IV. Shock impulse responses

In Chapter III, I studied the determinacy properties of different interest rate rule specifications with respect to the degree of activeness of the rule (measured by the inflation coefficient) and the target variables included were assessed within a New Keynesian framework with endogenous capital and adjustment costs. Based on the results obtained, I will now assess the characteristics of the convergence path back to steady state after a shock occurs, implied by active and passive rules under three possible specifications for each class: (i) rules with a sole inflation target; (ii) rules with an inflation and output target and (iii) rules with inflation and output gap target and interest-rate smoothing. The types of shocks entering the impulse responses are threefold: (i) a monetary policy unit shock; (ii) a technology unit shock and (iii) a consumption preference shock. In the subsequent analysis, policy rule specifications that yield determinacy of rational-expectations equilibrium (REE) and in addition involve quantitatively smaller deviations and fast, monotonic convergence path after a shock occurs would be preferred.

The chapter is organised as follows. Section 1 provides some general preliminary insights to the adjustment mechanisms in the system as a result of three types of shocks (monetary policy unit shock, technology unit shock and consumption preference unit shock) and identifies the two main transmission channels in the model (the real interest rate and the real marginal cost channel). Then in Sections 2 and 3 the adjustment paths of consumption, investment, the capital stock, real marginal cost, the output gap, the marginal product of capital, inflation, real wages and the nominal and real interest rate are traced for the case of active and passive rule specifications. Section 4 summarises the impulse response results.

1. Some preliminary remarks on the adjustment mechanisms in the system

In this subsection, I will offer some general preliminary insights to the adjustment mechanisms in the system as a result of three types of shocks (monetary policy unit shock, technology unit shock and consumption preference unit shock). As it will be further revealed in more detail, the deviations registered as a result of the occurrence of shocks within each of the two main group of rules (active vs. passive) share the same sign. The differences observed under the different interest-rate rule specifications within each group pertain rather to the magnitude of the responses and the period convergence to the steady-state level takes. More generally, a comparison between active and passive specifications reveals the crucial role of the real-rate response that is the determinant of differing dynamics of the remaining variables. A second initial transmission channel
pertains to real marginal cost (i.e. in the case of a technology shock).\textsuperscript{116} A closer look at the ten system equations reveals a common pattern of adjustment dynamics that can be anticipated before assigning numerical values to the reaction coefficients in the monetary policy specification.

1.1. Monetary policy unit shock

In accordance with the theoretical framework presented, a monetary policy unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_{t}$ in the policy rules (3.38) and (3.39) that is transmitted to the policy instrument, causing it to rise. The monetary policy shock term captures nominal interest rate changes that are not a result of the central bank’s response to the target variables as prescribed by the rule. Under rational expectations, expected inflation will sink.

Investment, consumption and output gap dynamics as evident by (3.32'), (3.25) and (3.26) are all triggered by the impulse to the real interest rate. The Fisher equation $r_t = i_t - E\pi_{t+1}$ postulates that the dynamics of the real interest rate is approximated by the difference between the deviations of expected inflation and the nominal interest rate. Due to the expected rise in the real interest rate as a result of the shock under both active and passive policy\textsuperscript{117}, negative spikes of differing magnitude depending on the policy rule specification selected occur in investment, consumption and the output gap immediately after the shock, followed by a gradual return to the steady-state level\textsuperscript{118}. The stronger deviation in investment compared to consumption is straightforward in the case of a monetary policy shock as the real interest rate enters (3.32') with a coefficient $\Xi = 1.5$ and (3.25) with a coefficient $\sigma^{-1} = 0.2$. Since according to equation (3.26) the output gap is a weighted average of consumption and investment, its immediate response can be expected to have an intermediate value. The magnitude of the output gap response reveals the significance of the endogenous capital assumption for the model’s quantitative results: under constant capital, the output gap response to a monetary policy unit shock would still be negative, but of a considerably smaller magnitude, as it would only incorporate the relatively more moderate fall in consumption. Still, because of assigning a higher weight to consumption ($\omega_c = 0.78$) than to investment ($\omega_{inv} = 0.22$) in (3.26), the adjustment path of the output gap can be anticipated to match the dynamics in consumption more closely than that of investment.

\textsuperscript{116} Real marginal cost dynamics determine the inflation response. Under sticky prices, the real marginal cost channel plays a quantitatively modest role, as firms cannot adjust their prices immediately after the shock occurs. Changes in expected inflation, however, play a crucial role and are transmitted nearly one-to-one to current inflation (as $\beta = 0.99$).

\textsuperscript{117} The rise in the real interest rate as a result of the positive blip in the nominal interest rate can only be circumvented if an immediate positive spike of comparable magnitude in inflation expectations occurs.

\textsuperscript{118} As the shock is assumed to be of temporary nature.

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The impact on investment is transmitted to capital with a one-period lag as evident from (3.35). The value assigned to the rate of depreciation $\delta = 0.025$ in the capital accumulation equation determines the significantly smaller maximum response of capital compared to the initial deviation in investment. The speed of adjustment of the capital stock to its steady-state level can be anticipated as being slower than that of investment. This result is a logical consequence of the fact that capital is a predetermined variable as specified in equation (3.35). By contrast, investment according to equation (3.32') does not depend on the past realisations of any of its determinants and can therefore respond immediately and in full magnitude as soon as the shock occurs.

In comparison to the response of capital and the output gap the magnitude of the deviation of the marginal product of capital will be of a considerably smaller magnitude, due to the relatively small value of the steady-state marginal product of capital $(mpk = 0.04)$ that enters equation (3.34) as a coefficient. The assumption of a steady-state real interest rate of 2 percent p.a., depreciation rate of 0.025, steady-state unit adjustment cost and steady-state marginal adjustment cost of 0.05 and 0.21 respectively in (A3.6) $mpk = \rho (1 + \bar{C}) + \delta (1 + \bar{C}) / rmc$ imply a relatively weaker response of marginal product of capital to deviations in output and capital.

The assumption of sticky wages in (3.37), modelled by the inclusion of a fixed probability $\eta_w (\eta_w = 0.75)$ that nominal wages cannot be adjusted in the current quarter (which implies that on average wages are re-set once a year) and the partial history-dependence of the variable determines the sluggish adjustment of the real wage. The transmission of the shock to real wages occurs through the adjustment of the inflation expectations $E_{\pi_{t+1}} - \bar{\pi}$ and through the dynamics of the inflation differential $\pi_t - \bar{\pi}$. Quantitatively, with $\beta = 0.99$, the coefficient on the inflation differential $1/(1 + \beta)$ is only slightly higher than the coefficient on expected inflation $\beta / (1 + \beta)$. As the two terms enter (3.37) with opposite signs, the inflation transmission channel plays a role only as long as the changes in expected inflation are not countervailed by a proportional blip in actual inflation. In the initial period after the shock such a development can be assumed, with a subsequent disappearance of the effect leading to a gradual convergence of the real wage to steady state.

The responses of capital, the output gap and real wage determine the dynamics of real marginal cost, as evident from equation (3.33). Compared to the output gap dynamics, the path of real marginal cost is expected to show a lengthier adjustment process due to its partial dependency on the dynamics of the capital stock. A more moderate maximum response compared to output seems also plausible for the same reason.

A monetary policy unit shock can be anticipated to have a quantitatively small and non-persistent impact on inflation. As evident from equation (3.36), the monetary impulse is transmitted by real marginal cost. Under sticky prices,
even with a strong response of real marginal cost to the shock, inflation remains hardly affected, as the value of the fixed probability that households cannot adjust their price $\eta_p = 0.75$ (i.e. priced adjusted once a year on average) implies that the coefficient $(1-\beta_\eta)(1-\eta_p)(1-\alpha_{pf})/\eta_p(1-\alpha_{pf} + \alpha_{pf}\theta)$ equals 0.02. Thus, the initial negative blip in inflation is significantly smaller than the unit shock. Until the effect subsides completely, the path of inflation will continue to mimic the deviation of real marginal cost on a smaller scale.

Although the direct impact of the monetary policy unit shock on the nominal interest rate is straightforward, the final adjusted outcome is worth further discussion. As far as the nominal interest rate is concerned, its final response depends essentially on three factors. Firstly, the choice of an active or a passive rule with respect to inflation plays quite logically a significant role. Secondly, under output-gap targeting, the response of the policy instrument depends on the change in inflation in (3.38) and (3.39) and of the output gap. Since the impulse to inflation is expected to be quite moderate, the effect of decline in actual output will prevail. A fall in actual output would motivate decreasing the nominal interest rate, thus (at least partly) offsetting the initial shock impulse. Thirdly, the magnitude of the interest-rate change depends on whether interest-rate smoothing is added to the monetary policy rule and on the size of the interest-rate coefficient $\lambda_i$. In the calibration of in Chapter III, Subsection 4.1 the choice of $\lambda_i = 0.8$ implies that under interest-rate smoothing the path of the nominal interest rate is to a significant extent history-dependent. Thus the maximum response of the nominal interest rate will remain modest and its adjustment will be characterised by a lengthy, graduate convergence to steady state.

1.2. Technology unit shock

In accordance with the theoretical framework presented, a technology unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_A$ in the AR(1) process $A_t = \rho_A A_{t-1} + \varepsilon_A$ that enters the real marginal cost condition (3.33).

The initial transmission of the technology unit shock occurs through the immediate and quantitatively large effect on real marginal cost in (3.33). This negative initial impulse is then transmitted to inflation as evident from (3.36). The assumption of sticky prices, reflected in the reaction coefficient $0 < (1-\beta_\eta)(1-\eta_p)(1-\alpha_{pf})/\eta_p(1-\alpha_{pf} + \alpha_{pf}\theta) < 1$ determines a relatively modest negative deviation of inflation from steady state.

The negative spike in inflation induces a partial response of the real wage. The initial impulse on the real wage bears the opposite sign of the inflation deviation- thus, real wage is characterised by a positive deviation from its steady-state value as a result of the labour-augmenting technology unit shock. The response is initially triggered by the inflation expectations and then sustained by the inflation differential and the history-dependence on own past realisations of the real wage. The latter property implies a more gradual adjustment in time.
As a result of the negative blip in actual inflation, the nominal interest rate is reduced in accordance with the policy rule. Of course, under a passive rule and/or under interest-rate smoothing the response of the policy instrument is quantitatively smaller as under an active rule and/or no history-dependence of the nominal interest rate. As far as the impact of output-targeting is concerned, the results in the case of a technology shock differ from those under a monetary policy shock. A technology unit shock typically induces a positive spike in actual output, thus ceteris paribus requiring an increase in the nominal interest rate. A negative blip in the policy instrument as a response to the shock can therefore be expected with certainty only in the case when inflation is the only target variable in the policy rule. Under inflation- and output-targeting the path of the nominal interest rate is more difficult to predict. Since under a rule of the form (3.38) or (3.39) a fall in inflation requires reducing the nominal interest rate, whereas increased actual output implies raising it, it can be expected that under inflation- and output-targeting the monetary policy response will be weaker under both active and passive policy than in the case of inflation-targeting only.

The sign of the initial impulse depends on the magnitude of the inflation and the output responses, as well as the values of the reaction coefficients $\lambda_x$ and $\lambda_y$.

The responses of investment, consumption, the output gap, capital and the marginal product of capital to a technology unit shock all are triggered by the dynamics of the real interest rate. Again, differing magnitudes of the maximum responses of investment and consumption can be anticipated due to the values of the coefficients assigned to the real interest rate in (3.32') and (3.25), $\Xi = 1.5$ and $\sigma^{-1} = 0.2$ respectively. Since according to equation (3.26) the output gap is a weighted average of consumption and investment, its immediate response will have an intermediate maximum value. Again, the response of the real interest rate is determined by the Fisher equation $r = i - E\pi_{t+1}$. Because, as explained above, the nominal interest rate response cannot be predicted with certainty, the initial impulse on the real interest rate can also vary depending on the interest-rate rule specification entering the system. What can be concluded even without explicit knowledge of the numerical results, however, is that under quantitatively too weak a response of the nominal interest rate that is not sufficient to offset the change in the inflation expectations determined by (3.36) the real interest rate can actually increase. Alternatively, under a sufficiently strong response of the nominal interest rate the deviations of both the nominal and the real interest rate will bear the same sign. Thus, a more moderate response to inflation (passive rule) in the case of a technology shock acts counter-cyclically; a

119 The value of $\Xi$, the semi-elasticity of investment in the investment function (4.27'), is yielded by substituting for the depreciation rate $\delta$, the scale parameter of the adjustment-cost function $\phi_2$ and marginal adjustment cost in steady state $C_1$ in $\Xi = 1/(1+\delta)\phi_2C_1$. 

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stronger response to inflation (active rule), on the other hand, reinforces the effect of the shock.

As far as capital and the marginal product of capital are concerned, the technology shock is channelled through its impact on investment and the output gap respectively. It can therefore be expected that the paths of capital and the marginal product of capital will be characterised by a weaker initial response and a lengthier convergence process. In addition, the deviations in investment are channelled with a time lag to the dynamics of capital. In comparison to the response of capital and the output gap the magnitude of the deviation of the marginal product of capital is quite modest, due to the inclusion of steady-state unit and marginal adjustment costs.

1.3. Consumption preference unit shock

In accordance with the theoretical framework presented, a consumption preference unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_i$ in the AR(1) process $\nu_t = \rho \nu_{t-1} + \varepsilon_t$ that enters the consumption equation (3.25). The consumption preference shock denotes a shift of the household’s preferences towards consumption in the utility function (3.1).

The initial transmission of the shock occurs through the immediate effect on consumption as in (3.25), causing a positive blip observed immediately after the shock. Under the parameter values chosen, the initial impulse to consumption can be assessed as being quite moderate (0.14 times the shock). Through its effect on consumption, the preference shock is channelled to the output gap (see equation (3.26)) which is also expected to register a positive spike. The magnitude of the output reaction can be predicted as smaller than the initial impulse to consumption in (3.25), based on the value of the consumption coefficient $\omega_c = 0.78$ in the output identity (3.26). For a clear-cut prediction of the sign of the output deviation, the sign and size of the investment response should also be taken into account.

In order to determine the adjustment path of investment as a result of the consumption preference shock, the response of the real interest rate should be given detailed consideration. For a prediction about the real-interest rate response, the adjustment of the nominal interest rate and of expected inflation are to be examined. If the consumption-enhancing effect prevails in (3.26) and a positive output gap is registered, the nominal interest rate should be increased in accordance with the policy rules (3.38) or (3.39) if output-targeting is pursued. As far as inflation is concerned, according to (3.36) the triggering impulse is given by the adjustment of real marginal cost. The history-dependence of capital in (3.35) and the real wage in (3.33) imply that at least initially after the shock the path of the real marginal cost will mimic the dynamics of the output gap on a smaller scale, given by the coefficient $0 < \alpha_{pf} / (1 - \alpha_{pf}) < 1$. Thus, if actual output is characterised by a positive deviation from steady state, real marginal cost will
also register a positive spike, inducing a rise in inflation as given by (3.36). Increased inflation has two main impact mechanisms to the system. Firstly, it is an additional impulse for the monetary authority to raise the nominal interest rate, so that the effect of the positive output gap in the policy rule is reinforced. In other words, when both inflation- and output targeting are pursued, it could be expected that under an output-boosting scenario the response of the nominal interest rate is likely to be stronger than in the case of inflation-targeting only for both an active and a passive policy stance. The second influence channel of increased inflation can be sought in terms of the real interest rate dynamics. According to (3.36), changes in expected inflation play a comparatively more significant role for the dynamics of actual inflation than the deviations of real marginal cost, as reflected by the size of the coefficients
\[
\frac{0.99}{\varphi_{t}^{6.9}} \quad \text{and} \quad \frac{(1 - \beta \eta_{p})(1 - \zeta_{p})(1 - \alpha_{pp})}{\eta_{p}(1 - \alpha_{pp} + \alpha_{pp} \theta)} = 0.02.
\]

The rise in the real interest rate releases an initial fall in investment, followed by a monotonic adjustment to its steady-state level. Capital as a predetermined variable responds with a time lag. The deviations of capital and the output gap from steady state, entering the term \((\hat{y}_{t} - k_{t})\) in equations (3.34) and (3.33) determine the responses of marginal product of capital and real marginal cost respectively. A positive, however quantitatively weaker response can be expected for both the marginal product of capital and the real marginal cost.

The positive initial effect on real marginal cost is transmitted to inflation as evident from (3.36), whereby the maximum impact on inflation is expected to be quantitatively small. Finally, as in (3.37) the real wage response is driven by the dynamics of inflation expectations and the positive inflation differential and then sustained by the and the history-dependence on own past realisations of the real wage.

2. Active rule

2.1. The case of inflation-targeting only

This subsection shows the impulse responses of \(\hat{c}_{t}, \hat{\ln v}_{t}, \hat{y}_{t}, \hat{\text{rmc}}_{t}, \hat{k}_{t}, \hat{mpk}_{t}, \hat{\omega}_{t}, \hat{\pi}_{t}, r_{t}\) and \(i_{t}\) as for three shocks: the random component of monetary policy \(\varepsilon_{\text{m},t}\), the technology shock \(\varepsilon_{\text{A},t}\) and the preference shock \(\varepsilon_{\text{P},t}\) when monetary policy is defined in terms of a slightly modified Taylor rule of the form (3.38)\(^{120}\). Here no output-targeting and no interest-rate smoothing enter the monetary policy rule and the effective response coefficient to inflation deviations takes the value of 1.3\(^{121}\). As already mentioned, the “hat” variables denote deviations of the

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120 The difference to the baseline Taylor specification (3.38) is the exclusion of the output gap target.
121 As it is evident from the determinacy analysis in Chapter III, Subsection 4.2.3, for an active rule without an output gap target, only inflation coefficient values in the interval [1.0, 1.3] guarantee determinacy of REE. The choice of the coefficient value at 1.3 has
actually registered variable values from their steady-state levels. The magnitude of a variable response to a one-percent shock is measured on the vertical axis of each impulse response figure—thus, a value of 0.5 for example means that the variable’s response is half as large as the shock.

2.1.1. Monetary policy unit shock

In accordance with the theoretical framework presented, a monetary policy unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_i$ in the policy rule (3.38). Figure 4.1 reports impulse responses to a monetary policy unit shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a monetary unit shock, are as in the case of a standard Taylor rule with output-targeting again characterised by a relatively fast convergence to the steady state. All variables, including capital, converge within 60 quarters. The main distinction from the impulse responses under a Taylor specification with output-targeting\(^{122}\) lies in the magnitude of the maximum deviation from steady state induced by the monetary policy unit shock.

For all variables, when inflation is the only target variable entering the policy rule, the shock generates a stronger response that is up to twice as strong as under an active rule with both inflation- and output-targeting. The reason for these differences lies in the dynamics of the nominal interest rate (that also influence the real interest rate adjustment path) under the specification (3.38). The strongest deviations are reported for investment, the output gap, the nominal and the real interest rate. Except for the exact values of the maximum deviations registered, the results in the case of inflation-targeting only comply with those under the standard Taylor specification\(^{123}\).

Again, negative spikes in investment, consumption and the output gap are observed immediately after the shock, followed by a gradual return to the steady-state level. Here the investment response is characterised by the sharpest fall (3 times as large as the shock). Compared to investment, consumption shows a more moderate response (about 0.5 times the shock) and a fast adjustment to its steady-state value. As a weighted average of consumption and investment, the immediate response of the output gap has an intermediate value equal to the size of the monetary policy unit shock. The paths of consumption, investment and output gap plotted on Fig. 4.1 reveal the significance of the endogenous capital assumption for the model’s quantitative results. Under constant capital, the output gap response to a monetary policy unit shock would still be negative, but of a smaller magnitude, as it would only incorporate the fall in consumption.

\(^{122}\) See Chapter IV, Subsection 2.2.

\(^{123}\) I.e. bear the same sign.
The maximum negative response of capital (approximately 0.15 times the size of the shock) is significantly smaller than the initial fall in investment. Again, it takes about 6 quarters until capital reaches its largest negative response. As a predetermined variable, capital is also characterised by a longer-lasting adjustment to its steady-state level than investment, taking about 60 quarters.

The deviation of the marginal product of capital (-0.04 times the shock at its minimum) is twice as strong as when output enters the central bank reaction function. Algebraically this is determined by the relatively small value of the steady-state marginal cost (0.04) that enters equation (3.34) as a coefficient. The assumption of a steady-state real interest rate of 2 percent p.a., depreciation rate of 0.03, steady-state unit adjustment cost and steady-state marginal adjustment cost of 0.05 and 0.21 respectively in (A3.6)\(^{124}\) imply a relatively weaker response of marginal product of capital to deviations in output and capital. The initial negative blip in the marginal product of capital is triggered by the fall in actual output and further sustained by the longer-lasting adjustment of capital.

The sluggish adjustment of the real wage over the entire 60 quarters is determined by the partial history-dependence of the variable as seen from (3.37) and by the assumption of sticky wages. The latter is modelled by the inclusion of a fixed probability \(\eta_w (\eta_w = 0.75)\) that nominal wages cannot be adjusted in the current quarter, which implies that on average wages are re-set once a year.

The responses of capital, the output gap and real wage determine the dynamics of real marginal cost, as evident from equation (3.33). Compared to the output gap dynamics, the path of real marginal cost reaches a more moderate maximum negative value (0.5 times the shock), but does not adjust monotonically to its steady-state value. Instead, 4 quarters after the shock real marginal cost overshoots the steady-state value, reaching a maximum positive value of 0.08 about 7 quarters after the initial impulse. After that, real marginal cost converges monotonically to the steady—state level. While the initial negative impulse to real marginal cost is mainly a result of the immediate decline of the output gap after the shock, the overshooting part is essentially explained by the slow and lasting response of capital and the real wage.

A monetary policy unit shock has a quantitatively small and non-persistent impact on inflation. As evident from equation (3.36), the monetary impulse is transmitted by real marginal cost. Under sticky prices, despite the strong response of real marginal cost to the shock, inflation remains hardly affected, as the value of the fixed probability that households cannot adjust their price \(\eta_p = 0.75\) (i.e. priced adjusted once a year on average) implies that the coefficient \((1-\beta\eta_p)(1-\eta_p)(1-\alpha_p \theta)/\eta_p(1-\alpha_p \theta + \alpha_w \theta)\) equals 0.02. Thus, the initial negative blip in inflation is negligibly small. Until the effect subsides completely after 16

\(^{124}\) See Appendix.
quarters, the path of inflation includes overshooting dynamics in the fourth quarter before steady-state value is reached.

As far as the nominal interest rate is concerned, according to the policy rule (3.38) its deviation depends on the unit shock itself and the responses of the target variable (the inflation differential). The monetary authority’s reaction to the unit shock involves an increase in the nominal interest rate equal to the unit shock, followed by a gradual convergence to the steady-state level. The effect of the monetary impulse disappears completely after 10 quarters. The Fisher equation \( r = i - E_{\pi} \) postulates that the dynamics of the real interest rate is approximated by the difference between the paths of expected inflation and the nominal interest rate. Due to the quantitatively weak response of actual and expected inflation, the real interest rate response (a positive blip with a maximum value as large as the shock itself, followed by a monotonic decrease) matches the nominal interest rate dynamics.
In conclusion, the analysis of the impact of a monetary policy unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs and a standard Taylor specification for monetary policy shows that the only long-lasting deviations from steady-state values concern the capital stock and the real wage, which take almost 60 quarters to converge. Consumption, the output gap, the real and the nominal interest rate, on the other hand, all return to their steady-state values within a maximum of 10 quarters. These results basically confirm the long-run monetary neutrality of the model.
2.1.2. Technology unit shock

In accordance with the theoretical framework presented, a technology unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_A$ in the AR(1) process $A_t = \rho A_{t-1} + \varepsilon_A$ that enters the real marginal cost condition (3.33). Figure 4.2 reports impulse responses to a technology unit shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a technology unit shock, are generally of a much smaller magnitude that those occurring as a result of a monetary policy unit shock and in each case of a lower value than the shock itself. In the case of a sole inflation target in the monetary policy rule, adjustment of all model variables considered reveals oscillatory paths. A further distinction in the case of a technology shock compared to the monetary policy unit shock’s impact is the slower adjustment to the steady-state values of all variables. The strongest deviations are reported for real marginal cost, real wage and investment.

The initial transmission of the shock occurs through the immediate effect on real marginal cost. A large negative spike of nearly 0.9 times the shock is observed immediately after the shock, followed by a gradual return to the steady-state level within the next 20 quarters. This negative initial impulse is then transmitted to inflation as evident from (3.36). As evident from the coefficient $0 < (1 - \beta \eta_p)(1 - \eta_p)(1 - \alpha_{pf}) / \eta_p(1 - \alpha_{pf} + \alpha_{pf} \theta) \ll 1$ the assumption of sticky prices determines the negative, but relatively modest (0.1 times the shock) deviation of inflation from steady state. As a result of the negative inflation differential, the nominal interest rate is reduced in accordance with the policy rule (3.38), followed by overshooting dynamics between the twelfth and the sixtieth quarter. The path of the real interest rate mimics on a smaller scale that of the nominal interest rate. Due to the negative response of inflation, the initial negative blip in the real interest rate is more moderate than the nominal interest decrease, as explained by the Fisher equation $r = i - \pi_{t+1}$.

Investment, consumption, the output gap, capital and the marginal product of capital all reveal an initial positive response to the technology shock, followed by a countervailing negative deviation of a comparatively larger magnitude before their steady-state values are reached. The strongest deviations in consumption, the output gap and the marginal product of capital all occur within the first 12 quarters, while it takes about 35 quarters until the maximum impact of the shock on capital unfolds. The technology shock is channelled to consumption and investment through its impact on the real interest rate; the considerably differing magnitudes of the maximum responses of investment and consumption can be traced to the values of the coefficients assigned to the real interest rate in (3.32’) and (3.25), $\Xi = 1.5^{125}$ and $\sigma^{-1} = 0.2$ respectively. Again, since according to

\[125\text{ The value of } \Xi, \text{ the semi-elasticity of investment in the investment function (4.32’), is yielded by substituting for the depreciation rate } \delta, \text{ the scale parameter of the adjust-} \]
equation (3.26) the output gap is a weighted average of consumption and investment, its immediate response has an intermediate largest positive and negative value of about 0.1 and –0.1 times the size of the technology shock respectively.

The largest positive and negative responses of capital (approximately 0.02 and –0.08 times the size of the shock respectively) are significantly smaller than the strongest deviations in investment. In addition, the deviations in investment are channelled with a time lag to the dynamics of capital. It takes the capital stock a whole 35 quarters until it reaches its largest negative deviation. Once again, capital is also characterised by a longer-lasting adjustment to its steady-state level than investment- even after 60 quarters, capital remains under its steady-state level.

In comparison to the response of capital and the output gap the magnitude of the deviation of the marginal product of capital (about 0.003 times the shock in both directions) is again quite modest, due to the inclusion of steady-state unit and marginal adjustment costs. Both the sluggish adjustment of marginal product of capital over more than 60 quarters and the undershooting path registered after the forth quarter following the shock can be traced back to the different adjustment dynamics of capital and output gap discussed above.

Finally, the impulse response of the real wage is worth some consideration. As a result of the labour-augmenting technology shock, the variable reaches a quantitatively significant maximum positive deviation from steady state of nearly 0.5 times the shock after 12 quarters and converges monotonically to its steady-state value thereafter. The response is initially triggered by the inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage.

\[ \Xi = \frac{1}{(1 + \delta) \Theta_2 C_1} \]

The magnitude of the impulse response of real wage is significant especially compared to the magnitude of the responses of the other model variables.
In conclusion, the analysis of the impact of a technology unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs shows that the only long-lasting deviations from steady-state values concern the capital stock that takes more than 60 quarters to converge. Compared to the impact of a monetary policy shock, convergence to the steady-state values generally appears to be a longer-lasting process. For most variables (except inflation, real marginal cost and real wage) the magnitude of the observed deviations is relatively smaller than in the case of a monetary policy unit shock. The reason for the milder impact of a technology unit shock is that in the model it induces a more moderate response of the nominal interest rate cuts as a reaction to the inflation differential that quantitatively exceed the latter and thus generate a moderate real-interest rate response. Through the real-interest-rate channel investment and consumption report initial positive deviations significantly smaller than the size of the shock.

2.1.3. Consumption preference unit shock

In accordance with the theoretical framework presented, a consumption preference unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_v$ in the AR(1) process $\nu_t = \rho \nu_{t-1} + \varepsilon_v$ that enters the consumption equation (3.25). Figure 4.3 reports impulse responses to a consumption preference unit shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a technology unit shock, are of a very small magnitude and in each case of a much lower value than the shock itself. Another distinction in the case of a preference shock is that the adjustment to the steady-state values for all variables occurs much faster than in the case of a technology or a monetary policy shock. Within approximately 16 quarters after the initial impulse all variables apart from capital and the real wage have returned to their
steady-state values. The strongest deviations as a result of the shock are reported for consumption, the output gap and real marginal cost.

The initial transmission of the shock occurs through the immediate effect on consumption as in (3.25). A positive blip of 0.2 percent is observed immediately after the shock, followed by a fast return to the steady-state level within the first 4 quarters. Through its effect on consumption, the preference shock is channelled to the output gap (see equation (3.26)) which also reports a sharp rise by 0.15 percent, followed by a rapid convergence to steady state.

The positive output gap transmits the impulse to the real marginal cost which shows an initial positive spike of almost 0.09 times the shock, followed by a gradual convergence to steady state within the first 4 quarters. The positive initial effect on real marginal cost is transmitted to inflation as evident from (3.36), whereby the maximum impact on inflation occurs immediately after the shock and is quantitatively small (an increase of 0.002 times the shock). The impulse disappears in less than 4 quarters. As a result of the inflation differential, the nominal interest rate is increased in accordance with the policy rule (3.38), but the response is of a smaller magnitude (0.003 times the shock at its peak). After the first quarter, the nominal interest rate is gradually decreased and reaches its steady-state value in the fourteenth quarter. The path of the real interest rate mimics that of the nominal interest rate.

The rise in the real interest rate releases an increase in investment of a very small magnitude, followed by a gradual adjustment within 12 quarters. Capital initially responds to the increase in investment by a gradual increase, reaching a maximum positive deviation from its steady-state level 10 quarters after the shock. After that, capital converges to steady state after approximately 60 quarters. The deviations of capital and the output gap from steady state, entering the term \(g_{t-10}^{\gamma}/g^{k}_{t-16}\) in equation (3.34) determine the responses of marginal product of capital. Due to the combined impact of the output gap and the capital fluctuations, the maximum response of marginal product of capital (0.006 times the shock) is stronger than that of capital.

Finally, as in (3.37) the real wage response is driven by the positive inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage. Unlike inflation, the real wage takes about 2 quarters to reach its highest negative deviation of 0.002 times the shock.
In conclusion, a consumption preference unit shock has quantitatively a relatively modest effect on the model variables. Its initial impact on consumption, the output gap and investment is alleviated by the increase in the real interest rate (caused by the nominal interest rate hike). The moderate responses of all other variables are determined by the magnitude of the deviations in the two latter variables in particular.

2.2. The case of inflation- and output-targeting

This subsection shows the impulse responses of $\hat{c}$, $\hat{\text{inv}}$, $\hat{y}$, $\hat{\text{rmc}}$, $\hat{k}$, $\hat{\text{mpk}}$, $\hat{\omega}$, $\pi$, $r$, and $i$, as for three shocks: the random component of monetary policy $\varepsilon_i$, the technology shock $\varepsilon_A$, and the preference shock $\varepsilon_\alpha$ when monetary policy is defined in terms of a baseline Taylor rule of the form (3.38). Here no interest-rate smoothing enters the monetary policy rule and the effective response coefficients to inflation and output deviations take the values of 1.5 and 0.5 respectively.

2.2.1. Monetary policy unit shock

In accordance with the theoretical framework presented, a monetary policy unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_i$ in the policy rule (3.38). Figure 4.4 reports impulse responses to a monetary policy unit shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a monetary policy unit shock, are characterised by a relatively fast convergence to the steady state. Only as far as capital is concerned the shock impulse is still present after 60 quarters. The strongest deviations are reported for investment, the output gap, the nominal and the real interest rate.

Negative spikes in investment, consumption and the output gap are observed immediately after the shock, followed by a gradual return to the steady-state.
level. Here the investment response is characterised by the sharpest fall (2 times as large as the shock). Compared to investment, consumption shows a more moderate response (about 0.3 times the shock) and a fast adjustment to its steady-state value. The output gap’s immediate response has an intermediate value of about 0.7 times the size of the monetary policy unit shock. It takes investment, consumption and the output gap less than 8 quarters until the effect of the monetary policy unit shock subsides completely.

The maximum negative response of capital (approximately 0.1 times the size of the shock) is significantly smaller than the initial fall in investment. Contrary to the immediate impact of the shock on investment, it takes about 6 quarters until capital reaches its maximum negative response. Moreover, capital is also characterised by a longer-lasting adjustment to its steady-state level than investment— even after 60 quarters, capital remains slightly under its steady-state level. These results are a logical consequence of the fact that capital is a pre-determined variable as specified in equation (3.35). Investment according to equation (3.32'), however, does not depend on the past realisations of any of its determinants and can therefore respond immediately and in full magnitude as soon as the shock occurs. As in the case of inflation-targeting only, once again the marginal product of capital responds moderately (-0.02 times the shock).

The sluggish adjustment of the real wage over the entire 60 quarters is determined by the partial history-dependence of the variable as seen from (3.37) and by the assumption of sticky wages. The responses of capital, the output gap and real wage determine the dynamics of real marginal cost, as evident from equation (3.33). Compared to the output gap dynamics, the path of real marginal cost reaches a more moderate maximum negative value (0.4 times the shock), but does not adjust monotonically to its steady-state value. Instead, 4 quarters after the shock real marginal cost overshoots the steady-state value, reaching a maximum positive value of 0.05 about 7 quarters after the initial impulse. After that, real marginal cost converges monotonically to the steady-state level. While the initial negative impulse to real marginal cost is mainly a result of the immediate decline of the output gap after the shock, the overshooting part is essentially explained by the slow and lasting response of capital and the real wage.

A monetary policy unit shock has a quantitatively small and non-persistent impact on inflation. As evident from equation (3.36), the monetary impulse is transmitted by real marginal cost. Under sticky prices, despite the strong response of real marginal cost to the shock, inflation remains hardly affected. Thus, the initial negative blip in inflation is less than 0.005 times the shock. Until the effect subsides completely after 16 quarters, the path of inflation includes overshooting dynamics (a maximum of 0.006 in the fourth quarter) before steady-state value is reached.

According to the policy rule (3.38), the nominal interest rate response depends on the unit shock itself and on the responses of the target variables (infla-
tion differential and output gap). The monetary authority’s reaction to the unit shock involves an increase in the nominal interest rate of 0.7 times the shock, followed by a gradual convergence to the steady-state level. The effect of the monetary impulse disappears completely after 10 quarters. The Fisher equation $r_t = i_t - E_t \pi_{t+1}$ postulates that the dynamics of the real interest rate is approximated by the difference between the paths of expected inflation and the nominal interest rate. Due to the quantitatively weak response of actual and expected inflation, the real interest rate response (a positive blip with a maximum value of about 0.7 percent, followed by a monotonic decrease) matches the nominal interest rate dynamics.
In conclusion, the analysis of the impact of a monetary policy unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs and a standard Taylor specification for monetary policy shows that the only long-lasting deviations from steady-state values concern the capital stock and the real wage, which take at least 60 quarters to converge. Consumption, investment, the output gap, the real and the nominal interest rate, on the other hand, all return to their steady-state values within a maximum of 10 quarters.

2.2.2. Technology unit shock

In accordance with the theoretical framework presented, a technology unit shock is modelled as an upward blip of 1 percent in the shock term $e_t$ in the AR(1) process $A_t = \rho_t A_{t-1} + e_t$ that enters the real marginal cost condition (3.33). Figure 4.5 reports impulse responses to a technology unit shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Again, the strongest deviations are reported for real marginal cost, real wage and investment. The initial transmission of the shock occurs through the immediate effect on real marginal cost. A large negative spike of almost 0.9 percent is observed immediately after the shock, followed by a gradual return to the
steady-state level within the next 20 quarters. This negative initial impulse is then transmitted to inflation as evident from (3.36).

As a result of the increased inflation differential, the nominal interest rate is reduced in accordance with the policy rule (3.38), reaching a minimum value of slightly above 0.1 times the shock. As the output gap also enters the monetary policy rule, the increase in actual output as a result of the technology shock implies that the actual nominal interest rate hike will eventually be of a smaller magnitude than under an active rule incorporating inflation-targeting only. Nevertheless, as a result of the large reaction coefficient assigned to inflation and the quantitatively small impact of the shock on the output gap, the path of the nominal interest rate mimics that of actual inflation.

For the model specification chosen, a Taylor rule with no interest-rate smoothing induces a negative blip in the real interest rate of approximately 0.03 percent immediately after the shock occurs, followed by a gradual convergence to the steady-state value within the next 20 quarters. The real-interest rate response induced by the nominal interest rate fall additionally reinforces the positive deviations of investment, consumption and the output gap and acts procyclically. This effect can be offset by a stronger emphasis on output-targeting in the monetary policy rule, measured by the value of the coefficient $\lambda$. Investment, consumption, the output gap, capital and the marginal product of capital all reveal an initial positive response to the technology shock, followed by a countervailing negative deviation of a comparatively smaller magnitude before their steady-state values are reached. The strongest deviations in consumption, the output gap and the marginal product of capital all occur immediately after the shock, while it takes 9 quarters until the maximum impact of the shock on capital unfolds. The technology shock is channelled to consumption and investment through its impact on the real interest rate; the considerably differing magnitudes of the maximum responses of investment (0.23 times the shock) and consumption (0.03 times the shock) can be traced to the values of the coefficients assigned to the real interest rate in (3.32') and (3.25), respectively. Again, since according to equation (3.26) the output gap is a weighted average of consumption and investment, its immediate response has an intermediate maximum value of about 0.08 times the size of the technology shock.

The maximum positive response of capital (approximately 0.03 times the size of the shock) is significantly smaller than the strongest increase in investment. In addition, the deviation in investment is channelled with a time lag to the dynamics of capital. It takes the capital stock whole 9 quarters until it reaches its highest positive deviation from its steady-state level. Once again, capital is also characterised by a longer-lasting adjustment than investment—even after 60 quarters, capital remains under its steady-state level.
In comparison to the response of capital and the output gap the magnitude of the deviation of the marginal product of capital (about 0.004 times the shock) is again quite modest, due to the inclusion of steady-state unit and marginal adjustment costs. Finally, as a result of the labour-augmenting technology shock, the variable reaches a quantitatively significant\footnote{The magnitude of the impulse response of real wage is significant especially compared to the magnitude of the responses of the other model variables.} maximum positive deviation from steady state of 0.4 times the shock after 11 quarters and converges monotonically to its steady-state value thereafter. The response is initially triggered by the inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage.

In conclusion, the analysis of the impact of a technology unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs and a standard Taylor specification of the monetary policy rule shows that the only long-lasting deviations from steady-state values concern the capital stock that takes more than 60 quarters to converge. Compared to the impact of a monetary policy shock, convergence to the steady-state values generally appears to be a longer-lasting process. In addition, the inclusion of an output gap target causes a smaller initial response of the nominal interest rate compared to the case with inflation-targeting only. As a result, deviations in the real nominal rate, investment, capital and the output gap turn out to be of a relatively smaller magnitude. Moreover, output-targeting limits the oscillations in the adjustment paths of consumption, investment, capital and the output gap.

2.2.3. Consumption preference unit shock

In accordance with the theoretical framework presented, a consumption preference unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_o$ in the AR(1) process $v_t = \rho v_{t-1} + \varepsilon_o$ that enters the consumption equation (3.25). Figure 4.6 reports impulse responses to a consumption preference unit shock for
the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a consumption preference unit shock, are of a very small magnitude and in each case of a much lower value than the shock itself. Another distinction in the case of a preference shock is that the adjustment to the steady-state values of nearly all variables (except for the capital stock and the real wage) occurs much faster than in the case of a technology or a monetary policy shock. Within approximately 16 quarters after the initial impulse all variables apart from capital and the real wage have returned to their steady-state values. The strongest deviations as a result of the shock are reported for consumption, the output gap and investment.

The initial transmission of the shock occurs through the immediate effect on consumption as in (3.25). A positive blip of almost 0.2 is observed immediately after the shock, followed by a fast return to the steady-state level within the first 5 quarters. Through its effect on consumption, the preference shock is channelled to the output gap (see equation (3.26)) which also reports a sharp rise by 0.12, followed by a rapid convergence to steady state.

As a result of the positive output gap, the nominal interest rate is increased in accordance with the policy rule (3.38), but the response is of a smaller magnitude (0.06 times the shock at its peak). After the initial blip, the nominal interest rate is gradually decreased and reaches its steady-state value in the forth quarter. The path of the real interest rate mimics that of the nominal interest rate.

The rise in the real interest rate releases an initial fall in investment of 0.12 times the shock, followed by a monotonic adjustment within 4 quarters. Capital initially responds to the negative blip in investment by a gradual decrease, reaching a maximum negative deviation from its steady-state level 3 quarters after the shock. After that, the negative dynamics is reversed and capital converges to steady state after approximately 60 quarters. The deviations of capital and the output gap from steady state determine the responses of marginal product of capital and real marginal cost respectively. The maximum response of marginal product of capital (0.005 times the shock) occurs immediately after the shock. After the initial positive blip, the marginal product of capital converges to steady state within 4 quarters. The response in real marginal cost shows a similar path – an initial positive spike of 0.07 times the shock, followed by a gradual convergence to steady state within the first 4 quarters.

The positive initial effect on real marginal cost is transmitted to inflation as evident from (3.36), whereby the maximum impact on inflation occurs immediately after the shock and is quantitatively small (an increase of 0.002). The impulse disappears in about 4 quarters. The real wage response is driven by the dynamics of inflation expectations and then sustained by the positive inflation differential and the history-dependence on own past realisations of the real wage. Unlike inflation, the real wage takes about 2 quarters to reach its highest
negative deviation of slightly above 0.002 times the shock. This negative deviation persists until about 60 quarters after the initial impulse.
In conclusion, a consumption preference unit shock has a modest effect on the model variables. Its initial impact on consumption, the output gap and investment is alleviated by the increase in the real interest rate (caused by the nominal interest rate hike). The moderate responses of all other variables are determined by the magnitude of the deviations in the two latter variables in particular. Compared to the case with inflation-targeting only, output-targeting induces a stronger response of the nominal interest rate, which in turn leads to a higher positive spike in the real interest rate. The latter result explains the strong negative impulse to investment and the capital stock. The fall in investment partly offsets the initial positive blip in consumption, thus generating a more moderate intermediate positive output gap response. In other words, the monetary policy stance under an active baseline Taylor rule specification plays a stabilising role in the case of a consumption preference unit shock.

2.3. The case of inflation- and output-targeting with interest-rate smoothing

This subsection shows the impulse responses of $\hat{e}_r$, $\tilde{\text{inv}}$, $\hat{y}$, $\hat{\text{rmc}}$, $\hat{k}$, $\hat{mpk}$, $\hat{x}$, $\hat{\omega}$, $\hat{\pi}$, $\hat{r}$ and $\hat{i}$ as for three shocks: the random component of monetary policy $\varepsilon_v$, the technology shock $\varepsilon_A$ and the preference shock $\varepsilon_o$, when monetary policy is defined in terms of an active rule of the form (3.38). Here interest-rate smoothing enters the monetary policy rule ($\lambda_i = 0.8$) and the effective response coefficients to inflation and output deviations take the values of 1.5 and 0.5 respectively.

2.3.1. Monetary policy unit shock

In accordance with the theoretical framework presented, a monetary policy unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_v$ in the policy rule (3.38). Figure 4.7 reports impulse responses to a monetary policy unit shock.
shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Large negative spikes in investment, consumption and the output gap are observed immediately after the shock, followed by a gradual return to the steady-state level. Investment response is characterised by the sharpest fall (three times as large as the shock) and relatively quick adjustment (12 quarters). Compared to investment, consumption shows a more moderate response (-0.4). The output gap’s immediate response is of a comparable value to the shock itself. It takes both consumption and the output gap approximately 12 quarters until the effect of the monetary policy unit shock subsides completely.

The maximum negative response of capital (approximately 0.2 times the size of the shock) is significantly smaller than the initial fall in investment. Contrary to the immediate impact of the shock on investment, it takes about 6 quarters until capital reaches its maximum negative response. Capital is also characterised by a longer-lasting adjustment to its steady-state level than investment—only after 60 quarters capital tends to reach its steady-state level. As in the previous two subsections, the deviation of the marginal product of capital remains moderate and tends to persist for most of the period observed. The sluggish adjustment of the real wage is also familiar from the previous two experiments.

The responses of capital, the output gap and real wage determine the dynamics of real marginal cost, as evident from equation (3.33). Compared to the output gap dynamics, the path of real marginal cost reaches a more moderate maximum negative value (0.6 the shock), but does not adjust monotonically to its steady-state value. Instead, 7 quarters after the shock real marginal cost overshoots the steady-state value, reaching a maximum positive value of slightly under 0.1 about 8 quarters after the initial impulse. After that, real marginal cost converges monotonically to the steady—state level. While the initial negative impulse to real marginal cost is mainly a result of the sharp immediate decline of the output gap after the shock, the overshooting part is essentially explained by the slow and lasting response of capital and the real wage. A monetary policy unit shock has a quantitatively small and non-persistent impact on inflation. As evident from equation (3.36), the monetary impulse is transmitted by real marginal cost. Under sticky prices, despite the strong response of real marginal cost to the shock, inflation remains hardly affected. The effect subsides completely after 16 quarters.

As far as the nominal interest rate is concerned, according to the policy rule (3.38) its deviation depends on the unit shock itself, the responses of the target variables (inflation differential and output gap) and the past deviation of the variable from its steady-state value. The monetary authority’s reaction to the unit shock involves a more gradual increase in the nominal interest rate compared to the cases without interest-rate smoothing— it takes two quarters until the maximum response unfolds. Another distinction from the responses of the
nominal (and real) interest rate to a monetary unit shock when no lagged nominal interest rate enters the central bank’s rule (see Chapter IV, Subsections 2.1 and 2.2) is that under interest-rate smoothing the maximum response of both variables remains more moderate (0.5 times the shock). After the initial positive deviation, monotonic convergence to the steady-state value occurs within 16 quarters. Again, due to the quantitatively weak response of inflation, the real interest rate response (a positive blip with a maximum value of 0.5, followed by a monotonic decrease) matches the nominal interest rate dynamics.
In conclusion, the analysis of the impact of a monetary policy unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs shows that the only long-lasting deviations from steady-state values concern the capital stock and the real wage, which take more than 60 quarters to converge. Consumption, the output gap, the real and the nominal interest rate, on the other hand, all return to their steady-state values within approximately 16 quarters. Compared to the results under a baseline Taylor rule in Subsection 2.2, all variables except the nominal and the real interest rate are characterised by larger deviations from their steady-state values when interest-rate smoothing is introduced. The history-dependence of the nominal and real interest rate explains the smoother adjustment paths of both variables, as well as the quantitatively smaller but longer-lasting impact of the shock.

2.3.2. Technology unit shock

A technology unit shock is modelled as an upward blip of 1 percent in the shock term \( \varepsilon_A \) in the AR(1) process \( A_t = \rho_A A_{t-1} + \varepsilon_A \) that enters the real marginal cost condition (3.33). Figure 4.8 reports impulse responses to a technology unit shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.
Variable deviations, caused by a technology unit shock, are generally of a much smaller magnitude that those occurring as a result of a monetary policy unit shock and in each case of a lower value than the shock itself. Adjustment to the steady-state values of all variables (except for real marginal cost) is longer-lasting than in the case of a monetary shock. An interesting result differing from the cases without interest-rate smoothing is the fact that the impact on investment, the output gap and consumption does not unfold immediately after the occurrence of the technology shock. Instead, the largest deviations from steady state are registered only after 2 quarters. The strongest deviations are reported for real marginal cost, investment and the real wage.

The initial transmission of the shock occurs through the immediate effect on real marginal cost. A large negative spike of almost 0.9 percent is observed immediately after the shock, followed by a gradual return to the steady-state level within the next 20 quarters. This negative initial impulse is then transmitted to inflation as evident from (3.36). As a result of the inflation differential, the nominal interest rate is reduced in accordance with the policy rule (3.38), but the response is more gradual. The largest decrease in the nominal interest rate is registered after 3 quarters and is 0.09 times as large as the shock, followed by oscillatory convergence to the steady-state value within more than 60 quarters. The initial positive blip of the real interest rate in the first quarter is explained by the immediate sharp decrease in inflation (and expected inflation) and the initially quantitatively smaller decrease in the nominal rate. After that, the nominal interest rate effect prevails and path of the real interest rate mimics on a smaller scale that of the nominal interest rate.

Investment, consumption, the output gap, capital and the marginal product of capital all reveal an initial positive response to the technology shock, followed by a countervailing negative deviation of a comparatively smaller magnitude before their steady-state values are reached. The strongest deviations in consumption, the output gap and the marginal product of capital all occur within the first four quarters, while it takes about 12 quarters until the maximum impact of the shock on capital unfolds. The technology shock is again channelled to consumption and investment through its impact on the real interest rate. The maximum response of investment (0.5 times the shock) is significantly stronger than that of consumption and consumption (0.08 times the shock). The output gap responds by a positive blip of about 0.17 times the size of the technology shock.

The maximum positive response of capital (approximately 0.08 times the size of the shock) is significantly smaller than the strongest increase in investment. In addition, the deviations in investment are channelled with a time lag to the dynamics of capital. It takes the capital stock a whole 12 quarters until it reaches its highest positive deviation. Once again, capital is also characterised
by a longer-lasting adjustment to its steady-state level than investment— even after 60 quarters, capital remains under its steady-state level.
In comparison to the response of capital and the output gap the magnitude of the deviation of the marginal product of capital in both directions is again quite modest, due to the inclusion of steady-state unit and marginal adjustment costs. Both the sluggish adjustment of marginal product of capital over 40 quarters and the undershooting path registered after the eight quarter following the shock can be traced back to the different adjustment dynamics of capital and output gap discussed above. Finally, the real wage reaches a maximum positive deviation from steady state of 0.45 times the shock after 12 quarters and converges monotonically to its steady-state value thereafter. The response is initially triggered by the inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage.

In conclusion, the analysis of the impact of a technology unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs shows that the long-lasting deviations from steady-state values concern numerous model variables (the capital stock, real wage, inflation, the nominal interest rate and investment) that take more than 60 quarters to converge. Compared to the impact of a monetary policy shock convergence to the steady-state values generally appears to be a longer-lasting process. For all variables the magnitude of the observed deviations is relatively smaller than in the case of a monetary policy unit shock. A monetary policy unit shock under a Taylor rule with interest-rate smoothing generates the largest initial deviations in consumption, investment and the output gap of all active rule specifications considered. The largest negative response of the nominal interest rate is more modest here than in the two cases without interest-rate smoothing and, after the first quarter is quantitatively not sufficient to offset a pro-cyclical fall in the real interest rate.

2.3.3. Consumption preference unit shock

A consumption preference unit shock is modelled as an upward blip of 1 percent in the shock term $\varepsilon_i$ in the AR(1) process $v_i = \rho_v v_{i-1} + \varepsilon_i$, that enters the con-
umption equation (3.25). Figure 4.9 reports impulse responses to a consumption preference unit shock for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a consumption preference unit shock, are again of a very small magnitude and in each case of a much lower value than the shock itself. Moreover, in the case of a preference shock is that the adjustment to the steady-state values for all variables occurs much faster than in the case of a technology or a monetary policy shock. Within approximately 16 quarters after the initial impulse all variables apart from capital, the real wage and the marginal product of capital have returned to their steady-state values. The strongest deviations as a result of the shock are reported for consumption, investment and the output gap.

The initial transmission of the shock occurs through the immediate effect on consumption as in (3.25). A positive blip of 0.17 percent is observed immediately after the shock, followed by a fast return to the steady-state level within the first 4 quarters. Through its effect on consumption, the preference shock is channelled to the output gap (see equation (3.26)) which also reports a sharp rise by 0.09 percent, followed by a rapid convergence to steady state.

As a result of the positive output gap, the nominal interest rate is increased in accordance with the policy rule (3.38), but the response is of a smaller magnitude (0.004 times the shock at its peak). After the first quarter, the nominal interest rate is gradually decreased and reaches its steady-state value in the fourteenth quarter. Because of the negligibly small impact of the shock on inflation, the path of the real interest rate mimics that of the nominal interest rate.

The rise in the real interest rate releases an initial fall in investment of 0.2 times the shock, followed by a monotonic adjustment within 8 quarters. Capital initially responds to the negative blip in investment by a gradual decrease, reaching a maximum negative deviation from its steady-state level 8 quarters after the shock. After that, the negative dynamics is reversed and capital converges to steady state after approximately 60 quarters. The deviations of capital and the output gap from steady state determine the responses of marginal product of capital and real marginal cost respectively. Due to the combined impact of the output gap and the capital fluctuations, the maximum response of marginal product of capital (0.004 times the shock) is stronger than that of capital. The response in real marginal cost shows an initial positive spike of almost 0.5 times the shock.

The positive initial effect on real marginal cost is transmitted to inflation as evident from (3.36), whereby the maximum impact on inflation occurs immediately after the shock and is quantitatively small (an increase of 0.001 percent). The impulse disappears in 12 quarters. Finally, as in (3.37) the real wage response takes about 12 quarters to reach its highest negative deviation of 0.003
times the shock. This negative deviation persists until about 60 quarters after the initial impulse.
In conclusion, a consumption preference unit shock has quantitatively a relatively modest effect on the model variables. Its initial impact on consumption, the output gap and investment is alleviated by the increase in the real interest rate (caused by the nominal interest rate hike). The moderate responses of all other variables are determined by the magnitude of the deviations in the two latter variables in particular. The results for a consumption preference unit shock for a Taylor rule with interest-rate smoothing are comparable to these under a baseline Taylor specification. The major difference pertains to the more moderate and gradual responses of the nominal and real interest rate. The induced negative deviation in investment is stronger than under a baseline Taylor rule; thus, the positive output gap impulse is smaller under interest-rate smoothing and the monetary policy stance acts stabilising.

3. Passive rule

3.1. The case of inflation-targeting only

As it is evident from the determinacy analysis in Chapter III, Subsection 4.2.3, an interest-rate rule with $\lambda_r^* < 1$ and $\xi_r = 0$ does not yield determinacy of rational-expectations equilibrium for any value of the inflation coefficient under unity. Thus, the impulse response of each variable under a passive rule with a sole inflation target would reveal one adjustment path among several possible, generated by picking the smallest eigenvalue of the system within the unit circle. Still, alternative scenarios cannot be ruled out and therefore no reliable shock analysis can be carried out.

3.2. The case of inflation- and output-targeting

This subsection shows the impulse responses of $c_t$, $\hat{inv}_t$, $y_t$, $\hat{rmc}_t$, $\hat{k}_t$, $\hat{mpk}_t$, $\hat{\omega}_t$, $\pi_t$, $r_t$ and $i_t$ as for three shocks: the random component of monetary policy $\varepsilon_{\eta_t}$, the technology shock $\varepsilon_{\lambda_t}$ and the preference shock $\varepsilon_{\theta_t}$. Monetary policy is...
defined in terms of a passive Taylor rule with inflation and output coefficients both equal to 0.5\textsuperscript{128}.

### 3.2.1. Monetary policy unit shock

Figure 4.10 reports impulse responses to a monetary policy unit shock (an upward blip of 1 percent in the shock term $\varepsilon_i$ in the policy rule (3.38) for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

The variable responses to a monetary policy unit shock under a passive rule with inflation- and output-targeting do not differ substantially from the results under a baseline active Taylor rule. Compared with the case of a passive rule with a sole inflation target, more moderate negative spikes are observed in investment, consumption and the output gap immediately after the shock, followed by a gradual return to the steady-state level. Investment response reports by the sharpest fall (twice the shock). Compared to investment, consumption shows a more moderate response (0.25) and a faster adjustment to its steady-state value. As a weighted average of consumption and investment, the immediate response of the output gap has an intermediate value of about -0.7 times the size of the monetary policy shock. It takes both consumption and the output gap approximately 6 quarters until the effect of the monetary policy unit shock subsides completely.

The maximum negative response of capital (approximately 0.1 times the size of the shock) is significantly smaller than the initial fall in investment. Contrary to the immediate impact of the shock on investment, it takes about 6 quarters until capital reaches its maximum negative response. As a predetermined variable, capital is also characterised by a longer-lasting adjustment to its steady-state level than investment- even after 60 quarters, capital remains under its steady-state level.

Again, in comparison to the relatively strong response of capital and the output gap the magnitude of the deviation of the marginal product of capital (-0.03 times the shock at its minimum) is relatively weak. Both the sluggish adjustment of marginal product of capital over almost 60 quarters and the overshooting path registered after the forth quarter following the shock can be traced back to the different adjustment dynamics of capital and output gap discussed above. The sluggish adjustment of the real wage is determined by the partial history-dependence of the variable as seen from (3.37) and by the assumption of sticky wages.

\textsuperscript{128} For the values originally proposed by Casares and McCallum (2006), the effective response coefficient assigned to the output gap in (3.39) is so small that no significant difference to the case with a sole inflation target can be observed. The reason for choosing $\lambda_i = \lambda_y = 0.5$ is the fact that, as shown in Chapter III, Subsection 4.2.3, the coefficient values $\lambda_{\pi} = \lambda_y = 0.5$ yield a determinate rational-expectations equilibrium.
The responses of capital, the output gap and real wage determine the dynamics of real marginal cost, as evident from equation (3.33). Compared to the output gap dynamics, the path of real marginal cost reaches a more moderate peak negative value (0.4 times the shock), but does not adjust monotonically to its steady-state value. Instead, 4 quarters after the shock real marginal cost slightly overshoots the steady-state value; thereafter, it converges monotonically to the steady—state level. While the initial negative impulse to the real marginal cost is mainly a result of the sharp immediate decline of the output gap after the shock, the overshooting part is essentially explained by the slow and lasting response of capital and the real wage.

A monetary policy unit shock has a quantitatively small and non-persistent impact on inflation, transmitted by the real marginal cost. The initial negative blip in inflation is less than 0.01 times the shock. In addition, until the effect subsides completely after 16 quarters, the path of inflation reveals overshooting dynamics before steady-state value is reached 16 quarters after the initial impulse.
The nominal interest rate adjustment is triggered the unit shock itself, as well as the responses of the target variables (inflation differential and output gap). The monetary authority’s reaction to the unit shock involves an increase in the nominal interest rate of 0.7 times the shock in the first quarter, followed by a gradual convergence to the steady-state level within the next 7 quarters. The Fisher equation $r_t = i_t - E_t \pi_{t+1}$ postulates that the dynamics of the real interest rate is approximated by the difference between the paths of inflation and the nominal interest rate. The real interest rate response (a positive blip with a maximum value
of 0.7 times the shock, followed by a monotonic decrease) matches the nominal interest rate dynamics.

In conclusion, the analysis of the impact of a monetary policy unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs shows that the only long-lasting deviations from steady-state values concern the capital stock and the real wage, which take more than 60 quarters to converge. Consumption, the output gap, inflation, the real and the nominal interest rate, on the other hand, all return to their steady-state values within approximately 20 quarters. These results are consistent with the ones under a baseline active Taylor rule.

3.2.2. Technology unit shock

Figure 4.11 reports impulse responses to a technology unit shock (an upward blip of 1 percent in the shock term $\varepsilon_A$ in the AR(1) process $A_t = \rho_A A_{t-1} + \varepsilon_A$ that enters the real marginal cost condition (3.33) for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a technology unit shock, are, with the exception of the real marginal cost, real wage and inflation responses, of a much smaller magnitude than those occurring as a result of a monetary policy unit shock and in each case of a lower value than the shock itself. Moreover, adjustment to the steady-state values of nearly all variables (except capital and the real wage) is more sluggish in the case of a technology shock than under a monetary policy shock. The strongest deviations are reported for real marginal cost, real wage, investment and inflation.

The initial transmission of the shock occurs through the immediate effect on real marginal cost. A large negative spike of almost 0.9 times the shock is registered immediately after the shock, followed by a gradual return to the steady-state level within the next 60 quarters. This negative initial impulse is then transmitted to inflation as evident from (3.36). The assumption of sticky prices determines the negative, but relatively modest (0.1 times the shock) deviation of inflation from steady state. As a result of the increased inflation differential, the nominal interest rate is reduced in accordance with the policy rule (3.38), initially by slightly over 0.06 times the shock. The initial positive blip in the real interest rate is explained by the initial decrease in expected inflation in (3.36) that in the first 4 quarters quantitatively exceeds the negative effect on the nominal interest rate. Thus, in accordance with the Fisher equation $r_t = i_t - E_t \pi_{t+1}$, the real interest rate reports initially a positive deviation from steady state of almost 0.02.

Investment, consumption, the output gap, capital and the marginal product of capital all reveal an initial negative response to the technology shock, followed by a countervailing positive deviation of a comparatively smaller magnitude before their steady-state values are reached. The strongest deviations in
consumption, the output gap and the marginal product of capital all occur within the first eight quarters. The technology shock is channelled to consumption and investment through its impact on the real interest rate; the maximum responses of investment (0.1 times the shock) is much larger than that of consumption (0.01 times the shock). The immediate response of the output gap reaches a fall of about -0.03 times the size of the technology shock at its negative peak. As far as capital is concerned, an initial decline of 0.01 times the shock is followed by a longer-lasting positive deviation of a comparable maximum value.

As a result of the labour-augmenting technology shock, the real wage reaches a quantitatively significant maximum positive deviation from steady state of 0.45 times the shock after 12 quarters and converges monotonically to its steady-state value thereafter. The response is initially triggered by the inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage.

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129 The magnitude of the impulse response of real wage is significant especially compared to the magnitude of the responses of the other model variables.
In conclusion, the analysis of the impact of a technology unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs shows that the only long-lasting deviations from steady-state values concern the capital stock and the real wage that take more than 60 quarters to converge. Compared to the impact of a monetary policy shock convergence to the steady-state values generally appears to be a longer-lasting process. For most variables the magnitude of the observed deviations is relatively smaller than in the case of a monetary policy unit shock. In comparison to the active specification with an inflation and an output gap target, here the technology unit shock has a milder impact as
it induces more moderate nominal interest rate cuts as a reaction to the decrease in inflation that cannot offset the latter and thus generate a rise in the real interest rate. Through the real-interest-rate channel investment, consumption and the output gap report negative deviations significantly smaller than the size of the shock.

3.2.3. Consumption preference unit shock

Figure 4.12 reports impulse responses to a consumption preference unit shock (an upward blip of 1 percent in the shock term $\varepsilon_{\nu}$ in the AR(1) process $\nu_t = \rho \nu_{t-1} + \varepsilon_{\nu_t}$ that enters the consumption equation (3.25) for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

The results for a consumption preference unit shock under a passive specification with inflation- and output-targeting do not differ significantly from the findings under a baseline active Taylor rule. Variable deviations are of a very small magnitude and in each case of a much lower value than the shock itself. The adjustment to the steady-state values for all variables occurs much faster than in the case of a technology or a monetary policy shock. Within approximately four quarters after the initial impulse most variables apart from capital and the real wage have returned to their steady-state values. The strongest deviations as a result of the shock are reported for consumption, investment and the output gap.

The initial transmission of the shock occurs through the immediate effect on consumption as in (3.25). A positive blip of almost 0.2 times the shock is observed immediately after the shock, followed by a fast return to the steady-state level within the first 4 quarters. Through its effect on consumption, the preference shock is channelled to the output gap (see equation (3.26) which also reports a sharp rise by 0.12 percent, followed by a rapid convergence to steady state.

As a result of the positive output gap, the nominal interest rate is increased in accordance with the policy rule (3.38) and the response is 0.06 the shock at its peak. After the first quarter, the nominal interest rate is gradually decreased and reaches its steady-state value in the forth quarter.

The path of the real interest rate mimics that of the nominal interest rate. The rise in the real interest rate releases an initial fall in investment of 0.12 times the shock, followed by a monotonic adjustment within 4 quarters. Capital initially responds to the negative blip in investment by a gradual decrease, reaching a maximum quantitatively small negative deviation from its steady-state level 4 quarters after the shock. After that, the negative dynamics is reversed and capital converges to steady state after more than 60 quarters. The deviations of capital and the output gap from steady state, entering the term $(\hat{y}_t - \hat{k}_t)$ in equations (3.34) and (3.33) determine the responses of marginal product of capital and real marginal cost respectively. Due to the combined impact of the output gap and
the capital fluctuations, the maximum response of marginal product of capital (0.005 times the shock) is equal in absolute value to that of capital. The response in real marginal cost shows a similar path – an initial positive spike of 0.06 times the shock, followed by a gradual convergence to steady state within the first 4 quarters.

The positive initial effect on real marginal cost is transmitted to inflation as evident from (3.36), whereby the maximum impact on inflation occurs immediately after the shock and is quantitatively small (an increase of 0.002 times the shock). The impulse disappears in less than 4 quarters. Finally, as in (3.37) the real wage response is driven by the positive inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage. Unlike inflation, the real wage takes about 2 quarters to reach its highest negative deviation of 0.002 times the shock. This negative deviation persists until about 60 quarters after the initial impulse.
In conclusion, a consumption preference unit shock has quantitatively a relatively modest effect on the model variables. Its initial impact on consumption, the output gap and investment is alleviated by the increase in the real interest rate (caused by the nominal interest rate hike). The moderate responses of all other variables are determined by the magnitude of the deviations in the two latter variables in particular.
3.3. The case of inflation- and output-targeting with interest-rate smoothing

The impulse responses in this subsection are calculated based on a passive Taylor rule with inflation and output coefficients both equal to 0.5\textsuperscript{130} and interest-rate smoothing, whereby the lagged interest rate coefficient is equal to 0.8 as proposed by Casares and McCallum (2006).

3.3.1. Monetary policy unit shock

Figure 4.13 reports impulse responses to a monetary policy unit shock (an upward blip of 1 percent in the shock term $e_i$ in the policy rule (3.38) for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

The results under a monetary policy shock do not differ from these with a passive rule and inflation-targeting only. Negative spikes in investment, consumption and the output gap are observed immediately after the shock, followed by a gradual return to the steady-state level. Investment response is characterised by the sharpest fall (3 times as large as the shock) and gradual adjustment within 32 quarters. Compared to investment, consumption shows a more moderate response (0.5 times the shock) and a faster adjustment to its steady-state value. Since according to equation (3.26) the output gap is a weighted average of consumption and investment, its immediate response has an intermediate value approximately as large as the monetary policy shock. It takes both consumption and the output gap approximately 8 quarters until the effect of the monetary policy unit shock subsides completely. The paths of consumption, investment and output gap plotted on Figure 4.13 reveal the significance of the endogenous capital assumption for the model’s quantitative results. Under constant capital, the output gap response to a monetary policy unit shock would still be negative, but of a considerably smaller magnitude, as it would only incorporate the fall in consumption.

The maximum negative response of capital (approximately 0.15 times the size of the shock) is significantly smaller than the initial fall in investment. Contrary to the immediate impact of the shock on investment, it takes 5 quarters until capital reaches its maximum negative response. Moreover, capital is also characterised by a longer-lasting adjustment to its steady-state level than investment- even after 60 quarters, capital remains under its steady-state level.

In comparison to the relatively strong response of capital and the output gap the magnitude of the deviation of the marginal product of capital (-0.04 times the shock at its minimum) might at first seem worth further consideration. Algebraically this is determined by the relatively small value of the steady-state mar-

\textsuperscript{130} At the end of this subsection, the results under the values originally proposed by McCallum and Casares (2006) for (3.39) are shown.
ginal product of capital (0.04) that enters equation (3.34) as a coefficient, implying a relatively weaker response of marginal product of capital to deviations in output and capital. The sluggish adjustment of the real wage is determined by the partial history-dependence of the variable as seen from (3.37) and by the assumption of sticky wages. The latter is modelled by the inclusion of a fixed probability $\eta_w (\eta_w = 0.75)$ that nominal wages cannot be adjusted in the current quarter, which implies that on average wages are re-set once a year.

The responses of capital, the output gap and real wage determine the dynamics of real marginal cost, as evident from equation (3.33). Compared to the output gap dynamics, the path of real marginal cost reaches a more moderate maximum negative value (0.5 times the shock), but does not adjust monotonically to its steady-state value. Instead, 4 quarters after the shock real marginal cost overshoots the steady-state value; thereafter, real marginal cost converges monotonically to the steady—state level. While the initial negative impulse to real marginal cost is mainly a result of the sharp immediate decline of the output gap after the shock, the overshooting part is essentially explained by the slow and lasting response of capital and the real wage.

A monetary policy unit shock has a quantitatively small and non-persistent impact on inflation. As evident from equation (3.36), the monetary impulse is transmitted by real marginal cost. Under sticky prices, despite the strong response of real marginal cost to the shock, inflation remains hardly affected, as the value of the fixed probability that households cannot adjust their price $\eta_p = 0.75$ (i.e. prices adjusted once a year on average) implies that the real marginal cost coefficient $\left(1 - \beta p \right) \left(1 - \eta_p \right) \left(1 - \alpha_p \right) \eta_p \left(1 - \alpha_p + \alpha_p \theta \right)$ equals 0.02. Thus, the initial negative blip in inflation is less than 0.01 the shock. Until the effect subsides completely after 16 quarters, the path of inflation involves overshooting dynamics before steady-state value is reached.

As far as the nominal interest rate is concerned, according to the policy rule (3.38) its deviation depends on the unit shock itself, the responses of the target variables (inflation differential and output gap) and the past deviation of the variable from its steady-state value. The monetary authority’s reaction to the unit shock involves an increase in the nominal interest rate half as large as the shock in the first quarter, followed by a gradual convergence to the steady-state level. The effect of the monetary impulse disappears completely after 8 quarters. The Fisher equation $r_t = i_t - E_t \pi_{t+1}$ postulates that the dynamics of the real interest rate is approximated by the difference between the paths of inflation and the nominal interest rate. Due to the quantitatively weak response of inflation, the real interest rate response (a positive blip with a maximum value half as large as the shock, followed by a monotonic decrease) matches to a great extent the nominal interest rate dynamics.
In conclusion, the analysis of the impact of a monetary policy unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs shows that the only long-lasting deviation from the steady-state value concern the capital stock, which takes more than 60 quarters to converge. Consumption, the output gap, the real and the nominal interest rate, on the other hand, all return to their steady-state values within 8 quarters. These results basically confirm the long-run monetary neutrality of the model.

3.3.2. Technology unit shock

Figure 4.14 reports impulse responses to a technology unit shock (an upward blip of 1 percent in the shock term $\epsilon_A$ in the AR(1) process $A_t = \rho A_{t-1} + \epsilon_A$ that enters the real marginal cost condition (3.33) for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a technology unit shock, are generally of a much smaller magnitude that those occurring as a result of a monetary policy unit shock and in each case of a lower value than the shock itself. Another distinction in the case of a technology shock is the slower adjustment to the steady-state values of nearly all variables (except real marginal cost and the nominal and real interest rate). The strongest deviations are reported for real marginal cost, real wage and investment. The adjustment paths of near all variables resemble the ones under a passive interest-rate rule and a sole inflation target. Compared to the active specification with interest-rate smoothing, the impulse responses of consumption, investment and the output gap are of a smaller magnitude. Through the moderate nominal interest rate cuts, passive policy generates a rise in the real interest rate that acts in a stabilising manner.

The initial transmission of the shock occurs through the immediate effect on real marginal cost. A large negative spike of almost 0.9 times the shock is registered immediately after the shock, followed by a gradual return to the steady-state level. This negative initial impulse is then transmitted to inflation as evi-
dent from (3.36). The assumption of sticky prices determines the negative deviation of 0.09 times the shock of inflation from steady state. As a result of the increased inflation differential, the nominal interest rate is reduced in accordance with the policy rule (3.38), but the response is quantitatively smaller. The initial positive blip in the real interest rate is explained by the initial decrease in expected inflation in (3.36) that in the first 10 quarters quantitatively exceeds the negative effect on the nominal interest rate. Thus, in accordance with the Fisher equation \( r_t = i_t - E_{\tau_t} \pi_{t+1} \), the real interest rate reports a positive deviation from steady state.

Investment, consumption, the output gap, capital and the marginal product of capital all reveal an initial positive response to the technology shock. The strongest deviations in consumption, the output gap and the marginal product of capital all occur within the first 8 quarters, while it takes longer until the maximum impact of the shock on capital unfolds. The technology shock is channelled to consumption and investment through its impact on the real interest rate; the considerably differing magnitudes of the maximum responses of investment (0.18 times the shock) and consumption (0.05 times the shock) are again observed. The immediate response of the output gap reaches a maximum value of about 0.08 times the size of the technology shock.

The maximum positive response of capital is significantly smaller than the strongest increase in investment. In addition, the deviations in investment are channelled with a time lag to the dynamics of capital. Once again, capital is also characterised by a longer-lasting adjustment to its steady-state level.

In comparison to the response of capital and the output gap the magnitude of the deviation of the marginal product of capital (about 0.002 times the shock in both directions) is again quite modest, due to the inclusion of steady-state unit and marginal adjustment costs. Both the sluggish adjustment of marginal product of capital over 60 quarters and the undershooting path registered after the twentieth quarter following the shock can be traced back to the different adjustment dynamics of capital and output gap discussed above.
Figure 4.14: Responses to a technology unit shock under a passive rule with inflation- and output-targeting and interest-rate smoothing
Finally, the impulse response of the real wage is worth some consideration. As a result of the labour-augmenting technology shock, the variable reaches a quantitatively significant\textsuperscript{131} maximum positive deviation from steady state of 0.4 times the shock after 10 quarters and converges monotonically to its steady-state value thereafter. The response is initially triggered by the inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage.

In conclusion, the analysis of the impact of a technology unit shock in a model with sticky prices and wages, endogenous capital and adjustment costs shows that the long-lasting deviations from steady-state values concern the marginal product of capital, inflation and the real wage that take more than 60 quarters to converge. Compared to the impact of a monetary policy shock convergence to the steady-state values generally appears to be a longer-lasting process. For most variables except the real marginal cost, inflation and the real wage the magnitude of the observed deviations is relatively smaller than in the case of a monetary policy unit shock. The reason for the milder impact of a technology unit shock is that it induces nominal interest rate cuts as a reaction to the increased inflation differential that quantitatively exceed the latter and thus generate a rise in the real interest rate as well. Through the real-interest-rate channel the positive impulse to investment, consumption and the output gap remains moderate and the variables report positive deviations significantly smaller than the size of the shock.

3.3.3. Consumption preference unit shock

Figure 4.15 reports impulse responses to a consumption preference unit shock (an upward blip of 1 percent in the shock term $\varepsilon_0$ in the AR(1) process $v_t = \rho v_{t-1} + \varepsilon_0$ that enters the consumption equation (3.25) for the model specification with sticky prices and wages, endogenous capital and adjustment costs.

Variable deviations, caused by a consumption preference shock, are of a very small magnitude and in each case of a much lower value than the shock itself. Another distinction in the case of a preference shock is that the adjustment to the steady-state values for all variables occurs much faster than in the case of a technology or a monetary policy shock. Within approximately 16 quarters after the initial impulse all variables apart from capital and the real wage have returned to their steady-state values. The strongest deviations as a result of the shock are reported for consumption, the output gap and real marginal cost.

The initial transmission of the shock occurs through the immediate effect on consumption as in (3.25). A positive blip of 0.2 the shock is observed immediately after the shock, followed by a fast return to the steady-state level within the first 4 quarters. Through its effect on consumption, the preference shock is

\textsuperscript{131} The magnitude of the impulse response of real wage is significant especially compared to the magnitude of the responses of the other model variables.
channelled to the output gap (see equation (3.26) which also reports a sharp rise by 0.1 percent, followed by a rapid convergence to steady state.

As a result of the positive output gap, the nominal interest rate is increased in accordance with the policy rule (3.38), but the response is of a smaller magnitude (0.005 times the shock at its peak). After the first quarter, the nominal interest rate is gradually decreased; the path of the real interest rate mimics that of the nominal interest rate with an initial positive blip of slightly under 0.005.

The rise in the real interest rate releases a positive response of investment, followed by an adjustment within 12 quarters. The impulse to capital is also extremely modest. The deviations of capital and the output gap from steady state determine the responses of marginal product of capital and real marginal cost respectively. Due to the combined impact of the output gap and the capital fluctuations, the maximum response of marginal product of capital (0.004 times the shock) is stronger than that of capital. After the initial positive blip, the marginal product of capital converges to steady state within 6 quarters. The response in real marginal cost shows a similar path – an initial positive spike of 0.06 times the shock, followed by a gradual convergence to steady state within the first 6 quarters.

The positive initial effect on real marginal cost is transmitted to inflation as evident from (3.36), whereby the maximum impact on inflation occurs immediately after the shock and is quantitatively small (an increase of 0.002 times the shock). The impulse disappears in less than 4 quarters. Finally, as in (3.37) the real wage response is driven by the positive inflation differential and then sustained by the dynamics of inflation expectations and the history-dependence on own past realisations of the real wage. Unlike inflation, the real wage takes about 20 quarters to reach its highest negative deviation of 0.005 times the shock. This negative deviation persists for more than 60 quarters after the initial impulse.

In conclusion, a consumption preference unit shock has quantitatively a relatively modest effect on the model variables. Its initial impact on consumption, the output gap and investment is alleviated by the increase in the real interest rate. The moderate responses of all other variables are determined by the magnitude of the deviations in the two latter variables in particular.
In addition, the impulse responses to a monetary policy unit shock, a technology unit shock and a consumption preference unit shock under the policy rule specification (3.39) with $\lambda^*_e = 0.3$, $\lambda^*_y = 0.02$ and $\lambda^*_i = 0.8$ (as calibrated by Casares and McCallum (2006)) reveal large variable oscillations for all three shocks. This reveals the importance of sufficiently strong responses to inflation and the output gap in the policy rule. These impulse responses are not plotted here, as a “bumpy” convergence path is associated with uncertainty and additional costs in terms of output and thus represents a monetary policy option that should rather be avoided.

4. Preliminary summary of results

Using the results from the determinacy analysis in Chapter III, active and passive rules in three possible specifications for each class were tested in this part: (i) rules with a sole inflation target; (ii) rules with an inflation and output target and (iii) rules with inflation and output gap target and interest-rate smoothing. The types of shocks entering the impulse responses are threefold: (i) a monetary policy unit shock; (ii) a technology unit shock and (iii) a consumption preference shock.

There are several important findings resulting from the impulse responses in Sections 2 and 3. Firstly, the distinction between active and passive rules has implications for the sign of the variable deviations, but not for their magnitude or persistence. For instance, a technology unit shock induces a real interest rate decrease under all active rule specifications and the opposite effect under all passive rule specifications. However, the speed and path of the convergence and the maximum deviations from steady state reported differ significantly depending on the choice of target variables, the best performance under all shocks

132 In the case of oscillatory paths the deviations in the direction mentioned above are quantitatively larger than the deviations in the opposite direction.
being reported for the active and passive rule with both an inflation and an output target. As evident from Chapter III, passive policy induces multiple rational-expectations equilibria, so that only the active inflation-targeting rule specification is relevant for monetary policy-making. However, the latter is associated with lengthier and more oscillatory convergence path to steady state, as compared with rules with both an inflation and output gap target.

Secondly, both for active and passive policy, longer-lasting convergence, relatively greater variable deviations and more frequent oscillatory adjustment paths for each shock are reported for the specification with a significant degree of interest-rate smoothing. Thirdly, the sign and exact magnitude of the model variables’ responses to a monetary policy unit shock do not differ between the active and the passive specification, as long as identical target variables enter the rule. The responses to a consumption preference unit shock do not differ significantly across the six interest rate rule specifications and therefore offer very limited insights to the analysis.

Lastly, the more significant differences between the active and passive specifications including identical variables are registered in the case of a technology unit shock. This can be traced back to the differing magnitudes of the nominal interest rate responses that induce negative real-interest rate deviations under active policy and positive real-interest rate deviations from steady state under passive policy. Thus, passive policy stance acts stabilising as the technology shock impact is countervailed by the real interest rate increase. By analogy, active policy boosts the shock impulse and contributes to larger deviations of investment, consumption and the output gap. This tendency can be at least partially offset by the introduction of an output target to the policy rule.