

■ RAMSES – a new general equilibrium model for monetary policy analysis

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Introduction

For little more than one year now a new macroeconomic general equilibrium model of the Swedish economy is being used at the Riksbank for producing forecasts, interpreting economic developments and calculating effects of monetary policy interventions, for example. The model, called RAMSES (the Riksbank Aggregate Macromodel for Studies of the Economy of Sweden), is tailored to describe the development of a number of central macroeconomic time series with the aid of the best available econometric methods. In its methodology the model is in the scientific front line. The model is general in the sense that in principle it aims to explain the entire economy, not just a particular component such as private consumption or the labour market. But that does not mean that RAMSES describes every major aspect of the Swedish economy equally well.²

Before looking at the model in more detail, it may be appropriate to consider why the Riksbank uses formal models in monetary policy analyses. Reality is so complex that a model, be it ever so extensive, is bound to be just a simplified version of how the economy actually functions. Even so, using formal models that draw on lessons from economic theory and practical experience has great advantages. The interdependent relationships between different economic components and sectors are so numerous that it is difficult, not to say impossible, to forecast the economic future or analyse effects of a shock by studying individual relationships separately. With a model, a consistent framework can be constructed to

¹ The authors have had fruitful discussions with and received valuable comments from Kerstin Mitlid, Stefan Palmqvist, Staffan Viotti and Anders Vredin but are solely responsible for any remaining errors and obscurities.

² The modelling of fiscal policy and the credit market, for example, is not particularly sophisticated in RAMSES. Forecasting work therefore also uses partial models – based on economic theory or mainly on statistical correlations – that focus on a particular variable or sector.

obtain a comprehensive picture of the economy's components, instead of having to rely on fragmentary analyses that may not be entirely compatible. Thus, a model makes it easier to produce a consistent assessment of the future path of the economy's various components. That is particularly important when it comes to analysing alternative assumptions for the formulation of monetary policy. The effect of an interest rate adjustment on inflation depends not only on the reaction of aggregate demand, for example, but also on how the exchange rate reacts and what consequences that has for, say, patterns of consumption and imported inflation. Another advantage is that the model can serve as a tool for understanding the current economic situation and its future development. The observation of a current easing of inflationary pressure, for example, does not necessarily mean that an immediate policy rate reduction is the appropriate reaction because this depends on what is causing the lower inflation. If the cause is, say, supply factors and is thereby associated with rising GDP growth, the policy rate response would naturally be slighter and more gradual than if inflation is slowing on account of demand and is associated with a sharp drop in GDP growth. Another example concerns an upward development of wages: the policy rate should be raised only if wage increases are expected to exceed the rate that is judged to be in line with the development of productivity. With strong productivity growth, higher wage increases may be compatible with the inflation target and hence not require an increased policy rate. Further advantages are that using models to obtain more structured analyses makes it easier to explain forecasts and that a model can serve as a communication tool whereby internal analyses and discussions are held together. In addition, the systematic approach facilitates the evaluation of the forecast errors.

We now provide a somewhat more detailed description of the model. A general equilibrium model is a model which assumes that market mechanisms create a balance between supply and demand in every market in the economy. There are forecasting models which are general in the sense that they describe relationships between a number of sectors in the economy without being equilibrium models. An example is models consisting of a system of statistical relationships with limited support in economic theory, for instance unidentified vector autoregressive (VAR) models.³ Modern general equilibrium models, on the other hand, normally incorporate some specific assumptions about the behaviour of individuals and organisations.⁴ Individuals and households are assumed to maximise "utility" over the life cycle and firms are assumed to maximise the discounted present value of all future profits. This rational behaviour

³ See, for example, Sims (1980).

⁴ See Kydland & Prescott (1982).

also means that individuals and firms base their conduct on the best possible forecasts of the future they are able to obtain. Their expectations are rational. Thus, when RAMSES is used to forecast private sector behaviour, it is assumed that, for example, the effects of monetary policy interventions will be influenced by the private sector's forecasts of how the Riksbank normally will act.

Prior to the 1980s, the approach to analysing and forecasting inflation and the business cycle was dominated, not by general equilibrium models but by Keynesian models. Models of the latter type assume that players in the economy are governed by various rules of thumb. Neither do such models usually assume that expectations of the future are formed rationally; simple projections of earlier patterns in the data are used instead. One reason for choosing this way of describing the economy was the lack of technical tools (theories and computers) that are essential for solving complex systems of equations with forward-looking expectations. But another reason was that the earliest versions of general equilibrium models for studying macroeconomic developments seemed to be at odds with the data. Kydland & Prescott's (1982) fundamental model of the real business cycle, for instance, which emphasised the supply side's importance for understanding macroeconomic developments, was criticised for a lack of empirical realism.⁵ The economy seemed to be characterised by much greater rigidities than might be expected if it were governed by market mechanisms and rational households and firms. However, the Keynesian models, which instead emphasised the importance of demand for understanding business cycles, ceased to describe data as well as before from the 1970s onwards, when stagflation (low growth combined with high inflation) showed up in the western world and these models failed to catch a number of structural shifts.⁶ In the past decade, extensive academic research, using technical innovations, has developed a new generation of macroeconomic general equilibrium models where the emphasis in economic description is on the supply side but where demand in the short run also plays a role through the existence of various market imperfections combined with nominal and real rigidities. Due to the market imperfections and rigidities, the responses to various disturbances occur more gradually in the model. These second generation macroeconomic general equilibrium models are commonly referred to as New-Keynesian models and have sound, well-documented empirical properties.⁷ The Riksbank's new model, RAMSES, belongs to this category.

⁵ See, for example, Cogely & Nason (1995).

⁶ See, for example, Lucas (1976).

⁷ See, for example, Christiano, Eichenbaum & Evans (2005) and Smets & Wouters (2003).

The purpose of this article is to provide a thorough yet simple description of RAMSES' theoretical structure and empirical characteristics, together with a couple of examples of how the model is used in the regular monetary policy analysis.⁸ The article is arranged as follows. RAMSES' cornerstones and theoretical properties in both the long and the short run are presented in the next section, with particular emphasis on the Riksbank's behaviour in the model. We then exemplify the uses of the model in two ways. First we describe how the model could be used to study effects of two alternative scenarios with higher wages. Then we use the model to interpret the path of inflation in 2003–06 with a view to understanding the underlying causes of the low inflation outcome in that period. We also examine the role monetary policy played in stabilising inflation and establishing a lower level in the 1990s. This is followed by a section that explains how the model is estimated on data for Sweden and compares RAMSES' forecasting performance with the performances of some alternative forecasting tools as well as with the Riksbank's historical assessments. Some final reflections conclude.

The model's theoretical properties

This section describes the model's theoretical structure and the mechanisms that determine how monetary policy affects resource utilisation and inflation in the short and long run.

RAMSES' CORNERSTONES

RAMSES consists of numerous different households and firms that interact in markets for goods, capital and labour. As in many other modern New-Keynesian general equilibrium models, markets for goods and labour are assumed to be characterised by monopolistic competition. This means that firms and employees, instead of taking prices and wages as given, are aware that they can influence them by their behaviour. However, as price and wage stickiness is assumed to exist, monetary policy is able to affect the real economy (output and labour supply, for example) in the short run because nominal prices and wages do not freely adjust to a change in the nominal interest rate.

The model also includes a central bank that sets the short-term interest rate and a government sector that is assumed to finance its consumption expenditure by taxing labour and consumption. There is also a foreign economy that, since Sweden is a small open economy, is assumed

⁸ A detailed description of the model's theoretical structure is given in Adolfson, Laséen, Lindé & Villani (2005). A fuller empirical evaluation is presented in an article by the same authors (Adolfson, Laséen, Lindé & Villani, 2007).

to be unaffected by domestic economic developments in Sweden. In the model, consumer and investment goods are partly imported from the rest of the world and a part of domestic output is exported.

Without the nominal stickiness, RAMSES would closely resemble the first generation of macroeconomic general equilibrium models, for instance the real business cycle model presented by Nobel laureates Kydland & Prescott (1982). The formulation of monetary policy would then be irrelevant for business cycle analysis because monetary policy's impact on the real economy is very limited when prices and wages are entirely flexible; monetary policy would then be reduced to a tool for influencing the level of inflation only. An instructive introduction to a simple model of the real business cycle and how New-Keynesian aspects can be incorporated in it is to be found in Goodfriend (2002) and is recommended for a fuller understanding of the fundamental mechanisms contained in general equilibrium models. The description below is confined to RAMSES' most important aspects.

Households

Let us begin with households' behaviour in the model. Households are assumed to maximise their utility consumption and leisure over time, given a limited budget with earned as well as capital incomes. Households have access to an international credit market for investment or borrowing at the short-term nominal interest rates set by the domestic and foreign central banks. Households decide how much they consume today compared with tomorrow and how they divide their time between work and leisure. Leisure is determined by deciding the wage they are prepared to work for, assuming wage stickiness.⁹ Given the wage, firms then decide labour demand. As holders of capital, households also decide how much to invest in the capital stock, which is then lent to firms.¹⁰

The nominal rigidities in the economy are accompanied by real rigidities. Households are averse to rapid changes in their pattern of consumption and for firms it is costly to change their investments. In this way, frictions that are supported in the data can be taken into account in the model while still assuming that rational behaviour and market mechanisms determine the economy's long-term path. It should, however, be borne in mind that it is not the real frictions as such, only the nominal

⁹ Individual households are not free to choose their wage in every period, so overall wage development is sticky. This is modelled with the aid of Calvo probabilities (see Calvo, 1983), which means that while certain individuals are able to choose their desired wage, others have their earlier wage indexed in a standard way that does not allow for new shocks in the economy.

¹⁰ It does not seem unreasonable that households own firms as direct shareholders or via pension funds or other mutual funds. This is not modelled explicitly but the simplified assumption is of little consequence for the analyses that are made with the model.

frictions, that enable monetary policy to have short-run effects. Nevertheless, the real rigidness are important because they influence how interest rate changes affect the economy.

The fact that Sweden is a small open economy with relatively extensive foreign trade has to be incorporated in the model. We assume that households' basket of goods consists of domestic as well as imported items. The rate of core (UNDIX) inflation in RAMSES therefore comprises a domestically generated component, inflation from domestic products, π_t^d , and a component connected with the rest of the world, inflation from imported consumer goods, $\pi_t^{m,c}$. UNDIX inflation (π_t) can then be written in log-linearised form:

$$(1) \quad \hat{\pi}_t = (1 - \tilde{\omega}_c) \hat{\pi}_t^d + \tilde{\omega}_c \hat{\pi}_t^{m,c},$$

where $\tilde{\omega}_c$ is the weight for imported goods. Statistics Sweden usually assigns approximately 35 per cent of the items in the UNDIX basket to the imported category. However, prices for these products partly mirror domestically generated processing costs, for example distribution costs for transportation and retailing. In RAMSES the weight is therefore set to about 27 per cent. We shall return to the determination of π_t^d and $\pi_t^{m,c}$ after explaining the behaviour of firms in the model.

As a model for a small open economy, RAMSES also needs to describe how the nominal exchange rate is determined. The starting point here is an interest rate parity condition that assumes a freely floating currency. As mentioned earlier, households have access to an international credit market that enables them to invest in both domestic and foreign bonds, though domestic households that borrow capital abroad have to pay a risk premium on top of the foreign short-term interest rate. It seems reasonable to assume that the exchange rate adapts so that the expected yield in the domestic currency is the same regardless of the type of asset in which households invest. However, as this condition – uncovered interest rate parity – has relatively limited empirical support, we have modified it to include the correlations between the risk premium and the exchange rate's expected path that are supported in the data.^{11,12}

Firms

We shall now describe how firms act in RAMSES. The goods market is characterised by monopolistic competition, with each domestic firm pro-

¹¹ For a test of uncovered interest rate parity see, for example, Fama (1984) and Duarte & Stockman (2005).

¹² For a fuller description of the modified interest rate parity condition and how it affects the determination of the exchange rate and the model's empirical characteristics, see Adolfson, Laséen, Lindé & Villani (2007).

ducing a particular kind of good with the aid of labour and capital rented from households. Thus, each firm has a certain degree of monopoly power and can therefore set its price as a mark-up on its nominal marginal costs.¹³ The size of the mark-up depends in the long run on households' propensity to substitute one firm's type of product for others. The greater this propensity, the smaller will be firms' profit margins in the long run. When firms have reason to alter the mark-up, this affects inflation gradually and with some time lag because prices are rigid in RAMSES. The underlying reasons for price stickiness are menu costs, the cost to firms for obtaining new information about the demand situation and the structure of costs for a particular product, and firms' reluctance to disturb customer relations by adjusting prices frequently.¹⁴ So in the event of a change in the economy, nominal prices are adjusted to a new long-term and stable equilibrium, not immediately but gradually. The difference is absorbed by the mark-up, which fluctuates when conditions change.

Firms are assumed to maximise the discounted present value of all future profits under the assumption that prices can not adjust freely.¹⁵ The existence of price stickiness means that expectations of future inflation are taken into account when firms set prices today. As future inflation mirrors the likely future path of marginal costs, firms base their pricing on these expectations. Profit maximisation leads to the New-Keynesian Phillips curve, which can be written in a simplified (log-linearised) form as:

$$(2) \quad \hat{\pi}_t^d = E_t(\hat{\pi}_{t+1}^d) + \gamma (m\hat{c}_t + \hat{\lambda}_t^d),$$

where inflation, $\hat{\pi}_t^d$, is dependent on expected future inflation, $E_t(\hat{\pi}_{t+1}^d)$, firms' real marginal costs, $m\hat{c}_t$, which are equivalent to the wage share of production costs (that is, to real unit labour costs, w_t), with $\hat{\lambda}_t^d$ interpreted as a shock to the desired price mark-up, for example a change in competition. The parameter γ regulates the degree of stickiness in firms' price setting: the longer the interval between price adjustments, the lower the value of γ and hence the smaller the impact on inflation from changes in costs and mark-ups. Equation (2) can also be written so that the rate of inflation today $\hat{\pi}_t^d$ is a discounted sum of all future real marginal costs. This means that if firms foresee a future increase in real marginal costs (for instance because nominal wages are rising faster than productivity), they will ensure partial compensation for this by raising prices today. As

¹³ This can be expressed mathematically as $P_t = \lambda_t^d MC_t$, where λ_t^d is the mark-up and MC_t the firm's nominal marginal costs.

¹⁴ Evidence of price and wage rigidities is also to be found in empirical studies of the price-setting behaviour of Swedish firms; see, for example, Apel, Friberg & Hallsten (2005).

¹⁵ This is modelled with the Calvo model, see Calvo (1983).

a result, real marginal costs return in time to the equilibrium level and so does inflation. Thus, the price-setting behaviour of firms is forward-looking, whereas with the Phillips curves in the early Keynesian models, firms were assumed to be mostly backward-looking.

Another assumption in RAMSES is that a separate category of firms import consumer and investment goods. They purchase intermediate products in the world market for subsequent processing and sale to households. The marginal cost is accordingly equivalent to the procurement cost expressed in Swedish kronor. Possible examples of the goods are textile garments and food products that are repackaged for distribution to retailers. The import firms are able to produce goods that differ from the ones produced by their competitors and accordingly have some degree of monopoly power that enables them to set the price as a mark-up on the marginal costs. In a world with flexible prices, the optimal price of imported products would therefore be given by:

$$(3) \quad P_t^m = \lambda_t^m P_t^* S_t,$$

where λ_t^m is the mark-up (profit margin), P_t^* is the world market price and S_t is the nominal exchange rate expressed as the cost in Swedish kronor of purchasing one unit of foreign currency. However, as import price stickiness is assumed, too, price formation is also influenced by expectations of future inflation. Moreover, the stickiness prevents import firms from adjusting prices fully when, for instance, a weaker exchange rate causes an increase in procurement costs. In the short run the model accordingly captures what is usually called an incomplete exchange rate pass-through: instead of immediately passing exchange rate movements on in prices in a one-to-one relationship, firms absorb a part of the change in profit margins. One reason for doing so may be that the exchange rate movement is expected to be transient and recurrent price adjustments might disturb customer relations. Another may be that a firm prefers to defend its market share from other producers that do not have the same structure of costs and are therefore not exposed to the same effect of exchange rate movements.

Domestic goods are exported in the same way in the model; that is, by a separate category of firms which produce domestic goods and distribute them to households abroad. Price-setting by export firms resembles that by import firms. Stickiness is likewise assumed to prevent the free adjustment of export prices in foreign currency, so an incomplete exchange rate pass-through also applies in the export sector (this means, for instance, that the price of Volvo cars in the United States does not rise immediately when the dollar depreciates against the krona).

The central bank

In RAMSES the Riksbank is assumed to determine the level of the policy rate in the light of how inflation and GDP are developing. This is a relevant description of monetary policy in most inflation-targeting regimes, though of course it is a simplification of reality.¹⁶ The interest rate rule in the model has the following form:

$$(4) \quad R_t = f(\pi_t - \bar{\pi}_t, y_t, \Delta\pi_t, \Delta y_t, x_t, R_{t-1}) + \varepsilon_{R,t}$$

where f is a function that describes how the policy rate (R_t) is set in relation to the gap between actual underlying inflation and the inflation target ($\pi_t - \bar{\pi}_t$), the level of the GDP gap (y_t)¹⁷, the change in the rate of underlying inflation ($\Delta\pi_t$), the change in the GDP gap (Δy_t), the real exchange rate gap (x_t)¹⁸ and the policy rate in the preceding period. The inclusion of the earlier policy rate allows for lags in the interpretation of new information and also mirrors the aversion to unduly rapid interest rate changes. The Riksbank accordingly acts gradually, a behaviour that is usually called interest rate smoothing (see, for example, Woodford, 1999).

The parameters in the monetary policy rule presented above are estimated to give a relatively close approximation to the Riksbank's real-life policy rate decisions over the years. This means, for instance, that the policy rate has been increased/decreased when underlying inflation has been above/below the inflation target or when the GDP gap has been positive/negative. The discrepancies between the historical policy rate decisions and the decisions that would have resulted from a strict application of the model's interest rate rule can be seen as a measure of the element of monetary policy surprises. The surprises are embodied in the variable $\varepsilon_{R,t}$ which is assumed to be random and independent over time. Some surprises can be said to represent temporary changes on the monetary policy strategy; others may be due to the Riksbank's practice of raising the policy rate in discrete steps of, say, 25 or 50 basis points, whereas the monetary policy rule in the model does not have such a stepwise appearance.

The specification of the reaction function raises at least two important questions. One is why the Riksbank is not assumed to react to the

¹⁶ In many economic models, including RAMSES, monetary policy is described with the aid of a Taylor rule; see Taylor (1993).

¹⁷ The GDP gap, y_t , is defined as the percentage deviation of actual GDP, Y_t , from the long-term sustainable (steady-state) level of output, \bar{Y}_t , i.e. $y_t = \ln Y_t - \ln \bar{Y}_t$.

¹⁸ The real exchange rate gap, x_t , is calculated as the percentage deviation of the actual real exchange rate from an assumed equilibrium level that is constant in Adolfson et al. (2005, 2007) but varies over time in the version of the model that is used for forecasts.

prospects for future inflation. The answer is that the reaction function should be regarded as a reduced form that contains most of the relevant information that determines the outlook for future inflation. Another question is why the Riksbank does not consider more variables than are included in equation (4), for example house prices and other indicators. The answer is that the Riksbank is assumed to consider other factors only insofar as they affect the Bank's assessment of resource utilisation and inflation prospects. Thus, it is assumed that the Riksbank does not react directly to factors such as a stronger development of house prices or credit growth.

Other components

As RAMSES describes a small open economy, the domestic economy does not influence either GDP, inflation or interest rates abroad. In their decisions, domestic households and firms accordingly take these foreign variables as given. The interaction of these three variables is therefore described in a separate set of equations.

The government sector is likewise modelled with the aid of a separate set of equations for public expenditures, income tax, value-added tax and employers' contributions. The government sector's budget can run a surplus or a deficit but in both cases this is transferred directly to households. In other words, households behave in such a way that a budget deficit, for example, is balanced by increased saving; this means that fiscal policy interventions are of little consequence in the model.¹⁹

A financial sector is included in RAMSES, albeit as a very simplified version of reality. As mentioned earlier, households have access to an international credit market for borrowing and investment. The model also has a domestic financial intermediary that accepts households' deposits of financial capital and lends capital to firms for funding borrowing costs. It follows that interest rate changes have a direct impact on firms' marginal costs. This is a simple way of representing that monetary policy has certain effects on supply in that firms tend to borrow for their operations.²⁰

As in the seminal work of Kydland and Prescott (1982), fluctuations in aggregate quantities and prices are partly driven by changes in foreign conditions and fiscal policy discussed above, but also other stochastic variables (shocks) with different probability distributions. These probability distributions are the starting point for estimations of the model. The

¹⁹ This household behaviour is usually described as conforming to Ricardian equivalence: households plan consumption on the basis of their expected total lifetime income rather than actual current income.

²⁰ A more realistic model of monetary policy's interaction with the financial sector is presented in Cristiano, Rostagno & Motto (2007).

size and time path of the shocks are determined when the model is estimated on its links to the variables that can be observed in the data (see the Appendix). As each shock enters the model's structure in a particular way that is predetermined, it can be given a definite interpretation. The shocks, which are exogenous in the model, represent such things as changes in productivity, preferences and firms' competitive situation.²¹

The model can be formulated as a number of mathematical conditions that describe how households and firms act, given the assumption of an optimising behaviour with rational expectations and with the short-term nominal interest rate controlled by the Riksbank. RAMSES contains 24 equations for this. Together with the equations for conditions abroad, the conduct of fiscal policy and the course of shocks to the economy, they constitute a consistent mathematical system of non-linear differential equations that produces a fairly acceptable picture of how the economy develops over time.

THE MODEL'S LONG-TERM DYNAMICS

An established opinion among most academic economists, as well as in the central bank world, is that in the long run the levels of output and employment are not influenced by monetary policy, being determined instead by labour supply and technology. This view characterises RAMSES; in keeping with the mainstream literature in the field (see, for example Woodford, 2003), it is assumed that monetary policy is incapable of permanently affecting either output or employment in the long run, that is, in the steady state.²² If the Riksbank were to decide to implement a more expansionary policy, the end result would simply be higher inflation.

Denoting the sustainable rate of productivity growth as μ_Y , per-capita GDP growth in steady state is given by

$$(5) \quad \frac{\bar{Y}_t - \bar{Y}_{t-1}}{\bar{Y}_{t-1}} \equiv \mu_Y,$$

where \bar{Y}_t indicates that it is the long-term sustainable level of GDP per capita in period t that is intended.²³ Monetary policy cannot generate a permanently higher rate of output and thereby higher employment. In

²¹ Note that this view of shocks differs from Keynesian models, where all residuals are regarded as "model errors". Here they can be given a structural interpretation instead.

²² Steady state refers here to the state of the economy when all shocks have been fully incorporated into the economy and prices and wages are flexible.

²³ In the long run, the level of per-capita GDP is determined by the growth of labour productivity, which matches the growth of technology. The GDP growth rate is given in turn by the increase in the level of per-capita GDP plus the growth of labour supply.

this perspective, inflation is only a monetary phenomenon, which means that the Phillips curve (the relationship between inflation and some measure of resource utilisation) is vertical in the long run.

Thus, neither the level of GDP nor its growth rate in the long run can be influenced by the Riksbank changing its policy rate. But the central bank does determine the long-term rate of inflation. For a 2 per cent rate of inflation in the long run, the short-term nominal interest rate must in time equal the inflation target (2%) plus productivity's growth rate (say 2.25%), so that the following equation holds:

$$(6) \quad \bar{R} = \bar{\pi} + \mu_Y,$$

where the yield on the real capital stock (the real interest rate) approximately equals productivity's growth rate, μ_Y .²⁴ The thinking behind equation (6) is simple: for a household to hold a nominal bond, the nominal yield should be equivalent to what the household would have obtained by investing instead in the capital stock (μ_Y) plus a compensation for the reduction of the asset's nominal purchasing power ($\bar{\pi}$).

As RAMSES is a model for a small open economy, the long-term paths of the nominal and the real exchange rates are also endogenous in the model. In the version of RAMSES that is used for the Riksbank's internal analyses it is assumed that the domestic inflation target is the same as in the rest of the world and that domestic productivity in the long run is also the same in Sweden as elsewhere. Consequently, in the long run there is no appreciation or depreciation of either the real or the nominal exchange rate (see the box).

The nominal exchange rate S_t measures the cost in kronor of buying one unit of foreign currency. When S_t rises/falls, a unit of foreign currency costs more/less (the krona depreciates/appreciates). The exchange rate in the model is a weighted average of a variety of exchange rates (a TCW index). The real exchange rate Q_t is by definition given by $Q_t = S_t P_t^* / P_t$, where P_t^* and P_t are the foreign and the domestic CPI, respectively. In the same way as for the nominal exchange rate, the real exchange rate is said to depreciate/appreciate when Q_t rises/falls. So a higher/lower value of Q implies that the cost in kronor of buying a foreign basket of goods increases/decreases relative to the cost of buying a basket of Swedish goods. Taking μ_Y^* to be foreign productivity growth, the long-term path of the nominal exchange rate is determined as follows:

²⁴ This relationship holds exactly in the absence of capital taxes and given a discounting factor of one.

$$(B.1) \quad \ln \bar{S}_{t+1} - \ln \bar{S}_t = \bar{R} - \bar{R}^* \\ = (\bar{\pi} + \mu_Y) - (\bar{\pi}^* + \mu_Y^*),$$

where the second equality follows from equation (6) and where $\bar{\pi}^*$ denotes the rate of foreign inflation and $\ln \bar{S}_{t+1} - \ln \bar{S}_t$ is the percentage change in the nominal exchange rate.²⁵ Countries with an exchange rate that depreciates in the long run should accordingly have higher nominal interest rates than the rest of the world. Another implication is that if the foreign and the domestic productivity growth rates are the same in the long run, the domestic currency will depreciate if the domestic inflation target is higher than the inflation target in the rest of the world.

The definition of the real exchange rate, together with the relationship between the nominal exchange rate, the inflation target and the productivity differential in equation (B.1), can be used to derive the following relationship, which determines the real exchange rate's long-term path:

$$(B.2) \quad \ln \bar{Q}_{t+1} - \ln \bar{Q}_t = \mu_Y - \mu_Y^*,$$

This means that the path of the real exchange rate is ultimately determined by the productivity differential between the domestic economy and the rest of the world. If in the long run domestic productivity growth is higher than abroad, in the long run the real exchange will depreciate.²⁶

This result – that a country's real exchange rate depreciates if its productivity growth is higher than abroad – flatly contradicts the Balassa-Samuelson hypothesis (see Balassa, 1964, and Samuelson, 1964). While the hypothesis does have some support when developing and industrialised economies are compared, it seems to have little support in a comparison of real exchange rates among developed economies; see, for example, Lee & Tang (2007) and the references there. As the exchange rates in the TCW index are mainly those of industrialised countries, there seems to be reasonably good agreement between RAMSES and data on the real exchange rate and productivity differentials.

²⁵ An implicit assumption in this account is that the factors which determine the short-term dynamics of the risk premium do not affect the risk premium in the long run and therefore disappear in the long run. This means that the GDP share for total net wealth vis-à-vis the rest of the world is irrelevant for the exchange rate's long-term path.

²⁶ That the real exchange rate depreciates in such a notional situation is logical because otherwise the domestic economy would ultimately be the global economy. The economic reasoning behind a depreciation of the real exchange rate is that foreign currency prices for Swedish goods must fall to induce the rest of the world to buy the increased volume of export in such a case. An alternative way of looking at this is that in such a case, Swedish export firms are more productive than firms abroad and their production costs are therefore lower; this enables them to have lower selling prices than firms abroad without any loss of profit. As productivity is directly related to the real interest rate in RAMSES, equation (B.2) also implies that a higher real interest rate than abroad leads in the long run to a real exchange rate depreciation.

2.3 MONETARY POLICY'S SHORT-RUN EFFECTS

The description above indicates that in the long run, monetary policy acts mainly by stabilising firms' and households' inflation expectations around the stated inflation target. This is somewhat different from the everyday picture and the frequently-heard argument that monetary policy's influence on inflation comes from its impact on aggregated demand. Both arguments are correct in RAMSES, however, since monetary policy has effects on the real economy because prices and wages are sticky.²⁷ The notion that monetary policy cannot have a lasting effect on the level of employment or output is the prevailing view among economists but there is still broad agreement that the economy's cyclical path is driven not only by changes in labour supply or production technology, for example, but also by monetary policy.²⁸

Besides the nominal rigidities in RAMSES (price and wage stickiness), which are necessary if monetary policy is to affect resource utilisation, the path of the economy in the model is affected by real rigidities. The two most important real rigidities are habit formation in households' consumption behaviour and adjustment costs for changing the degree of investment.²⁹ With these two frictions, the economic impact of a monetary policy tightening occurs more gradually than it would without them. Thus, it is a combination of nominal and real rigidities in RAMSES that gives rise to reasonable effects of interest rate adjustment's, commonly referred to as the monetary policy transmission mechanism.

In RAMSES, a *temporary* policy rate increase leads to falling demand for goods and services because the real interest rate rises when price and wage are sticky. A *temporary* increase refers here to an increase of, say, 0.25 per cent in $\varepsilon_{R,t}$, with a return to the long-term equilibrium level of 4.25 per cent that is determined by the systematic component of the interest rate rule (how the unexpected increase today affects the future paths of inflation and the GDP gap). That households lower their demand for consumer goods is rational because a higher interest rate makes saving for future consumption more profitable. Investment also falls because the higher interest rate increases borrowing costs. With lower demand, output declines and so, therefore, does demand for labour and capital. The price of factors of production then falls, which reduces firms' marginal costs. Lower marginal costs lead in time to price reductions, which lowers the rate of inflation. This is the traditional *interest rate channel*.

²⁷ The degree of price and wage stickiness is determined empirically, using the best available estimation techniques; see the section below on estimating the model with Bayesian methods.

²⁸ Monetary policy has real effects in the short run, so the coefficients in the systematic component of the reaction function affect the way in which different shocks affect the economy. For a fuller discussion, see for example Giavazzi & Mishkin (2006).

²⁹ The relevance of the two real rigidities has been determined by evaluating how the model fits the historical variation in the data.

As RAMSES is a model for an open economy, the interest rate increase also causes the krona to appreciate relative to other currencies and that in turn weakens the balance of trade. To some extent, this accentuates the fall in demand. Inflation is affected as well because a stronger exchange rate lowers the price of imported goods at the same time as decreased net exports leads to a weakening of domestic demand and thereby contributes to the slowdown in domestic prices. This mechanism for monetary policy's economic impact is commonly called the *exchange rate channel*.

In time, prices and nominal wages will be adjusted downwards more and more by firms and households as the interest rate increase results in a contraction of the nominal money supply. Monetary policy's effect on the level of economic activity accordingly diminishes. When prices and wages have finally been fully adjusted by firms and households, the economy will return to the path that would have been forecast without the policy rate increase. Inflation finally returns to the targeted rate, the level of GDP returns to the steady-state equilibrium path \bar{Y}_t and the interest rate is back at its initial level. Thus, the monetary policy tightening does not affect either the level of GDP or its growth rate in the long run, in accordance with equation (5) above. An alternative way of putting this is that in the long run the level of GDP is determined solely by supply and monetary policy acts like a demand shock that only affects the GDP gap in the short and medium run.

The model's applications

An important part of the Riksbank's analysis of future economic developments is the analysis of scenarios concerning possible future paths for wages, interest rates or a different economic development abroad, for example. RAMSES can be used to analyse the combined consequences of a proposed alternative scenario. This is done by letting one or more exogenous shocks in the model, for instance a change in productivity or in price mark-ups, generate an alternative economic development. The model's other forecasts are then conditioned upon the predetermined development of these variables.³⁰ Similarly, one can study how the model's dynamic course in the various alternative scenarios is affected by alternative assumptions about, for example, the degree of nominal stickiness or the conduct of economic policy. In the following subsections we exemplify how two alternative scenarios can be analysed in the framework for RAMSES and how such an analysis can be structured by

³⁰ As mentioned earlier, the shocks in RAMSES describe conditions that cannot be explained within the model (see the section on RAMSES' cornerstones). The shocks can therefore be revised so that the model replicates the desired path for a particular variable.

the model. The first scenario involves households obtaining real wage increases that exceed what prevailing productivity allows; in the second, increases in productivity that are lasting but not permanent motivate higher real wage increases than normal. Thus, both scenarios concern real wage increases but the shocks that cause them differ.

Besides using RAMSES for forecasting and scenarios, the Riksbank needs to understand the current economic situation and what the main driving forces have been in the recent past. This information is, of course, also useful for assessments of the economic future. A model can be used to analyse a particular economic development's underlying causes. As the shocks in RAMSES can be interpreted in economic terms (shocks that represent progress in productivity is one example), an opinion about which shocks have been important for the economy's historical development can be formed by excluding the shocks from the model one at a time. This can provide an indication of what would have happened in the economy if various shocks had not occurred. For instance, what part has the high productivity played for the low inflation in the 2000s and how would inflation have developed without the unexpectedly high productivity? The third subsection presents examples of such an exercise in which the model interprets the causes of the low inflation in the past three years.

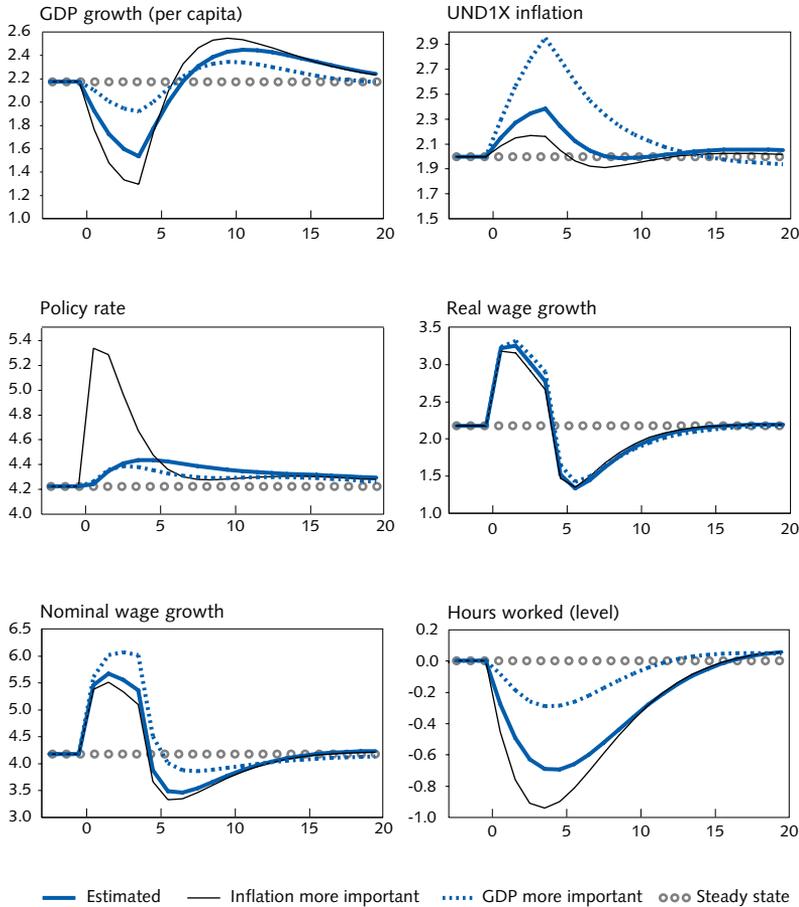
AN ALTERNATIVE SCENARIO WITH HIGHER WAGES

Chart 1 presents an example of an alternative scenario with higher wages. The assumption is a temporary upward shift of about one percentage point in the rate of real wage increases, from the long-term stable rate of 2.2 per cent to about 3 per cent.³¹ The chart shows how inflation, GDP, nominal wages and hours worked change in such a scenario. The higher rate of wage increases weakens firms' demand for labour and GDP growth falls below the long-term stable rate. As the real wage rise is not matched by increased productivity, labour demand decreases and the number of hours worked falls. The higher wage increases also lead to higher marginal costs for firms, which strengthens inflationary pressure. How much and how quickly inflation rises depends on the conduct of monetary policy. The solid curve represents what happens when the Riksbank sets the policy rate more or less in accordance with its historical decisions, that is, in line with the estimated interest rate rule. This causes

³¹ This is generated in the model with the aid of a shock that reduces labour supply. The magnitude of the shock that is fed into the model is set to 0.59 per cent, which is equivalent to the estimated standard deviation. The real wage response is then determined endogenously in the model in relation to how other determinants of real wages are affected by, for instance, the monetary policy reaction to this shock. We start here from steady state but the scenario can of course be arranged around a specific main scenario.

Chart 1. Average economic growth with higher wages and alternative monetary policy tightenings.

Percentage annual changes



the Riksbank to raise the policy rate about 20 basis points to return inflation to its long-term equilibrium approximately two years ahead. The higher interest rate also contributes to the slowing of GDP growth. To illustrate the monetary policy deliberations such a scenario evokes, the chart also includes two alternative monetary policy responses. The thin black curve is what happens when the Riksbank attaches most importance to the inflation target and pays little consideration to the real economy, while the dotted curve is when the Riksbank attaches greater weight to real stability.³² We see that when the real economy is hardly

³² The scenario with inflation as most important (dashed curve) is generated from the interest rate rule where the response coefficients to inflation's deviation from the target and to changes in inflation are set to 5 and 2.5, respectively and the change in the GDP gap is set to 0. The scenario with GDP as most important (dotted curve) is generated with the coefficients for the GDP gap and the change in the GDP gap updated to 1 and 0.5, respectively. This is to be compared with the solid curve, which is generated with the model's estimated interest rate rule, with coefficients of 1.7 and 0.3 for inflation and changes in inflation, respectively, and 0.04 and 0.1 for the GDP gap and changes in the GDP gap.

considered at all, the Riksbank raises the policy rate sharply to over 5 per cent to dampen inflationary pressure. GDP growth then weakens somewhat more than in the main case (solid curve). If, instead, the Riksbank attaches greater importance to real stability than to the inflation target, the increased inflationary pressure elicits just a marginal adjustment of the policy rate. Thus, to avoid a marked weakening of real growth, inflation is allowed to shoot up and thereby counter the real wage increases. In the somewhat longer run, the rate of real wage increases will slacken temporarily to below what is sustainable in the long-term so that the real wage level can return to its long-term path. As the shock is transient, GDP also returns to its long-term sustainable level. Thus, the chart shows that in such a scenario the Riksbank cannot simultaneously stabilise inflation and GDP. A trade-off between nominal and real volatility is called for.

AN ALTERNATIVE SCENARIO WITH HIGHER PRODUCTIVITY

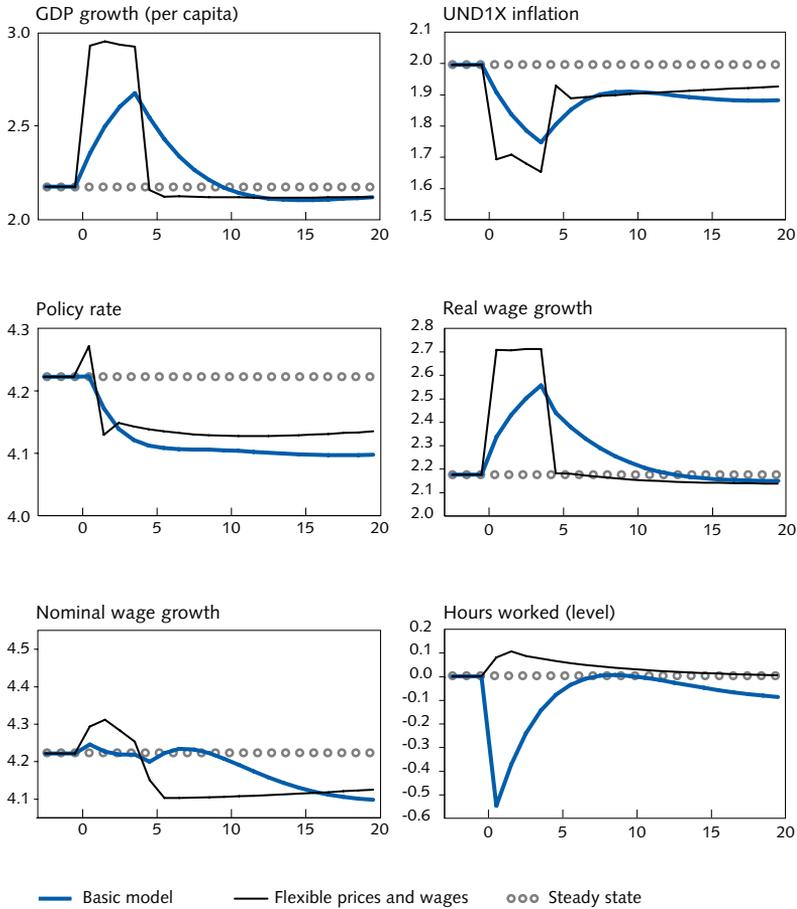
In the second exercise the assumption instead is that real wages rise on account of a lasting but not a permanent increase in total factor productivity (TFP). The duration of the increase is given by the model's estimates and is thus a guess with a firm foundation in the currently available information about the average duration of technological improvements in productivity.

Here, too, results are presented for variants of the model (see Chart 2). First there is the basic model, that is, the model that is actually used for Riksbank analyses. Then there is a variant of RAMSES that does not include the nominal and real rigidities, making this a real business cycle model, similar to Kydland & Prescott's (1982), for a small open economy.

As Chart 2 shows, a positive shock to TFP gives a strong real wage rise. But in contrast to Chart 1, inflation falls because with wage stickiness, the real wage increases are exceeded by underlying productivity growth and firms' marginal costs decline. As prices and real wages move in opposite directions, the nominal wage changes only slightly in relation to its long-term path. Notwithstanding a fall in the number of hours worked, per-capita GDP growth rises. Even so, the Riksbank lowers the policy rate because the monetary policy reaction function in the model attaches greater importance to the slackening of inflation. Due to the long duration of the shock, the adjustment back to the long-term steady state is relatively gradual.³³

³³ The duration of the TFP increase is such that 60 per cent of it remains after 5 years, that is, the root in the underlying AR(1) process for the non-permanent increase in TFP is 0.975.

Chart 2. Average economic development with higher productivity with and without nominal and real frictions.
Percentage annual changes



Compared with the responses in the basic model, excluding the nominal and real rigidities from the model gives effects that appear and disappear considerably faster. In the real business cycle model, the real wage increases are so rapid that nominal wages also rise initially. As the shock is not permanent, the economy will be brought back to the early forecast paths for the levels of real variables (per-capita GDP, for instance) and growth will therefore be below the rate in the long-term steady state for a long time to come.

A notable difference between the two models concerns the response in hours worked. Without nominal and real wage stickiness, labour supply rises, whereas it falls sharply in the basic model. Rising labour supply after a productivity shock is in line with the predictions from simple real business cycle models (Goodfriend, 2002; Kydland & Prescott, 1982), where households and firms benefit from a period of being more produc-

tive. In the model with nominal and real frictions, households find that it does not pay to work more. So in RAMSES such an increase in productivity can generate GDP growth combined with a fall in the number employed and hours worked, which resembles what happened in the Swedish economy in the period 2003–05.

These exercises and alternative scenarios show that a model like RAMSES can provide very valuable information about topical monetary policy problems. We have analysed the consequences of high productivity growth, a phenomenon that has characterised the Swedish economy in recent years, and of strong wage increases, a risk scenario that many have in mind when looking ahead a couple of years.

WHY WAS INFLATION SO LOW 2003–06?

By decomposing the results, RAMSES can also be used to throw light on the driving forces behind earlier economic developments. To illustrate this, we use the model to filter out the factors behind the low inflation in recent years.

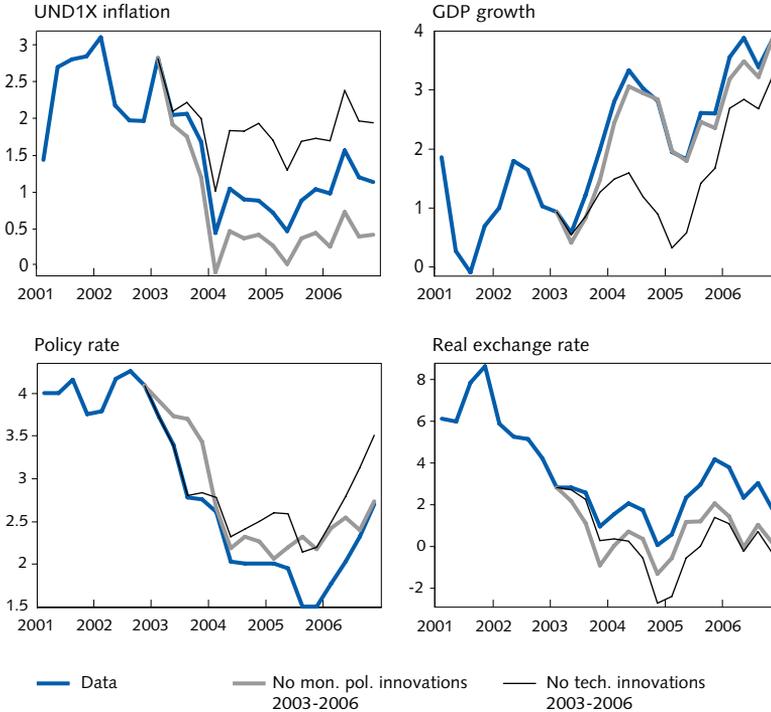
Chart 3 presents outcomes and model forecasts of inflation, GDP growth and the policy rate in the period 2003–06. The blue curves represent outcome data and the black curves show the model's forecasts of e.g. inflation given that no new shocks to productivity had occurred in the period. The latter implies that there were no technological improvements (or deteriorations) apart from the annual rate of 2.2 per cent. The grey curves show in turn what the model forecasts (including the productivity improvements) would have been if the Riksbank had strictly adhered to the estimated policy rate rule.

The chart shows that GDP growth exceeded what the model would have predicted in the absence of productivity shocks. Thus, the model interprets the difference between the blue and the black curves as a consequence of technological innovations that improved productivity in 2003–06 and led to high GDP growth and high real wage increases. Moreover, as the higher productivity also led to lower marginal costs for firms, inflation was below the rate that would have been expected without the reinforcement of productivity. In other words, the policy rate could be lower than would otherwise have been the case (the difference between the blue and the black curves).

The chart also shows that monetary policy in this period was unusually expansionary. The interpretation of the grey path of the policy rate being above the outcome data is that according to the model, in this period there were a number of expansionary “policy rate surprises” compared with the average historical pattern. Thus, inflation would have been even lower if the Riksbank's policy rate cuts in 2003–06 had not

continuously been somewhat larger than the estimated policy rate rule predicted. That in turn meant that the real exchange rate's depreciation was somewhat more marked than would otherwise have been the case. However, the combined effect of all this on GDP growth in the period would have been rather small.

Chart 3. Outcome and model predictions 2003-06 with alternative assumptions about economic shocks.
Per cent

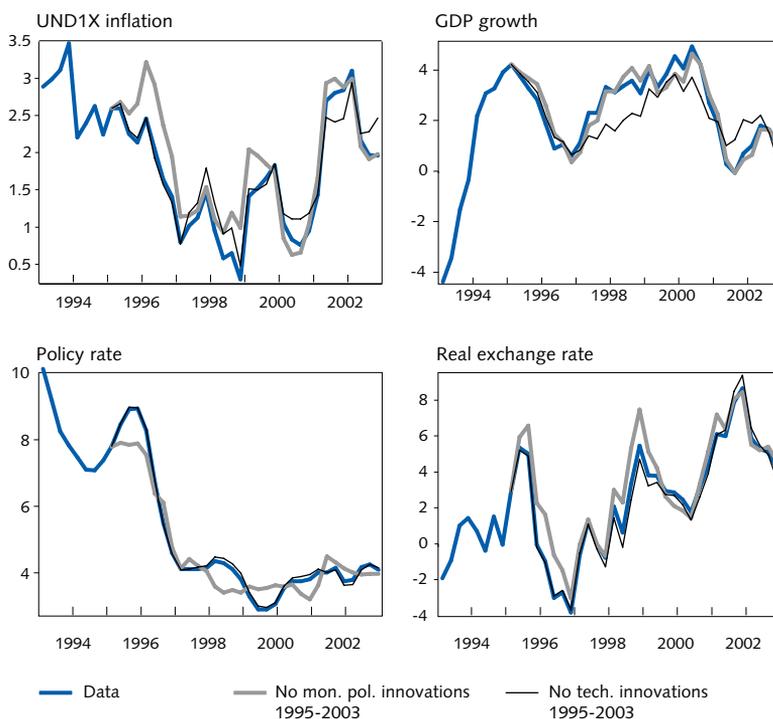


The model's interpretation of the course of events 2003–06 is accordingly that inflation was pressed down in these years by higher productivity, but also that it could have been even lower if monetary policy had not been more expansionary than normal. Is it the case that RAMSES always equates low inflation with improvements in productivity? To answer this, Chart 4 presents results of a similar analysis in which the model's predictions are decomposed into the same two components (productivity and monetary policy) ever since 1995. It will be seen that in 1997–98, for example, the model's prediction of inflation without technological innovations (black curve) is not all that different from the actual outcome (blue curve). So according to RAMSES, on that occasion it was not changes in productivity that led to the low inflation.

The chart also shows that part of the policy rate increase during 1995 represented a monetary policy tightening. The outcome was above

the policy rate the model would have predicted with the estimated interest rate rule (without any monetary policy “surprises”). It is worth noting, however, that without this relatively restrictive monetary policy, underlying inflation according to the model would have been above 3 per cent at the beginning of 1996 (grey curve). At the same time, the model indicates that the monetary policy tightening came a little late, so that this intervention contributed to inflationary pressure being somewhat low during 1998 in particular.

Chart 4. Outcome and model predictions 1995–2003 with alternative assumptions about economic shocks.
Per cent



The model's empirical properties

This section describes the empirical properties of the model and how its parameters have been estimated on data for Sweden. In line with Adolfson et al. (2006), we think it is important to evaluate RAMSES' empirical performance because it says something about the extent to which the model's predictions deserve to be taken seriously. As RAMSES is used in a forecasting environment, it seems natural to evaluate forecasting performance rather than the model's ability to conform to historical data. In order to judge whether RAMSES' predictive performance is satisfac-

tory or not, the forecasts in the model are compared with the Riksbank's assessment as well as with a number of statistical forecasting instruments with good documented forecasting properties. This is the same approach as in Adolfson et al. (2006).

MODEL ESTIMATIONS WITH BAYESIAN METHODS

The goal in the estimation phase of model work is to arrive at values of the parameters whereby RAMSES gives the best approximation to the historical paths of a number of macroeconomic time series. The theoretical *model variables* in RAMSES are linked with *measurement equations* to statistical observations of, for example, output, prices and interest rates (see also the Appendix). It is not necessary to include observed variables for every one of the model variables. There is in principle no empirical counterpart to some model variables (some of the shocks, for instance) and there is no satisfactory way of measuring others.³⁴ The estimation procedure involves using RAMSES' modelling structure together with the selected observed variables to form a picture of model variables for which measurements are not available.³⁵ It is, however, important that the set of observed variables is sufficiently informative for *identifying* the model's parameters and the underlying unobservable model variables, for instance the capital stock. Estimations of RAMSES are currently performed with the following 15 macroeconomic variables: GDP deflator, consumption, investment, real wages, real exchange rate, policy rate, hours worked, GDP, exports, imports, UND1X, investment deflator, foreign GDP, foreign inflation and foreign interest rate.

RAMSES is estimated on data from 1986 Q1 up to the present.³⁶ The choice of estimation period has to weigh quantity against quality: plenty of data is needed for the accuracy of the parameter estimates but the data should also refer to a period without sizeable structural changes. It can be argued that the major part of the financial market deregulations had been implemented by the beginning of 1986, making this a reasonable starting date for the estimation period. The next major structural change in the Swedish economy can be dated to the end of 1992, when the fixed exchange rate was abandoned, followed soon after by the Riksbank's announcement of a shift to an inflation-targeting regime. However, instead of making do with a smaller amount of data by choosing

³⁴ Examples of the latter type of variable are capacity utilisation and the capital stock. The measurement errors for these two variables are large because of the difficulties in valuing an effective capital stock and in telling from survey data what firms actually mean by capacity utilisation.

³⁵ The technical description of the model is presented in *state-space form* and the model variables that lack equivalents in the measurement equations are estimated with the *Kalman filter*.

³⁶ An additional five years of data from the period 1980–85 is used initially to form an opinion about the state of the economy at 1986 Q1, when the estimation period starts.

just the period after 1992, this structural change is modelled by having one monetary policy rule for the period 1986–92 and another for 1992 to the present.

For RAMSES estimations the Riksbank has used *Bayesian methods*, which combine the information in the measured variables with *prior information* about the model's parameters.³⁷ Prior information is knowledge derived from sources other than the chosen measured variables, for example studies of similar models for other countries, various types of micro data or even information of an institutional nature such as data on the duration of negotiated wages agreements.³⁸ Bayesian methods use *Bayes' theorem* to achieve an optimal combination of the information in data and the prior information. Besides the possibility of supplementing the information in data with other information, the Bayesian approach results in a more satisfactory empirical evaluation of the model and also means that the uncertainty in the estimation can be incorporated in a natural way in, for example, the forecast interval.

FORECASTING PROPERTIES OF THE ESTIMATED MODEL

As mentioned earlier, RAMSES can be used to forecast future economic developments in a consistent manner, as well as to interpret and understand the developments. In order to illustrate the model's forecasting properties, in this section forecasts using RAMSES are compared with those from other forecasting models as well as with the Riksbank's official inflation assessments in the *Inflation Report*. In addition, the accuracy of the different forecasting instruments is compared by evaluating their average forecasting performances.

In Chart 5, the outcome for yearly UND1X inflation is compared with forecasts 8 quarters ahead produced on a score of occasions between 1999 Q1 and 2006 Q2. The RAMSES forecasts are presented in the uppermost chart, followed by forecasts from a Bayesian VAR (BVAR) model³⁹ and finally the Riksbank's historical inflation forecasts.⁴⁰

³⁷ Koop (2003) is recommended as an introduction to Bayesian analysis. An introduction to Bayesian estimation of general equilibrium models is presented in An & Schorfheide (2007).

³⁸ A good example of the use of a priori information is the survey by Apel, Friberg & Hallsten (2005) of how frequently firms adjust prices. These micro data serve as a guide to the appropriate degree of price stickiness in the model.

³⁹ The BVAR model comprises seven variables: the rates of UND1X inflation and GDP growth, the policy rate, the real exchange rate and the foreign 3-month interest rate and rates of (TCW-weighted) CPI inflation and GDP growth. It is a direct time-series model that captures historical correlations in data without a closer foundation in economic theory. The parameters of the BVAR model are estimated with Bayesian methods, using prior information about the variables' long-term means (see Villani, 2005).

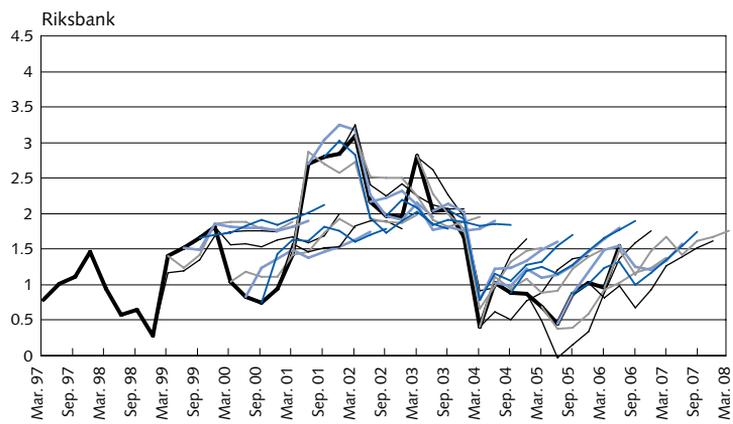
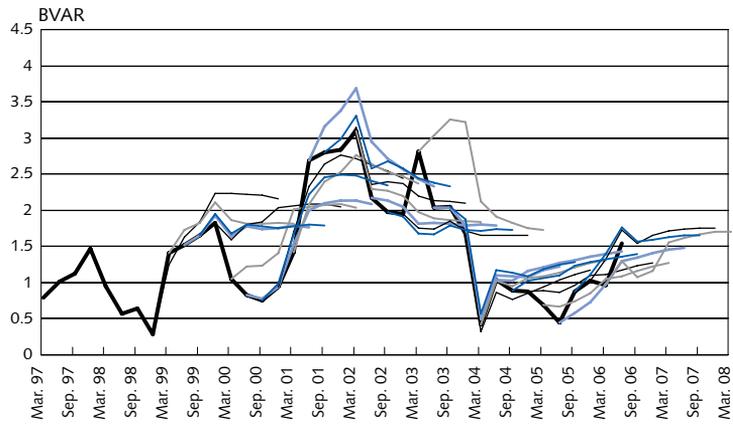
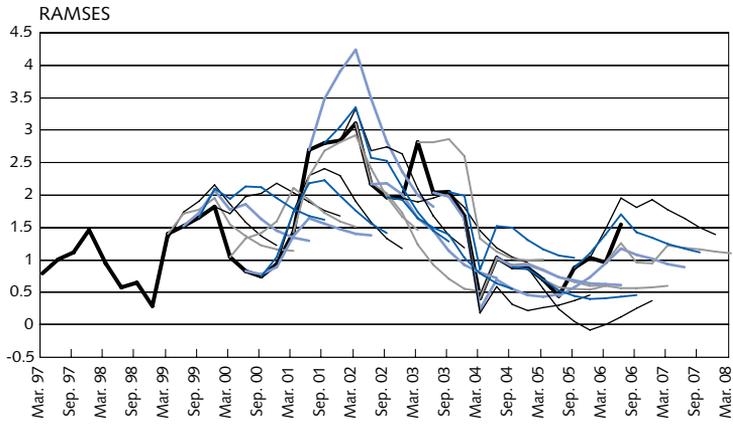
⁴⁰ The BVAR and RAMSES were introduced in the Riksbank's forecasting work at different times in 2005. There is a sense in which the comparison between the Riksbank's official forecasts and the model forecasts is somewhat difficult to interpret in the final quarters of the sample because in those quarters the latter were partly incorporated in the former. But as judgements make a large contribution to the Riksbank's official forecasts, we nevertheless chose to include 2006 in the analysis.

It can be seen that the methods give somewhat different patterns in the forecasts.⁴¹ RAMSES forecasts have a dispersion that is relatively large compared with inflation's outcome over time. The inflation forecasts with the BVAR model, on the other hand, seem to be generally sound but as they tend to be simple projections of the current quarter's inflation they are not very informative about inflation's future path. It is noteworthy, however, that in the event of a forecast error, the time series model soon incorporates changes in the pattern of inflation (see, for example, 2003 Q1 and Q2). Finally, the Riksbank's inflation forecasts seem to return to the 2 per cent target somewhat sooner than the forecasts with the two models. It should, however, be kept in mind that up to 2005 Q3 the Riksbank conditioned its forecasts on an unchanged policy rate, whereas we have not conditioned the model forecasts on a constant policy rate, so the two are not entirely comparable. But considering the large element of judgements behind the Riksbank's official forecasts, it seems fairly reasonable to assume that they have actually been closer to an unconditioned forecast than a conditioned.⁴²

⁴¹ Note that to assist comparisons of the models, the forecasts for a particular quarter are all plotted in the same colour.

⁴² If one supposes that the Riksbank's forecasts were in fact conditioned on a constant policy rate (which in 2003–05 would have been higher than the policy rate in practice), the overestimation of inflation in this period would presumably have been even greater because the outcome was below the paths for constant interest rates. In other words, a constant policy rate path in this period would have been restrictive rather than expansionary.

Chart 5. Outcome for UND1X inflation and sequential forecasts with alternative forecasting models.
 Percentage 4-quarter change



In order to evaluate the models' average forecasting performance, we use the root mean squared forecast errors for yearly UND1X inflation, yearly GDP growth and the policy rate.⁴³ This is done for forecasts of one to eight quarters ahead in the period 1999 Q1–2006 Q2 for inflation and the policy rate and in the period 2000 Q1–2006 Q2 for GDP growth. Only information that was available at the time of each forecast is used.⁴⁴ Note that in the absence of a real-time data base, the Riksbank's GDP growth forecasts are likely to be less accurate than the models' because revised GDP data were fed into the latter. However, we do evaluate the Riksbank's GDP forecasts against both real-time data and the latest revision (2006 Q2) of GDP outcomes. As the series on inflation are not revised over time, real time data are less of a problem when comparing inflation forecasts by the models with the Riksbank's assessments. It may even be the case that when the *Inflation Report* has been published at quarter ends, the Riksbank may have a slight advantage over the models because data on inflation and interest rates, for example, are then available for the first two quarters.

Chart 6 presents the annual percentage root mean squared errors for forecasts 1–8 quarters ahead for UND1X inflation, GDP growth and the policy rate for RAMSES, the BVAR model and the Riksbank. The chart also includes the accuracy of forecasts using a simple statistical correlation, an autoregression (AR(1)).⁴⁵ Once again, as the Riksbank conditioned its forecasts in this period on an unchanged policy rate (rather than publishing a path for the policy rate), we compare the models' policy rate forecasts with the implied forward interest rate. Thus, the models are not conditioned on an unchanged policy rate. That could, of course, affect the accuracy of the inflation forecasts, for example, though it is hard to say in which direction. It should be borne in mind that the unchanged policy rate applies only up to the forecast horizon.

The charts illustrate that the reliability of the alternative forecasting tools differs somewhat across the forecast variables. For underlying inflation, the forecast errors for RAMSES and the BVAR at short horizons are somewhat larger than for the Riksbank's assessments. The high degree of accuracy in the Riksbank's inflation forecasts for the first quarter is

⁴³ The root mean squared error (RMSE) is calculated for variable i and horizon h as

$$\text{RMKF}_i(h) = \sqrt{(1/N_h) \sum_{t=T}^{T+N_h-1} (x_{i,t+h} - \hat{x}_{i,t+h|t})^2}$$

where N_h is the number of forecasting occasions, x_i the actual outcome for variable i and \hat{x}_i the forecast given the information available up to and including the time of the forecast t .

⁴⁴ The first quarterly forecast is accordingly calculated with the information available up to 1998 Q4 (1999 Q4 for GDP). One additional observation 1999 Q1 (2000Q1) is then added to the data and the forecast for one to eight quarters ahead is calculated again. The parameters of the BVAR model are re-estimated every quarter, while for this exercise the parameters of the RAMSES model have been updated only annually because the estimation of RAMSES is more time-consuming.

⁴⁵ The autoregressive processes have been estimated separately for each variable in first differences for GDP and CPI. The repo rate was modelled in level. The forecasts were then converted to yearly growth rates.

not surprising because in many cases the Riksbank already has data for two-thirds of that quarter. At longer horizons (6–8 quarters), on the other hand, the models appear to perform better than the Riksbank's assessments. On the whole, we consider that the models' forecasting performance for underlying inflation compares remarkably well with the Riksbank's capacity in this respect. Compared with the BVAR, the reliability of RAMSES' inflation forecasts in the evaluation period is generally somewhat poorer. The forecast errors differ at most by approximately 15 basis points. Considering that RAMSES includes almost twice as many variables as the BVAR model, its slightly lower reliability is not particularly surprising. Compared with the BVAR model we have chosen to use here, RAMSES is accordingly capable of forecasting a much larger set of macroeconomic variables.

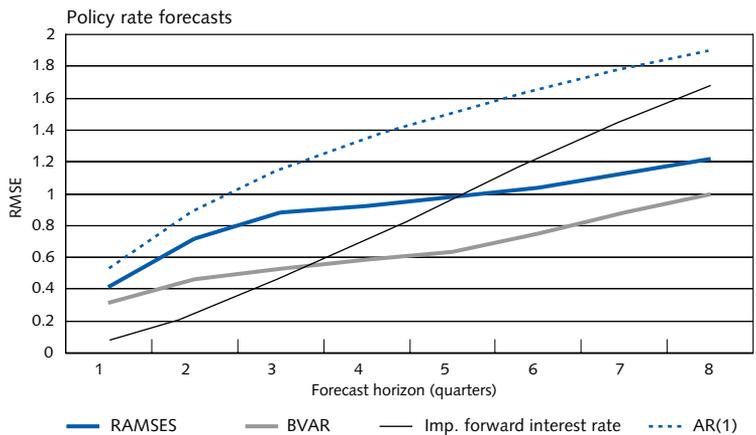
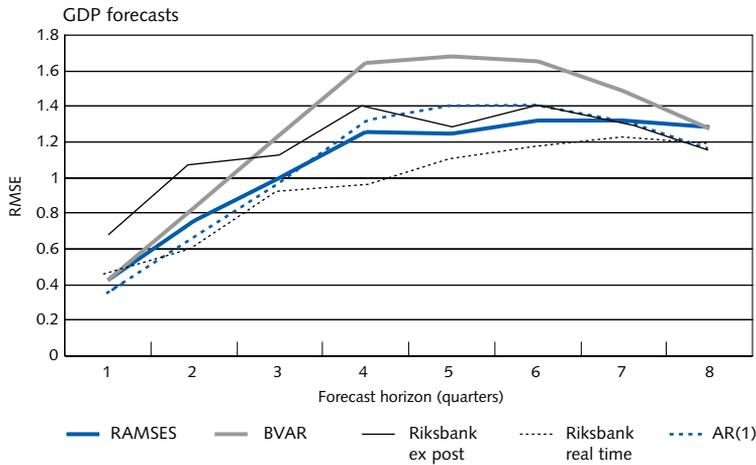
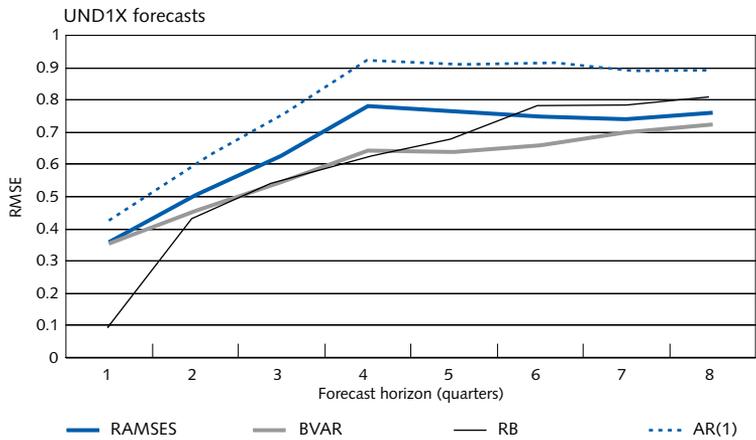
Chart 6 also presents the reliability of the GDP growth forecasts. The reliability of RAMSES GDP forecasts seems to compare relatively well in general with the BVAR forecasts, the Riksbank's assessments and, for that matter, an autoregression for GDP growth. The Riksbank's GDP assessments are actually not entirely comparable because the Riksbank did not have the revised GDP data when its inflation reports were published; an evaluation for real-time data indicates fairly satisfactory reliability for the Riksbank's GDP assessments.⁴⁶ At somewhat longer horizons, say two years ahead, however, the alternative forecasting tools do not seem to differ all that much in terms of reliability.

As the Riksbank did not publish policy rate forecasts prior to January 2007, the forecast error presented in Chart 6 concerns the implied forward interest rate curve based on market expectations.⁴⁷ It is worth noting that RAMSES' policy rate forecasts are somewhat less accurate than those of the BVAR model. At horizons up to one year the path of the implied forward interest rate performs somewhat better in forecasting the policy rate's future path, whereas the average reliability of the models appears to be better at somewhat longer horizons (5–8 quarters ahead).

⁴⁶ Another point worth noting is that the models use seasonally-adjusted GDP per capita, whereas the Riksbank forecasts total (annual) GDP growth.

⁴⁷ The implied forward interest rate curve is calculated from quarterly averages of the daily observations for a spectrum of government securities with different maturities. Bear in mind that as this curve includes maturity and risk premia, for example, it is not a perfect representation of market expectations of future monetary policy.

Chart 6. Accuracy of alternative models' forecasts of UND1X inflation, GDP growth and the policy rate.
Per cent



Note. RMSE = root mean squared error.

Conclusions

This article aims to present a relatively simple description of the principal characteristics of the RAMSES model, which is an important tool today for the Riksbank's monetary policy analysis. Moreover, RAMSES' empirical properties are compared with those of other, more statistical models as well as with the Riksbank's assessments in the period 1999–2006. We argue that empirical evaluations of models play a major part in elucidating the extent to which the models' predictions in other contexts deserve to be taken seriously.

All models are simplified representations of reality, so their analyses have to be combined with assessments of economic developments that models do not pick up satisfactorily. In this respect, RAMSES is no exception. We have therefore included a couple of examples to show how alternative scenarios can be analysed by combining the model with sector experts' more detailed knowledge.

As many aspects of the economy are modelled far too simple in RAMSES, this model is not appropriate for a number of purposes. One important example is that RAMSES does not include financial frictions, the importance of which for understanding the monetary policy transmission mechanism is discussed extensively in the literature. Another example is fiscal policy's very limited role in RAMSES. However, the work of developing models is a continuous process at the Riksbank and aims to learn from the shortcomings that are an inevitable feature of this field. In this work it is, of course, also important to document the models' empirical properties.

Finally, we wish to emphasise that while we do not believe that formal models such as RAMSES can replace the extensive analytical work of sector experts and others, the development of the new generation of general equilibrium models has now proved so successful in various ways that these models have earned a prominent place in a central bank's toolbox.

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Appendix

ESTIMATING RAMSES – STEP BY STEP

The mathematical form

RAMSES can be formulated mathematically as a system of non-linear differential equations with rational expectations. To simplify the estimation of the model's parameters, these equations are log-linearised around the model's steady state. A simplified example of such a linearised equation is the New-Keynesian Phillips curve for domestic inflation in equation (2). The parameter γ in the New-Keynesian Phillips curve is a function of β (the discounting factor) and ξ_d (the degree of price stickiness), which are two of the fifty or so structural parameters in RAMSES.

The goal of the estimation phase of model work is to identify the values of the structural parameters whereby RAMSES gives the best fit to the historical paths of a number of macroeconomic time series. Consequently, the theoretical model has to be linked to statistical measurements of, for example, output, prices, wages and interest rates. This is done in steps, as described below.

The reduced form

In the first step the above-mentioned system of equations is solved for a given set of parameters to obtain a *reduced form* of RAMSES.⁴⁸ This form is a description of the model's endogenous variables as a function of exogenous variables and shocks. The following system is a simplified example of a reduced form of two arbitrarily chosen endogenous variables, π and R :

$$(A.1) \quad \begin{aligned} \pi_t &= a_{11}\pi_{t-1} + a_{12}R_{t-1} + b_1x_t + c_1\varepsilon_t \\ R_t &= a_{21}\pi_{t-1} + a_{22}R_{t-1} + b_2x_t + c_2\varepsilon_t \end{aligned}$$

where x_t is an exogenous variable (for example external demand or external interest rate), and ε_t is an exogenous random variable, for example the λ_t^d shock in equation (2). All the parameters in the reduced form are (non-linear) functions of the model's structural parameters (for example β and ξ_d in equation (2)). With given values of these structural parameters, the reduced form can be used to, for instance, simulate the future development of the model economy. If π_t and R_t are taken to represent inflation and the policy rate, with ε_t as a cost shock, the system of equations in (A.1) results in the Riksbank raising the policy rate in the event of a lasting (but non-permanent) increase in costs. This makes it

⁴⁸ The log-linearised system of equations is solved numerically with the AIM algorithm, developed by economists at the US Federal Reserve (Anderson & Moore, 1985).

reasonable that both the coefficients in front of ε_t are positive. The path back to the stable equilibrium is determined by the a coefficients, which in turn are (non-linear) combinations of the Riksbank's actions and the workings of the economy.

The measurement equations

The variables π_t and R_t in equation (A.1) are theoretical constructions for the model. The second and final step in connecting RAMSES with reality amounts to using *measurement equations* to link these *model variables* to *measured variables*, such as GDP and inflation. There does not have to be a measured variable for each model variable. For some model variables there is in principle no empirical equivalent; for others there are no satisfactory measurements.⁴⁹ In these cases the estimation procedure uses the model structure in RAMSES together with the chosen measured variables to arrive at a picture of model variables for which measurements are not available.⁵⁰ It is important, however, that the set of measured variables is sufficiently informative to make it possible to *identify* the model's parameters and the underlying non-observable model variables, for example the capital stock. At present, 15 macroeconomic variables are used for estimations of RAMSES.

Likelihood

The reduced form, combined with the measurement equations and probability distributions for shocks, specify a simultaneous probability distribution for the measured variables. The probabilities the model assigns to different paths of the chosen measured variables can then be calculated for chosen values of the structural parameters. A reasonable estimation of the model's parameters maximises the probability the model assigns to the observed historical path of the measured variables. This estimation is thus the set of parameters that maximises the model's *likelihood function* $p(y | \theta)$, where y denotes all the chosen measured variables over the chosen observation period, θ contains all the model's parameters and $p(y | \theta)$ is the probability distribution (density) for y given θ . Note that the likelihood function is regarded as a function of the parameter θ and data (y) are known values. Assuming that the model contains only one parameter, an example of the appearance of the likelihood function is the black curve in Chart A.1. There the likelihood function shows that a value around 0.75 for θ gives the model with the best fit to historical data.

⁴⁹ Examples of variables of the latter type are capacity utilisation and the capital stock.

⁵⁰ In technical terms, the model is set up in *state-space form* and the *Kalman filter* is used to estimate the model variables for which there are no equivalents in the measurement equations.

Moreover, a value of θ outside the interval from 0.5 till 0.9 gives a model that is not compatible with data.

Bayesian methods

The Riksbank has used *Bayesian methods* for estimations of RAMSES. These methods also make use of the likelihood function but combine this information with *prior information* about the model's parameters. Prior information is knowledge about the model's parameters that is derived from sources other than the chosen measured variables. Examples are information from other studies of similar models for other countries, various kinds of micro data, or even information of an institutional nature such as the duration of negotiated wage agreements. As the reliability of this type of information varies, it is summarised in probability distributions for the respective parameters, *prior distributions*. The Riksbank can therefore specify the most probable value of each parameter as well as the uncertainty around this value in terms of a probability distribution. This does not mean that the Riksbank perceives the model's parameters as random in the traditional sense; it simply mirrors the fact that the Riksbank's information about the parameter is incomplete. An example of a prior distribution is the blue curve in Chart A.1. Bayesian method uses *Bayes' theorem* to arrive at an optimal combination of the information in the likelihood function and prior information. The combined distribution, which summarises prior and data information, is called the *posterior distribution*. The red curve in the chart represents the posterior distribution for parameter θ . In this example the data information is stronger than the prior information, which means that the posterior distribution is closer to the likelihood function.

