



Graphical Analysis of the new Neoclassical Synthesis

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Abstract

In this paper we present a graphical analysis framework for the new neoclassical synthesis, which can be used to explain and interpret the behavior of the new neoclassical model under shocks. We elaborate the role of expectations on output and inflation as well as the influence of the monetary authority.

1 Introduction

The so-called new neoclassical synthesis has become a focus of research in the area of monetary policy since the late nineties and is developing into a framework that might establish itself as a standard-model in macroeconomics literature, analogous to the well-known IS-LM-AS model. One of the key success factors of the traditional IS-LM-AS model was the fact that it is relatively easy to understand and can be analyzed by graphical means, which is particularly important for teaching purposes. For that reason, the question arises whether the new neoclassical synthesis can be learned and understood analogously by a graphical analysis. It is quite interesting to note that past research in the area of the new neoclassical synthesis focused on the theoretical framework, i.e. the underlying microfoundation, stability analysis, etc., without trying to develop a framework to exploit the new model for teaching purposes analogous to the traditional model. Some authors have presented simple graphical charts for the new synthesis (cf [10], [11], [12]) – without developing a graphical analysis that fully exploits the implications of the new model framework, especially regarding the importance of expectations and the role of the monetary authority. In [11] and [12] a model without money is discussed in a graphical analysis, where the LM curve was replaced by an interest rate rule and hence contains some aspects of the new neoclassical synthesis. However, the forward-looking behavior of the system, i.e. the role of expectations, is not included. In [2] a thorough graphical analysis is developed in order to compare different monetary policies under the new neoclassical model framework, i.e. the focus of the authors is not on the full explanation of all characteristic features of the new standard model, but on comparing different monetary policy functions.

The purpose of our paper is to close this gap, i.e. to develop a more sophisticated graphical analysis toolkit that enables the user to analyze the implications of the new neoclassical synthesis in the form that most authors refer to as a new standard, especially the behavior of the economy under shocks, the role of expectations and the influence of the monetary authority. Therefore, we discuss shocks on both the demand side and the supply side of the economy as well as a change

in the monetary policy regime. However, there is a variety of further sub-cases, that can be analyzed in the same way as shown below and that can be discussed in lectures or exams.

2 The model

Although there is a large number of publications by different authors in the area of the new neoclassical synthesis extending the model framework in various ways, most authors rely on the same fundamental model equations as the starting point (cf [1], [3], [4], [5], [6], [7], [8], [9], [10], [13], [14], [15], [16], [17]). This standard model consists of a forward-looking IS curve, describing the demand for goods depending on the current real interest rate and expected future income, the inflation-adjustment curve (IA curve), describing the forward-looking pricing behavior of firms under the assumption of Calvo-style price stickiness, and the monetary policy curve (MP curve), describing the interest rate policy of the monetary authority. The IS curve is derived (within the underlying microfoundation) from the utility function of a representative household with consumption and real money balances as endogenous variables¹ and an intertemporal budget-constraint, which introduces a forward-looking behavior on the demand-side of the economy, since economic subjects face the choice between consumption and saving in every period.

The microfoundation of the IA curve based on the Calvo-model assumes that every period a fixed percentage $1 - \omega$ of randomly chosen firms can adjust their prices. The price setting is based on the assumption of firms acting under monopolistic competition, maximizing the present value of future profits and hence incorporating forward-looking behavior into the supply-side of the economy. The remaining percentage of firms ω has to keep their prices at least till the next period.

The monetary policy is typically characterized by a Taylor-style interest rate rule depending on the endogenous variables output and inflation. Originally, Taylor showed by empirical analysis that this type of interest rate rule mimics the behavior of the monetary authority in the US. Within the new neoclassical synthesis the Taylor interest rate rule has become the standard description of the monetary policy for both theoretical reasons (the corresponding system can be analyzed analytically, including stability analysis) and practical reasons, since the rule is consistent with the inflation-targeting performed by many central banks.

It has become common practice to write the underlying equations using the nom-

¹Some authors use a more generalized approach, where the utility function additionally depends on an household's labour supply (cf [15], [17]).

inal interest rate i_t as endogenous variable. However, we will use the real interest rate r_t as endogenous variable, since it facilitates the graphical analysis for reasons explained below. Additionally, the model contains the inflation rate π_t and the output y_t at time t as endogenous variables. Hence, the model equations we will use as a basis of our analysis read as follows:

$$\text{IS curve: } y_t = E_t y_{t+1} - a_1(r_t - \bar{r}_t) \quad (1)$$

$$\text{MP curve: } r_t = r_0 + c_1 \pi_t + c_2(y_t - \bar{y}) \quad (2)$$

$$\text{IA curve } \pi_t = \beta E_t \pi_{t+1} + \varphi(y_t - \bar{y}) + \epsilon_t^s \quad (3)$$

with positive coefficients a_1 , c_i and φ , the discount factor $\beta \leq 1$ and inflation shocks ϵ_t^s . Demand shocks are expressed as variations in the natural rate \bar{r}_t and hence the IS curve does not explicitly contain a random disturbance variable. The natural output \bar{y} is the output-level which would be achieved in the absence of price stickiness. The natural interest rate \bar{r}_t denotes the interest rate where the demand for goods equals the natural output level. The constant φ measures the impact of output fluctuations on the price setting behavior (and thus inflation) of firms: In case output is above the natural rate, firms face higher marginal costs (e.g. they have to increase labour input, which requires higher real wages) and hence they increase prices faster than when output equals its natural rate, as prices are set using constant mark-ups on marginal costs in the underlying model of firms under monopolistic competition. The case $\varphi = 0$ represents the case of completely inflexible prices (all firms are stuck with their prices forever, i.e. $\omega = 1$), whereas the case $\varphi = \infty$ shows the case of completely flexible prices, i.e. all firms can adjust their prices in every period (i.e. $\omega = 0$) and thus inflation reacts infinitely elastic to demand fluctuations, which implies an output-level of $y = \bar{y}$ at all times. It can be shown that the coefficients of the interest rate rule have to fulfil the condition

$$c_1 \varphi + c_2(1 - \beta) > 0 \quad (4)$$

in order to ensure the stability of the system (for details cf [1]). Put simply, the stability condition (4) ensures that the monetary authority raises the real interest rate (or equivalently, raises the nominal interest by more than one-to-one) to counteract inflation.

Some authors assume that the parameter r_0 in the interest rate rule (2) always equals the natural interest rate – a very strong assumption, because it requires the monetary authority to know the value of the natural interest rate at all times. Instead, we will explicitly discuss the possibility of a time-lag between shocks impacting the natural interest rate and the monetary authority adjusting its parameter r_0 to the new natural rate, as discussed below.

It is interesting to compare the model equations (1), (2) and (3) to models used by different authors for presenting the key results of the new neoclassical synthesis graphically. In [11] and [12] Romer presents a graphical model for the use in lectures that is similar to the model (1) to (3) in the sense that it is a model without money, presenting the monetary policy by a Taylor rule. However, the forward-looking character of the system is neglected, i.e. the term $E_t y_{t+1}$ in the IS curve. Further, instead of describing the determination of present inflation as being influenced by expected future inflation in the IA curve (3), Romer states a simpler IA curve, which is not microfounded but motivated by empirical results:

$$\dot{\pi}_t = \lambda(y_t - \bar{y}) \quad (5)$$

The idea behind (5) is the fact that in times of economic recession $y_t < \bar{y}$, inflation tends to fall, whereas in boom phases inflation is typically rising according to empirical results. The parameter $\lambda > 0$ represents the adjustment speed of inflation. Romer's model turns out to allow a relatively simple graphical analysis, but neglects the role of expectations.

Further, in [2] a graphical comparison of different monetary policies is performed using a new IS curve of the form (1). I.e. the authors analyze several alternatives to the afore-mentioned Taylor-rule (2), whereas the focus of our analysis will be to analyze in detail all aspects of the new neoclassical model (1), (2) and (3), which most authors refer to as a new standard. To conclude, the authors cited above avoid the discussion of how rational expectations formed by economic subjects can be reflected in the graphical analysis. In the following, we want to include the aspect of expectations into the graphical analysis, since it is a key component of the new neoclassical synthesis, that has to be accounted for in a graphical analysis if the new theory is meant to become the new work-horse in lectures in macroeconomics.

3 Steady-State

The system (1), (2) and (3) is in a so-called non-stochastic steady-state if no shocks occur

$$\bar{r}_t =: \bar{r}, \quad \epsilon_t^s = 0 \quad \forall t$$

and the values of the endogenous variables are not expected to change in time, i.e.

$$E_t y_{t+1} = y_t =: y, \quad E_t \pi_{t+1} = \pi_t =: \pi, \quad r_t := r, \quad \forall t$$

which can be used in the IS curve (1) to obtain:

$$y = y - a_1(r - \bar{r}) \implies r = \bar{r}$$

Thus, a steady-state state implies that the interest rate set by the monetary authority equals the economy's natural interest rate. Using equations (2) and (3) one receives the following equations:

$$r_0 = \bar{r} - c_1\pi - c_2(y - \bar{y}) \quad (6)$$

$$\pi(1 - \beta) = \varphi(y - \bar{y}) \quad (7)$$

which can be combined to:

$$\bar{r} = r_0 + \left(c_1 \frac{\varphi}{1 - \beta} + c_2 \right) (y - \bar{y}) \quad (8)$$

Equation (8) is a line in the $r - y$ plane and represents combinations of the real interest rate $r = \bar{r}$ and output y , where the expectations of the economic subjects of these variables equal the values of these variables and hence (in absence of shocks) the endogenous variables are constant. Equation (8) also indicates how far the output y deviates from the natural output if the central bank parameter r_0 is not adjusted to equal the natural real interest rate. Analogously, equation (7) determines combinations of inflation and output in the $\pi - y$ plane, where the expectations of the economic subjects equal the observed values of these variables in the absence of shocks. This relationship can also be written in the form of a long-term Phillips curve:

$$\pi = \frac{\varphi}{1 - \beta} (y - \bar{y}) \quad (9)$$

The long-term Phillips curve (9) is steeper than the short-term Phillips curve (i.e. the IA curve). In case $\beta \rightarrow 1$ the long-term Phillips curve is vertical, i.e. there is no inflation-output trade-off as we will discuss below.

In the following graphical analysis of shocks we will always assume that the economy is originally in an steady-state, characterized by $r_0 = \bar{r}_t$, $y_0 = \bar{y}$ and thus (using equation (6)) $\pi_0 = 0$.

It is important to mention that the model (1), (2) and (3), which is derived through a micro-foundation, theoretically allows for a long-term inflation-output trade-off according to equation (9) if one assumes $\beta < 1$, in contrast to the empirical consensus that such a long-term trade-off does not exist, i.e. there is a tension between empirical results and the freedom in the choice of parameters within the theoretical model setup. Since our intention is to develop a very general graphical analysis toolkit for the standard model (1), (2) and (3), we will solve this conflict by assuming in all our graphs that the long-run Phillips curve (9) is very close to being vertical, thus not conveying the message that a significant trade-off could exist, but at the same time allowing interesting discussions in lectures and seminars about the impact of $\beta < 1$ versus $\beta = 1$ in the model – the latter case can be derived by simply turning the curve (9) fully vertical.

4 Graphical model

We start our analysis with the construction of the demand-side and the supply-side of the economy, before we enter the discussion of shocks. The demand-side is described by the IS curve (1) and can be plotted in the $r - y$ plane. The monetary policy curve (2) can also be plotted in the same diagram, where the inflation rate π is an additional parameter of the curve, determining the position of the MP curve in the $r - y$ space. Analogous to the traditional IS curve and LM curve in the $i - y$ plane (where the LM curve has the price-level p as additional position parameter instead of the inflation rate), one can construct the aggregated demand curve (AD curve) in the $\pi - y$ plane by using a set of MP curves for different values of the position parameter π , as shown in Figure 1. Further, the IA curve (3) can be plotted in the $\pi - y$ plane, describing the pricing behavior of the supply-side. In an steady-state, the IA curve and the AD curve intersect at the natural output \bar{y} and the inflation rate $\pi_0 = 0$.

The reason for using the real interest rate r rather than the nominal interest rate $i = r + \pi$ within the graphical analysis framework now becomes clear: By using the real interest rate, the IS curve does not contain the inflation rate as position parameter and thus a set of MP curves for different values of π only has to be used in order to construct the AD curve. If the system is formulated using the nominal interest rate, the construction of the AD curve would be complicated, as the IS curve would have to be shifted as well for different values of the inflation rate π . The same statement is true when analyzing shocks: Changes in inflation change the position of the MP curve and – if the nominal interest rate is used as endogenous variable – would also change the position of the IS curve, unnecessarily complicating the graphical analysis. For this reason, we construct our graphical analysis framework using the real interest rate.

For a given steady-state, the only difference between our graphical model in Figure (1) to the model of Romer (cf [11], [12]) is the fact that Romer's IA curve (5) is horizontal, which is not the case for our model equation (3). However, the model we present is a lot more complex as regards the dynamic behavior as we will show in the following: The new neoclassical model is a multi-period model due to the appearance of future expectations of output and inflation in the model equations and hence it includes a dynamic behavior, in contrast to the classical IS-LM-AD model. Thus, it is important to include the role of expectations into the graphical analysis, especially when shocks occur. Therefore, based on the model equations discussed above, we will focus on two aspects of the behavior of the economy after the occurrence of shocks:

- The reaction of the central bank, which has two components:
 1. The MP curve (2) itself shows how the central bank immediately ad-

justs the interest rate according to current values of output and inflation, given the intersection parameter r_0 and the natural output parameter \bar{y} .

2. If the shock turns out to be long-lasting or permanent implying corresponding long-lasting or permanent shifts in the natural rate \bar{r} or the natural output level \bar{y} , we assume that the central bank will adjust its parameter r_0 or \bar{y} in equation (2) to the new values. However, we assume that this adjustment occurs with a time-lag and will only be performed by the monetary authority in case of permanent, or at least long-lasting, economic changes. The reasoning behind this assumption is the fact that both the real interest rate and the natural output are difficult to measure in reality and thus an adjustment of the model parameters r_0 and \bar{y} on a quarterly basis, for example (like the adjustment of the interest rate by most central banks), is hardly possible. Furthermore, frequent adjustments of the parameters of the central bank's policy function is not advantageous since it decreases the credibility and transparency of the central bank, making it look like a discretionary policy not following a rule-based policy in public. Thus, in the following we will refer to the term long-lasting shocks as to shocks
 - that last sufficiently long such that the central bank is able to detect the economic disturbance and
 - for which an adjustment of the central bank's reaction function is justified to stabilize the economy around the steady-state $\pi_0 = 0$, $y = \bar{y}$ and can be made transparent to the economic subjects without endangering the credibility of the central bank.

- The adjustment of expectations of economic subjects and firms and their influence on the model, especially on output and inflation. The new neoclassical synthesis is derived through a microfoundation, based on the assumption of economic subjects with rational expectations, i.e. households are assumed to be able to anticipate expected values of future output and inflation given present information and their knowledge of the underlying model equations. To promote a graphical analysis of shocks within our model-framework, that is consistent with rational expectations and allows to show the dynamics of adjustment processes after shocks, we make the following assumptions typically used within the new neoclassical synthesis:

1. The system is stable², i.e. the Taylor-condition (4) is fulfilled, which means that changes of expectations cannot lead to explosive paths of the system.

²For a detailed discussion of stability issues, cf [1], [10].

2. After a shock has occurred (per definition, shocks come unforeseen), economic subjects adjust their rational expectations in the following way: They are aware of the underlying model equations for the economy and they know the system is stable and that consequently the economy will stabilize in a new steady-state, provided the shock lasts sufficiently long for the economy to adjust expectations, as we will assume in the following. Hence, economic subjects with rational expectations will anticipate that the economy will move into a steady-state characterized by

$$\begin{aligned} y_t &= E_t y_{t+1} \\ \pi_t &= E_t \pi_{t+1} \end{aligned} \tag{10}$$

again (we obviously restrict our analysis to the occurrence of a single shock that lasts for several periods). The conditions (10) are representend by the curve (8) in the $r - y$ space and the curve (9) in the $\pi - y$ space, which we will refer to as steady-state curves in the following, since they indicate combinations of endogenous variables where expected and realized variables are equal in the absence of further shocks. Consequently, when it comes to analyzing the behavior of the system under shocks that last long enough to allow the economic subjects to adjust their rational expectations, the economy will be found in a point on these steady-state curves after expectations have been adjusted. In addition, as can be seen from condition (8), the central bank can accommodate demand shocks by adjusting the parameter to fulfil $r_0 = \bar{r}_t$, moving the economy along these steady-state curves back to

$$\begin{aligned} \pi &= 0 \\ y &= \bar{y}. \end{aligned} \tag{11}$$

To sum up, when analyzing the influence of shocks within our graphical framework, we will show three aspects, assuming that the economy starts in the steady-state (10) and (11):

- In the very short-term expectations entering the IS curve and IA curve as well as the parameters in the central bank's reaction function (2) are fixed, because the shock is unforeseen. Hence, the endogenous variables react to the shock with constant expectations, which means that the IS curve and the IA curve (whose positions are determined by the parameters $E_t y_{t+1}$ and $E_t \pi_{t+1}$ respectively) are not shifted due to a change of expectations. However, the central bank reacts immediately, adjusting the real interest rate according to the Taylor-rule (2), leaving the parameters r_0 and \bar{y} unchanged. Since π_t is a position parameter of the MP curve, the latter can

shift upwards or downwards in the very short term. As a result, in the short term the economy is (can be) off the steady-state curves.

- In the medium term, rational expectations of economic subjects and firms regarding future output and inflation will adjust (provided the shock lasts long enough), based on the knowledge of economic subjects about the size of the shock and that the system will stabilize in a steady-state. The modified expectations will result in a new position of the economy on the steady-state curves $\pi_t = E_t \pi_{t+1}$ and $y_t = E_t y_{t+1}$ in the $r - y$ space and $\pi - y$ space. Since inflation expectations are the position parameter of the IA curve and output-expectations are the position parameter of the IS curve, these curves will shift according to the change of expectations, which can lead to an amplification of the impact of shocks, as we will show in the following. To be more precise, when discussing (expectation) adjustment processes for various examples below, we will derive the movement of the curves shown using the following assumptions:
 - The possible steady-states of the system (i.e. states fulfilling the conditions (10)) are shown as separate curves in the graph.
 - We will not plug the steady-state conditions (10) into the IS or AD curve. Instead, these curves are shifted parallelly by inserting the adjusted expected inflation $E_t \pi_{t+1}$ and expected output $E_t y_{t+1}$ on the right hand side of equations (1) and (3). The reason for not using the conditions (10) in the IS or AD curve is that in our graphs, the IS and AD curve are meant to demonstrate the short-term behavior of the system, i.e. the behavior when new shocks occur, which are unforeseen and not taken into account into the expectations and hence can lead the system away from a state fulfilling (10). The long-term steady-state behavior of the system is already described by the steady-state curves.
- If the shock under consideration affected the demand side of the economy and hence changed the value of the natural interest rate, the central bank can adjust its Taylor-rule to achieve $r_0 = \bar{r}_t$ in the long run. As mentioned above, we consider this adjustment to be reasonable only for long-lasting changes in the natural interest rate due to practical difficulties and time-lags in the measurement process of the natural interest rate. Furthermore, (too) frequent adjustment of the central bank's policy function has to be avoided from a transparency and credibility point of view. However, even if we believe that the monetary authority's ability to observe and react to changes in the natural interest rate is at least as fast as the ability of economic subjects to adjust their expectations, it still makes sense to distinguish between the reaction of economic subjects in terms of adjustment of their

expectations and the reaction of the central bank regarding its parameters in the graphical analysis, to see how both components influence the economy. Moreover, we assume that the change of the central bank's parameters in its policy function will be made transparent and taken into account by economic subjects and firms immediately, i.e. inflation and output expectations are adjusted correspondingly when the change occurs without delay.

An analogous statement holds for shocks in the natural output \bar{y} , which also appears as a parameter in the policy reaction function (2) and has to be adjusted if long-lasting productivity shocks occur, changing the value of the natural output level.

5 Analysis of a monetary expansion

Monetary expansion in our model (1) till (3) means a decrease of the real interest rate for given values of output and inflation and consequently a downward shift of the MP curve. In the language of equation (2) this means a reduction of the parameter r_0 . Since the source of the shock is the monetary authority itself, we distinguish between the short-term and long-term effects on economic subjects and firms only, as indicated in Figure (2):

- In the short term, expectations are fixed and the IS curve is therefore fixed as well. However, due to the reduction of the parameter r_0 (i.e. since the monetary authority decreased interest rates for given values of output and inflation), the MP curve shifts downward and the AD curve to the right, leading to higher inflation $\pi_1 > \pi_0$ and higher output $y_1 > \bar{y}$. Economically speaking, the output increase is due to the fact that lower interest rates result in higher demand for goods, which explains the shift of the AD curve. Higher demand makes firms increase output above the natural level, which leads to an increase of marginal costs and (due to the underlying model of constant mark-up prices) to an increase in inflation. At the end of the short-term period, the economy is off the steady-state curve, since inflation and output expectations (which remained unchanged in the short term) do not coincide with the actual increased values of output and inflation.
- In the medium term, economic subjects will adjust their rational expectations, taking into account the impact of the monetary expansion, expecting higher output (if $\beta < 1$) and hence higher income in the future, increasing present demand, and as a result the IS curve and the AD curve shift to the right. It is important to mention that the steady-state curve (8) in the $r - y$ diagram shifts to the right as well, because r is its position parameter. Moreover, on the supply side firms also adjust expectations, i.e.

they will take into account higher expected inflation rates in today's pricing decisions, thus increasing present inflation. Since inflation expectations are a position parameter of the IA curve, the curve shifts upwards, as does the MP curve. The result is lower output and higher inflation. However, if $\beta < 1$ output still remains above the original level (i.e. $\bar{y} < y_2 < y_1$). Only in the case of a vertical long-term Philipps curve (i.e. $\beta = 1$) there is no trade-off between output and inflation and the economy returns to the original output level $y_2 = \bar{y}$. After the adjustment of expectations, the economy is back on the steady-state curves $\pi = E\pi$ and $y = Ey$.

To conclude, in the short term the monetary expansion clearly increased output and inflation. In the long run, if one assumes (almost) vertical steady-state curves (which corresponds to values of β close to one), after expectations on the demand side and the supply side have been adjusted, there is (almost) no trade-off anymore, and the monetary expansion created higher inflation only and hardly any output effect. The question of whether there is exactly no trade-off in the long-run, or a negligible output effect only, depends on whether it is assumed that $\beta = 1$ or that β is close to one. Empirical studies conclude that β is very close to one (cf [10], [17]), i.e. the long-term trade-off between output and inflation can be regarded as negligible, without answering the question whether β is exactly one or close to one.

6 Analysis of demand shocks

As mentioned above, in our model demand shocks are modelled through their impact on the natural real interest rate and hence in our graphical analysis they are visible as a shift of the IS curve (1). We assume that the demand shock under consideration lasts for several periods of time, so that adjustment processes on the part of economic subjects and firms and of the monetary authority can be observed. We assume an adverse demand shock – in the language of equation (1) this means a reduction of the natural interest rate from \bar{r}_0 to \bar{r}_2 . As discussed above, we break down the reaction of the economy into different steps, starting from the original steady-state $(\bar{r}_0, \bar{y}, \pi_0)$, as shown in Figure (3):

1. Assuming unchanged expectations in the very short term (the shock is unforeseen), the reduction of the natural rate will shift the IS curve to the left, since the demand for goods has decreased given the level of the real interest rate – cf. Figure 3. Consequently, the AD curve shifts to the left as well and lower demand for goods leads to a reduced output-level $y_1 < \bar{y}$ and reduced inflation rate $\pi_1 < \pi_0$ – this is because the reduced output leads to reduced marginal costs of firms and hence (based on the underlying Calvo-model of constant mark-up prices) reduces the incentive for firms to increase prices.

In addition, in the very short term, the monetary authority will react according to its reaction function (2), i.e. it will lower its real interest rate to $r(\pi_1, y_1) < r(\pi_0, \bar{y})$ because of the lower inflation and output level – the lower inflation level shifts the MP curve downwards. In this situation, the economy is off the steady-state curves, since $y < Ey$ and $\pi < E\pi$. At the end of the first phase, the economy is in the state (r_1, y_1, π_1) .

2. In the medium term rational expectations of economic subjects and firms will anticipate the influence of the demand shock on the economy (assuming the shock lasts sufficiently long) lowering their inflation and output expectations compared with the initial state before the shock – we assume economic subjects and firms will co-ordinate on a stable steady-state (i.e. $\pi = E\pi$ and $y = Ey$) and thus the economy will return to a point on the steady-state curves (8) and (9) in both the $r - y$ space and $\pi - y$ space. In our graphical analysis this means that the IS curve shifts to the left (as the expected future output is its position parameter) and the IA curve (with position parameter $E_t\pi_{t+1}$) shifts downwards. Owing to the lower level of inflation, the MP curve shifts downwards again and the real interest rate reaches the new natural rate $r_2 = \bar{r}_2 < r_1 < \bar{r}_0$.
3. If the demand shock is long-lasting, the monetary authority can adjust its interest rate policy by setting $r_0 = \bar{r}_2$ in the Taylor-rule (2), which would undo the output and inflation effects of the demand shock: The decrease of the parameter r_0 shifts the MP curve downwards and the steady-state curve in the $r - y$ plane to the right, the corresponding decrease of the real interest rate increases the demand for goods and thus output. As a consequence, the marginal costs of firms increase, as do their incentives for price increases, resulting in higher inflation. Because output and inflation expectations increase simultaneously (we assume that the change of the policy function will be transparent and taken into account by economic subjects and firms immediately), the IS curve and AD curve shift to the right, whereas the IA curve shifts upwards due to increasing inflation expectations. The economy reaches the state $(\bar{r}_2, \bar{y}, \pi_0)$, i.e. inflation and output are the same as before the shock, but the decrease in the real interest rate has been fully accommodated by the monetary authority.

To conclude, the economy reaches the natural output level \bar{y} and the original inflation rate $\pi = 0$ again, but with lower real interest rates. It is interesting to note two key results:

- If economic subjects expect the demand shock and its influence on the economy to last for some time, this leads to an amplification of the impact of the shock on inflation.

- The monetary authority can restore the natural output and inflation rate by accommodating the change of the natural interest rate.

7 Analysis of productivity shocks

As an example for a shock on the supply side of the economy we consider a shock in the productivity of firms, expressed as a sudden but permanent (or at least long-lasting) increase of the natural output from \bar{y} to the new level $\bar{y}_2 > \bar{y}$, which could be due to technical progress. For the sake of simplicity, we assume in the following that the natural interest rate \bar{r}_t that is compatible with the natural output level stays the same³. As before, we break down the reaction of the economy to the shock into different time-scales, as shown in Figure (4):

- In the very short term, the expectations of economic subjects and firms and the reaction function of the monetary authority are fixed, i.e. the monetary authority still works with the "old" value of \bar{y} in its reaction function (2). Thus, we assume that the increase of the natural output only impacts the supply side of the economy (where the technical progress and hence the productivity shock stems from) in the short term, i.e. the IA curve from equation (3) shifts downwards, because \bar{y} is its position parameter, lowering the inflation rate to π_1 and increasing output to y_1 . Owing to the fall in inflation, the MP curve shifts to the right and the monetary authority lowers the real interest rate to r_1 . Economically speaking, in the very short term the increase of productivity lowers firms' marginal costs, reducing incentives for price increases according to the underlying Calvo-model (where firms use constant mark-ups on marginal costs for setting prices) and thus reducing inflation and pushing output.
- In the medium term, economic subjects will recognize the productivity shock and take it into account in their rational expectations, i.e. they will lower their inflation expectations and increase their output expectations – higher expected future income consequently increases the demand for goods and shifts the IS curve and the AD curve to the right, resulting in a further increased output level y_2 . Moreover, since we assume that the higher natural output level \bar{y}_2 is only visible on the demand side of the model, but has not been accounted for within the central bank's reaction function (2), the steady-state curve (8) becomes more complicated, i.e. by

³Changes in the natural rate have already been analyzed in the previous section. If the change of the natural output results in a change of the natural interest rate, the latter effect can be analyzed analogously as in Section 6.

combining equation (6) with the old parameter value \bar{y} and (7) with the new parameter value \bar{y}_2 we obtain:

$$\bar{r} = r_0 + c_1 \frac{\varphi}{1 - \beta} (y - \bar{y}_2) + c_2 (y - \bar{y}) \quad (12)$$

Thus, we can conclude from (12) that in the very short term the steady-state curve in the $r - y$ -diagram shifts to the right. Simultaneously, the steady-state curve (9) in the $\pi - y$ curve shifts to the right. Further, the decrease of inflation expectations on the supply side lowers current inflation again to π_2 due to the forward-looking pricing behavior of firms, shifting the IA curve even further downwards and the MP curve further to the right. Once again, we see that the adjustment of expectations on the side of economic subjects and firms amplifies the impact of the shock on inflation. Since the economy is on the steady-state curves the real interest rate once again reaches the original value $r = \bar{r}$.

- If the productivity shock is expected to be permanent or long-lasting, the monetary authority will adjust its reaction function (2), replacing the parameter \bar{y} by the new value \bar{y}_2 , which makes the monetary authority decrease interest rates for given values of inflation and output, and which shifts the MP curve even further to the right, resulting in an output increase to the new natural level \bar{y}_2 . Assuming that the change in monetary policy will be made transparent and taken into account simultaneously in the rational expectations of economic subjects and firms, the IS curve and AD curve shift to the right because of the forward-looking character of economic subjects, resulting in the increased expected future output \bar{y}_2 and expected inflation π_0 . At the same time, the steady-state curve (12) in the $r - y$ -space shifts to the right again.

In the end, the economy reaches the new natural output-level \bar{y}_2 , the natural interest rate level \bar{r} , which according to our assumption is unchanged, and the original inflation rate π_0 .

8 Conclusion

The new neoclassical synthesis can only replace the well-known IS-LM-AS model in lectures and textbooks if it can be used as a work-horse for various economic discussions and graphical analysis, especially for teaching purposes. So far, research in the area of the new neoclassical synthesis was focused on the theoretical framework, whereas its application and exploitation for the graphical discussion of various economic situations, especially after shocks, was neglected.

We have shown that the new model contains various phenomena that are not explained within the classical IS-LM-AS framework, especially the role of expectations, which can be understood by graphical analysis. One of the most important characteristic features of the new model is its forward-looking behavior, which can be seen within the graphical analysis by the fact that future income expectations determine the position of the IS curve, whereas future inflation expectations determine the position of the IA curve. Thus, changes or shocks in expectations lead to a shift in the corresponding curves, changing the values of the endogenous variables output, inflation and real interest rate. An important conclusion is the fact that a monetary expansion / contraction can have a noticeable impact on output in the short run; however, after expectations adjust, the effect on output is zero (or at least negligible) and only the inflation rate is influenced, which reproduces the classical dichotomy.

Another interesting characteristic feature of the graphical analysis is the time-horizon: We assumed that shocks come unforeseen, i.e. expectations adjust only after the shock has been recognized and taken into account by economic subjects, and a change of monetary policy is only performed if shocks are deemed to be permanent or long-lasting. However, the graphical analysis can be performed analogously with different assumptions as to the timing, i.e. it could be assumed that firms (i.e. the supply side) adjust expectations faster than private households (i.e. the demand side) or that the central bank adjusts its policy function before the private sector adjusts expectations. This makes the graphical analysis an ideal toolkit for teaching purposes, as students can discuss different sub-cases of adjustment processes in lectures or exams.

Compared to the graphical analysis of Romer, the advantage of our analysis is that we present a graphical analysis framework for the model equations, which are derived from a microfoundation and most authors refer to as the new neoclassical synthesis, i.e. they have become a common standard in literature. Thus, for teaching purposes, it is important to be able to explain and analyze the new standard model in its full complexity by a graphical analysis, as we presented above. Admittedly, the analysis is more complex and yields more complex graphs than the simplified model of Romer and may thus require more background knowledge.

Nevertheless, it is also important to mention the limits of the model and its graphical interpretation. First of all, the model (1) to (3) is a log-linearisation of more general non-linear model equations derived within the underlying microfoundation, which are used to describe the behavior of economic subjects (i.e. their utility function) and firms (i.e. their profit-maximizing price-setting behavior, cf [15], [17]). Thus, the behavior of the system after shocks derived from

the linearized system is only valid for small perturbations of the system, where the linearisation is a sufficiently good approximation. The same statement holds for the stability condition (4): for the general non-linear system, this condition is only a necessary condition for local stability (i.e. for sufficiently small perturbations around the steady-state) rather than a sufficient condition for global stability, as in the case of the linear system.

The graphical analysis framework presented above permits explanations of various details of the behavior of the economy under shocks not contained in the traditional IS-LM-AS system, especially the role of expectations. As a consequence, the graphical analysis becomes quite sophisticated, the figures presented in the previous sections are more complicated compared to the analysis charts of the traditional IS-LM-AS model. To allow the use of the new neoclassical model in lectures for first or second year students, Romer presented a simplified version of an economy without money in his lecture notes [11], [12], which represent a good trade-off between complexity and understandability of an economical model without money. For more advanced students, however, the framework presented above will be more fruitful, as it allows for an enriched discussion of the behavior of the economy.

9 Appendix – Figures

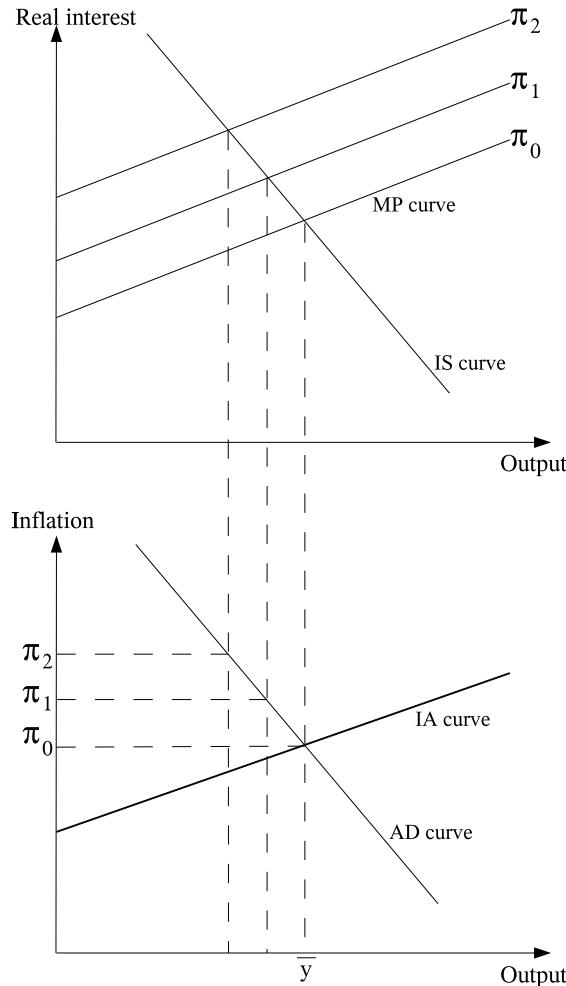


Figure 1: Above: The *IS* curve determines the demand for goods depending on the real interest rate and expected future income. The *IS* curve shifts to the right with increasing future expected income Ey . The *MP* curve indicates the real interest rate set by the monetary authority with the inflation rate π as a position parameter, i.e. it shifts upwards with increasing inflation. The *AD* curve is constructed by plotting a set of *MP* curves for different values of π and tracing the corresponding intersections between the *IS* curve and the set of *MP* curves in the $\pi - y$ chart below. The *IA* curve describes the pricing behavior of companies and shifts upwards with increasing expected future inflation $E\pi$. The intersection of the *AD*- and *IA* curve determines output and inflation. In the absence of shocks output equals the natural output \bar{y} and inflation equals $\pi_0 = 0$.

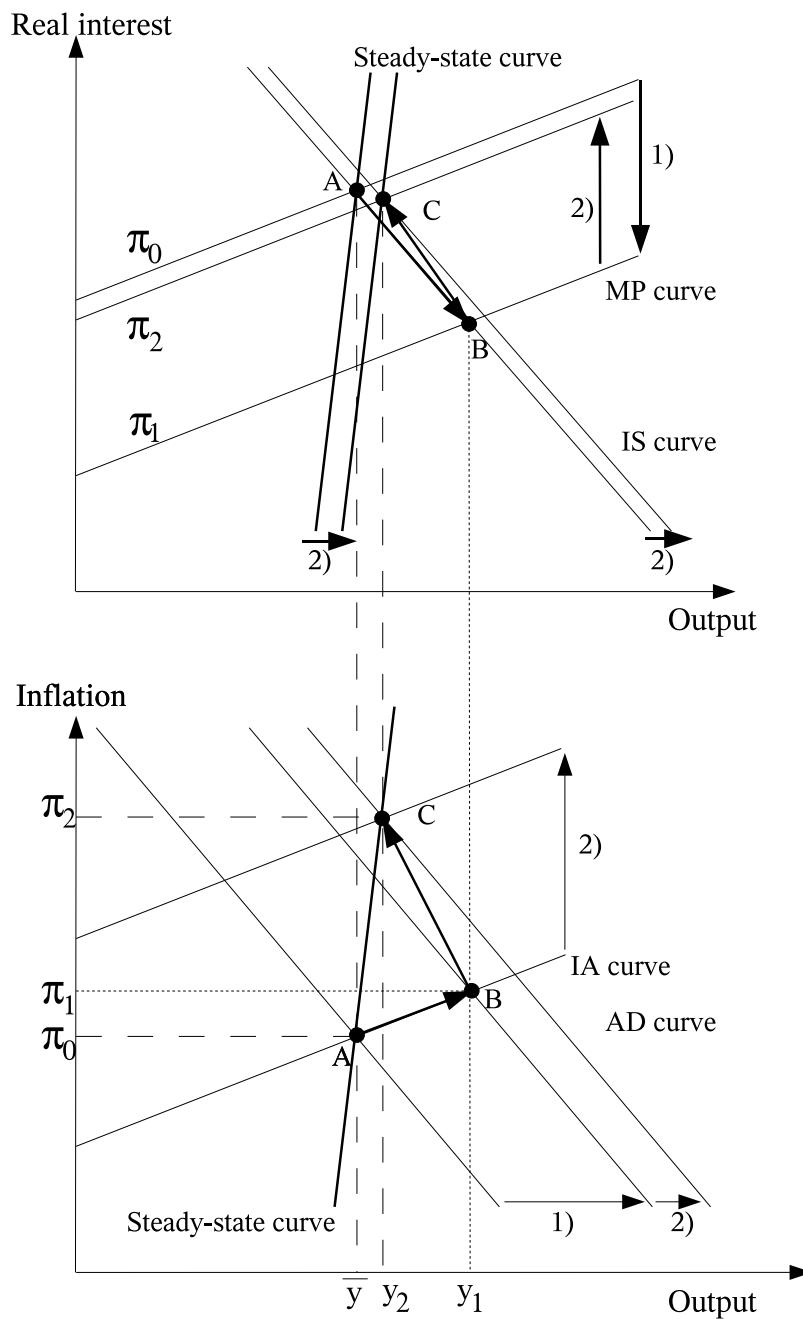


Figure 2: Monetary expansion: In the steady-state A with inflation at π_0 and output at the natural level \bar{y} , a monetary expansion occurs, i.e. the monetary authority generally reduces the interest rate in its policy function for given values

of output, i.e. the MP curve shifts downwards as part of move 1), indicating the short term consequences of the interest rate reduction, i.e. the consequences before economic subjects are able to adjust their expectations. Further, the AD curve shifts to the right, because r_0 is its position parameter. In the short-term move 1), expectations regarding output and inflation have not changed yet, i.e. the IS curve (with expected future income as position parameter) and IA curve (with expected future inflation as position parameter) remain unchanged. Consequently, in the short term the economy moves along the given IS curve to point B with higher than before output and higher inflation. However, in the medium term, economic subjects will adjust their rational expectations, anticipating that the economy will stabilize on a new steady-state. Thus, due to their understanding of the economic system and the change of monetary policy, they will expect higher output (moving the IS curve to the right as expected output is its position parameter) and higher inflation (shifting the IA curve upwards). At the same time the steady-state curve in the upper diagram shifts to the right, because in the steady-state expected interest rates are lower than before for a given value of expected output. As a consequence, the adjustment of expectations shown as move 2) shifts the economy to point C , with inflation and output higher than in point A . However, since (for realistic parameter values of the system) the steady-state curves are (close to being) vertical, point C and A are (close to being) identical in the upper diagram and thus there is no relevant stimulation of output after rational expectations have been adjusted, the monetary expansion resulted mainly in higher inflation.

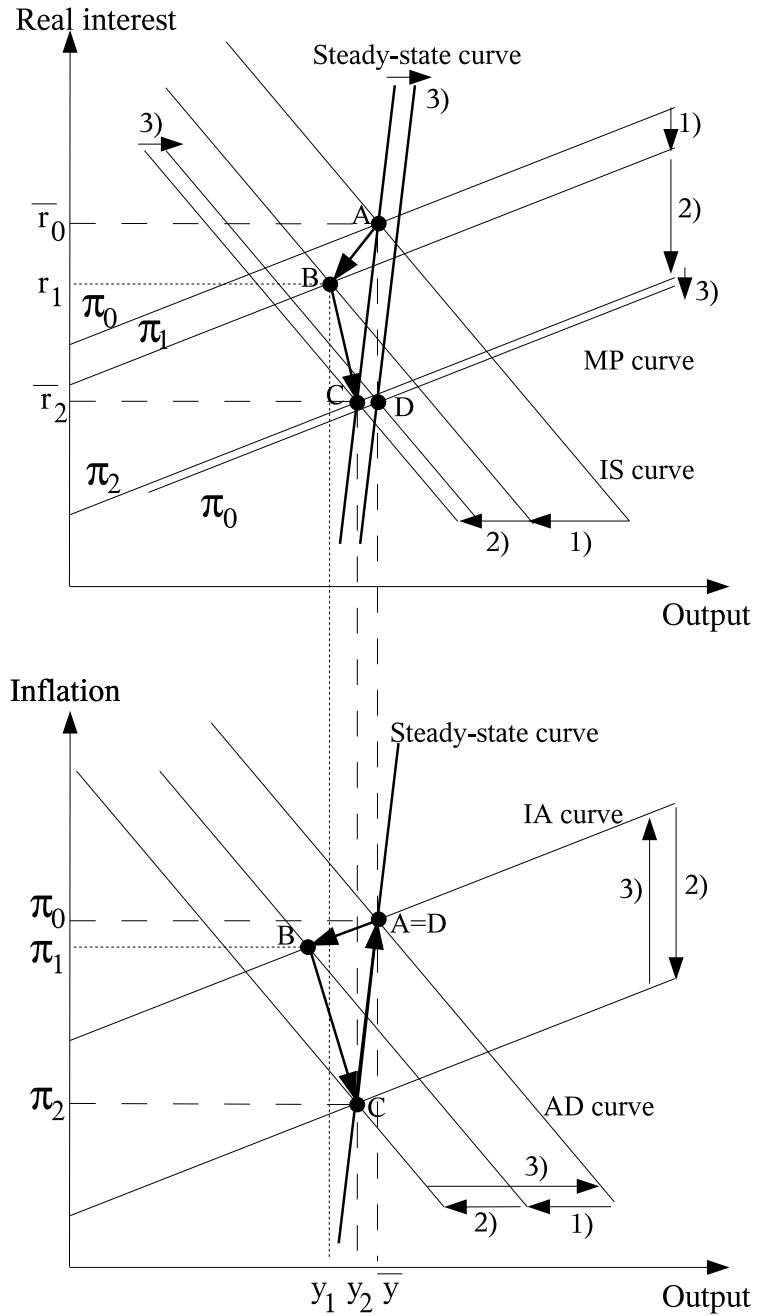


Figure 3: Adverse demand shock: In the steady-state A with inflation at π_0 , the real interest rate at \bar{r}_0 and output at the natural level \bar{y} , an adverse demand shock occurs, meaning that the IS curve and consequently the AD curve shift to

the left. The move 1) from point A to B indicates the short-term consequences of the demand shock, i.e. the consequences before economic subjects are able to adjust their rational expectations: Since expectations regarding output and inflation have not changed yet, the IA curve remains unchanged and the economy performs the move 1) along the given IA curve to a state B off the steady-state curve of lower than before output, lower inflation and lower real interest rate, whereas the MP curve shifts downward as inflation is its position parameter. However, in the medium term, economic subjects will adjust their rational expectations, anticipating that the economy will stabilize on a new steady-state, indicated by the move 2). Thus, they will expect lower output (moving the IS curve and AD curve further to the right, since expected future output is their position parameter) and lower inflation (shifting the IA curve downwards, since expected inflation is its position parameter). The economy moves as indicated by the move 2) from point B to the new point C on the steady-state curves with lower output and inflation than in point A as well as a lower real interest rate – the reason being the forward looking behavior of rational subjects, i.e. a decrease in expected future income reduces present demand and reduced expected future inflation reduces present incentives for price increases. Furthermore, if the adverse demand shock turns out to be (sufficiently) long-lasting, the monetary authority can adjust its policy function to reflect the fact that the natural interest rate of the economy has reduced to the value \bar{r}_2 . Thus, the monetary authority will generally reduce the interest rate set for given levels of output, i.e. the MP curve will be shifted downwards. Consequently, the steady-state curve in the upper diagram shifts to the right, since in a steady-state, expected interest rates are then lower for any given level of expected output. Since the central bank has accommodated the shock by incorporating the new natural interest rate in its policy function, the economy performs move 3) back to the natural output level and initial inflation rate π_0 . In the final state D, only the real interest rate has changed compared with the initial state A before the shock, whereas the consequences of the demand shock on output and inflation have been compensated by the monetary authority.

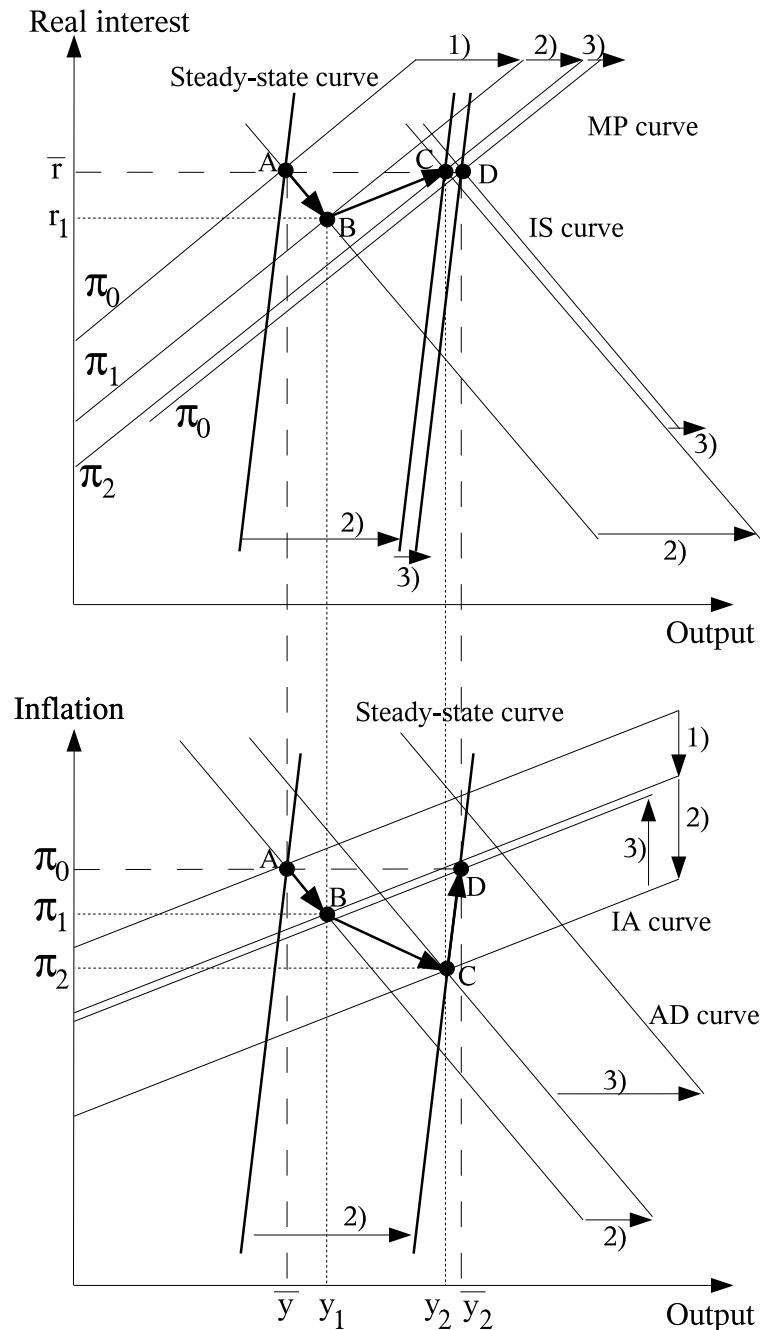


Figure 4: Impact of a productivity shock: In the steady-state A with inflation at π_0 , the real interest rate at \bar{r}_0 and output at the natural level \bar{y} , a favorable productivity shock occurs, shifting the natural output from \bar{y} to \bar{y}_2 . In the short-term

move 1), the productivity shock has not yet been understood by economic subjects and the monetary authority, and consequently expectations regarding output and inflation have not changed yet. Hence, the IS curve and the AD curve are not shifted in the short-term move from point A to B, as expectations remain unchanged. However, the IA curve shifts downwards as the natural output is its position parameter. Thus, the economy moves along the given IS curve and AD curve to point B with higher output and lower inflation. The inflation reduction shifts the MP curve to the right, as inflation is its position parameter. However, in the medium term, economic subjects will recognize the productivity shock and take it into account in their rational expectations, anticipating that the economy will stabilize on a new steady-state with higher productivity and lower inflation compared to state A. Hence, the IS curve and AD curve shift to the right, since expected output is their position parameter. The IA curve shifts downwards, since expected inflation is its position parameter. Further, the steady-state curves shift to the right in move 2), since in a steady-state, higher output is expected for given values of expected inflation and expected real interest. Thus, the economy moves from state B to a new state C on the steady-state curves with output higher than in state B and inflation lower. The MP curve shifts to the right since inflation is its position parameter. Moreover, if the productivity shock turns out to be (sufficiently) long-lasting, the monetary policy can adjust its policy function to reflect the fact that the natural output level has increased. Hence, the monetary authority generally decreases its interest rate set for any given level of output, i.e. the MP curve shifts to the right as shown in move 3). At the same time, the steady-state curve in the $r - y$ -space shifts to the right, since in a steady-state economic subjects then expect higher output for any given level of expected real interest. Consequently, the economy moves from state C to point D onto the steady-state curves. Since economic subjects understand that the monetary authority accommodates the productivity increase, they will anticipate the consequences on output and inflation in their rational expectations, i.e. they expect an output increase to the new natural level \bar{y}_2 , which shifts the IS curve and AD curve to the right as part of move 3), and higher inflation than in point C, which shifts the IA curve upwards. Thus, after the productivity shock has been accommodated by the monetary authority, only output has increased compared with the initial state A, inflation and the real interest rate are as before the shock occurred.

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