

## LECTURE 7

### MORE ON RBC + NOMINAL RIGIDITIES

#### 1 More on RBC (model calibration)

- Start with a general equilibrium, dynamic, stochastic model.
- In general the model has no closed form solution. It needs to be solved numerically → need functional form for preferences and technology and numerical value for parameters.
- Choice of functional forms. Broadly arbitrary BUT only a number of production and utility functions are consistent with existence of non-degenerate steady state. Furthermore, only some of them are consistent with stylized facts (e.g. only Cobb-Douglas technology generates constant capital income share as in the data)
- Choice of numerical value for parameters. Calibration. Two sources of information:

- Microeconomic studies (e.g. labour supply elasticity)
- Choose remaining parameters such that certain moments (e.g. means and covariances) of the endogenous variables generated by the simulation of the model match the corresponding moments from the data. Need as many moment conditions as the number of parameters left to determine.
- Once calibration is successful use the model to do policy analysis i.e. to study the model's predicted response of endogenous variables to shocks.
- This can also be used as a test of the model (e.g. does the model generate covariances between endogenous variables in line with those in the data OTHER THAN those used in the calibration). This is an alternative to estimating the model using the data and doing hypothesis testing (does not suffer from Lucas critique). Model as a measurement tool.

## 2 Keynesian (and New-Keynesian) theories of business cycle fluctuations.

- RBC: Arrow-Debreu environment. Start from preferences and technology. Derive equilibrium. Real shocks to technology (supply shocks) as main source of fluctuation. No role for money as centralized, complete markets. Output is fully determined by factors of production and technology.
- Keynesian theories:
  - Economic environment not specified: reduced-form aggregate functions. Disadvantages: What do shocks represent? Budget constraints (e.g. Ricardian equivalence?) Welfare analysis? Advantages: simple, can be solved with pen and paper, better intuition.
  - Money demand (from a microtheoretic point of view markets must be incomplete for money to be demanded despite being dominated in rate of return).
  - Emphasizes (real and monetary) demand shocks. Where from? Preferences, government expenditure/taxes.
  - Central bank sets one nominal variable (money supply or short term interest

rate) exogenously.

- One other rigid or sticky (i.e. exogenous) nominal variable: price or expectation of price. **Two nominals make a real.**

## 2.1 Goods and money market equilibrium (Aggregate demand)

- Goods market equilibrium (IS curve).

$$Y = C(Y - \bar{T}, r) + I(r) + \bar{G}. \quad (1)$$

Consumption and income negatively related to real interest rate. Consumption increases less than one-for-one with disposable income.

- Money market equilibrium.

Originally LM curve, nowadays **monetary policy reaction function** (MPRF):

$$r = r(Y - \bar{Y}, \pi - \bar{\pi}) \quad (2)$$

CB increases the real interest rate if output and inflation are above some target levels.

- Aggregate demand. Combinations of output and inflation such that the goods and money markets are in equilibrium.
  - Substitute  $r$  away from the first two equations above to obtain the aggregate demand (AD) curve

$$Y = Y^{AD}(\pi - \bar{\pi}, \bar{T}, \bar{G}, \bar{Y}) \quad (3)$$

- Aggregate demand is downward sloping.
- Aggregate demand shocks: any shock to AD curve.
- Aggregate demand (i.e. consumption, investment and MPRF) can (and should) be microfounded from first principles.

## 2.2 Nominal rigidities (static expectations)

- Other than money market, nothing above is substantially different from Ramsey. Absent other rigidities, goods and factor market equilibrium determine equilibrium output and real interest rate. Nominal interest rate affects price level or

inflationary expectations. Classical dichotomy: can solve for real variables without looking at money market. The money market equation is just appended to the rest.

- Third block of the model: factor markets equilibrium. Assume  $K$  is exogenously given, so we need only to consider labour market equilibrium.

– Wage setting (possibly labour supply) equation:

$$\frac{W}{P^e} = g(L) \quad (4)$$

Workers wage demands are increasing in the level of employment.

Two possible interpretations: (1) Non-competitive labour market. Workers “bargaining power” is increasing in the level of employment (decreasing in the unemployment rate. (2) Competitive labour market. Labour supply increasing in the real wage.

Workers’ wage demands depend on the price level they expect to prevail.

Two possible interpretations: (1) workers do not observe the actual price level

(Phelps); (2) workers observe the actual price level but have signed a contract to supply labour at the nominal wage  $W$ , set before the actual price level is realized (we will see this below).

– Price setting equation (allowing for imperfect competition):

$$P = \mu(L) \frac{W}{F_L(\bar{K}, AL)} \quad (5)$$

Firms set prices as a markup  $\mu(L)$  over marginal cost.  $\mu(L) = 1$  if product market is perfectly competitive.  $\mu(L) > 1$  otherwise.

– Production function:

$$Y = F(\bar{K}, AL). \quad (6)$$

- The current (actual and expected) price level and the rate of inflation are related by

$$P = (1 + \pi)P_{-1} \quad (7)$$

and

$$P^e = (1 + \pi^e)P_{-1}. \quad (8)$$

- Aggregate supply: combinations of inflation and output for which the labour market is in equilibrium.

**No nominal rigidity (the classical case)**

- An equilibrium with no nominal rigidity is a vector  $[L, Y, r, W, P, P^e, \pi, \pi^e]$  such that eqs. (1), (2), (4), (5), (6), (7) and (8) hold and  $P^e = P$ .
- If  $P = P^e$ , output is fully determined on labour market. It depends only on  $A, K, \mu$  and  $g(\cdot)$ . Labour market “block” (eqs. (4)- (6)) independent of the goods and money market equilibrium equations.
- Vertical aggregate supply. Eliminate  $W/P$  from (4) and (5) to obtain

$$g(L) = \frac{F_L(\bar{K}, AL)}{\mu(L)}, \quad (9)$$

which fully determines  $L$  and, from the production function,  $Y$ .

- Aggregate demand shocks have no effect on equilibrium output. Goods market shocks affect only the real interest rate (e.g. preference shocks in Ramsey). Money



market shocks affect only on nominal variables (money neutrality).

#### Rigid price expectations

- An equilibrium with (exogenous) rigid price (or inflation) expectations is a vector  $[L, Y, r, W, P, \pi]$  such that eqs. (1), (2), (4), (5), (6) and (7) hold.
- $P^e$  is exogenously given. Eliminate  $W$  from price setting and wage setting equation.
- Labour market block can no longer be solved independently from goods and money market.
- $L$  is above its value in the absence of nominal rigidities if  $\pi > \pi^e$  and below viceversa.
- Upward sloping AS.
- Shocks to AD affect equilibrium output.
- Countercyclical real wage in response to demand shocks

### Rigid nominal wage

- An equilibrium with (exogenous) rigid nominal wage is a vector  $[L, Y, r, P, P^e, \pi, \pi^e]$  such that eqs. (1), (2), (5), (6), (7) and (8) hold and  $P^e = P$ .
- $W$  is exogenously given and workers supply any amount of labour. Wage setting equation does not apply.
- Labour market block can no longer be solved independently from goods and money market.
- Price setting equation implies a positive relationship between  $L$  and  $P$  (or  $\pi$ ).
- Non vertical aggregate supply. Since in the data the real wage is acyclical/mildly procyclical we need  $F_L(\bar{K}, AL)/\mu(L)$  to be rather constant.
- As long as  $\mu(L) \geq 1$  ( $P > MC$ ) firms are willing to adjust production in response to changes in demand.
- Shock to AD affect equilibrium output.

- If constant mark up, countercyclical real wage. So if goods market are competitive (mark up constant and equal to one) the model is at odds with the data. We need imperfectly competitive good markets and countercyclical mark up for  $F_L(\bar{K}, AL)/\mu(L)$  to be acyclical or mildly procyclical. The empirical evidence is that price mark ups are acyclical or mildly countercyclical, so this could work provided the marginal product of labour does not change too much with the level of employment.

#### **Rigid nominal price**

- An equilibrium with (exogenous) rigid nominal price is a vector  $[L, Y, r, W, P^e, \pi^e]$  such that eqs. (1), (2), (4), (6) and (8) hold and  $P^e = P$ .
- $P$  is exogenously given, rather than chosen by firms. Price setting equation does not apply as long as  $P > MC$ .
- Labour market block can no longer be solved independently from goods and money market.
- AS horizontal until  $L$  is such that  $MC < P$  and vertical thereafter.

- Shocks to AD affect equilibrium output if output is below full employment.
- Procyclical real wage (see wage setting equation).

None of the conclusion above changes if the central bank sets the money supply rather than the nominal interest rate.

### 2.3 Nominal rigidities (rational expectations)

- While the rigid expectation case implies that the trade-off between prices and output persists only as long as expectations are not correct, the other two cases seem to imply a permanent trade-off. This does not make sense eventually workers will revise their wage demands up<sup>1</sup> and firms their set price if their real purchasing power/ profit margin keeps deteriorating (“you cannot fool all the people all the time”).
- Expectations are endogenous. Need to model them.
- Many ways to do endogenize expectations.

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<sup>1</sup>In fact, one can interpret the rigid wage case as one in which workers fixed the nominal wage on the basis of expectations that turn out to be incorrect ex post

- Rational expectations assumes that expectations equal the mathematical expectation based on the information set available to agents. This includes the knowledge of the true model that describes the economy. Agents know the model as well as the economist/econometrician. The model is used to form expectations, hence the term "model-consistent-expectations".
- Hence, the expectation of the forecast error is zero conditional on the available information set. No systematic mistakes.
- We have already used the rational (model consistent) expectation assumption.
  - Ramsey model. Agents forecast of equilibrium path coincides with true path. In the absence of uncertainty, agents expectations are realized with probability one (perfect foresight).
  - RBC (Ramsey with uncertainty). Because of uncertainty, the equilibrium path is a stochastic process (a sequence of random variables). Expectations of equilibrium path equal expectations of the stochastic process. The ex post realization of the process may differ from its expected value but the deviation could not be forecast on the basis of past information.

We now want to show that the “surprise” aggregate supply of the rigid expectation case obtains also in the case of rigid wages once the wage is chosen on the basis of all information available at the time it was set.

- Aggregate demand. We work with the price level rather than the inflation rate. We shrink the goods and money market model in the aggregate demand curve which would prevail if money demand were independent of the interest rate (quantity theory of money). As simple as possible:  $MV = PY$ . In logs

$$m + v = p + y \quad (10)$$

- Labour market block.

– Production function.  $Y = AL$ . In logs

$$y = a + l \quad (11)$$

– Wage setting equation. Assume  $g(L) = L^\gamma$  with  $\gamma > 0$ . If workers have correct expectations

$$w - p = \gamma l \quad (12)$$

– Price setting equation. Assume  $\mu(L) = L^\delta$  with  $-1 < \delta$  (mark up can be procyclical or countercyclical). Given production function it is  $F_L = \alpha A$  and the price setting equation is

$$w - p = a - \delta l, \quad (13)$$

where the additional restriction  $\gamma > -\delta$  is required for total factor productivity shocks to increase equilibrium employment.

With endogenous expectations price expectations are part of the equilibrium vector.

Consider the fully flexible and the rigid wage case.

1. No rigidity. Equilibrium is a vector  $[y, l, w, p]$  such that (10)- (13) hold. Labour market block fully determines equilibrium output. AD together with vertical AS determines price level.
2. Wage is set before shocks are realized. Ex post workers supply any amount of labour firms demand at the fixed wage. Equilibrium is a vector  $[y, l, w, p, p^e, w^e]$  such that  $w = E(w)$  where  $E(p)$  and  $E(w)$  solve (10)- (13) in expectation. Given  $w$ ,  $[y, l, p]$  satisfy eqs. (10), (11), (13).

Subtracting equation (13) from its expectation and using the fact that it is  $w = E(w)$  we obtain

$$p - E(p) = -[a - E(a)] + \delta [l - E(l)] \quad (14)$$

Using (11) to replace for  $l$  and  $E(l)$  we obtain the “surprise” aggregate supply function

$$p - E(p) = -(1 + \delta)[a - E(a)] + \delta [y - E(y)]. \quad (15)$$

Only unexpected shocks to price and total factor productivity make output deviate from its flexible price equilibrium  $E(y)$ .