfectly
- This means that the full specification of an econometric model must include a set of error terms on the (behavioural) equations
- Simulations with RE models have to be explicit about the nature of the shocks:
  - are they permanent or transitory?;
  - are they anticipated or unanticipated?; and
  - do they affect the endogenous or exogenous variables?
- With rational expectations, there is a difference between these alternative assumptions which arises from the system solution of the model, rather than from any structural component

Stochastic simulation (1)

- Models including rational expectations present special solution problems
- One issue is that with forward-looking variables, a closed-form (analytical) solution does not necessarily exist
- Stochastic simulations are useful in defining and quantifying the uncertainty associated with a model forecast or simulation (Blake (1996))
- They are a numerical technique that allows us to quantify and investigate the uncertainty which is inevitably associated with any large econometric model
- Stochastic simulations perform a large number of model simulations, where each simulation differs from the others on account of a different set of 'shocks' administered to the model

Stochastic simulation (2)

- These shocks, which can be random drawings from a particular distribution, re-sampled (or bootstrapped) residuals or imposed from outside the model, may be added to the equations, the parameters or even the exogenous variables
- Given this repeated experiment it is then possible to calculate a range of statistics, such as the mean, the standard deviation and the higher moments of the solution of the model variables
- As the number of simulations undertaken increases, these summary statistics should provide a good guide to the stochastic performance of the whole model

Stochastic simulation (3)

- The main procedure used to reduce the uncertainty of the estimate of the mean of the distribution is the technique of **antithetic** errors (Calzolari (1979))
- In practical terms, this means that the sets of residual errors to be applied in each stochastic simulation are not completely independent of the other sets
- In fact, they are generated in **pairs**, where the second set of each pair is minus the first set
- This produces a group of errors which are perfectly symmetric around the mean of the error process

Model-consistent expectations and EViews

- If we assume that there is no uncertainty in the model, imposing model-consistent expectations simply involves replacing any expectations that appear in the model with the future values predicted by the model
- In EViews, we can simply write out the expectation terms that appear in equations using the lead operator…
- …and run a **deterministic solution** of the model using EViews' ability to solve models with equations that contain future values of the endogenous variables
- When we add uncertainty to the model, the situation becomes more complex…
- …meaning that EViews at present is unable to perform **stochastic simulations** of RE models

The rational-expectations solver package in EViews

- The software library `mce_solve` provides code for the solution of linear and non-linear models under model-consistent or rational expectations in EViews
- This code is more reliable and efficient than the RE algorithm built into EViews (Fair-Taylor) at solving models with model-consistent expectations
- The `mce_solve` library includes two RE algorithms: E-Newton and E-QNewton
- These algorithms iterate to find a model's RE solution with a sequence of updates to either exogenous estimates of the model's future-dated endogenous variables or exogenous components of such estimates and are described in (gory) detail in Brayton (2011)

Summary

- The role of expectations formation in both theoretical and applied macroeconomics is of central importance
- Models including rational expectations present special solution problems
- But thanks to a recent RE solver package for EViews, solving and forecasting linear and non-linear models under model-consistent expectations has become much easier
- Suitable terminal conditions are required to yield a model-consistent solution for models involving future expectations
- We need to differentiate between different assumptions about the shocks hitting the RE model
- Stochastic simulations are useful in defining and quantifying the uncertainty associated with a model forecast or simulation

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