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A New Keynesian Workbook

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Introduction

Over the past couple of decades a large body of literature analysing the business cycle fluctuations has employed the New Keyensian models. This framework introduces the traditional Keynesian emphasis on the short-term price stickiness into the neoclassical paradigm that features dynamic optimisation and microfoundations. Thepresent paper builds on recent pedagogical literature that introduces the New Keynesian framework into undergraduate economics curricula by considering several versions of the standard New Keynesian model and by describing an Excel-based application that facilitates learning the internal logic of these models.

A large body of recent pedagogical literature has suggested alternatives to the traditional Keynesian IS/LM–AS/AD framework. Colander (1995) discusses the analytical gaps in the standard AS/AD model. Taylor (2000) and Romer (2000) point out that modern central banks do not target money supply but interest rates and replace the price level with inflation in the AS/AD model. Walsh (2002) emphasises the fact that central banks do not set their interest rate targets exogenously but, to a large extent, in response to inflation and he modifies the analysis to account for the fact that output needs to be normalised by its natural level. Carlin and Soskice (2005) and Bofinger *et al*. (2006) build on this work to present extensive graphical apparatuses for the analysis of models related to the baseline New Keynesian model that describes the interplay of inflation, output gap and interest rate. Guest (2003) and Turner (2006) suggest different modifications of the model that improve its pedagogical accessibility. Finally, the model has made solid inroads into undergraduate textbooks: Stiglitz and Walsh (2002) and Taylor (2007) emphasise inflation targeting at the principles level using graphical analysis whereas Carlin and Soskice (2006) and Jones (2007) provide an extensive treatment of a dynamic New Keynesian model at the intermediate level.

This paper complements existing pedagogical work by providing an easy-to-use Excel-based interface where students can develop intuition about the model by changing parameters and studying the effects of different shocks. The most extensive addition to the current body of work concerns introducing dynamic effects into the model, as endogenous variables adjust to exogenous disturbances. These dynamic effects are summarised by shifts in the model's structural relations and the impulse responses of endogenous variables. This setup allows us to move beyond the standard static models and examine the implications of differences in agents' expectations as well as additional issues, such as the time-inconsistency of optimal policy. Hence different sections of this paper provide examples of variations of the model that are suitable for coverage in principles through intermediate to advanced elective courses.

The rest of the paper is organised as follows. First, I briefly discuss the baseline New Keynesian model and a static version of a three-variable model that is very similar to the one discussed in Bofinger *et al*. (2006). This model provides a direct response to the Romer (2000) challenge that '[e]ven the easiest models with microeconomic foundations are much harder than corresponding ingredients of IS-LM-AS'. Next, we provide a basic dynamic extension of the model in the previous section by assuming that inflationary expectations are not pegged to the long-run inflation rate but adjust adaptively. We then extend the basic setup into the standard dynamic setting that features rational expectations and persistent exogenous shocks. This variant of the model can be explicitly derived from microfoundations. Discussion is supplemented using examples from the companion Excel workbook. Finally, we have a concluding section.

Static New Keynesian models

This section considers two static variants of the New Keynesian model. Following the nomenclature established by Svensson (2002, 2003), the conduct of monetary policy is described by either an instrument or a targeting monetary policy rule. The 'instrument' model assumes that the central bank sets the nominal interest rate according to the Taylor rule, in response to output gap and inflation. Taylor (1993) was first to suggest a version of this rule as a descriptor of monetary policy conduct in the United States. However, Svensson (2002, 2003) argues that although such rules are likely to describe a substantial share of monetary policy decision making, the dynamic minimisation of the social welfare loss may provide a more rich, flexible and accurate description of what modern central banks do in practice. The 'targeting' model, therefore, assumes that the central bank minimises a social welfare loss given by a weighted average of squared departures of inflation from its target level set by the central bank and output from its potential level.

The first baseline New Keynesian model describes the joint interaction of three sets of macroeconomic actors. The IS relation describes the behaviour of households, the AS (aggregate supply) relation represents the firms' pricing decisions, and the MR (monetary rule) relation characterises the conduct of monetary policy by the central bank.[1] These equations jointly determine three endogenous variables: nominal interest rates (i), output gap (x, percentage difference between actual output and its potential level) and inflation (π):

$$x = \sigma r^{*} - \sigma(i - \pi) + \varepsilon^{x}, \tag{1}$$

$$\pi = \pi^{*} + \kappa x + \varepsilon^{\pi}, \tag{2}$$

and

$$i = i^{*} + \gamma_{\pi}(\pi - \pi^{*}) + \gamma_{x} x + \varepsilon^{i}. \tag{3}$$

Here r^* is the natural interest rate that is consistent with the long-run output gap of zero, π^* can be interpreted as the central bank's target rate of inflation and private sector's long-term inflationary expectations, and i^* is the nominal interest rate that is consistent with the output gap of zero and these expectations ($i^* = r^* + \pi^*$). Parameters have the standard economic interpretations: σ is the elasticity of intertemporal substitution; κ is the slope of the aggregate supply relation that signals the degree of price stickiness (flatter AS implies stickier prices); γ_π gauges central bank's response to departures of inflation from the long-term target, whereas γ_x measures its sensitivity to the output gap. Plugging (3) into (1) and solving for inflation, one can obtain the aggregate demand schedule. As Clarida *et al*. (1999) point out, the model's stability condition, also known as the Taylor principle, that gives rise to the downward-sloping demand schedule, requires that $\gamma_\pi > 1$.

The setup above constitutes the 'instrument' version of the baseline model, whereby the central bank defines the instrument of its policy – the nominal interest rate – in terms of the other variables of interest. (1) and (3) can be jointly analysed in the IS/MR model, where inflation is taken as exogenous. Together these two equations can be used to derive the downward-sloping (in the x-π plane) aggregate demand schedule that together with aggregate supply determines the equilibrium rate of inflation.

Instead of following this instrument rule, the central bank may discretionarily minimise the social welfare loss associated with volatility of deviations of inflation from the target and of output gap subject to aggregate supply:

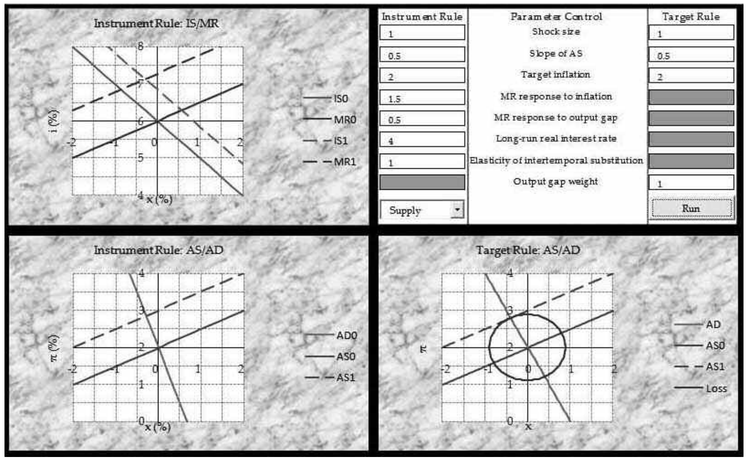
$$\Delta i = \frac{1}{\sigma}\varepsilon^{x}. \tag{4}$$

where α defines the relative weight of output gap volatility for social preferences. Note that since demand and monetary shocks can be offset by adjusting the nominal interest rate accordingly, it is only the supply shocks that present a tradeoff between stabilising inflation and output gap. The discussion below, therefore, focuses on the effects of a supply shock in this model.[2]

Figure 1 presents the effect of a 1% supply shock in both the 'instrument' and 'targeting' variants of the model. In the former case, the shock shifts the AS schedule upwards, leading to inflation above the target and negative output gap. Higher inflation shifts the MR schedule upwards, because the central bank responds to higher inflation by increasing interest rates more than proportionately. The IS schedule also shifts upwards proportionately due to the change in inflation: for output gap to remain constant, the real interest rate has to remain constant as well; hence a percentage increase in inflation should be offset by a percentage increase in the nominal interest rate.[3] This figure illustrates the Taylor principle: in order to achieve stability through a downward-sloping aggregate demand, the central bank should respond to a percentage increase in inflation by raising the nominal interest rate by more than 1%.

In the targeting panel, the shock has the same effect on aggregate supply. The ensuing tradeoff between output gap and inflation is illustrated by the elliptical welfare loss function, with the new AS schedule being a tangent to this function. The panel illustrates that the central bank cannot offset a supply shock and has to pick a combination of inflation and negative output gap in its optimal response to it.

Figure 1: Adverse Supply Shock in the Static Models



Since higher inflation will have an effect on the position of the IS and MR schedules, their position will require secondary adjustments in response to monetary or demand shocks. Either of those shocks will shift the AD schedule and, for an upward-sloping AS relation, will generate higher inflation. Figure 2 illustrates this point for a positive demand shock. IS' illustrates the shift of the IS schedule due to the shock keeping inflation constant, whereas IS1 describes the schedule's final position. As before, higher inflation pushes the IS schedule farther up. MR0 shifts to MR1 as the central bank raises the nominal interest rate in response to higher inflation.

Notice that in the targeting model there is no social welfare loss at all. This happens because the central bank can simply offset the demand shock by adjusting the nominal interest rate:

$$\Delta i = \frac{1}{\sigma} \varepsilon^{x}.$$

This is even though the implied IS schedule shifts in response to the demand shock. The central bank can pick another interest rate on this new IS schedule that eliminates social welfare loss by restoring the AD schedule at its pre-shock position.

One way to motivate the presence of monetary shocks in the monetary rule (3) is by emphasising that the conduct of monetary policy happens in real time, when the full information about the actual levels of variables is unavailable to central banks. Therefore, they may temporarily deviate from following rules that otherwise characterise their policy conduct well. Such deviations may be described by monetary shocks, ε^{i}.[4]

Figure 2: Positive Demand Shock in the Static Models

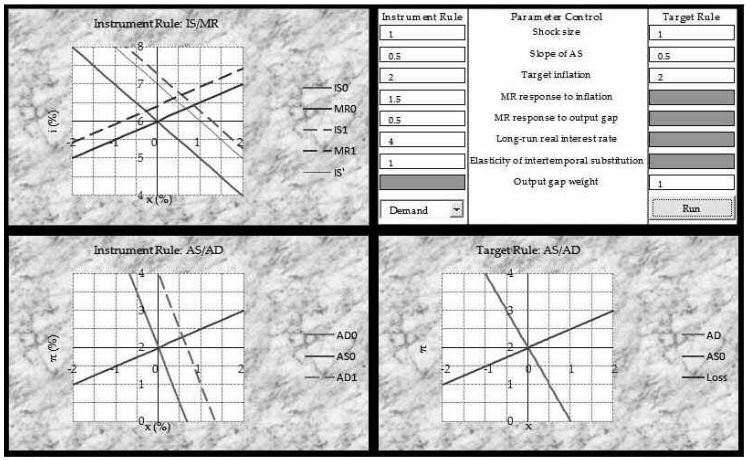


Figure 3: Negative Monetary Shock in the Static Models

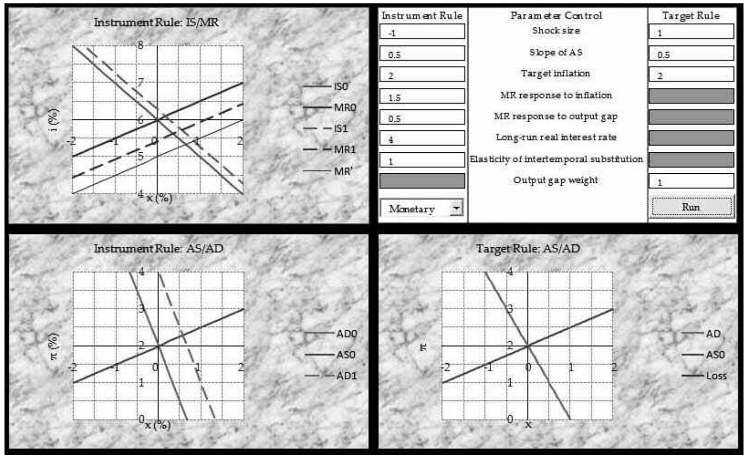


Figure 3 describes the effect of a negative (or expansionary) monetary shock that may be caused by the central bank's underestimation of the true current level of inflation or output gap. (Nothing shifts in the targeting plane because the assumption of optimal policy conduct does not allow for such errors in judgement.) In the IS/MR model, the MR schedule initially shifts down directly to MR' in response to the shock that drives the nominal interest rate below the level warranted by the true levels of inflation and output gap. This stimulates aggregate demand, which shifts out from AD0 to AD1, leading to higher equilibrium inflation due to the upward-sloping AS schedule. Higher inflation prompts an upward-shift of IS to IS1 and MR to MR1. Insofar as this judgement error is transitory, the economy will be able to adjust back to the long-run equilibrium level. A description of such an adjustment requires the introduction of a dynamic component into the model. The next section describes how this can be accomplished through adaptive inflationary expectations.

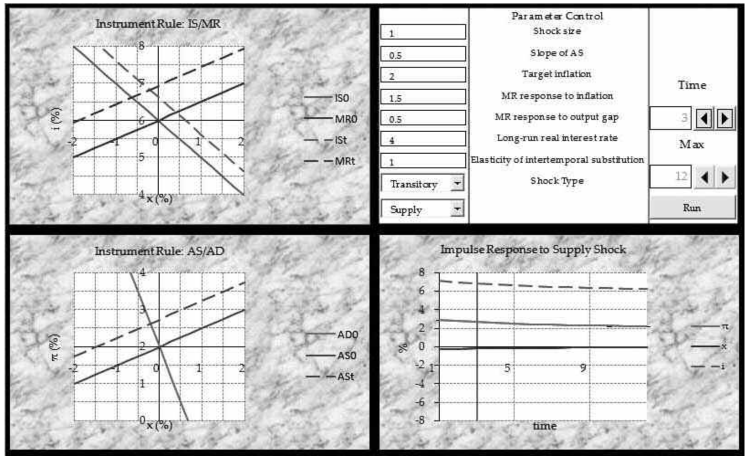
A New Keynesian model with adaptive inflationary expectations

As in Carlin and Soskice (2006) or Jones (2007), the basic static model of the previous section can be easily extended into the dynamic context by introducing adaptive inflationary expectations. Hence the three-equation model becomes:

$$x_t = \sigma r^* - \sigma (i_t - \pi_t) + \varepsilon_t^x, \tag{5}$$

$$\pi_t = \pi_{t-1} + \kappa x_t + \varepsilon_t^\pi, \tag{6}$$

Figure 4: Adverse Supply Shock in the Adaptive Expectations Model



and

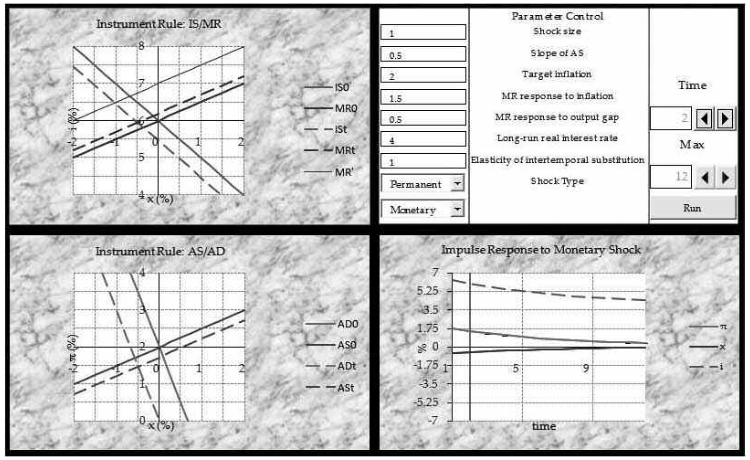
$$i_t = i^* + \gamma_\pi (\pi_t - \pi^*) + \gamma_x x_t + \varepsilon_t^i. \tag{7}$$

The difference between equations (6) and (2) signals that instead of pegging their inflationary expectations to the long-term inflation level, economic agents now form them adaptively, by observing equilibrium inflation in the previous time period. This mechanism not only shows the short-run equilibrium in immediate response to a shock, as in the previous section, but also makes it possible to trace the dynamics of the economy's adjustment to a long-run equilibrium.

Extending the economy into this context also allows us to distinguish between temporary/transitory and permanent demand and monetary shocks. (A permanent supply shock would just result in a perpetually shifting AS schedule without a new long-run equilibrium being reached.) A permanent demand shock may be motivated by the change in the long-term real interest rate, whereas a permanent monetary shock may be motivated by a change in the long-run target inflation rate (e.g. to accomplish a disinflation). Transitory shocks disappear in the period after their initial impact. Impulse responses graph the trajectory of endogenous variables following the shock.

Figure 4 documents the effect of an adverse supply shock. Initially, the AS schedule shifts upward but since the AD schedule is downward-sloping, the equilibrium level of inflation is below the vertical intercept of the AS schedule (initially given by the

Figure 5: Permanent Positive Monetary Shock in the Adaptive Expectations Model



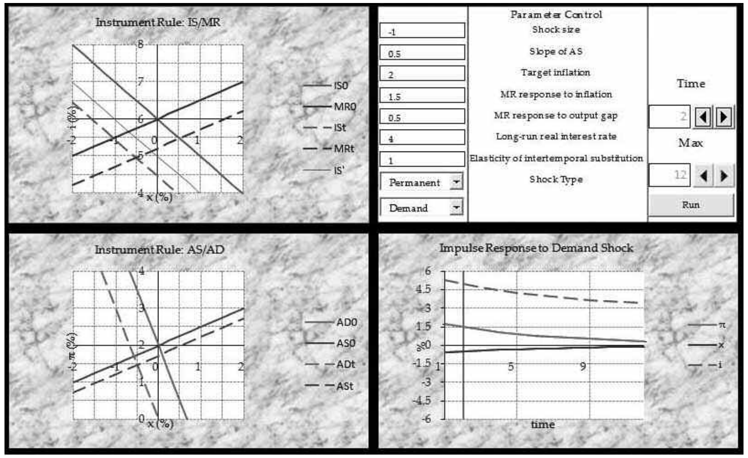
long-term level of inflation plus the size of the shock).[5] In the subsequent time period, the shock disappears and the intercept of the AS schedule now becomes the equilibrium inflation level from the previous time period. As the central bank continues to stabilise against inflationary pressure, eventually the AS schedule returns to the initial position. Since inflation returns to the original value, IS and MR schedules return to their initial positions as well. Impulse responses document the corresponding evolution of the model's variables in response to the shock: inflation and the interest rate initially increase and the output gap falls in response to the stabilising monetary contraction. As the effects of the shock dissipate, the variables return to their long-term values.

Figure 5 demonstrates the effect of a permanent increase in the nominal interest rate, a situation that is comparable to a disinflationary effort on behalf of the central bank. Algebraically, this can be illustrated by specifying the shock in terms of the difference between the target inflation rates. In particular, if the central bank chooses a lower inflation target, so that $\pi_1^* < \pi_0^*$ and sets $\varepsilon_t^i = -(\gamma_\pi - 1)(\pi_1^* - \pi_0^*) > 0,$ we have that the MR schedule now becomes:

$$i_t = r^* + \pi_0^* + \gamma_\pi(\pi_t - \pi_0^*) + \gamma_x x_t - (\gamma_\pi - 1)(\pi_1^* - \pi_0^*) = r^* + \pi_1^* + \gamma_\pi(\pi_t - \pi_1^*) + \gamma_x x_t.$$

The immediate effect of the shock is to generate an upward shift of the MR schedule and a downward shift of the AD schedule. As equilibrium inflation falls, the AS schedule starts shifting downwards. In the subsequent time period, a transitory shock would make the AD schedule return back to its initial position; the

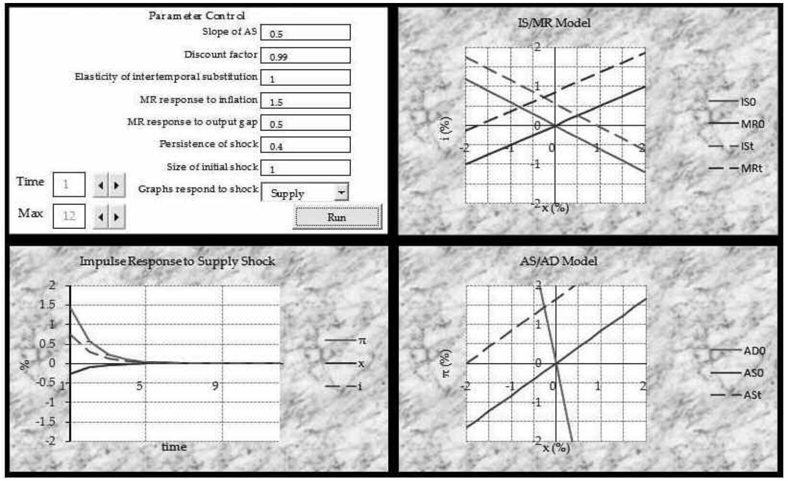
Figure 6: Permanent Negative Demand Shock in the Adaptive Expectations Model



new position of the MR schedule would have to account for the lower inflation. In this case, however, the AD schedule stays at the same position, which is necessary to accomplish disinflation. As the AS schedule keeps shifting down, the output gap gradually increases back to zero; this adjustment process stabilises at a lower equilibrium level of inflation. Impulse responses detail the trajectory of the variables as disinflation is undertaken: The nominal interest rate increases initially to achieve a negative output gap, but as the lower inflation target is nearer, the output gap returns back to zero and the nominal interest rate falls to reflect the accomplished disinflation.

Figure 6 demonstrates the effect of a permanent negative demand shock, which can be motivated by changes in the long-run real interest rate, r^*, or be viewed as the limiting case of a very persistent shock with the standard candidates for motivating it: contractionary fiscal policy or decreases in wealth. The ongoing global financial crisis may well be described by such a shock. The immediate adjustment to the shock follows the discussion above but in the opposite direction, since a positive demand shock was considered there. As IS shifts to IS′ due to the shock and aggregate demand falls to AD1, we have lower equilibrium inflation which pushes IS further down to IS1 and MR to MR1. In the next time period, firms will recognise that inflation has decreased and will set their inflationary expectations accordingly, which leads to the downward shift of the AS schedule. Hence equilibrium inflation will continue to fall until the economy reaches the zero output gap level. This dynamic matches well with the sharp reversal in inflation

Figure 7: Adverse Supply Shock in the Rational Expectations Instrument Model

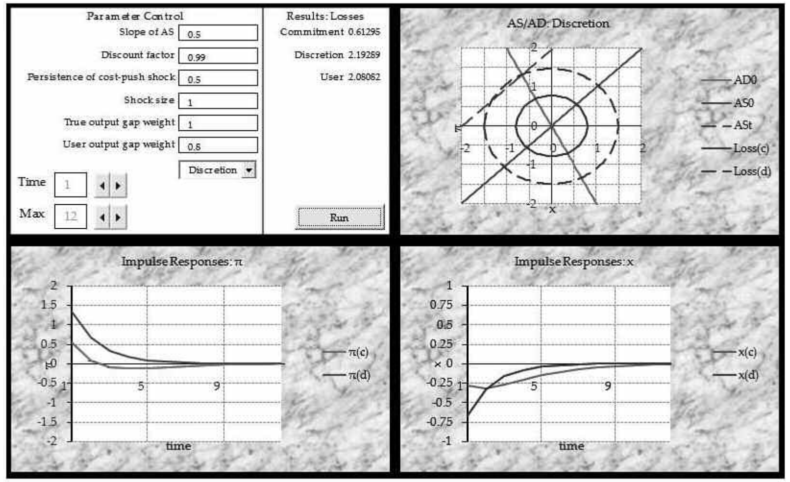


rates in the major industrialised economies that may, in some cases, threaten to turn to deflation.

Rational expectations variants of the New Keynesian model

Modern microfounded macroeconomic models typically treat variables of interest in short-term models as percentage deviations from their steady state values and, more importantly, feature rational expectations formed by economic agents. Woodford (2003) provides an authoritative treatment of such models.[6] The main difference with the models described above is the presence of forward-looking inflationary expectations terms and the dynamics being generated by persistent shocks that follow an autoregressive process of order 1. The set of theoretical issues that arises in these models is markedly different from the cases covered in the previous two sections. For instance, Figure 7 illustrates the effect of a 1% cost-push shock. As before, the Phillips curve shifts upwards; the effect of higher inflation dominates that of the lower output gap, shifting both the IS (due to lower real interest rate) and MR (due to higher inflation) schedules upward. Note, however, that the inflation rate responds by *more* than the size of the cost-push shock right away.[7] This happens because the firms in the economy anticipate that inflation will persist into the future and immediately set higher prices.

Figure 8: Adverse Supply Shock in the Rational Expectations Targeting Model



The targeting case in the rational-expectations context opens up the possibility for the discussion of the time inconsistency of optimal policy and optimal central banker conservatism in the spirit of Rogoff (1985). Figure 8 illustrates the responses to inflation and the output gap to a cost-push shock under both discretion and commitment; the intuitive difference between the two is particularly clear for low levels of persistence. Although the policy under commitment generates negative output gaps in the future, by when the effects of a cost-push shock may have already dissipated, this lowers inflationary expectations and results in lower social welfare losses in the long run. Since the commitment device that makes it possible for the central bank to operate over forward-looking expectations may not be readily available, a lower weight on the output gap volatility term in the social welfare loss than that of the rest of the society may bring the outcomes closer to the commitment ideal.

Concluding remarks

Given the popularity of the New Keynesian model among policy-makers and academics, one should hope that its treatment at all levels of undergraduate instruction – principles through advanced electives – will become much more extensive. This paper has provided discussion of some fundamental issues that can be explored using several versions of the New Keynesian model and illustrated these issues using an Excel-based workbook. The latter allows us to implement a relatively straightforward graphical apparatus whose difficulty level, at least for the static and adaptive expectations models, is certainly comparable to the one in the traditional undergraduate texts.

Notes

1 The version of the IS equation presented in Section 4 can be derived as the Euler equation for the household's intertemporal utility maximisation problem. The forward-looking AS relation can be derived as the first-order condition with respect to price for a monopolistically competitive firm in a staggered pricing setting. The Taylor rule is imposed by the central bank.

2 For a more detailed treatment of the static model, see Bofinger *et al*. (2006).

3 Another way of seeing why the IS schedule shifts is as follows: Higher inflation, *ceteris paribus,* lowers the real interest rate, stimulating aggregate demand, which can be modelled as a rightward IS shift.

4 The temporary deviations can be described as transitory shocks in below.

5 MR' and IS' schedules in the adaptive expectations model show the positions of the respective relations in response to the shock under the assumption that inflation is at the long-run level. Schedules marked by 't' designate the position of the respective relations at that particular time period.

6 This paper provides only a brief description of issues that arise in the rational-expectations context. More detailed information is available at the author's website.

7 Graphically, persistence affects the slopes of the schedules as well. Formal derivations are available in the technical appendix and the companion questionnaire discusses these effects more extensively.

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