Mika Kortelainen

Edge: a model of the euro area with applications to monetary policy

Bank of Finland Studies
E:23 • 2002

Edge: a model of the euro area with applications to monetary policy

---

SUOMEN PANKKI
BANK OF FINLAND
P.O. Box 160
FIN – 00101 HELSINKI
FINLAND

Phone: +358 9 1831
Fax: +358 9 174 872
Email: publications@bof.fi

Subscriptions to the E series of the Bank of Finland's research publications and changes in address details

Old address details

Company ....

....

Name ....

Address ....

....

New address details/subscriptions

Company ....

....

Name ....

Address ....

....

☐ New subscription ☐ Cancellation ☐ Number of copies

Mika Kortelainen

Edge: a model of the euro area with applications to monetary policy

Bank of Finland Studies
E:23 • 2002

The views expressed in this study are those of the author and do not necessarily reflect the views of the Bank of Finland.

ISBN 952-462-001-4
ISSN 1238-1691
(print)

ISBN 952-462-002-2
ISSN 1456-5951
(online)

Vammalan Kirjapaino Oy
Vammala 2002

(Published also as A-204, Helsinki School of Economics and Business Administration, ISBN 951-791-715-5, ISSN 1237-556X)

Abstract

We ask the question: Does it matter whether expections on monetary policy are heterogeneous across agents in the economy? We tackle this issue with the aid of a dynamic general equilibrium model with nominal rigidities. The most important features of the model include consumption/saving decisions according to Blanchard's stochastic lifetimes approach; valuation of private financial wealth according to the present value of capital income; overlapping Calvo wage contracts in the labour market; and a neoclassical supply side with Cobb-Douglas technology. The model is calibrated to match the first and second moments of the publicly available euro area data. In simulation checks we find that the autocorrelation structure of the model, when subjected to stochastic shocks, also resembles that of the euro area data. Furthermore, diagnostic simulation results of the model provide intuitively appealing economic responses. In studying the effect of heterogeneity of expectations, we distinguish between central bank expectations and private sector expectations. The results show that if private sector expectations differ from central bank expectations, there will be real costs to the economy. We also show that the existence of a learning mechanism in the economy results in significantly smaller costs to the economy. And we find that random shifts interpreted as lack of transparency cause changes in private sector expectations, which generate costs in the form of higher variablility in the economy. All in all, our results show that heterogeneity of expectations on monetary policy may generate economically significant costs.

Key words: EDGE, rational expectations, heterogeneous expectations, learning, dynamic general equilibrium model

Tiivistelmä

Tässä tutkimuksessa etsitään vastausta kysymykseen, mikä merkitys on sillä, ovatko rahapolitiikkaa koskevat odotukset heterogeenisia. Jotta tähän kysymykseen pystyttäisiin vastaamaan, tutkimuksessa rakennetaan dynaaminen yleisen tasapainon malli, jossa on nimellisiä jäykkyyksiä. Mallin tärkeimpiin ominaisuuksiin kuuluvat Blanchardin stokastisen eliniän kulutus- ja säästämispäätökset, yksityisen pääomavarallisuuden arvostaminen pääomatulojen nykyarvona, työmarkkinoiden limittäiset Calvo-sopimukset, ja neoklassinen tarjonta Cobb-Douglas hyötyfunktiolla. Mallin ensimmäinen ja toinen momentti kalibroidaan vastaamaan julkisesti saatavilla olevaa euroalueen dataa. Stokastisilla simuloinneilla tuotettu mallin ristikorrelaatiorakenne muistuttaa euroalueen datan ristikorrelaatiorakennetta. Mallin diagnostiset simulointitulokset ovat talousteoreettisesti luontevia. Heterogeenisten odotusten merkitystä rahapolitiikassa tarkastellaan erottamalla rahapolitiikkaa koskevat yksityisen sektorin ja keskuspankin odotukset toisistaan. Simulointitulokset osoittavat, että kun yksityisen sektorin odotukset poikkeavat keskuspankin odotuksista, talouteen aiheutuu reaalisia kustannuksia. Lisäksi osoitetaan, että nämä kustannukset ovat pienemmät, jos taloudessa on jokin oppimekanismi, joka poistaa erot eri agenttien odotuksissa. Havaitaan myös, että rahapolitiikkaan kohdistuvissa yleisön odotuksissa ilmenevät satunnaiset poikkeamat, joiden tulkitaan kuvaavan häiriöitä rahapolitiikan läpinäkyvyydessä, aiheuttavat kustannuksia vaihtelevuuden voimistumisen vuoksi. Tulokset osoittavat, että heterogeeniset rahapolitiikkaodotukset voivat aiheuttaa merkittäviä taloudellisia kustannuksia.

Asiasanat: EDGE, rationaaliset odotukset, heterogeeniset odotukset, oppiminen, dynaaminen yleisen tasapainon malli

Foreword

The present study analyses the effects of heterogeneous expectations. When I joined the Bank of Finland's Research Department in autumn 1999, the head of the department, Juha Tarkka, personally guided my interest towards monetary policy issues which could justify the use of heterogeneous expectations in dynamic general equilibrium models. Juha's wizardly way of presenting well founded questions and ideas has thoroughly improved my work. I owe my deepest thank to Juha for supervising this study. I also would like to thank professor Pekka Ilmakunnas, David Mayes, Jouko Vilmunen and professor Matti Virén, who are also members of the supervisory group, for much practical advice and for commenting on several versions of the study and other related research papers.

Special thanks go to my external examiners, professor Andrew Hughes Hallet and Jukka Lassila. They made important comments on a preliminary draft and guided me through the literature.

Many professors and colleagues have discussed with me the problems of the study and have commented on parts of it. Among them, Jarmo Kontulainen, Mika Kuismanen, Hanna-Leena Männistö and Antti Ripatti truly deserve my warmest thanks. Parts of this study have been presented in seminars and I would collectively thank all the participants for useful comments, especially Benjamin Hunt from the IMF, who was my discussant at the Bank of Canada Workshop in summer 2000. I would like to thank Hope Pioro from the Bank of Canada for suggestions on use of the Troll simulation software. The librarians at the Bank of Finland library have been fast and efficient in finding the background material. Glenn Harma has been of invaluable help in improving my English. I thank Päivi Nietosvaara for her editing and Heli Tikkunen for collecting the data used in the study.

Last but not least, I want to thank my wife Susanne and my daughters, Emma, Eva and Sofia, for their encouragement and patience.

Helsinki, August 2002
Mika Kortelainen

Contents

1 Introduction

1.1 Why macromodels?

Why, in general, are macroeconomic models needed? There are at least three areas in which models are needed: forecasting, policy analysis and education. Usually people understand that macroeconomic models are needed for forecasting future paths of certain interesting macroeconomic variables such as output and inflation. Furthermore, macroeconomic models may provide base for constructing probability distributions around central forecasts by means of stochastic simulations. In addition, macroeconomic models may be used to answer such policy analysis questions as what would happen if fiscal or monetary policy were eased or tightened. Macroeconomic models also have an educational role: by publishing the macroeconomic models that it uses, the central bank shows how it thinks about the economy. In reality, it may happen that actual forecasts and policy simulations are not based solely on the macroeconomic models that the central banks use. Nevertheless, the macroeconomic models form a tight structure which may help to explain the thinking on which the policy actions are based. Furthermore, publishing models and forecasts, ie being transparent, also enhances the dialogue between the central bank and the public. This forms excellent grounds for building a macroeconomic model to fulfil these tasks. In some sense our motivation is also to link the representative agent framework to a DGE model in order to narrow the gap between current theoretical macroeconomics and practical macroeconomic models.

1.2 Features of modern macromodels

The precursor to modern economic theory was the IS-LM model that was based on Hicks' interpretation of Keynes' General Theory.

The original theory held the price level fixed and hence the IS-LM model was appended by the theory of price adjustment, also known as the Phillips curve. This IS-LM-AS model formed the neo-classical consensus of economic theory.

At about the same time, applied macroeconomists were working to build large-scale macroeconomic models which would be useful in formalising these theoretical advances. Tinbergen was among the first in the building of more formal macroeconometric models, and this research agenda was extended by the Cowles commission. As a result, the neo-classical theory was adopted as the foundation for large structural Keynesian macroeconometric models.

In the 1970s this neo-classical synthesis broke down for two reasons, one empirical and one theoretical (see Mankiw 1990). The empirical reason was based on the fact that the prevailing neo-classical theory was at odds with the rising inflation and unemployment rate experienced during the 1970s.

The theoretical reason was based on Friedman (1968) and Phelps (1967), who reasoned from microeconomic principles that the empirical relationship between inflation and unemployment would break down if policy makers tried to exploit it. Friedman and Phelps argued that the natural rate of unemployment should depend on labour supply, labour demand, optimal search times and other microeconomic fundamentals and not on the average rate of money growth.

A more exhaustive attack on prevailing neo-classical theory was provided by the Lucas (1976) critique, which showed that large macroeconometric models treated expectations in a cavalier way and were thus no better grounded in microeconomic principles than was the Phillips curve. Lucas argued that policy changes also affect individuals' expectations about the future and that this is not taken care of by the expectation formation mechanisms used in macroeconometric models.

In addition, the model identification process that forms the basis for macroeconometric models was questioned by Sims (1980). Sims argued that if the restrictions implied by economic theory are not properly accounted for the dynamic terms used for identification are invalid, since these purely dynamic terms cannot help in the structural identification and the expectations make identification difficult.

The breakdown of the neo-classical consensus thus occurred in both its theoretical and empirical aspects. As a result, macroeconomics and macroeconometric models were left in confusion, division and excitement. Subsequent developments in macroeconomic model building have led to a variety of responses, ie vector autoregressive (VAR), real business cycle (RBC), and dynamic general equilibrium (DGE) models. Below, we review the key assumptions behind modern macroeconomic theory and some additional assumptions that have been applied with the EDGE model.

1.2.1 Optimising behaviour

The breakdown of the neo-classical consensus also stimulated macroeconomic research aimed at fixing the failures. First, the IS-LM model was appended with an expectations-augmented Phillips curve. However, the more comprehensive criticism of Lucas showed that the model also lacked an expectations formation mechanism as well as other microeconomic foundations. Hence, macroeconomic theory was swayed toward developing better microeconomic foundations for economic models. Sound microeconomic foundations of key behavioural relationships should be derived from intertemporal optimisation of microeconomic agents, ie from first principles.

The incarnation of this intertemporal optimisation of microeconomic agents is the so-called representative agent model, which forms the backbone of modern macroeconomic theory. In the representative agent model the economy consists of many agents whose behaviour is sufficiently similar to be summarised by a single representative agent.

The representative agent model is useful not only for its analytical tractability but also because it comprises both rational expectations and utility maximisation. The former is of utmost importance since it introduces both backward and forward looking dynamics into the behaviour of the economy. The latter is equally important since it provides a basis for analysing welfare effects of different macroeconomic shocks. Thus, the representative agent model provides a tight structural framework and avoids the arbitrariness which has characterised earlier macroeconomic models.

The representative agent model has been incorporated in two different strategies for building a model incorporating microeconomic foundations, ie bottom-up and top-down.

In the bottom-up approach, model building starts with various problems faced by consumers, firms and policy makers etc. The equilibrium in each market is thus sufficiently described and policy rules are applied as necessary to characterised the model as dynamically stable. These models are quite precise and detailed in describing behaviour in each market. The New Keynesian literature is associated with the bottom-up approach. Even though some think that these are not as appealing as models obtained via the top-down approach, they do describe the economy in detail and are thus quite well adapted to producing forecasts and policy analysis in a consistent manner.

The top-down approach involves model building starting from a single decision problem faced by a benevolent central planner. This approach is closely associated with the real business cycle literature, which is based on Kydland and Prescott's (1982) effort to build a modified version of the neo-classical stochastic growth model. This model, also known as the real business cycle model (RBC), appeared to be able to replicate the key stylised facts of macroeconomics. In RBC models business cycles are often viewed as originating solely from technology shocks. Kydland and Prescott do not claim this to be the case but rather that the approach implies that ex-post assessment of a model's ability to replicate the key observations enables the identification of sources of economic shocks.

So far neither approach produces models that can be said to establish a new neoclassical consensus theory. Nevertheless, advances in both New Keynesian and neo-classical research have firmed the view that this new consensus is on its way. This is nicely summarised by Danthine (1997):

'*This systematic process of model enrichment following the confrontation with observations is precisely what makes it possible to foresee the dynamic GE models developed around the neoclassical stochastic growth model – but possibly evolving towards friction-prone non-Walrasian models – growing into the successors to IS-LM.*'

A very prominent model which incorporate many desireable features is the New Neoclassical Synthesis model (see below).

A slightly different response to critics of IS-LM-AS model is the vector autoregression (VAR) models proposed by Sims. VAR models are capable of describing regularities in the data in a less restricted way than in the structural econometric models. In other words, VARs allow the data to determine the model. The theoretical restrictions applied to the VAR models are quite limited. Nevertheless, the choices as to the number of lags as well as the variables to be included in the system do impose some restrictions on the model.

A VAR model is estimated statistically as a dynamic system for a chosen set of variables, eg output, inflation and interest rates. In this system the current level of each variable depends on its own lagged levels as well as the lagged levels of all other variables. The residuals of this system comprise the unexplained movements in the system and are influenced by exogenous shocks. Hence, the residuals are determined by the joint effect of different exogenous shocks and thus have no economic interpretation.

If some identification restrictions can be imposed on the VAR model, it is possible to transform the system into a moving average representation. This yields two advantages. First, the exogenous shocks become orthogonal and, second, the dynamic structure of shocks can be given an economic interpretation. However, the choice of appropriate identification restrictions remains an area of contention.

Sims' method for choosing the identification restrictions includes both constraints on contemporaneous effects of exogenous shocks to endogenous variables as well as restrictions on the causal chain of interactions between exogenous shocks and endogenous variables. Critics of Sims' approach point out that the economic structure implied by the identification restriction is often not plausible. Furthermore, the results are also sensitive to the ordering of the variables in the VAR model.

The criticism of Sims' approach has led to alternative ways of identification via Structural VAR (SVAR) models. SVARs are VARs which have been identified by using restriction derived from the economic theory. Hence, SVARs employ both the statistical methodology of VARs and some economic theory. The alternative identification methods with SVARs impose restrictions on contemporaneous effects of exogenous shocks on endogenous variables (Bernanke method) or on the long-run effects of exogenous shocks on levels of particular endogenous variables (Blanchard-Quah method) or both (Gali method), or impose restrictions on cointegration relationships (King-Plosser-Stock-Watson method) (see Bank of England 1999).

There are several advantages of the SVAR method. The time series paths of exogenous shocks are observed; the impulse responses of exogenous shocks to endogenous variables are obtained; decomposition of each exogenous shock on the forecast errors becomes possible; and the historical decomposition can be used to reveal the relative importance of exogenous shocks to endogenous variables in sub-samples.

Even though VAR and SVAR models are based more on data regularities than on economic theory, their main use in forecasting and economic analysis is best characterised as complementary rather than rival to the more traditional theory-driven economic models. The difficulty in using VARs for policy analysis is that they treat policy partly as unexpected events and partly as being determined by the history of the variables appearing in the VAR system. Exogenous policy shocks can be identified with VAR, but such shocks are not easy to relate to actual policy events. Because VARs isolate the unsystematic component of policy and estimate its impact on the economy, they cannot be used to measure the effect of the systematic part of the policy. Thus, VARs are more naturally used in forecasting than in policy analysis.

1.2.2 Rational expectations

As noted above expectations were modelled in a cavalier way in the neo-classical synthesis. These traditional approaches assumed that unobservable expectations can be replaced by current and lagged values of variables, resulting in a backward-looking dynamic or distributed lag model. Prior to the breakdown of the neo-classical consensus, perhaps the most advanced form of expectations formation was the adaptive expectations hypothesis formulated by Nerlove (1958).

The concept of rational expectations was proposed by Muth (1961). Muth's paper had been widely read but not properly understood as regards application to macroeconomics. In late 1960s and in early 1970s Lucas and other economists were able to formalise and extend the concept of rational expectations equilibrium. Since then rational expectations have comprised the dominant strategy for formulating expectations.

Rational expectations means simply that economic agents, ie consumers and firms, rationally maximise utility and profits respectively. In other words, when the consumer maximises utility over his expected lifetime he has to solve a dynamic intertemporal problem, which inherently incorporates consideration about the future. If the consumer considers the future rationally, he uses all available information as best he can.

Some important implications of the rational expectations hypothesis are viewed by Mankiw (1990):

Policy irrelevance

Rational expectation has generated many applications. In one application, Sargent and Wallace (1975) showed that if agents form expectations rationally then monetary policy is irrelevant to output and employment. This happens because rational expectations imply that agents cannot be surprised systematically by monetary policy and the inflation generated by monetary surprises must be expected. Therefore, if monetary policy is to have an effect, it must be non-systematic. It cannot be used to boost the economy in a slump. Subsequent research by Fischer (1977) has, however, showed that systematic monetary policy can have a stabilising effect in a model economy with sticky wages.

Rules versus discretion

Assume that the monetary authority is concerned about inflation and unemployment rates. The monetary authority faces a dilemma if it tries to lower inflation expectations in a credible way. If there is a positive tradeoff between inflation and unemployment, a simple announcement of a lower inflation policy by the monetary authority is not credible since agents have formed their expectations about the future rationally. Thus, when agents form expectations rationally using all available information, they also consider the monetary authority's incentive structure and observe that the monetary authority has an incentive to renege on the low inflation policy. Therefore, rational expectations make the low inflation policy not credible. This is also known as inflation bias, as the monetary authority has an incentive to ignor the announced policy rule and use its discretion.

Time consistency

The above problem may also been seen as the problem of time consistency of optimal policy. This arises simply because the incentive structure prevents the monetary authority from implementing its initial announced policy in a time consistent manner and, since rational agents observe this, they do not believe the policy announcement in the first place. An implication of this is that monetary policy-makers may do a better job if their discretionary power is taken away. In other words, the incentive structure of the monetary authorities must be such that they can fully commit to the announced policy in a time consistent manner, so that also the policy will be credible in the eyes of rational agents.

The rational expectation paradigm has led the discussion in the direction of dynamic games between intellectual agents. Some academics claim that the rational expectations assumption is excessively demanding in the sense that it requires that agents know a great deal about the overall structure of the model, functional forms, parameters, and the distributions of residuals, when they make their optimisation decisions. However, an econometrician trying to infer the structure of the model has considerable difficulty in finding out exactly how this rational expectation equilibrium emerges. Hence, it has been suggested that representative agents may in fact be only boundedly rational and may use various kinds of adaptive learning schemes to form expectations (see Sargent 1993, Sargent 1999 and Evans and Honkapohja 2001). If this is the case, then the econometrician would be in a better position and would be able to infer how the expectational equilibrium is actually achieved.

Note that if an econometrician is able to infer and exploit expectational errors made by the representative agent, then people are indeed boundedly rational. However, this also means that the representative agent would leave some profit opportunities unexploited or be satisfied with a lower utility level than could be attained through optimising schemes under the rational expectations assumption. It could be argued that one would need to respecify the preference structure of the representative agent and derive a new model under the assumption of rational expectations with this new set of preferences rather than incorporating adaptive expectations into the model. It is much easier to accept a deficiency of the econometrician than a deficiency of the representative agent. Nevertheless, adptive learning mechanisms may be of interest in themselves since they generate interesting dynamics in the model.

1.2.3 Nominal rigidities

Short-run price and wage stickiness implies an important role for monetary disturbances (ie changes in money growth rate or changes in nominal interest rates) by making short-run monetary policy non-neutral. Specifically, the nominal rigidities prevent prices and wages from adjusting completely to monetary disturbances in the short run. Furthermore, this incomplete short-run adjustment may help to explain the observed persistency of the inflation rate.

The staggered nominal wage contracts model by Taylor (1979) assumes that the mark-up added to wages is constant and hence wage changes are directly translated into price changes. In Taylor's model wages are contracted for two periods and workers are concerned about expected real wages and unemployment over the contract period.

In the staggered contracts model by Calvo (1983), prices are fixed and can be changed only randomly. Only a fraction of the firms can reset prices in each period, and these firms take into account that the other firms' prices are fixed for the current period. Prices are assumed to depend on aggregate price and the output gap.

The quadractic price adjustment cost model by Rotemberg (1982) assumes that firms minimise costs of changing prices and charging prices which are not optimal. The optimal price in the absence of adjustment costs would be equal to the marginal cost obtained by maximising profits subject to the demand and technology. Using the assumption that all firms are identical, the representative firm's solution is given by the aggregate price equation.

Both the Taylor and Calvo staggered-contracts models, as well as Rotemberg's quadractic price adjustment cost model, can be written in the form of the expectations-augmented Phillips curve (see Roberts 1995). As nominal rigidities are the main reason for the functional form of this Philips curve, it is also called the New Keynesian Philips curve.

Fuhrer and Moore (1995a) have suggested that it is the inflation rate and not just the price level that is sticky. In their model, wage contracts are defined by wages relative to average real contract wages in effect over the life of the wage contract. Specifically, in setting the real value of a nominal contract, a representative agent tries to adjust for the current excess demand as well as for the average of the expected real contract index. As a result their inflation equation has both lags and leads of the inflation rate and cannot thus respond like a jump variable to new information about monetary policy. Thus they are able to show that their model captures the inflation persistence that is found in the data but not in the sticky price level models. Roberts (1997) has shown that the Fuhrer-Moore type of sticky inflation equation may arise in the sticky price model if expectations are not rational.

1.2.4 Policy rules

In macromodels the policy rules are imposed to pin down the solution.

The fiscal policy rule is imposed to guarantee the necessary budget constraints are met and that the fiscal balances are solvable and that the solution converges. A useful way of formulating this fiscal policy rule is as an income tax rule. With this type of rule, the government always balances its budget through tax changes. The target variable could be the level of government debt.

The monetary policy rule is used to pin down the growth rate of the undetermined price level. With a Taylor-type of monetary policy rule, nominal interest rates may be tied to nominal targets, eg inflation or monetary base, or to real targets such as output gaps or unemployment gaps.

1.2.5 Dynamic general equilibrium

During the past 20 years macroeconomic theory has changed considerably. A new industry standard has been established, based on dynamic stochastic general equilibrium (DSGE) models. This development, which started with the seminal work of Kydland and Prescott (1982), has progressed rapidly. Kydland and Prescott focused on the neoclassical growth model of Solow (1956) and Swan (1956). They made assumptions about the functional form of preferences and assigned values obtained from other studies to the parameters for preferences and technology. They further added random shocks to the technology process. Their results showed that their simple model could explain many of the features of fluctuations in aggregate data. This work led to a flourish of empirical studies based on simple calibrated general equilibrium models.

It was soon found that even though the DSGE, á la Kydland and Prescott, was able to explain much of the actual aggregate data, the convergence of these models to equilibrium was far too fast. This observation led to the inclusion of rigidities in the model, which prevented the model from collapsing to an equilibrium immediately after a shock. These rigidities in wage and price formation were especially important, as they implied an important role also for monetary policy, since policy shocks did have temporary effects. Thus, these types of model have been used in modelling the economy and especially in analysing monetary policy.

1.2.6 Calibration

Calibration may be seen as a natural extension of economic theory (see Cooley 1997). Early economic theories were purely verbal, but after a while the dimishing returns of pure verbal theorising made it clear that something else was needed. The rigor of mathematical methods gave economic theories formal structure with precision and clarity. However, mathematical theorising also has its limits, and so the focus has shifted to calibration and quantitative theory of artificial economies, which seems to promise novel ways of modelling the economy.

In a calibration exercise economic theory is used as a guideline for restricting the model. One looks for numerical values of parameters which fit this theoretical structure to the data. In a calibration process the preferences and technologies of the theoretical model are used to restrict different possible solutions and data in such a way that the selected outcome will posess certain properties like balanced growth etc.

In doing the actual calibration exercise one can look to other studies using similar methods in order to obtain parameters. However, parameter values used elsewhere should not be applied as such but should be calibrated to the model and data at hand. In doing so, the emphasis in the calibration exercise is on the theory.

Econometric estimation and calibration should be viewed as complementary rather than subsitutive. Econometric estimations seek after the best fit of the data and the theoretical model. Calibration does basically the same thing, but more emphasis is placed on the economic theory in the sense that the measurement and data are determined by the economic theory. Thus, the calibration method may be less prone to overemphasis of statistical fit. In this sense calibration may be relatively well adapted to large macroeconomic models, which are usually dominated by econometric estimation.

1.3 Existing models

1.3.1 Small analytical models

Small analytical macroeconomic models are typically based on a few key assumptions: optimising agents, rational expectations and nominal rigidities. The most simplistic small analytical macromodels describe the economy with just three equations: aggregate demand and aggregate supply curves and a monetary policy rule (see eg McCallum and Nelson 1999 or Rotemberg and Woodford 1999). These models are attractive because they start from first principles and carefully employ the optimising behaviour of representative agents. The Euler equation representations of key behavioural equations thus have solid microfoundations. Furthermore, the expectation formation mechanism is assumed to be rational expectations, which is by now standard practice with macroeconomic models. Below, we view briefly the Coenen-Wieland, Fuhrer-Moore and New Neoclassical Synthesis models.

Coenen – Wieland model

For the euro area a small forward looking model is presented by Coenen and Wieland (2000). This model builds on good economics practice by taking forward-looking agents and nominal rigidities as cornerstones. Different price contracting models are applied, eg Taylor's nominal wage contracting model and the relative real wage contracting model of Fuhrer and Moore. Output and prices are then modelled via VAR, and the model is closed by a Taylor rule. This study does not proceed directly to modelling the optimising behaviour of rational agents but nevertheless uses elegant forward lookingness and nominal rigidities to study alternative monetary policy strategies.

Fuhrer – Moore model

Fuhrer – Moore model is a rational expectations structural macroeconomic model for the United States (see Fuhrer and Moore 1995b). The Fuhrer – Moore model consists of an overlapping–contracts specification of prices, an aggregate demand curve linking the output gap to its own lags and to the ex ante long-term real interest rate, and a monetary policy reaction function. This simple model is found to fit US macroeconomic data reasonably well.

Fuhrer and Moore are able to give a structural interpretation to the negative correlation between real output and nominal interest rates. The negative correlation is said to arise because of the structural interaction between leaning-against-the-wind monetary policy, aggregate supply that adjusts sluggishly to inflation, and aggregate demand that relates output to the rationally expected long-term real rate of interest.

In addition, Fuhrer and Moore employ their model to examine by counterfactual simulations the effect of alternative policies on competing policy objectives. They find that a monetary policy which reacts vigorously to both output and inflation reverses the sign of the correlation between the nominal interest rate and future inflation rates to positive and strengthens the positive correlation between future nominal interest rates and inflation. Furthermore, they show that with the more vigorous policy, a small decrease in inflation variability is purchased at the cost of higher variability of both output and the nominal interest rate.

New Neoclassical Synthesis model
Goodfriend and King (1997) and Goodfriend and King (2001) build a New Neoclassical Synthesis (NSS) model, using intertemporal optimisation and rational expectations. The NNS model also includes the New Keynesian features of imperfect competition and costly price adjustment. In this model demand is determined in the short run on the basis of monopolistic competition and sticky prices, while in the long run the output is determined by the supply side.

In the NNS model, monetary policy works through the mark-up, which is defined as the ratio of the average firm's price to its marginal cost of production. Easing of monetary policy increases aggregate demand, which raises marginal costs and hence lowers the mark-up. A lower mark-up generates a further increase in output and employment. Goodfriend and King argue that price stability should be the objective of monetary policy. They further characterise price stability as neutral policy since it keeps output close to potential. This potential output is not constant, as agents respond to productivity shocks and other disturbances; hence the neutral policy must also be activist. Thus, optimal monetary policy tries to keep the mark-up constant.

In the NNS model the price level is sticky but contrary to the Fuhrer-Moore model not the inflation rate. US macroeconomic data indicate persistence inflation, Goodfriend and King argue that the NNS model with flexible inflation, can produce artificial data that exhibit the inflation persistence found in the actual data. This, according to Goodfriend and King, is a result of the way the Federal Reserve has pursued monetary policy by allowing the mark-up to covary with inflation.

1.3.2 Large models

However, these small analytical models are by nature very simplistic and typically assume eg that capital formation is exogenous. Thus, a lot of interesting dynamics are missing from these models. Furthermore, the models are typically closed-economy models and thus do not include exchange rate considerations. In addition, the narrow structure of these models is a limiting factor when one wants to take a detailed look at the economy. Hence, one is inclined to use large structural models in forecasting and policy analysis. Below we describe briefly three large macroeconomic models ie the QPM, FRB and AWM models, of which the first is calibrated and the latter two are estimated.

Bank of Canada's QPM

The Bank of Canada's Quarterly Projection Model (QPM) is a large scale macroeconomic model of the Canadian economy. QPM is used for forecasting and policy analysis (see Black et al 1994, Armstrong et al 1995 and Coletti et al 1996). QPM is calibrated to the data, so that the parameters reflect reasonable responses. QPM has also been a successful prototype, influencing the models of the Reserve Bank of New Zealand and Riksbanken.

QPM actually consist of two models: a well-defined neo-classical steady-state model and a dynamic model which describes the adjustment paths from the current state to the steady-state. QPM includes three key groups of representative agents: consumers, firms and government. Consumers define the level of private wealth by maximising their utility; firms determine capital stock by profit maximisation decisions; and government defines the debt levels by determining levels of government expenditure and taxation. These stocks are balanced with the rest of the world through net foreign assets. Furthermore, the exchange rate adjusts to balance the current account with payments on the foreign debt. Thus, QPM has complete stock-flow accounting.

The dynamics of QPM are determined by intrinsic dynamics, expectation dynamics and policy adjustment. The intrinsic dynamics arise from adjustment costs, which capture the idea that adjustment is costly and therefore occurs over time. Expectations in QPM are specified to have both forward-looking and backward-looking elements and are thus neither purely 'rational' nor 'adaptive'. Policy rules in QPM define the endogenous fiscal policy, which determines taxes and government expenditure on an exogenously determined path for the debt-to-GDP ratio, and endogenous monetary policy rules with the inflation target as a nominal anchor.

QPM is developed to satisfy the needs of forecasting and policy analysis and is currently calibrated. However, it will in the future include some estimation of certain blocks of the model.

Federal Reserve Board's FRB model

The FRB model is a quarterly macroeconometric model of the US economy (see Brayton and Tinsley 1996 and Reifschneider, Stockton and Wilcox 1997). The FRB model has some 50 key behavioural equations and about 300 identities. A key novelty of this model, compared to previous models of the Federal Reserve Board, is the inclusion of explicit expectations formation mechanisms. The FRB model is used to provide forecasts and policy analysis.

The long run solution in the FRB model is determined by the neo-classical conditions of equilibrium while the short-run behaviour involves sticky-price disequilibrium, which causes monetary policy to have significant short-term effects on real activity. Specification of the key behavioural equations of the FRB model is derived from the formal optimisation problems of representative agents facing adjustment costs. These frictions arise from staggered contracts, habit formation, labour training, investment planning and installation costs. The costs of adjustment with such frictions are approximated by a higher-order polynomial, which makes the adjustment costly, not only in terms of level but also growth rate. Formulating the optimisation problem in this way yields key behavioural equations in a tightly parameterised error correction form. In order to estimate the key behavioural equations, the expectations of future variables are first computed with small-scale VAR models.

Asset prices are defined by the arbitrage equations, and the value of corporate equities equals the present value of expected dividends. Furthermore, the FRB model also specifies formal rules for the conduct of monetary and fiscal policy.

European Central Bank's AWM model

The ECB's AWM model is a quarterly macroeconomic model for the euro area (see Fagan et al 2001). The AWM model is developed for the assessment of economic conditions in the euro area, forecasting, policy analysis and for understanding the functioning of the euro area economy.

The supply side of the AWM model is neoclassical and includes a Cobb-Douglas production function. In the short-run the model is demand-driven, while in the long-run the neoclassical theory applies. The key behavioural equations in the AWM model are estimated.

Furthermore, the AWM model has both fiscal and monetary policy rules.

The model is currently based primarily on backward looking expectations. But the inclusion of forward looking expectations is seen as an important future strand of development for the AWM model.

1.4 Why not satisfactory?

We find that the above models are not satisfactory for our purposes, which is to analyse the credibility of monetary policy when central bank and private sector have heterogeneous expectations. Most of the models do build on rigourous microfoundations, but these are not pushed forward to analyse monetary policy when agents' expectations differ. In addition, we feel that the treatment of the exchange rate is unsatisfactory in the prevailing models, which seldom endogenise the exchange rate; those that do are not based on the pure uncovered interest rate parity. Furthermore, we do not include any artificial rigidities in consumption behaviour that would change the model outcomes from those predicted by the consumption theory that derived from the microfoundations.

1.5 EDGE

Our main goal is to build an advanced simulation tool that conforms to the rigorous industry standards. We proceed with a threefold strategy. First, we build a modern macroeconomic model for use in both forecasting and policy analysis. Our emphasis is however on the latter task. Second, we do a calibration exercise to fit the model to the publicly available euro area data and examine the relative merits and deficiencies of the calibration method with respect to our case. Third, we employ the model to analyse monetary policy credibility under the assumption of heterogeneous expectations of monetary policy. This strategy equips us to discuss about the credibility of monetary policy.

Hence, in this study a Euro area Dynamic General Equilibrium model (EDGE) is built and used to illustrate the analysis of monetary policy credibility in Europe.[1] Since the establishment of the EMU, this has become an object of study in applied macroeconomic modelling (see Coenen and Wieland 2000, Wouters and Dombrecht 2000 and Fagan et al 2001). The particular ingredients of our model are microeconomic foundations via optimising behaviour of representative agents and explicit treatment of expectations via the assumption of rational expectations. We will also show how the model can be used to analyse heterogeneous expectations, with less than perfect credibility. EDGE has nominal rigidities in the short run which allow monetary policy to have real effects. Hence, it can be characterised as having a Keynesian short run with some 'non-Keynesian' properties due to rational expectations, while the long-run is neoclassical.

EDGE builds on experience gained with the forward looking BOF5 model of the Finnish economy (see Willman et al 2000). The most important features of EDGE include consumption/saving decisions according to Blanchard's stochastic lifetimes approach, the valuation of private financial wealth according to the present value of capital income, overlapping Calvo wage contracts in the labour market, and a neoclassical supply side with Cobb-Douglas technology. In addition, the exchange rate is determined by uncovered interest rate parity and monetary policy is described by the Taylor rule.

As the diagnostic simulations show, the economy of EDGE adjusts rapidly back to long-run equilibrium after a shock. It seems that the Keynesian features, namely price and wage rigidities, are short-lived and thus the behaviour of the model is fairly New Classical even in the short run. The immediate adjustment to transitory shocks is fast, as is the return to long-run equilibrium. With permanent shocks, the steady state may shift as well, which causes the adjustment process to be significantly slower than with temporary shocks. In particular, the adjustment to equilibrium of assets is slow, especially for net foreign assets.

Even though EDGE has fairly quick adjustment-to-equilibrium mechanisms, the simulation results are not in conflict with the theory. In particular, it turns out that the unit root in the exchange rate, which allows for sudden jumps, accelerates the relative price adjustments and thus makes the adjustment process faster. Together

[1] Some parts of this paper have already been discussed elsewhere: Kortelainen (2001), Tarkka and Kortelainen (2001) and Kortelainen and Mayes (2002).

with the Taylor rule, the simulation results of the model are in most cases plausible, both in size and sign.

Some limitations of the model

Here we explain briefly some other important assumptions which underlie the EDGE model.

Small open economy assumption (exogenous global variables)

The foreign variables are exogenous. This is of course a rather limiting assumption since the euro area is a relatively significant economic area in the world economy. Hence, it may well be the case that economic decisions made in the euro area have effects on the global economy and thus shift the global variables accordingly. In order to take account of these shifts one runs into the problem of modelling the world economy which clearly goes beyond the scope of this work. Therefore, we make a simplifying assumption by keeping the global variables exogenous and concentrate our effort on the euro area.

Role of money (missing)

In conformity with the existing litterature, money is left out of the model. It is interesting to see that one is able to model the economy in a quite satisfactory way without including money. A model that excludes money is adequate to explain interesting macroeconomic phenomena such as output, inflation, interest rates, exchange rates etc. Nevertheless, money could be added in subsequent versions of the model and could be used eg as an alternative in analysing optimal monetary policy rules.

Labour supply (exogenous)

The assumption that the representative agent supplies labour exogenously is rather limiting. This could be relaxed later, with some repercussions for the model. Overlapping generations models, viz Lucas' island model, showed that labour supply decisions are interlinked with the Phillips curve. Furthermore, endogenising the labour supply would probably also alter the way in which changes in government policies are transmitted to the economy.

Perfect competition

It is assumed that the representative firms operate under perfect competition. This assumption may not be well founded, as the euro area still consists of twelve national markets with national competition. The competition in national markets may still be quite weak. In the future, competition will increase as the firms start to compete in the whole euro area and thus it is possible that the competition will approach perfect competition in the very long run. This assumption differs from the recent advances in the field, as the monopolistic competition is becoming an industry standard (see eg Goodfriend and King 1997, Goodfriend and King 2001, Obstfeld and Rogoff 1995 and Kollmann 1997) We also note that the level of competition may well be related to size and openness of the economy.

Population growth

We have assumed no population growth in the euro area, which may be fairly close to the prevailing situation. However, population growth may be of importance if the euro area starts to attract foreign labour in the future. Therefore, we feel that the inclusion of population growth in the model is important in the context of long-run scenarios.

In the EDGE model we have assumed that the Phillips curve exists and this is included through the nominal Calvo contracts. While this is a rather ad hoc assumption, the Lucas example shows that the Phillips curve may indeed emerge in a general equilibrium. This issue needs to be considered further in forthcoming modifications of the EDGE model.

The public sector in EDGE includes two agents: the fiscal and monetary authorities. These are assumed to work separately and not to co-ordinate their actions. One view of the public sector starts from the optimising behaviour of the government sector. One defines the objective function and solves the model in a such way that public sector behaviour can be characterised by an Euler equation. This approach is not used here. Instead the public sector is treated as an exogenous entity and only the closure rules exhibit some behaviour.

Fiscal policy and the closure rule

Fiscal policy in EDGE is largely exogeneous. It provides, however, the important budget constraint to the economy. Public expenditure is modelled by just assuming that it mimics the growth of output. This renders fiscal policy procyclical, whereas the data imply that public expenditure may have been used in a countercyclical manner.

Nevertheless, there is a rule for direct taxes which effectively drives public debt and net lending toward targeted values. These targeted values may be set at Mastricht criteria levels. This keeps the government sector in balance in the long run and thus closes the model.

Monetary policy and the Taylor rule

We assume that monetary policy can be described by the Taylor rule. We have also used the coefficient values originally proposed by Taylor in his work describing US monetary policy. We do this for the sake of comparison; but one could easily exclude the output gap from the Taylor rule and focus on price stability.

1.6 Organisation of the study

The rest of this study is organised as follows. In chapter 2 we build a dynamic general equilibrium model starting from first principles. We show first how we obtain the key behavioural equations and then we merely list some other interesting equations and identities. In the next chapter, we first describe briefly the publicly available data that we have employed. Next we show how we calibrate the EDGE model to these euro area data. Furthermore, we show some stochastic simulation results which mimic the correlation structure of the data and finally do some diagnostic simulations to highlight the economic behaviour of the model. In chapter 4 we use this model to analyse the effects of different expectational assumptions regarding the variables relevant to monetary policy. We start with the permanent expectational errors and show how these result permanent real costs to economy. In addition, we consider temporary expectational errors by introducing an exogenous decay mechanism which removes the expectational errors. Moreover, we consider introducing an adaptive learning mechanism into the model, which also removes the expectational errors. As a result, the real cost to the economy also vanishes in the long run. In the last subsection, we examine random expectational errors, which we interpret as shifts in monetary policy transparency. Here, we also find that the random expectational errors are costly to the economy, as they increase the variability. The final chapter concludes the study.

2 The model

In this chapter, we describe in more detail the theory behind the quarterly euro area dynamic general equilibrium (EDGE) model. We start with the key behavioural equations, which comprise the core of the dynamic model. First, we show how consumption is derived from the household maximisation problem. Next, we analyse the problem of the firm and obtain investment demand, labour demand and inventory demand. Furthermore, we show how prices are derived from the firm's problem. In analysing the firm's problem we assume that the above problems can be solved separately. Households and firms together determine wages as overlapping Calvo contracts in the labour market. In addition to these, trade and price equations of the core model are presented briefly, and finally some of the identities and policy disclosure rules needed to complete the model are presented.

After describing the dynamic model in detail we show the key principles by which the companion steady-state model is derived. This steady-state model is used to obtain the necessary terminal points for the EDGE model. In principle, the steady-state model can be used separately to analyse the long-run behaviour of the economy. The steady-state model is also helpful in stock-flow considerations since it defines explicitly the stock equilibria for private financial assets, capital stock, government debt and net foreign assets. The short-run flow equilibria of consumption, investment, government net lending and current account are described by the dynamic model. In this flow equilibria the stock equilibria may still be incomplete, but in the long-run even the stocks of assets will adjust fully to the steady-state stock equilibrium.

2.1 Dynamic model

2.1.1 Consumption

Consumption is modelled using Blanchard's stochastic lifetime approach, which is one of the most popular formulations of consumption (see Blanchard 1985). In the life-cycle model the representative consumer maximises the discounted utility of current and future consumption subject to the constraint that the present value of consumption does not exceed initial wealth. The stock of wealth is defined as the sum of the real value of assets held by the representative agent plus the present value of the flow of disposable labour income ie human wealth. Blanchard's life-cycle model includes uncertainty: representative agents constantly face the hazard of dying.

We model consumption in discrete time; the interest rate is not assumed to be constant; and we do not impose perfect foresight on the model. Thus, our formulation follows closely the derivation of consumption by Sefton and in't Veld (1999). Earlier treatment of Blanchard's model in discrete time can be found in Frenkel and Razin (1992) and Black et al (1994).

We assume that the representative agent maximises his constant-elasticity-of-substitution (isoelastic) utility function:

$$\begin{aligned} u(c) &= \frac{c^{1-\frac{1}{\sigma}}-1}{1-\frac{1}{\sigma}} \quad for \ \frac{1}{\sigma}>0, \frac{1}{\sigma}\neq 1 \\ &= \ln(c) \quad for \ \sigma = 1 \end{aligned}$$

The latter equation comes from L'Hôpital's rule. The elasticity of substitution in consumption, σ, is constant between any two points in time. Assuming a logarithmic utility function has important consequences since then income and substitution effects cancel out and thus the marginal propensity to consume is independent of the path of interest rates (see Blanchard and Fischer 1988).

Thus, assuming a logarithmic utility function, the representative agent maximises the discounted value of lifetime consumption:

$$\max E_t \sum_{j=0}^{\infty} \theta^j (1-p)^j \log c_{s,t+j}$$

where $\theta = (1+\varphi)^{-1}$ is the subjective discount factor and φ the rate of time preference. $c_{s,t}$ is the period t consumption of an agent born at time s. In each period the agent faces a constant probability of death, p. E_t is the expectations operator conditional on information at time t.

The periodic budget constraint at time t is

$$c_{s,t} + w_{s,t} = \frac{1 + z_{t-1} + \zeta_t}{1-p} w_{s,t-1} + y_{s,t}$$

where $w_{s,t}$ and $y_{s,t}$ are the period t financial wealth and labour income of an agent born at time s. $E_{t-1}z_{t-1}$ and $\zeta_t = z_{t-1} - E_{t-1}z_{t-1}$ are the expected return on wealth and windfall gain (unexpected return on wealth) between periods t-1 and t. Thus, $E_t z_{t-1} = z_{t-1}$, $E_{t-1}\zeta_t = E_{t-1}\left(z_{t-1} - E_{t-1}z_{t-1}\right) = 0$ and $E_t\zeta_t = E_t\left(z_{t-1} - E_{t-1}z_{t-1}\right) = z_{t-1} - E_{t-1}z_{t-1} = \zeta_t$.

The lifetime budget constraint[2] is

$$\sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod\limits_{k=0}^{j-1}\left(1 + z_{t+k} + \zeta_{t+k+1}\right)} c_{s,t+j} = h_{s,t} + \frac{1 + z_{t-1} + \zeta_t}{1-p} w_{s,t-1}$$

where $h_{s,t} = \sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod\limits_{k=0}^{j-1}\left(1 + z_{t+k} + \zeta_{t+k+1}\right)} y_{s,t+j}$ is the period t human wealth of an agent born at time s. In addition, a transversality condition is imposed to prevent agents from going infinitely in debt:

$$\lim_{T\to\infty} E_t \left(\frac{(1-p)^T}{\prod\limits_{k=0}^{T-1}\left(1 + z_{t+k} + \zeta_{t+k+1}\right)} w_{s,t+T} \right) = 0$$

The Lagrangean of the consumer's optimisation problem is:

[2] If j=0, we define $\frac{1}{\prod\limits_{k=0}^{-1}\left(1 + z_{t+k} + \zeta_{t+k+1}\right)} = 1$

$$
\begin{aligned}
L &= E_t \sum_{j=0}^{\infty} \theta^j (1-p)^j \log c_{s,t+j} \\
&\quad + \lambda_1 E_t \left(h_{s,t} + \frac{1+z_{t-1}+\zeta_t}{1-p} w_{s,t-1} \right. \\
&\qquad \left. - \sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod_{k=0}^{j-1} (1+z_{t+k}+\zeta_{t+k+1})} c_{s,t+j} \right) \\
&\quad + \lambda_2 E_t \left(\frac{(1-p)^T}{\prod_{k=0}^{T-1} (1+z_{t+k}+\zeta_{t+k+1})} w_{s,T} \right) \\
&= \log c_{s,t} + \theta(1-p) E_t \log c_{s,t+1} + \theta^2 (1-p)^2 E_t \log c_{s,t+2} + \ldots \\
&\quad + \lambda_1 \left(E_t h_{s,t} + \frac{1+z_{t-1}+\zeta_t}{1-p} w_{s,t-1} \right. \\
&\qquad - c_{s,t} - E_t \left(\frac{1-p}{1+z_t+\zeta_{t+1}} c_{s,t+1} \right) \\
&\qquad \left. - E_t \left(\frac{(1-p)^2}{\left(1+z_t+\zeta_{t+1}\right)\left(1+z_{t+1}+\zeta_{t+2}\right)} c_{s,t+2} \right) - \ldots \right) \\
&\quad + \lambda_2 E_t \left(\frac{(1-p)^T}{\prod_{k=0}^{T-1} (1+z_{t+k}+\zeta_{t+k+1})} w_{s,T} \right)
\end{aligned}
$$

where λ_1 is the Lagrangean multiplier associated with the lifetime budget constraint and λ_2 is the Lagrangean multiplier associated with the terminal condition.

The first order conditions with respect to consumption are

$$\frac{\partial L}{\partial c_{s,t}} = \frac{1}{c_{s,t}} - \lambda_1 = 0$$

$$\frac{\partial L}{\partial c_{s,t+1}} = \theta(1-p)E_t\frac{1}{c_{s,t+1}} - \lambda_1 E_t\left(\frac{1-p}{1+z_t+\zeta_{t+1}}\right) = 0$$

$$\frac{\partial L}{\partial c_{s,t+2}} = \theta^2(1-p)^2 E_t\frac{1}{c_{s,t+2}}$$

$$-\lambda_1 E_t\left(\frac{(1-p)^2}{\left(1+z_t+\zeta_{t+1}\right)\left(1+z_{t+1}+\zeta_{t+2}\right)}\right) = 0$$

etc. We assume that the rest of the usual Kuhn-Tucker conditions hold. Combining the above two first order conditions yields the Euler equation:

$$\theta E_t\left(\frac{1}{c_{s,t+1}}\right) = \frac{1}{c_{s,t}}E_t\left(\frac{1}{1+z_t+\zeta_{t+1}}\right)$$

Let us take a second order Taylor approximation of the Euler equation around points $E_t c_{s,t+1}$ and $E_t(1+z_t+\zeta_{t+1}) = 1+E_t z_t = E_t Z_t$:

$$\theta E_t\left(\frac{1}{c_{s,t+1}}\right) - \frac{1}{c_{s,t}}E_t\left(\frac{1}{Z_t}\right)$$

$$= \theta\left\{\left(\frac{1}{E_t c_{s,t+1}}\right)\underbrace{\left[1+\frac{E_t\left(c_{s,t+1}-E_t c_{s,t+1}\right)^2}{\left(E_t c_{s,t+1}\right)^2}\right]}_{\text{risk premium in expected consumption}}\right\}$$

$$-\frac{1}{c_{s,t}}\left\{\left(\frac{1}{E_t Z_t}\right)\underbrace{\left[1+\frac{E_t\left(Z_t-E_t Z_t\right)^2}{\left(E_t Z_t\right)^2}\right]}_{\text{risk premium in expected return}}\right\}$$

We assume zero risk premia in expected consumption and expected return. Hence, the Euler equation reduces to:

$$\theta E_t(1+z_t)c_{s,t} = E_t c_{s,t+1}$$

Inserting the Euler equation into the slackness condition (lifetime budget constraint), linearising and assuming that successive total returns, $Z_t = 1 + z_t + \zeta_{t+1}$, are uncorrelated, yields the consumption function at the micro level:

$$c_{s,t} = (1 - \theta(1-p)) \left(E_t h_{s,t} + \frac{1 + z_{t-1} + \zeta_t}{1-p} w_{s,t-1} \right)$$

In order to obtain aggregate consumption, we first define some aggregation functions: $C_t = \sum_{s=-\infty}^{t} p(1-p)^{t-s} c_{s,t}$ ie aggregate consumption is obtained by summing over all cohorts, s. Similar aggregation applies to human and financial wealth: $H_t = \sum_{s=-\infty}^{t} p(1-p)^{t-s} h_{s,t} =$

$$\sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod_{k=0}^{j-1} (1 + z_{t+k} + \zeta_{t+k+1})} \underbrace{\sum_{s=-\infty}^{t} p(1-p)^{t-s} y_{s,t+j}}_{Y_{t+j}} =$$

$\sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod_{k=0}^{j-1} (1 + z_{t+k} + \zeta_{t+k+1})} Y_{t+j}$ and $W_t = \sum_{s=-\infty}^{t} p(1-p)^{t-s} w_{s,t}$ and $W_{t-1} = \sum_{s=-\infty}^{t} p(1-p)^{t-s-1} w_{s,t-1}$. Thus, we can write the aggregate budget constraint:

$$C_t + W_t = (1 + z_{t-1} + \zeta_t) W_{t-1} + Y_t$$

The aggregated consumption function is then:

$$C_t = \Lambda \left(E_t H_t + (1 + z_{t-1} + \zeta_t) W_{t-1} \right)$$

where the marginal propensity to consume is $\Lambda = 1 - \theta(1-p)$. Leading consumption, taking expectations at time t, and substracting from the above yields:

$$C_t = E_t C_{t+1} + \Lambda \left(E_t(H_t - H_{t+1}) + (1 + z_{t-1} + \zeta_t) W_{t-1} - E_t(1 + z_t) W_t \right)$$

Leading aggregate human wealth, multiplying by $\left(\frac{1-p}{1 + z_t + \zeta_{t+1}} \right)$, adding Y_t to both sides, and inserting into the above enables us to write the aggregate consumption function as:

$$
\begin{aligned}
C_t &= \left(\frac{1-p}{1-(1-p)\Lambda}\right)\frac{E_tC_{t+1}}{E_t(1+z_t)} \\
&\quad + \left(\frac{p\Lambda}{(1-(1-p)\Lambda)}\right)((1+z_{t-1}+\zeta_t)W_{t-1}+Y_t)
\end{aligned}
$$

Next, let us define disposable income as $YD_t = z_{t-1}W_{t-1} + Y_t$. Thus the consumption becomes:

$$
\begin{aligned}
C_t &= \left(\frac{1-p}{1-(1-p)\Lambda}\right)\frac{E_tC_{t+1}}{E_t(1+z_t)} \\
&\quad + \left(\frac{p\Lambda}{(1-(1-p)\Lambda)}\right)((1+\zeta_t)W_{t-1}+YD_t)
\end{aligned}
$$

Define $W_{t-1} = \frac{A_{t-1}}{PC_t}$, $YD_t = \frac{YDN_t}{PC_t}$ and $E_t(1+z_t) = 1+r_t+\chi$,where r_t is the real interest rate, χ the equity premium, and PC the private consumption deflator. YDN is private nominal disposable income:

$$
YDN_t = YFN_t - TAX_t + INN_t + TRF_t - GOY_t + NFN_t - \delta \cdot PI_t \cdot K_{t-1}
$$

which is the value of GDP at factor cost net of government transactions, minus depreciation of capital stock, plus interest income on net foreign assets. δ is the depreciation rate. These enable us to write the consumption function in the following form, as it is actually used in the EDGE model:

$$
\begin{aligned}
C_t &= \left(\frac{1-p}{1-(1-p)\Lambda}\right)\left(\frac{E_tC_{t+1}}{1+r_t+\chi}\right) \\
&\quad + \left(\frac{p\Lambda}{(1-(1-p)\Lambda)}\right)\left((1+\zeta_t)\cdot\frac{A_{t-1}}{PC_t}+\frac{YDN_t}{PC_t}\right)
\end{aligned}
$$

and windfall gain:

$$
\zeta_t = \frac{A_t}{A_{t-1}} - 1 - \frac{YDN_t - C_t \cdot PC_t}{A_{t-1}} - \pi_{t-1}
$$

where π_t is the inflation rate. The asset accumulation equation is:

$$
\begin{aligned}
A_t &= \frac{1}{1+R_t/400+\chi}E_t(A_{t+1} - GDN_{t+1} - NFA_{t+1}) \\
&\quad + (PF_t \cdot Y_t - WN_t \cdot L_t - \delta \cdot PI_t \cdot K_{t-1} - \nu \cdot GOY_t) \\
&\quad + GDN_t + NFA_t
\end{aligned}
$$

These equations simply define current nominal assets as the discounted net present value of capital income. NFA_t is the net present value of capital income from abroad, and GDN_t is the net present value of interest income on government bonds. $PF_t \cdot Y_t - WN_t \cdot L_t - \delta \cdot PI_t \cdot K_{t-1} - \nu \cdot GOY_t$ is the net present value of capital income from firms. $PF_t \cdot Y_t$ is the value of production at factor cost; $WN_t \cdot L_t$ is total wages; $\delta \cdot PI_t \cdot K_{t-1}$ is depreciation; and $\nu \cdot GOY_t$ is the share of profits that is paid to the public sector in return for public investments.

2.1.2 Firm behaviour

Investment

Investment demand is derived along the lines of Hubbard et al (1993). In this model it is assumed that the representative firm maximises the discounted present value of expected real dividends. Note that this formulation includes not only investment decisions but also an adjustment cost for changing production capacity. The linear adjustment costs, as well as quadratic adjustment costs, have been applied widely in the literature (see eg Chirinko 1993 and Whited 1998). Translog adjustment costs are applied here (see Tarkka et al 1990a). Our approach is a slightly modified version of the investment function in the BOF5 model (see Willman et al 2000). We make some simplifying assumptions, ie no taxes and no bond financing. The firm's real dividend, $d_t = D_t/P_t^I$, in terms of the price of the investment good, P_t^I, is expressed as:

$$d_t = p_t F\left(K_t, N_t\right) - w_t N_t - \Gamma(K_t, K_{t-1}, K_{t-2}) - I_t$$

where $p_t = P_t/P_t^I$ is the relative price of output; $F(K_t, N_t)$ is the production function, where K_t is capital stock and N_t is labour input; WN_t is the nominal wage; and $w_t = WN_t/P_t^I$ is the real wage rate. $\Gamma(K_t, K_{t-1}, K_{t-2})$ is an adjustment cost function, which allows adjustment cost to be associated with both changes in the capital stock and the rate at which capital stock changes. I_t is real investment.

A representative firm i maximises the discounted value of expected real dividends:

$$E_t \sum_{j=0}^{\infty} \left[\prod_{h=0}^{t+1} \rho_h \right] d_{i,t+j}$$

subject to the capital accumulation equation:

$$K_{i,t} = I_{i,t} + (1-\delta) K_{i,t-1}$$

where ρ is the discount factor[3] and δ the rate of depreciation. The first order condition may be written as:

$$\begin{aligned} & \frac{\partial \Gamma(K_{i,t}, K_{i,t-1}, K_{i,t-2})}{\partial K_{i,t}} + \rho E_t \frac{\partial \Gamma(K_{i,t+1}, K_{i,t}, K_{i,t-1})}{\partial K_{i,t}} \\ & + \rho^2 E_t \frac{\partial \Gamma(K_{i,t+2}, K_{i,t+1}, K_{i,t})}{\partial K_{i,t}} \\ = \quad & p_t \frac{\partial F(K_{i,t}, N_{i,t})}{\partial K_{i,t}} \underbrace{-1 + \rho(1-\delta)}_{-\frac{r+\chi+\delta}{1+r+\chi}} \end{aligned}$$

where $\rho = (1+r+\chi)^{-1}$, r is the real interest rate, and χ is the equity premium. The adjustment cost function is assumed to be of the following translog form:

$$\begin{aligned} \Gamma(K_{i,t}, K_{i,t-1}, K_{i,t-2}) \quad = \quad & \frac{a_1}{2} \frac{(\Delta K_{i,t} - b_1 \Delta K_{i,t-1})^2}{K_{i,t-1}} \\ \approx \quad & \frac{a_1}{2} \Delta K_{i,t} \Delta \log K_{i,t} \\ & + \frac{a_1 b_1^2}{2} \Delta K_{i,t-1} \Delta \log K_{i,t-1} \\ & - a_1 b_1 \Delta K_{i,t} \Delta \log K_{i,t-1} \end{aligned}$$

where $0 < b_1 < 1$ and $\Delta \log K_t = \log K_t - \log K_{t-1}$. Taking the partial derivatives of this adjustment cost function yields:

[3] In analysing the problem of the firm, we assume a constant discount factor, which is a simplification of the time varying discount factor applied in the consumer problem.

$$
\begin{aligned}
\frac{\partial \Gamma(K_{i,t}, K_{i,t-1}, K_{i,t-2})}{\partial K_{i,t}} &= \frac{a_1}{2}\left(\Delta \log K_{i,t} + \frac{\Delta K_{i,t}}{K_{i,t}}\right) \\
&\quad -a_1 b_1 \Delta \log K_{i,t-1} \\
&\approx a_1 \Delta \log K_{i,t} - a_1 b_1 \Delta \log K_{i,t-1}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial \Gamma(K_{i,t+1}, K_{i,t}, K_{i,t-1})}{\partial K_{i,t}} &= -\frac{a_1}{2}\left(\Delta \log K_{i,t+1} + \frac{\Delta K_{i,t+1}}{K_{i,t+1}}\right) \\
&\quad +\frac{a_1 b_1^2}{2}\left(\Delta \log K_{i,t} + \frac{\Delta K_{i,t}}{K_{i,t}}\right) \\
&\quad +a_1 b_1 \left(\Delta \log K_{i,t} - \frac{\Delta K_{i,t+1}}{K_{i,t}}\right) \\
&\approx -a_1(1+b_1)\Delta \log K_{i,t+1} \\
&\quad +a_1 b_1 (1+b_1)\Delta \log K_{i,t}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial \Gamma(K_{i,t+2}, K_{i,t+1}, K_{i,t})}{\partial K_{i,t}} &= a_1 b_1 \frac{\Delta K_{i,t+2}}{K_{i,t}} \\
&\quad -\frac{a_1 b_1^2}{2}\left(\Delta \log K_{i,t+1} + \frac{\Delta K_{i,t+1}}{K_{i,t}}\right) \\
&\approx a_1 b_1 \Delta \log K_{i,t+2} - a_1 b_1^2 \Delta \log K_{i,t+1}
\end{aligned}
$$

Inserting these into the first order condition, defining $\Delta k_{i,t} = \Delta \log K_{i,t}$, and dividing by a_1 yields the micro-level capital stock equation:

$$
\begin{aligned}
&\rho^2 b_1 \Delta k_{i,t+2} - \left(\rho^2 b_1^2 + \rho(1+b_1)\right)\Delta k_{i,t+1} \\
&+ \left(\rho b_1 (1+b_1) + 1\right)\Delta k_{i,t} - b_1 \Delta k_{i,t-1} \\
= &\ \frac{1}{a_1}\left(p_t \frac{\partial F\left(K_{i,t}, N_t\right)}{\partial K_{i,t}} - \frac{r+\chi+\delta}{1+r+\chi}\right)
\end{aligned}
$$

Note that the micro-level capital stock equation is linear. Thus, the aggregate capital stock is obtained by aggregating directly over all firms:

$$\begin{aligned}
& \rho^2 b_1 \Delta k_{t+2} - \left(\rho^2 b_1^2 + \rho(1+b_1)\right) \Delta k_{t+1} + \left(\rho b_1 (1+b_1) + 1\right) \Delta k_t \\
& - b_1 \Delta k_{t-1} \\
= & \frac{1}{a_1} \left(p_t \frac{\partial F(K_t, N_t)}{\partial K_t} - \frac{r+\chi+\delta}{1+r+\chi} \right)
\end{aligned}$$

This is used in EDGE, with marginal product of capital given by the model's Cobb-Douglas production function.

Labour Demand

The long-run labour demand is defined by an inverted production function as in Tarkka et al (1990b) and Willman et al (2000). This ensures that the long-run effects of changes in capital stock and technical progress on labour demand are captured in a consistent way by the neoclassical supply side. This long-run labour demand is supplemented by adjustment costs in order to capture the relevant short-run dynamics of labour demand. Thus, we assume that the representative firm derives its labour demand by minimising a loss function for changes in labour and deviation of labour input from the optimal amount. The Cobb-Douglas production function is:

$$Y = T \cdot K^{\beta} \cdot L^{1-\beta}$$

where Y,T,K,L and β refer to output, total factor productivity, capital stock, labour and the factor share of capital in production. The evolution of total factor productivity is described in more detail in subsection 2.2 below. The above Cobb-Douglas production function is inverted to define the optimal labour input:

$$l_t^* = \left(\frac{Y_t}{T K_t^{\beta}} \right)^{\frac{1}{1-\beta}}$$

The loss-function for firm i governing the adjustment of the labour input yields:

$$\frac{1}{2} E_t \sum_{j=0}^{\infty} \rho^j \left[\left(l_{i,t+j} - l_{i,t+j-1} \right)^2 + b \left(l_{i,t+j} - l_{t+j}^* \right)^2 \right]$$

Taking the first order condition and inserting the optimal labour input yields the labour micro-level demand equation:

$$l_{i,t} = \frac{1}{1+b+\rho} l_{i,t-1} + \frac{\rho}{1+b+\rho} E_t l_{i,t+1} + \frac{b}{1+b+\rho} \left(\frac{Y_t}{T \cdot K_t^{\beta}} \right)^{\frac{1}{1-\beta}}$$

As this is linear with respect to labour, we can aggregate by summing over all firms:

$$l_t = \frac{1}{1+b+\rho} l_{t-1} + \frac{\rho}{1+b+\rho} E_t l_{t+1} + \frac{b}{1+b+\rho} \left(\frac{Y_t}{T \cdot K_t^{\beta}} \right)^{\frac{1}{1-\beta}}$$

This is applied directly in EDGE.

Inventory demand

The modelling of inventory demand is based on the idea that firms can deviate from the normal level of production derived by the production function, but only at cost. This is close to the inventory demand in the BOF5 model (see Willman et al 2000). Define realised production as a sum of sales and change in inventories, $Q_t = SALE_t + \Delta KI_t$, while the normal level of production with the existing inputs is given by the Cobb-Douglas production function, $Q_t^* = T \cdot K_t^{\beta} L_t^{1-\beta}$, and target inventory is assumed to be fixed relative to output, $KI_t^* = k \cdot Q_t^*$.

Assume that the representative firm minimises a quadratic loss function with respect to the level of inventories. This loss function for firm i is a combination of deviations of inventory level from target and production from the normal level of production:

$$\frac{1}{2} E_t \sum_{j=0}^{\infty} \rho^j \left[\varpi \left(KI_{i,t+j} - KI_{t+j}^* \right)^2 + \left(Q_{i,t+j} - Q_{t+j}^* \right)^2 \right]$$

where ρ is the discount factor and ϖ is adjustment parameter.

The first order condition gives micro-level inventory demand:

$$KI_{i,t} = kQ_t^* - \frac{1}{\varpi} \left(Q_{i,t} - Q_t^* \right) + \frac{\rho}{\varpi} E_t \left(Q_{i,t+1} - Q_{t+1}^* \right)$$

As this is a linear function, we obtain aggregate inventory demand by summing over all firms:

$$KI_t = kQ_t^* - \frac{1}{\varpi}\left(Q_t - Q_t^*\right) + \frac{\rho}{\varpi}E_t\left(Q_{t+1} - Q_{t+1}^*\right)$$

2.1.3 Prices and wages

Price formation

Price formation is similar to that of Rothemberg (1982). Note that this yields an apparently similar functional form to the Calvo model used below for wage formation. This type of wage and price formation induces rigidity in the model, which now adjusts incompletely to monetary disturbances in the short run. This incomplete short-run adjustment may help to explain the observed persistency of the inflation rate.

Perfect competition, which is assumed to prevail, ensures that prices equal marginal costs in the long-run: $p_t^* = \frac{WN_t \cdot L_t}{(1-\tau_t^{indirect})(1-\beta)Y_t}$ where $\tau_t^{indirect}$ is the indirect tax rate and WN_t is the nominal wage per employee. For the short-run we assume that firm i (i=1,...,m) smooths its price by a Rothembergian quadratic loss function:

$$L = \frac{1}{2}E_t\sum_{j=0}^{\infty}\widetilde{\rho}^j\left[\left(p_{i,t+j} - p_{i,t+j-1}\right)^2 + a\left(p_{i,t+j} - p_{t+j}^*\right)^2\right]$$

where $\widetilde{\rho}$ is the discount factor with the nominal interest rate and a is the adjustment parameter. This implies that when facing 'menu' costs firms balance the costs of adjusting prices with the costs of being out of equilibrium. Solving for the first order condition yields:

$$\frac{\partial L}{\partial p_{i,t}} = (p_{i,t} - p_{i,t-1}) + a(p_{i,t} - p_t^*) - \widetilde{\rho}E_t(p_{i,t+1} - p_{i,t}) = 0$$

Aggregating this linear equation over all firms and inserting the optimal long-run price yields the price equation:

$$
\begin{aligned}
P_t &= \frac{1}{1+a+\widetilde{\rho}}P_{t-1} + \frac{\widetilde{\rho}}{1+a+\widetilde{\rho}}E_t P_{t+1} \\
&\quad + \frac{a}{1+a+\widetilde{\rho}} \frac{WN_t \cdot L_t}{(1-\tau_t^{indirect})(1-\beta)Y_t}
\end{aligned}
$$

This is used directly in EDGE to model the value added deflator.

Wage formation

Wages are modelled as a Calvo contract (see Calvo 1983). We apply Calvo's model, originally derived in continuous time, in discrete time, as presented eg in Rothemberg (1987) and Walsh (1998). Calvo contracts are used widely in modelling price and wage formation (see eg Kollmann 1997, Kollmann 1999, Galí and Gertler 1999, Wouters and Dombrecht 2000, Goodfriend and King 1997 and Goodfriend and King 2001). Assume that firms make new wage contracts infrequently and that the arrival of these new contracts can be characterised as a Poisson process. Thus, new wage contracts are made at each period with the constant probability q. Since new wage contracts occur randomly, the interval between new contracts is also a random variable. Firm i minimises a quadratic loss function, where a loss arises whenever a new wage contract by firm i at time t, $wn_{i,t}$ deviates from an optimal wage, wn_t^*, subject to a Poisson process of making new wage contracts. $\widetilde{\rho}$ is the discount factor. Assume further that 1-q is the probability that the firm does not make a new wage contract at time t+1 and that existing contracts made at time t prevail. The loss function is thus:

$$
\frac{1}{2}\sum_{j=0}^{\infty}(1-q)^j \widetilde{\rho}^j E_t \left(wn_{i,t} - wn_{t+j}^*\right)^2
$$

Aggregating the first order condition yields:

$$
wn_t = (1-(1-q)\widetilde{\rho})wn_t^* + (1-q)\widetilde{\rho}E_t wn_{t+1}
$$

Next, we assume that the optimal real wage is contracted to be equal to the marginal product of labour adjusted for the current state of economy, as measured by the unemployment gap.[4] The positive parameter η, relates the unemployment gap to the optimal wage contracts. When there is a positive output gap, ie actual unemployment rate exceeds the NAIRU, then this deviation is multiplied by η to determine how far below the marginal product of labour the newly contracted optimal real wage should be. As stated in the footnote this form of contracted optimal real wage is assumed and not explicitly derived from the dynamic optimisation problem.[5] In nominal terms it amounts to:

$$wn_t^* = p_t \frac{(1-\beta)Y_t}{N_t} \cdot (1 - \eta \cdot (U_t - \overline{U_t}))$$

where $\overline{U_t}$ is the NAIRU unemployment, U_t is unemployment and $\dfrac{(1-\beta)Y_t}{N_t}$ is the marginal product of labour.

When there is a large number of firms, a fraction of them, q, negotiate new wage contracts at time t while the rest stick with the old contracts. Thus, the observed nominal time t wages per employee, WN_t, can be expressed as:

$$WN_t = q \cdot wn_t + (1-q) \cdot WN_{t-1}$$

Inserting the first order condition and the optimal wage contract enables us to write the wage equation as:

$$\begin{aligned} WN_t \quad = \quad & \frac{1-q}{1+(1-q)(1-q)\widetilde{\rho}} WN_{t-1} + \frac{(1-q)\widetilde{\rho}}{1+(1-q)(1-q)\widetilde{\rho}} E_t WN_{t+1} \\ & + \frac{q\,(1-(1-q)\widetilde{\rho})}{1+(1-q)(1-q)\widetilde{\rho}} \left[p_t \frac{(1-\beta)Y_t}{N_t} \cdot (1 - \eta \cdot (U_t - \overline{U_t})) \right] \end{aligned}$$

[4] The existence of a Phillips curve is assumed here. Some possible explanations linking the nominal and real sides of the economy include the Lucas supply function, the Lucas Island model and the wage contract model (see Turnovsky 1995).

[5] One possible story is to have a bargaining framework in the optimal real wages. In a right-to-manage model, the firm and the union (households) negotiate over the optimal real wages so that the weighted average of the union's utility function and firm's profit function is Nash maximised. This framework yields a functional form of optimal real wages similar to that applied here as a solution to the dynamic optimisation problem.

2.1.4 Rest of dynamic model

Unlike the derivation of equations in the previous subsections we merely list the trade equations here. This part of the model is not derived directly from the optimising behaviour of economic agents and is thus one of the weak parts of the EDGE model. Furthermore, we employ no dynamic aspects in these equations. An additional difficulty in interpreting these equations is that intra-euro area exports are not extracted from total exports in the euro area data. Thus, the total exports data include both intra-euro area exports and exports to non-euro area countries. This is problematic; we proceeded to include domestic demand in our export equation in order to capture the intra-euro area exports. A similar solution to the same problem is presented in Fagan et al (2001). Likewise, the export price equation includes a domestic price deflator to capture the pricing of intra-euro area exports.

Exports, X_t, are assumed to depend both on foreign demand, Y_t^*, and on domestic demand, $DD = C + CG + I + \Delta KI$, and on relative prices $PX/(P^* \cdot e)$, where PX_t is export prices, P_t^* is foreign prices and e_t is the exchange rate. α^{X,Y^*} is the elasticity of exports with respect to foreign demand, $\alpha^{X,DD}$ is the elasticity of exports with respect to domestic demand, $\alpha^{X,PX/(P^* \cdot e)}$ is the elasticity of exports with respect to relative price of exports, and $\alpha^{X,\text{constant}}$ is a constant term:

$$\begin{aligned}\log X &= \alpha^{X,Y^*} \cdot \log Y^* + \alpha^{X,DD} \cdot \log(C + CG + I + \Delta KI) \\ &\quad -\alpha^{X,PX/(P^* \cdot e)} \cdot \log(PX/(P^* \cdot e)) + \alpha^{X,\text{constant}}\end{aligned}$$

Imports, M_t, are assumed to depend on domestic demand, DD, and relative prices, PM/P , where PM_t is import prices and P_t is the output deflator. $\alpha^{M,DD}$ is the elasticity of imports with respect to domestic demand, $\alpha^{M,PM/P}$ is the elasticity of imports with respect to relative import prices, and $\alpha^{M,\text{cons tan t}}$ is a constant term:

$$\begin{aligned}\log M &= \alpha^{M,DD} \cdot \log(C + CG + I + \Delta KI) - \\ &\quad -\alpha^{M,PM/P} \cdot \log(PM/P) + \alpha^{M,\text{constant}}\end{aligned}$$

Since exports include intra-euro area exports export prices, PX, are assumed to be defined by both domestic prices, P,and foreign prices, P^*. $\alpha^{PX,P}$ is the elasticity of export prices with respect to domestic prices, $\alpha^{PX,P^*\cdot e}$ is the elasticity of export prices with respect to foreign prices and, $\alpha^{PX,\text{constant}}$ is a constant term:

$$\log PX = \alpha^{PX,P} \cdot \log P + \alpha^{PX,P^*\cdot e} \cdot \log(P^* \cdot e) + \alpha^{PX,\text{constant}}$$

Import prices, PM, are assumed to depend on export prices, PX, foreign prices, $P^* \cdot e$, and foreign commodity prices, $PC^* \cdot e$. $\alpha^{PM,PX}$ is the elasticity of import prices with respect to export prices, $\alpha^{PM,P^*\cdot e}$ is the elasticity of import prices with respect to foreign prices, $\alpha^{PM,PC^*\cdot e}$ is the elasticity of import prices with respect to foreign commodity prices, and $\alpha^{PM,\text{constant}}$ is a constant term:

$$\begin{aligned}\log PM &= \alpha^{PM,PX} \cdot \log PX + \alpha^{PM,P^*\cdot e} \cdot \log(P^* \cdot e) \\ &\quad + \alpha^{PM,PC^*\cdot e} \cdot \log(PC^* \cdot e) + \alpha^{PM,\text{constant}}\end{aligned}$$

The consumer price deflator, PC_t, depends on domestic prices, P, and import prices, PM. $\alpha^{PC,P}$ is the weight of domestic prices, $\alpha^{PC,PM}$ is the weight of import prices, and $\alpha^{PC,\text{constant}}$ is a constant term in the consumer price deflator:

$$\log PC_t = \alpha^{PC,P} \cdot \log P_t + \alpha^{PC,PM} \cdot \log PM_t + \alpha^{PC,\text{constant}}$$

The investment price deflator, PI_t, depends also on domestic prices, P, and import prices, PM. $\alpha^{PI,P}$ is the weight of domestic prices, $\alpha^{PI,PM}$ the weight of import prices, and $\alpha^{PI,\text{constant}}$ a constant term in the investment price deflator:

$$\log PI_t = \alpha^{PI,P} \cdot \log P_t + \alpha^{PI,PM} \cdot \log PM_t + \alpha^{PI,\text{constant}}$$

The above equations form the core of the dynamic model. In addition, there are some identities and policy variables. One interesting equation is the uncovered interest rate parity, which defines the exchange rate:

$$\log e_t = \log e_{t+1} + (R_t^* - R_t)/400$$

where R_t^* is the foreign nominal interest rate and R_t the domestic nominal interest rate. Of course, the model user may apply exogenous foreign exchange risk premia as necessary.

Policy rules are needed in the model to ensure the existence of a unique long-run equilibrium. On the fiscal policy side, the long-run budget balance is implemented by a closure rule which endogenises the income tax.

The public sector disclosure rule for the direct tax rate is as follows:

$$\begin{aligned} \Delta\tau_t^{direct} &= \alpha^{GDN/YEN} \cdot (GDN_t/YEN_t - \psi) \\ &\quad -\beta^{GLN/YEN} \cdot (GLN_t/YEN_t + \psi \cdot (\pi_{t-1} + g)) \end{aligned}$$

where $\Delta\tau_t^{direct}$ is the change in the direct tax rate. This assumes that taxes are adjusted to deviations in the debt-to-nominal GDP ratio (GDN_t/YEN_t) from the steady-state level, ψ, and similarly deviations of the ratio of public net lending to nominal GDP (GLN_t/YEN_t) from the steady-state level of debt-to-nominal GDP ratio, ψ, multiplied by the nominal growth rate of the economy $(\pi_{t-1} + g)$, where π_{t-1} is the inflation rate and g the real growth rate in the steady-state. $\alpha^{GDN/YEN}$ is the coefficient by which direct taxes react to changes in debt-to-nominal GDP ratio and $\beta^{GLN/YEN}$ the coefficient by which direct taxes react to changes in the ratio of public net lending to nominal GDP.

Monetary policy is endogenised by the Taylor rule (see Taylor 1993). It assumes that the nominal interest rate, R_t, is adjusted for deviations of actual inflation, π_t, from target, $\bar{\pi}_t$, as well as for the output gap represented by the unemployment gap, $(1-\beta)\cdot\left(U_t - \overline{U_t}\right)$, where U_t is the actual unemployment rate, $\overline{U_t}$ the NAIRU and $(1-\beta)$ the labour share of income. Ω is the smoothing parameter of interest rate:

$$\begin{aligned} R_t &= (1-\Omega)\cdot R_{t-1} \\ &\quad +\Omega \cdot \begin{bmatrix} 400 \cdot r^* + 100 \cdot \log\left(PC_t/PC_{t-4}\right) \\ +50 \cdot \left[\log\left(PC_t/PC_{t-4}\right) - 4 \cdot \bar{\pi}_t\right] \\ -50 \cdot (1-\beta) \cdot \left(U_t - \overline{U_t}\right) \end{bmatrix} \end{aligned}$$

A complete list of equations of the dynamic model is presented in appendix A.

2.2 Steady-state model

The above dynamic model also has a companion steady-state model, which enables us to solve the model forward. That is, the steady-state model explicitly defines the long-run equilibrium of the dynamic model.

In general the equations of the dynamic model are transformed to the steady-state equation by defining, for real variables:

$$x_{t+1} = (1+g)x_t$$

where g is the real (equilibrium) growth rate of the economy.

The real growth rate of the economy is derived from the Cobb-Douglas production function[6]

$$Y = T \cdot K^{\beta} \cdot L^{1-\beta}$$

Taking the total differential of the Cobb-Douglas production function yields:

$$dY = \underbrace{\frac{\partial Y}{\partial K}}_{\frac{\beta \cdot Y}{K}} \cdot dK + \underbrace{\frac{\partial Y}{\partial L}}_{\frac{(1-\beta)\cdot Y}{L}} \cdot dL + \underbrace{\frac{\partial Y}{\partial T}}_{\frac{Y}{T}} \cdot dT$$

thus

$$\underbrace{\frac{dY}{Y}}_{g} = \beta \cdot \underbrace{\frac{dK}{K}}_{g} + (1-\beta) \cdot \underbrace{\frac{dL}{L}}_{=0} + \frac{dT}{T}$$

and

$$g = \frac{1}{1-\beta} \cdot \Delta \log T$$

Government debt and net foreign assets are tied to output in the long run. Thus taking the derivative of the government debt-to-nominal GDP ratio yields:

$$d\left(\frac{GDN}{YEN}\right) = \frac{dGDN \cdot YEN - dYEN \cdot GDN}{YEN^2} = 0$$

[6] We choose to use the Cobb-Douglas production function for its analytical comprehensibility. Nevertheless, it is possible to extend this analyse by allowing for a CES production function which can incorporate explanations for the new economy. For a recent treament of the CES function, see Dimitz (2001) and Ripatti and Vilmunen (2001).

where YEN is nominal GDP. This is equal to

$$\frac{-GLN}{YEN} - \underbrace{\frac{dYEN}{YEN}}_{g+\bar{\pi}} \cdot \frac{GDN}{YEN} = 0$$

or equivalently to:

$$GDN = \frac{-GLN}{g+\bar{\pi}}$$

where $g+\bar{\pi}$ is the nominal growth rate. The net foreign assets equation is derived in a similar manner. In the steady-state solution, we set the ratio of government debt to nominal GDP while the ratio of net foreign assets to nominal GDP is solved endogenously by the model. A complete list of the equations of the steady-state model is presented in appendix B.

3 Data and calibration

In this chapter we first describe the data to which we fit our model. Next, we describe our calibration method and results, after which we proceed to build a long baseline for use in simulations. Finally, we present a range of diagnostic simulations which nicely describe the economic behaviour of the model.

3.1 Euro area data

Data for the euro area are obtained from public sources (see table 3.1). The base year for these data is 1995=100. The only period for which there are no missing observations is 1997Q1–1999Q4.

We define the euro area as consisting of 11 member countries. A new member, Greece, joined the euro area at the start of 2001 but is not yet included in the data.

Note that the exchange rate in our data is an effective exchange rate with trade weights. The foreign nominal interest rate that would be most compatible with that exchange rate would incorporate the same trade weights to calculate foreign interest rate. We did not use this but instead approximated the foreign interest rate by US three month interest rates.

Note also that the trade data in the national accounts of the euro area include intra-euro area trade, as explained above.

The general features of this data are presented in the cross-correlation table 3.2. It should be noted that these data cover a very short period, and thus the correlations are somewhat unreliable. Nevertheless, it is interesting to compare this eg to US data for the period 1954Q1–1991Q2 presented in Cooley and Prescott (1995), in Cooley and Hansen (1995) and here in table 3.3. In comparing these, we note that the comparisons are between the data of two large economies in different time periods. It should be emphasised that the cross correlations do not tell us anything about causality. Furthermore, the differences between these dataset may be due different shocks in different time periods. The euro area standard deviations are half or less

Table 3.1 **Data sources**

Model code	TROLL code	Explanation	Source
A	AST	Asset wealth	See Appendix A
C	PCR	Real consumption	ECB Monthly Bulletin Table 5.1 c12
CA	CAN	Current account	ECB Monthly Bulletin Table 8.1 c1
CG	GCR	Real public consumption	ECB Monthly Bulletin Table 5.1 c13
DD	FDD	Real domestic demand	ECB Monthly Bulletin Table 5.1 c11
e	EEN	Nominal effective exchange rate	ECB Monthly Bulletin Table 10 c1
g	g	Real growth in steady-state	Calibrated
GCN	GCN	Nominal public consumption	ECB Monthly Bulletin Table 5.1 c4
GDN	GDN	Nominal public debt	ECB Monthly Bulletin Table 7.2 c1
GIN	GIN	Nominal public investment	ECB Monthly Bulletin Table 7.1 c11
GLN	GLN	Public net lending	GYN – GIN – GCN
GOY	GOY	Nominal public other income	ECB Monthly Bulletin Table 7.1 c8 + 7.1 c11 + 7.1 c12
GYN	GYN	Nominal public dispos. income	TAX + TIN + GOY – TRF – INN
I	ITR	Real investment	ECB Monthly Bulletin Table 5.1 c14
IG	GIR	Real public investment	GIN / PI
INN	INN	Nominal public inter. outlays	ECB Monthly Bulletin Table 7.1 2 c5
K	KSR	Fixed capital stock	$(1-\delta)\cdot K(-1) + I$
ΔKI	DLSR	Change in inventories	ECB Monthly Bulletin Table 5.1 c15
KI	LSR	Inventories	$KI(-1) + \Delta KI$
N	LFN	Labour force	ECB Monthly Bulletin Table 5.4 c7 / 5.4 c8
L	LNN	Labour demand	N – Table 5.4 c7
M	MTR	Imports	ECB Monthly Bulletin Table 5.1 c18
NFA	NFA	Net foreign assets	ECB Monthly Bulletin Table 8.7 c1
NFN	NFN	Net factor income from abroad	ECB Monthly Bulletin Table 8.1 c4 + 8.1 c5
P	YED	GDP deflator	ECB Monthly Bulletin Table 5.1 c1 / 5.1 c10
PC	PCD	Consumer price deflator	ECB Monthly Bulletin Table 5.1 c3 / 5.1 c12
PC*	COMPR	World commodity prices	HWWA-Institut fur Wirtschaftsforschung, HWWA Raw materials price index, 1990=100, USD, rebased (1995=100)
PF	YFD	GDP deflator at factor price	$P\cdot(1-\tau^{indirect})$
P*	YWD	OECD GDP deflator	OECD Economic Outlook
PM	MTD	Import price deflator	ECB Monthly Bulletin Table 5.1 c9 / 5.1 c18
PI	ITD	Investment deflator	ECB Monthly Bulletin Table 5.1 c5 / 5.1 c14
PX	XTD	Export price deflator	ECB Monthly Bulletin Table 5.1 c8 / 5.1 c17
π	INFQ	Quarterly inflation rate	log(PC/PC(–1))
$\bar{\pi}$	INFT	Quarterly inflation target	Calibrated
r	STRQ	Domestic real interest rate	$R/400 - \pi$
r*	STRQF	Foreign real interest rate	R* / 400 – log(P*/P*(–1))
R	STN	Domestic nominal interest rate	ECB Monthly Bulletin Table 3.1 c3
R*	STNF	Foreign nominal interest rate	ECB Monthly Bulletin Table 3.1 c6
T	TFT	Technical progress	Solow residual
TAX	TAX	Direct taxes	ECB Monthly Bulletin Table 7.1 1 c3
τ^{direct}	TAR	Direct tax rate	TAX/YEN
$\tau^{indirect}$	TIR	Indirect tax rate	TIN/YEN
TIN	TIN	Indirect taxes	ECB Monthly Bulletin Table 7.1 1 c6
TRF	TRF	Public transfers	ECB Monthly Bulletin Table 7.1 2 c6
U	URX	Unemployment	ECB Monthly Bulletin Table 5.4 c8
U	URT	NAIRU	Hodrick-Prescott (1600) filtered U
WN	WIN/L	Nominal wages per employee	WIN/L
	WIN	Nominal wage sum	Eurostat new cronos
χ	χ	Equity premium	Calibrated
X	XTR	Exports	ECB Monthly Bulletin Table 5.1 c17
Y	YER	Real GDP	ECB Monthly Bulletin Table 5.1 c10
Y*	YWR	Real OECD GDP	OECD Economic Outlook
YDN	YDN	Nominal private dispos. income	$YFN - TAX + INN + TRF - GOY + NFN - \delta\cdot PI\cdot K$
YEN	YEN	Nominal GDP	ECB Monthly Bulletin Table 5.1 c10 * P
YFN	YFN	Nominal GDP at factor cost	$Y\cdot PF$
ζ	ζ	Windfall gain	See Appendix A

of equivalent standard deviations in the US data. This may reflect the fact the economic environment in the euro area was unexceptionally stable during the 1990s.

Here, we simply note the main features of euro area data described in table 3.2.

Private consumption, investment, exports and imports are procyclical vis-à-vis output and government consumption is counter-cyclical. The leads of private consumption are slightly more highly correlated with output, which implies that output peaks before private consumption. The lags of government consumption are more highly correlated with output, which implies that government consumption bottoms out before output peaks.

Labour demand and labour supply are procyclical and unemployment is counter-cyclical. The leads of the unemployment rate are more highly correlated with output, which implies that output peaks before the unemployment rate bottoms out.

Average real wage is counter-cyclical while the quarterly inflation rate is procyclical. The leads of quarterly inflation rate are more highly correlated with output, which implies that output peaks before inflation.

The nominal interest rate is procyclical while the nominal exchange rate is counter-cyclical. The leads of the nominal exchange rate are more highly correlated with output, which implies that output peaks before the exchange rate bottoms out. Furthermore, the leads of the nominal exchange rate are highly positively correlated with output, which implies that the exchange rate peaks before output peaks. The leads of the nominal interest rate are highly correlated with output, which implies that output peaks before the interest rate peaks. Moreover, the lags of the nominal interest rate are highly negatively correlated with output, which implies that the nominal interest rate bottoms out before output peaks.

3.2 Calibration

Calibration is used instead of estimation. As the euro area is so new, its behavior must be inferred from the past, rather than directly estimated from the previous aggregated behavior of its component

Table 3.2 **Cyclical behaviour of key variables of euro area economy, deviations from trend, 1991Q1–2000Q1**

		Cross-correlation of output with:										
Variable	**SD%**	**x(–5)**	**x(–4)**	**x(–3)**	**x(–2)**	**x(–1)**	**x**	**x(+1)**	**x(+2)**	**x(+3)**	**x(+4)**	**x(+5)**
Output component												
GDP	0.65	–0.55	–0.34	0.05	0.50	0.84	1.00	0.80	0.44	0.12	–0.21	–0.55
Private consumption												
C	0.62	–0.71	–0.63	–0.36	0.08	0.37	0.64	0.70	0.66	0.32	0.19	0.06
Fixed investment												
I	1.89	–0.59	–0.36	–0.04	0.36	0.66	0.89	0.78	0.51	0.15	–0.12	–0.20
Government consumption												
CG	0.65	–0.44	–0.41	–0.44	–0.52	–0.57	–0.42	–0.28	–0.15	0.02	0.15	0.39
Exports and imports												
X	2.18	–0.21	0.02	0.40	0.69	0.85	0.79	0.52	0.10	–0.27	–0.49	–0.58
M	2.50	–0.48	–0.27	0.14	0.51	0.80	0.93	0.80	0.46	–0.02	–0.35	–0.56
Labour force, labour demand and unemployment												
N	0.35	–0.28	0.01	0.18	0.35	0.41	0.37	0.25	0.09	0.10	0.22	0.30
L	0.63	–0.39	–0.15	0.04	0.28	0.50	0.67	0.70	0.65	0.55	0.41	0.22
U	0.38	0.34	0.21	0.05	–0.16	–0.43	–0.70	–0.85	–0.85	–0.69	–0.39	–0.05
Average real wage and quarterly inflation rate												
(WIN/LNN)/PCD*	0.39	–0.20	0.02	0.10	0.22	–0.21	–0.62	–0.47	–0.04	0.23	0.31	0.24
INFQ	0.36	–0.14	0.09	0.12	0.07	0.14	0.13	0.19	0.28	0.23	0.22	0.08
Nominal exchange and interest rate												
EEN	3.41	0.18	0.37	0.50	0.41	0.08	–0.22	–0.52	–0.76	–0.64	–0.36	–0.07
STN	0.78	–0.63	–0.65	–0.61	–0.39	–0.02	0.37	0.68	0.86	0.76	0.52	0.19

* Average real wage, 1995Q1–2000Q1

Table 3.3 **Cyclical behaviour of key variables of US economy, deviations from trend, 1954Q1–1991Q2**

		Cross-correlation of output with:										
Variable	**SD%**	**x(–5)**	**x(–4)**	**x(–3)**	**x(–2)**	**x(–1)**	**x**	**x(+1)**	**x(+2)**	**x(+3)**	**x(+4)**	**x(+5)**
Output component												
GNP	1,72	–0.02	0.16	0.38	0.63	0.85	1.00	0.85	0.63	0.38	0.16	–0.02
Consumption expenditures												
CNDS	0,86	0.22	0.40	0.55	0.68	0.78	0.77	0.64	0.47	0.27	0.06	–0.11
Investment												
INV	8,24	0.04	0.19	0.38	0.59	0.79	0.91	0.76	0.50	0.22	–0.04	–0.24
Government purchases												
GOVT	2,04	0.03	–0.01	–0.03	–0.01	–0.01	0.04	0.08	0.11	0.16	0.25	0.32
Exports and imports												
EXP	5,33	–0.48	–0.42	–0.29	–0.10	0.15	0.37	0.50	0.54	0.54	0.52	0.44
IMP	4,88	0.11	0.19	0.31	0.45	0.62	0.72	0.71	0.52	0.28	0.04	–0.18
Average hourly earnings and compensation												
WAGE	0,76	0.20	0.35	0.47	0.58	0.66	0.68	0.59	0.46	0.29	0.12	–0.03
COMP	0,55	0.24	0.25	0.21	0.14	0.09	0.03	–0.07	–0.09	–0.09	–0.09	–0.10
Labour input based in Household Survey												
HSHOURS	1,59	–0.06	0.09	0.30	0.53	0.74	0.86	0.82	0.69	0.52	0.32	0.11
Prices												
GNPDEF	0,88	–0.52	–0.63	–0.69	–0.70	–0.65	–0.57	–0.44	–0.31	–0.17	–0.04	0.08
CPI	1,43	–0.57	–0.66	–0.71	–0.72	–0.65	–0.52	–0.35	–0.17	0.02	0.19	0.34
INFLATION	0,57	–0.32	–0.23	–0.10	0.01	0.19	0.34	0.43	0.44	0.47	0.43	0.34
Interest rates												
TB1MO	1,29	–0.55	–0.41	–0.27	–0.03	0.20	0.40	0.42	0.44	0.36	0.32	0.25

Note: GNP-real GNP, 1982$; CNDS-consumption of nondurables and services, 1982$; INV-gross private domestic investment, 1982$; GOVT-government purchases of goods and servides, 1982$; EXP-exports of goods and services, 1982$; IMP-Imports of goods and services, 1982$; WAGE-Average hourly earning, 1982$ (Establishment Survey); COMP-average total compensation per hour, 1982$ (National Income Accounts); HSHOURS-total hours of work (Household Survey); GNPDEF-implicit GNP deflator; CPI-Consumer Price Index, all items; INFLATION-dln(CPI); TB1MO-1-month Treasury bill rate. The Establishment Survey sample is for 1964Q1–1991Q2. Sources: Table 1.1 in Cooley and Prescott and Table 7.1 in Cooley and Hansen in Cooley (ed.) 1995, Frontiers of Business Cycle Research, Princeton. Reprinted with the permission of the author.

parts. Furthermore, compatible euro area data are only of recent vintage and their quality may not yet be very good. Moreover, other countries will join the euro area in the near future, which will mean additional adjustments to the data.

We view calibration as a variant of econometric estimation. Many prefer econometric estimation to calibration on the grounds that the former is based on rigorous statistical theory, which enables use of statistically current criteria to reject models. Calibration, in contrast, involves an a priori model, which is fit to the data. Thus, calibration cannot choose between models on rigourous statistical grounds. Choice between models via calibration is more akin to eyeballing. However, if one regards calibration as Bayesian estimation with extreme priors, then calibration is indeed estimation.

An interesting aspect of calibration is that it can handle the model and the data as a system. Normally, with econometric procedures like ML and GMM, one is able to estimate one equation or one block of equations while keeping the rest of the model exogenous to this estimation procedure. The FIML method is ideal for estimating the whole model but is seldom used in practice. When calibration is done with the whole model, no free lunches are obtained by overfitting one equation, since this affects other parts of the model. In this sense, calibration when applied to the whole model is even more 'systematic' than any prevailing econometric estimation method.

Our methodology in calibration is the matching of moments (see eg. Kim and Pagan 1995). The EDGE model is calibrated to available euro area data described above, by trying to match the first moment. Nevertheless, we do carry out a battery of stochastic simulations to see if the variations in variables measured by the standard deviation and cross correlation structure of the model resembles that of the data. With respect to skewness and kurtosis, no attempt is made to relate these to those of the data.

As our second guideline we have ran a battery of diagnostic simulations. These were mainly in the context of checking model specification and possible typos in equation listings. We note that after finding errors in model specification or in equation lists, we returned to the calibration stage in order to recalibrate the model. Thus, the diagnostic simulations also generated recalibration of parameters.

A third guideline that we apply is the use of earlier experience gained from previous work in the field. In particular, we have looked to other countries, the United States being a natural candidate for comparison – that might be relevant to our case. However, we do this only to get a reasonable starting value for the equity premium.

A fourth possible guideline is to estimate equations. We estimated some relationships during the calibration process, but all those relationships that are currently used are the result of pure calibration.

3.2.1 Calibration of steady-state model

Calibration of the steady-state is done for the period 1997Q1–1999Q4, for which the data set included all the variables.

We calibrated the income share of capital, β, by calculating the income share of labour, $1 - \beta$, from the first order condition. Next, we used this β to calculate the Solow residual. The NAIRU is a Hodrick-Prescott filtered unemployment series (with smoothing parameter 1600). We assumed that the depreciation rate, δ, equals 1% per quarter. This depreciation rate was used in constructing the fixed capital stock series.

In calibrating of the steady-state, we assumed that the inflation target equals the period average of the inflation rate, which is 0.002697 per quarter. A similar assumption is used for the foreign real interest rate, which averages 0.008202 per quarter.

The equity premium, χ, is calibrated to be close to the US equity premium. Using US data for years 1800–1990, Siegel (1992), finds that the geometric real US short-term return is 2.95 and the geometric real US stock return is 6.2, which would correspond to roughly a 3% annual equity premium. In EDGE the equity premium, χ, is calibrated to be 0.9% per quarter, or roughly 3.6% pa. The real growth rate, g, is calibrated to be 0.5% per quarter.

The coefficient of the fundamental term in the consumption equation $\left(\dfrac{p\Lambda}{(1-(1-p)\Lambda)}\right)$ is calibrated to be 0.015 per quarter and the coefficient of the lead variable $\left(\dfrac{1-p}{1-(1-p)\Lambda}\right)$ is calibrated to be 0.6. We note that these coeffient values are well suited to the rest of the model and the data. We also add a caveat in this connection:

if these coefficient values are used and the 'deep' parameters are calculated, we obtain for the subjective discount factor $\theta = 1.641\,7$ and for the constant probability of death facing an agent $p = 0.41255$. Both figures are certainly too high by any reasonable measure. Interestingly, if we calculate the marginal propensity to consume with these parameter values we find that $1 - (1 - p) * \theta = 1 - (1 - 0.412\,55) * 1.641\,7 = 0.03558\,3$, which is in the range we would expect.[7] Thus, even though these deep structural parameters seem to be out of the range of approval separately, together they do comply with the data. What this implies is that either 1) the derivation used to obtain the consumption is not correct, 2) assumptions used in deriving consumption are not valid, 3) assumptions regarding the rest of the model are not correct, or 4) the data may not be correct. In our view this caveat is just a mirror image of the usual consumption problem, which has often led to modelling approaches where some additional lags of consumption are introduced in aggregate consumption. These approaches include liquidity constraints, myopic behaviour and habit formations. In the first two approaches, these constraints are not derived from first principles. Thus, if we want our model to fit the 'deep' parameters, we could introduce consumption lags. This 'solution' is not free of charge: the basic properties of our model would change. We opt to keep consumption as it stands, since this is in the line with the theory.

Foreign trade equations are calibrated to the data so that the nominal exchange rate is fairly close to the data at the end of the period. We note that these parameter choices also fulfill the Marshall-Lerner condition, ie that the sum of the elasticities of export and import volumes exceed unity. In our case this amounts to fact that devaluation of the exchange rate should improve the trade balance when domestic activity and prices are exogenous.

With this calibration we find that the steady-state solution is relatively close to the data (see figure 3.1 and table 3.5).

[7] Sefton and in't Veld (1999), for example, estimate marginal propensities to consume out of wealth at 0.03, 0.086, 0.06 and 0.04 for USA, Canada, UK and Germany respectively, in a Blanchard -type consumption model augmented with liquidity constrained consumers.

Table 3.4: Calibration of steady-state model

Parameter	Value	Description
β	0.415726	Income share of capital
δ	0.01	Depreciation rate
χ	0.009	Equity premium
–	0.6	Coefficient. of the lead in consumption equation
–	0.015	Coefficient of the fundamental term in consumption equation
g	0.005	Real growth in steady-state
ν	0.33	Share of profits paid to public sector
k	0.883242	Ratio of stock of inventories to real GDP
–	1.2	Elasticity of exports with respect to foreign demand
–	–0.409181	Elasticity of exports with respect to relative prices
–	0.63	Constant in exports equation
–	1.2	Elasticity of imports with respect to domestic demand
–	–0.9	Elasticity of imports with respect to relative prices
–	–3.9	Constant in imports equation
–	0.32	Elasticity of export prices with respect to domestic prices
–	–0.05	Constant in export price equation
–	0.48	Elasticity of import prices with respect to export prices
–	0.38	Elasticity of import prices with respect to foreign prices
–	–0.65	Constant in import price equation
–	0.9	Elasticity of consumer prices with respect to GDP deflator
–	0.01	Constant in consumer price equation
–	0.85	Elasticity of investment prices w.r.t. GDP deflator at factor cost
–	0.10	Constant in investment price equation
–	0.25	Coefficient of unemployment rate in transfers to GDP
–	0.2	Constant in investment price equation
γ	0.2	Ratio of government real consumption to GDP
ξ	0.028	Ratio of public real investment to GDP
ψ	0.7	Ratio of nominal public debt to GDP
b_4	0.2	Ratio of other public income to GDP

In table 3.5, the abbreviations stand for:

$$\%MD = mean\,deviation = 100 \cdot \frac{\frac{1}{T}\sum\limits_{t=1}^{T}\left(Y_t^s - Y_t^a\right)}{\frac{1}{T}\sum\limits_{t=1}^{T} Y_t^a}$$

$$\%MAD = mean\,absolute\,deviation = 100 \cdot \frac{\frac{1}{T}\sum\limits_{t=1}^{T}\left|Y_t^s - Y_t^a\right|}{\frac{1}{T}\sum\limits_{t=1}^{T} Y_t^a}$$

$$\%RMSE = \%\,root\,mean\,square\,error = 100 \cdot \frac{\sqrt{\frac{1}{T}\sum\limits_{t=1}^{T}\left(Y_t^s - Y_t^a\right)^2}}{\frac{1}{T}\sum\limits_{t=1}^{T} Y_t^a}$$

$$MAPE = mean\,absolute\,percent\,error = 100 \cdot \frac{1}{T}\sum_{t=1}^{T}\left|\frac{\left(Y_t^s - Y_t^a\right)}{Y_t^a}\right|$$

where Y_t^s and Y_t^a are the simulated and actual values of Y_t.

Mean deviation is problematic since it may be the case that positive and negative errors cancel out. Mean absolute deviation avoids this problem. Root mean square error penalises large individual errors more heavily and thus is more sensitive to unusually large errors than MAD. Mean absolute per cent error uses relative errors which allow a unit-free scale of evaluation.

In table 3.5 some variables such as the ratios of net foreign assets to nominal GDP and public debt to GDP are far from the levels in the data. Note, however, that our objective is not to fit the long-run steady-state equilibrium to the current state of business cycle.

Figure 3.1 **Calibration of steady-state deviations from data**

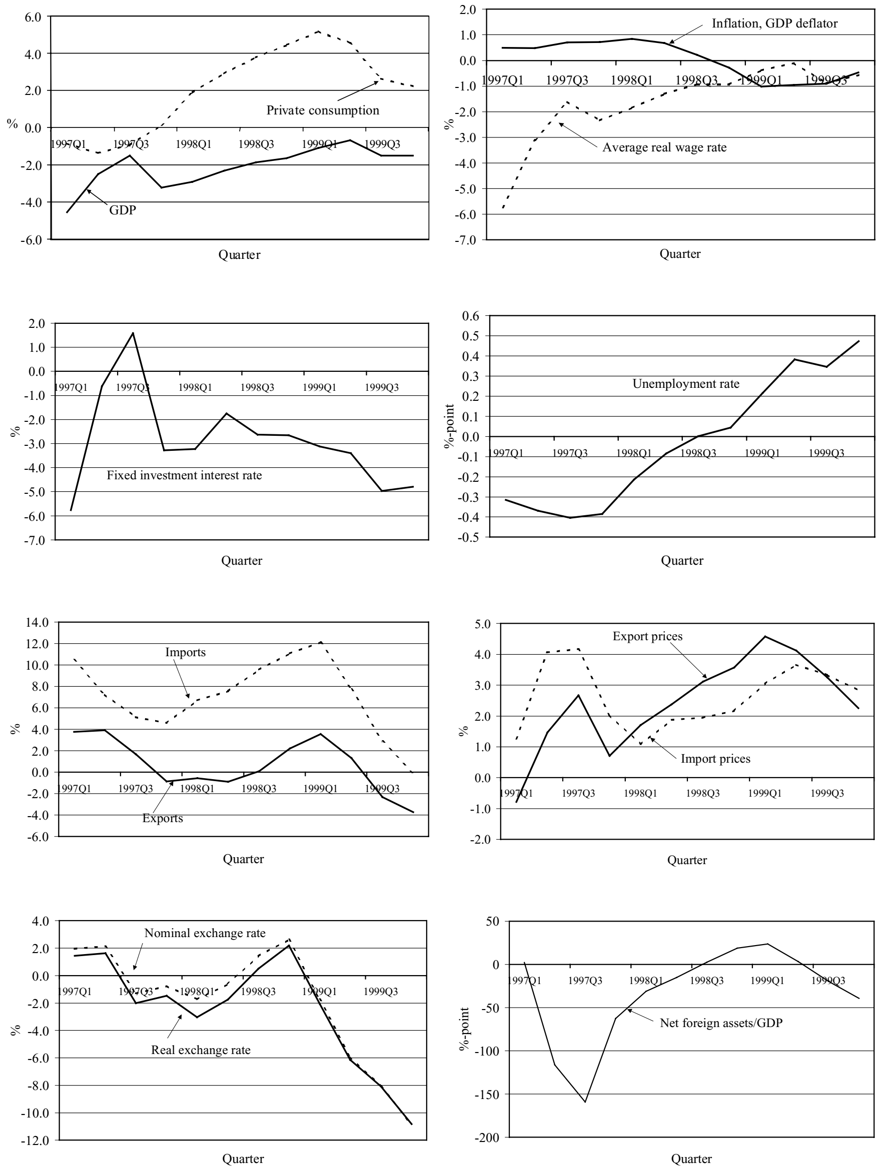

Table 3.5 **Ex post calibration/simulation accuracy of steady-state model**

		%MD	%MAD	%RMSE	MAPE
Real GDP	Y	–2.09	2.09	2.31	2.11
Private consumption	C	2.09	2.60	3.05	2.58
Fixed investment	I	–2.91	3.17	3.48	3.15
Exports	X	0.58	2.06	2.44	2.07
Imports	M	7.00	7.01	7.78	7.09
GDP deflator	P	0.56	0.57	0.69	0.57
Consumer price deflator	PC	0.70	0.70	0.82	0.70
Investment price deflator	PI	–0.01	0.35	0.39	0.35
Export price deflator	PX	2.41	2.54	2.80	2.55
Import price deflator	PM	2.62	2.62	2.81	2.62
Real wages	WR	–1.64	1.64	2.21	1.65
Labour demand	L	0.03	0.30	0.35	0.30
Nominal exchange rate	e	–2.04	3.34	4.72	3.26

		MD	MAD	RMSE
Annual inflation rate	INFY	1.05	1.05	1.06
Unemployment rate	U	–0.03	0.27	0.31
Nominal interest rate	R	0.67	0.70	0.90
Budget deficit/GDP	GLN/YEN	–0.32	0.34	0.52
Public debt/GDP	GDN/YEN	–14.27	14.27	14.89
Current account/GDP	CAN/YEN	–1.12	1.12	1.39
Net foreign assets/GDP	NFA/YEN	–32.71	41.13	62.44

For lower panel MD, MAD and RMSE are not divided by aggregate level of variable.

3.2.2 Calibration of dynamic model

In calibrating the dynamic model we also solve the model for period 1997Q1–1999Q4. We note that our data cover too short a period, since the dynamic model uses lagged values for net foreign assets, NFA. Therefore we extend the data set backward for variable NFA by using equations described in appendix A.

For the labour demand, wages and GDP deflator equations, the coefficients of the fundamentals, ie $\frac{b}{1+b+\rho}$, $\frac{q\,(1-(1-q)\widetilde{\rho})}{1+(1-q)(1-q)\widetilde{\rho}}$ and $\frac{a}{1+a+\widetilde{\rho}}$, are calibrated so that the adjustment speed (to change in fundamental term) of labour demand is fastest and the adjustment speed of prices is faster than that of wages. Furthermore, the coefficient of the unemployment gap, η, is calibrated to be 3 in the Phillips curve.

The reaction function of the monetary authority is assumed to be a Taylor rule (see Taylor 1993), ie the nominal interest rate is a function of the foreign real interest rate, the domestic inflation rate, the deviation of inflation from target, and the unemployment gap. The inflation deviation has a weight of 0.5, and the unemployment gap multiplied by the labour share of income has a weight of 0.5.

Inertia in interest rate setting may not be as important as is often thought. Arguments have been raised that central banks adjust the interest rate in response to new information within a quarter and that what appears as interest rate smoothing actually reflects the influence of some slow-moving ‘omitted variables’ in the monetary policy reaction function (see eg Rudebusch 2000). Hence, we did not smooth the interest rate response, ie Ω equals one.

Table 3.6: Calibration of dynamic model

Description	Value
Coefficient of lead in labour demand equation	0.483
Coefficient of lag in labour demand equation	0.492
Coefficient of fundamental term in labour demand equation	0.025
Coefficient of second lead in investment equation	–0.324
Coefficient of lead in investment equation	0.986
Coefficient of lag in investment equation	0.3378
Coefficient of fundamental term in investment equation	0.0005
Coefficient of lead in wage equation	0.49
Coefficient of lag in wage equation	0.5
Coefficient of fundamental term in wage equation	0.01
Coefficient of lead in price equation	0.485
Coefficient of lag in price equation	0.495
Coefficient of fundamental term in price equation	0.02
Coefficient of deviation of production in inventories equation	–0.5
Coefficient of lead in inventories equation.	0.494

The fit of this calibration with exogenous interest rate and exchange rate is presented in figure 3.2 and table 3.7.

Next, we endogenise the interest and exchange rates and induce an exchange rate premium. The latter is defined by the residual of the exchange rate equation and is plotted below in figure 3.3.

Figure 3.2 **Calibration of dynamic model with exogenous interest and exchange rates deviations from data**

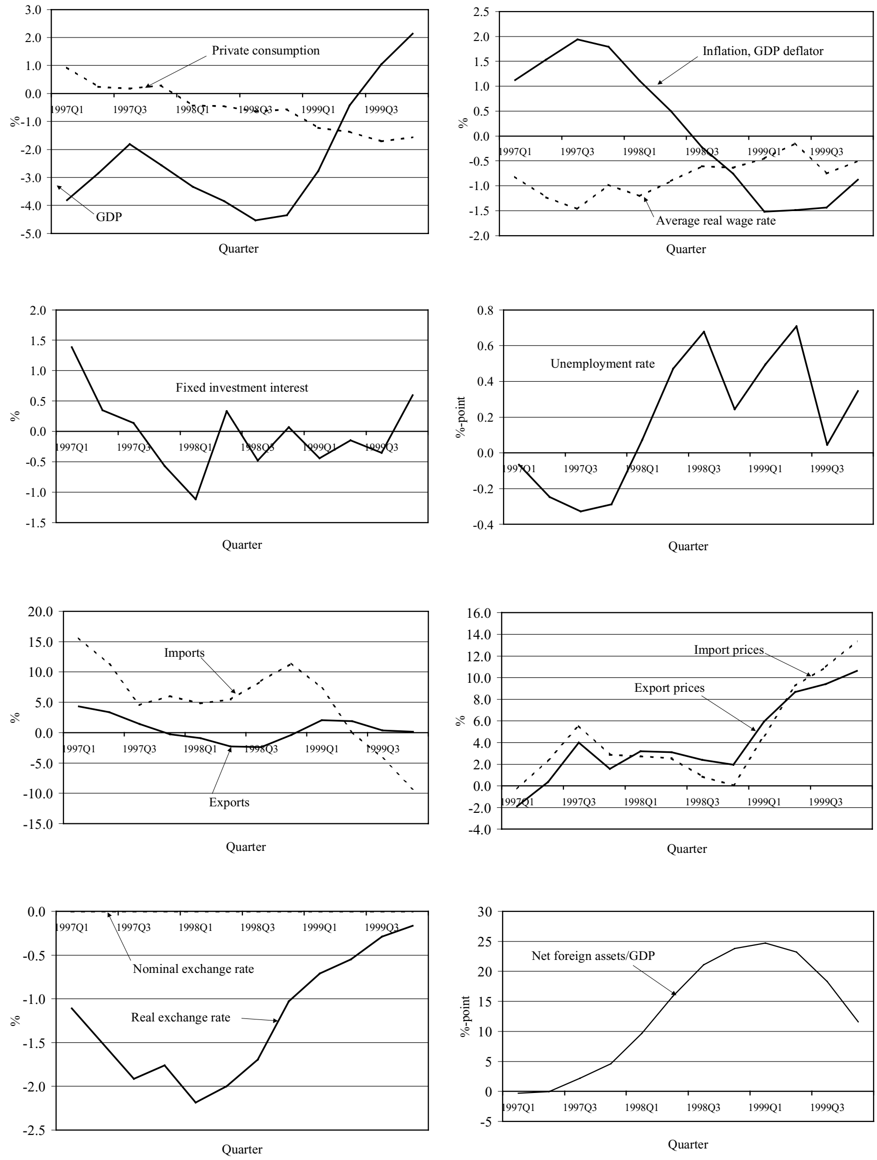

Table 3.7 **Ex post simulation accuracy of dynamic model with exogenous interest and exchange rate**

		%MD	%MAD	%RMSE	MAPE
Real GDP	Y	–2.23	2.78	3.03	2.79
Private consumption	C	–0.55	0.81	0.97	0.80
Fixed investment	I	–0.03	0.49	0.61	0.50
Exports	X	0.56	1.61	1.98	2.07
Imports	M	4.79	7.26	8.13	7.38
GDP deflator	P	1.26	1.26	1.43	1.26
Consumer price deflator	PC	1.51	1.51	1.60	1.51
Investment price deflator	PI	0.85	0.88	1.04	0.88
Export price deflator	PX	4.12	4.43	5.52	4.43
Import price deflator	PM	4.60	4.65	6.29	4.62
Real wages	WR	–0.81	0.81	0.88	0.81
Labour demand	L	–0.20	0.37	0.44	0.37
Nominal exchange rate	e	0	0	0	0

		MD	MAD	RMSE
Annual inflation rate	INFY	1.34	1.34	1.46
Unemployment rate	U	0.18	0.33	0.39
Nominal interest rate	R	0	0	0
Budget deficit/GDP	GLN/YEN	0.44	0.77	0.88
Public debt/GDP	GDN/YEN	3.40	4.02	4.32
Current account/GDP	CAN/YEN	0.22	1.54	1.92
Net foreign assets/GDP	NFA/YEN	13.02	13.10	16.01

For lower panel MD, MAD and RMSE are not divided by aggregate level of variable.

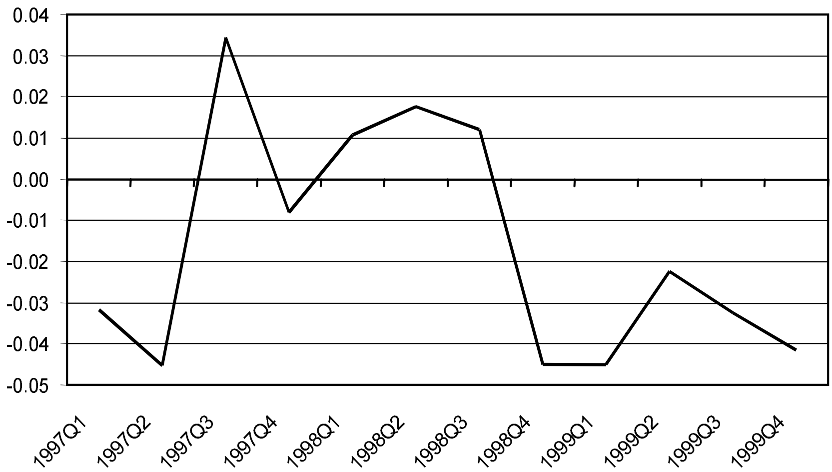

Figure 3.3. Exchange rate risk premium 1997Q1–1999Q4

The fit of this calibration with endogenous interest rate and exchange rate, together with exchange rate risk premium, is presented in figure 3.4 and table 3.8.

3.3 Baseline

In order to utilise our model more thoroughly we build a long simulation run beyond our data set. We call this ex ante simulation run the baseline. We emphasise that this baseline is purely a model-based simulation result and should not be interpreted as an ex ante forecast exercise.

We note that our dataset is a 'ragged edge' meaning that there are periods for which data exist for some variables but not for others. As we are not concerned here with forecasting, we use the last period for which all variables are observed to get our initial values. Thus, the end of our clean dataset is 1999Q4, and the simulation starts at 2000Q1.

Before discussing simulation results, we explain briefly how the model is solved. The EDGE model is coded and solved in the Troll simulation software. We employ the new stacktime (Laffarque-Boucekkine-Juillard) algorithm to solve the model forward

Figure 3.4 **Calibration of dynamic model with exchange rate risk premium deviations from data**

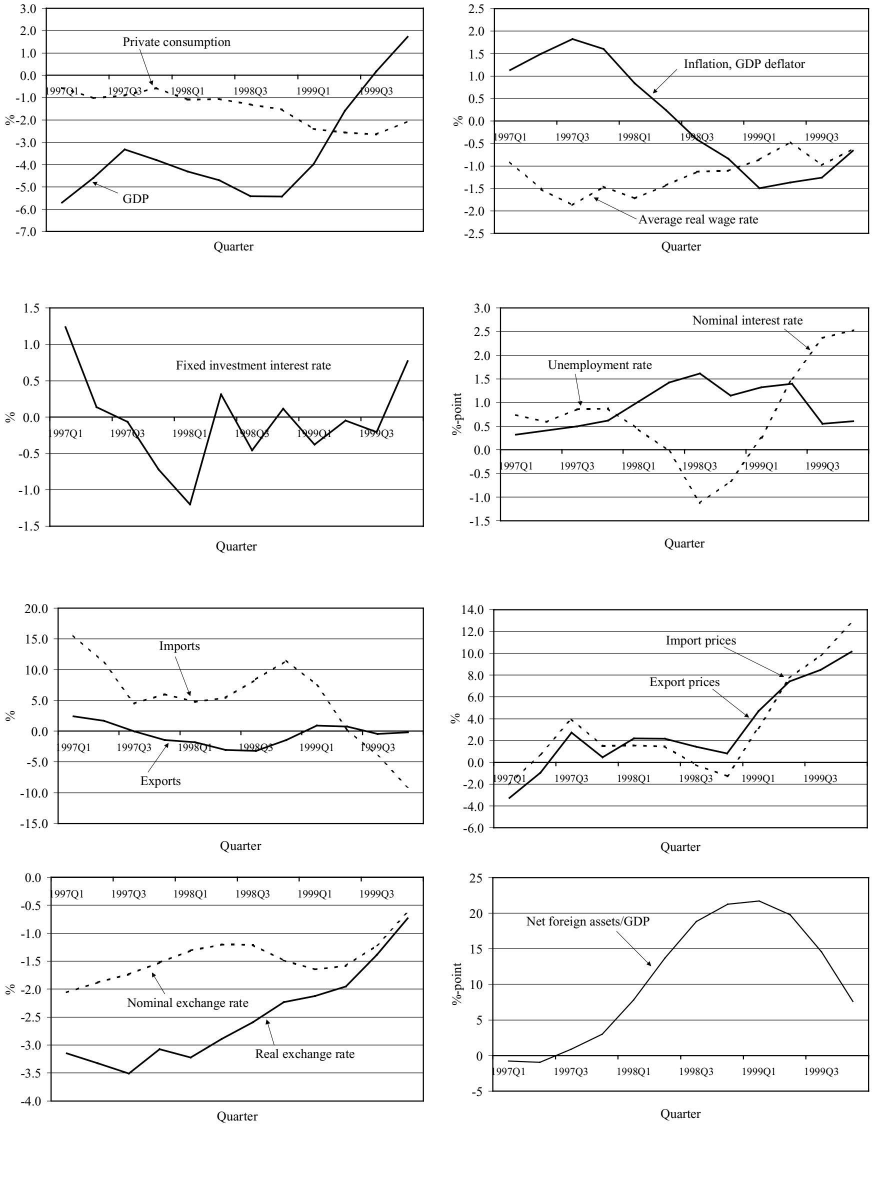

Table 3.8 **Ex post simulation accuracy of dynamic model with endogenous interest and exchange rates and exchange rate risk premium**

		%MD	**%MAD**	**%RMSE**	**MAPE**
Real GDP	Y	–3.38	3.70	4.05	3.73
Private consumption	C	–1.49	1.49	1.67	1.48
Fixed investment	I	–0.04	0.47	0.61	0.47
Exports	X	–0.53	1.43	1.74	1.45
Imports	M	4.82	7.22	8.08	7.35
GDP deflator	P	1.08	1.08	1.26	1.09
Consumer price deflator	PC	1.23	1.23	1.33	1.23
Investment price deflator	PI	0.52	0.68	0.81	0.68
Export price deflator	PX	3.03	3.73	4.87	3.73
Import price deflator	PM	3.29	3.88	5.53	3.85
Real wages	WR	–1.17	1.17	1.24	1.17
Labour demand	L	–1.02	1.02	1.13	1.02
Nominal exchange rate	e	–1.45	1.45	1.49	1.46

		MD	**MAD**	**RMSE**
Annual inflation rate	INFY	1.26	1.26	1.39
Unemployment rate	U	0.91	0.91	1.01
Nominal interest rate	R	0.69	0.99	1.24
Budget deficit/GDP	GLN/YEN	0.13	1.02	1.16
Public debt/GDP	GDN/YEN	5.10	5.10	5.60
Current account/GDP	CAN/YEN	–0.14	1.61	1.94
Net foreign assets/GDP	NFA/YEN	10.83	11.16	13.87

For lower panel MD, MAD and RMSE are not divided by aggregate level of variable.

(see Juillard 1996 and Hollinger 1996). Below, we illustrate two interesting aspects: the simulation horizon and the use of a terminal dummy.

Note that because we have a forward looking model we need terminal points. The length of a simulation period is not an innocent choice since there are typically some terminal adjustments. In order to minimise the effects of these terminal adjustments, we solve the model for fairly long periods. In a typical simulation, we first run the steady-state model for over 800 periods, ie 2000Q1–2200Q4. This steady-state run defines the endpoints for the dynamic model. After solving for the terminal points, we run the dynamic model forward for 800 periods ie from 2000Q1 to 2199Q4. We compare real GDP figures for two runs: one run is for 400 periods and the other is for 800 periods. We note that extending the period increases the solution value of real GDP by 0.006% in the first period (see figure 3.5). The period over which the simulation is run can be easily extended, but even with this solution period the % -difference due to terminal adjustment is negligible. Nevertheless, we use a 200-years simulation horison.

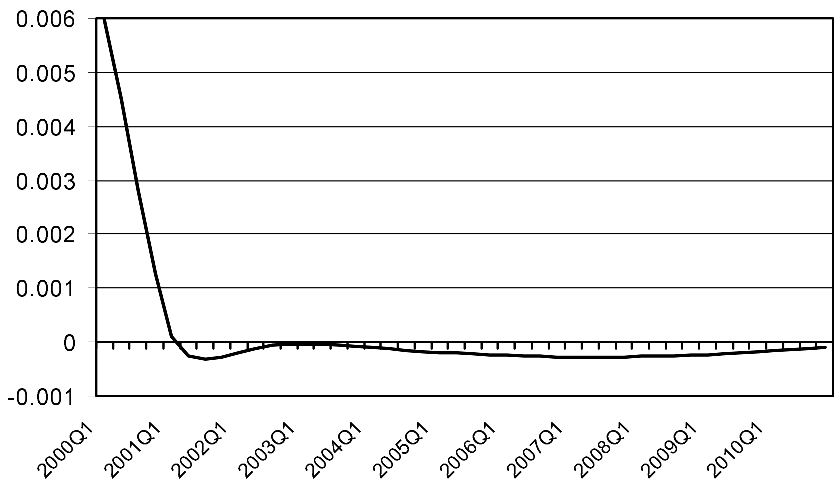

Figure 3.5. Difference in output between 200- and 100-year runs, 2000Q1–2010Q4, %

In solving the dynamic model forward we exploit a terminal dummy placed in the last period to be solved, 2199 Q4. For this last period, we modify our model by implementing a terminal dummy in the forward-looking equations that describe nominal variables, ie the nominal wage, nominal assets, GDP deflator and nominal exchange rate equations. The solution for these variables is corrected by the difference between the previous-period dynamic price level, multiplied by the inflation target, and the steady-state price level. As a result, our nominal variables do not necessarily – and in most cases never do – converge to the steady-state, while the real variables do converge. In figure 3.6 the nominal exchange rate is plotted in a steady-state (ss_een), in a dynamic solution with terminal dummies (dy_een) and in a dynamic solution with no terminal dummies (dy2_een).

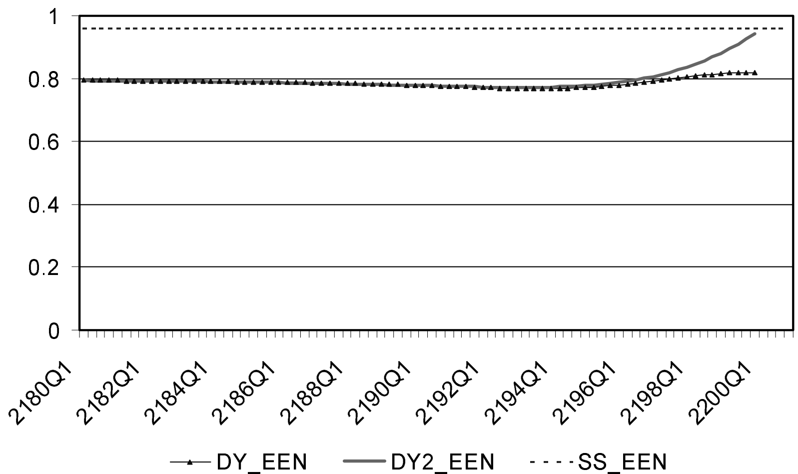

Figure 3.6. Nominal exchange rate, 2180Q1–2200Q4

In practice the effect of this correction to the short-run simulation results is even more negligible than the extension of the solution horizon from 100 years to 200 years (see figure 3.7). Nevertheless, we are swayed to keep this construction since it yields an intuitively more appealing solution by not tilting the nominal variables back to the steady-state in the long-run, as shown in figure 3.6.

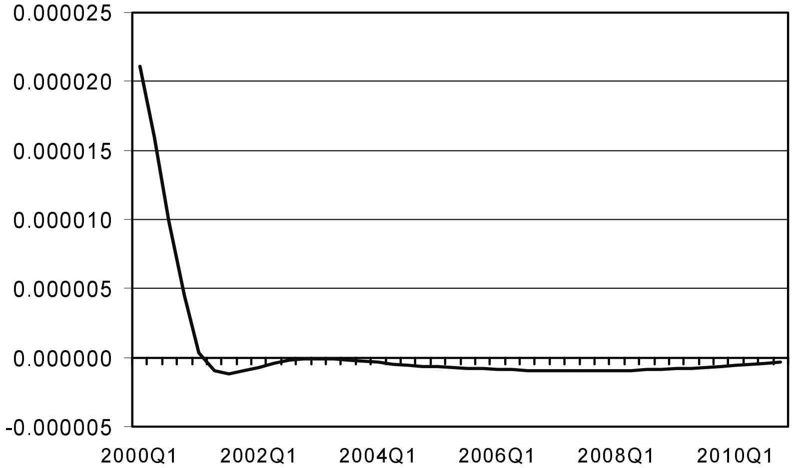

Figure 3.7. Difference in output between run without vs with terminal dummies, 2000Q1–2010Q4

In building the baseline solution we make the following assumptions with regard to exogenous variables: the nominal public debt-to-nominal GDP ratio is 0.7 in the steady-state; there is no population growth; the last value of NAIRU in the data, ie the 9.8%, is assumed to prevail in the steady-state; the inflation target is fixed at the data mean for 1997–1999, ie 0.002697 per quarter; foreign prices are assumed to grow at the rate $(1+0.002697)^4-1=0.010832$ pa; the foreign real interest rate is fixed at the data mean for 1997–1999, ie 0.008202 per quarter; the growth rate of foreign real GDP is assumed equal to the domestic rate, ie 0.005 per quarter; and the indirect and direct tax rates are fixed at the last data values, ie 0.144 and 0.124 respectively. We further assume that there is no risk premium, ie the risk premium is calibrated to zero in the future foreign exchange rate.

Next, we solve the steady-state model for periods 2000Q1–2200Q4. Using this steady-state for terminal values, we solve the dynamic model for the baseline solution for the period 2000Q1–2199Q4.

In order to compare the outcome for this artificial EDGE economy to the euro area data, we perform some stochastic simulations to obtain the correlation structure. We introduce first a technology shock, ε_t^{TFT}, which we assume is an iid process with distribution $N(0,\sigma^{TFT})$. We approximate the standard deviation by calculating the standard deviation of the total factor productivity from the data for 1997Q1–1999Q4, which is 0.00897 per quarter.

Next, we simulate the model with this stochastic shock for the next 150 years. In this simulation, 600 independent stochastic shocks are drawn from above distribution. The first shock is introduced in both steady-state and dynamic models for the first quarter, while the remaining 599 quarters are simulated with the expected (zero) value of future shocks. In the second period, a new stochastic shock is fed in both the steady-state and dynamic models while assuming that the shock is zero for the next 598 quarters. Hence, we feed, in succession, 600 random shocks to the model. This is of course only one sequence of draws from the normal distribution and the results are subject to a sampling error. Note, however, that the simulation period is relatively long, which may strengthen the validity of the results.

The cross-correlations of interesting variables with output are presented in table 3.9. From table 3.9 one can see a few interesting features of the EDGE model. The variances for real GDP, consumption and real wages are somewhat higher while for the other variables the variances are lower than in the data. The actual correlation structure with real variables clearly is akin to the data albeit there are certain differences. However, for real wages, inflation rate, nominal exchange and interest rates the correlation with output at time t seems to change sign. We interpret this as an indication that the actual data has been subjected to different shocks.

In order to have a different view of the artificial EDGE economy, we impose an alternative stochastic shock to the nominal exchange rate. We introduce an exchange rate shock, ε_t^{EEN}, which we assume is an iid process distributed $N(0, \sigma^{ENN})$. We approximate the standard deviation by calculating the standard deviation of the nominal exchange rate from the data for 1997Q1–1999Q4, which equals 0.0370 per quarter. We do however implement this shock with a slightly smaller standard deviation, ie $\sigma^{ENN} = 0.025$, so as to guarantee the solvency of the shock. The cross-correlation table of this shock is described in table 3.10. Note that the time t correlations of output with real wages and with the inflation rate are now consistent with the data. However, the variance of most variables is clearly too low compared to the data.

Table 3.9 **Cyclical behaviour of key variables of artificial EDGE economy based on stochastic tehnology shocks, deviations from trend**

		Cross-correlation of output with:										
Variable	**SD%**	**x(–5)**	**x(–4)**	**x(–3)**	**x(–2)**	**x(–1)**	**x**	**x(+1)**	**x(+2)**	**x(+3)**	**x(+4)**	**x(+5)**
Output component												
GDP	1.57	–0.05	–0.01	0.11	0.31	0.52	1.00	0.52	0.31	0.11	–0.01	–0.05
Private consumption												
C	1.49	–0.06	–0.01	0.09	0.29	0.51	0.97	0.69	0.47	0.23	0.06	–0.01
Fixed investment												
I	1.00	–0.37	–0.34	–0.27	–0.15	0.03	0.32	0.50	0.59	0.60	0.57	0.52
Exports and imports												
X	1.40	–0.05	–0.01	0.11	0.31	0.52	1.00	0.51	0.30	0.11	–0.01	–0.04
M	1.64	–0.07	–0.04	0.08	0.29	0.49	0.98	0.40	0.23	0.09	0.03	0.03
Labour demand and unemployment												
L	0.16	0.03	0.08	0.17	0.31	0.50	0.84	0.76	0.56	0.30	0.06	–0.12
U	0.15	–0.03	–0.08	–0.17	–0.31	–0.50	–0.84	–0.76	–0.56	–0.30	–0.06	0.12
Average real wage and quarterly inflation rate												
(WIN/LNN)/PCD	0.66	–0.31	–0.26	–0.18	–0.05	0.15	0.49	0.65	0.69	0.65	0.57	0.47
INFQ	0.29	–0.15	–0.17	–0.25	–0.38	–0.52	–0.85	–0.34	0.02	0.25	0.36	0.37
Nominal exchange and interest rate												
EEN	1.02	0.11	0.13	0.12	0.16	0.28	0.62	0.35	0.08	–0.19	–0.39	–0.44
STN	0.39	–0.13	–0.18	–0.22	–0.30	–0.42	–0.62	–0.67	–0.55	–0.31	0.11	0.35

Table 3.10 **Cyclical behaviour of key variables of artificial EDGE economy based on stochastic exchange rate shocks, deviations from trend**

		Cross-correlation of output with:										
Variable	**SD%**	**x(–5)**	**x(–4)**	**x(–3)**	**x(–2)**	**x(–1)**	**x**	**x(+1)**	**x(+2)**	**x(+3)**	**x(+4)**	**x(+5)**
Output component												
GDP	1.28	–0.18	–0.09	–0.13	0.00	0.23	1.00	0.25	0.02	–0.11	–0.09	–0.17
Private consumption												
C	0.30	–0.05	–0.10	0.01	–0.10	–0.14	–0.48	0.70	0.19	0.16	0.00	–0.14
Fixed investment												
I	0.58	–0.10	–0.08	–0.04	0.01	0.04	0.03	0.07	0.09	0.08	0.06	0.03
Exports and imports												
X	1.18	–0.17	–0.09	–0.13	0.00	0.23	1.00	0.22	0.01	–0.11	–0.08	–0.16
M	2.87	0.05	–0.01	0.08	–0.06	–0.21	–0.86	0.29	0.10	0.11	0.00	0.09
Labour demand and unemployment												
L	0.17	–0.34	–0.31	–0.32	–0.23	–0.01	0.67	0.67	0.51	0.29	0.13	–0.04
U	0.16	0.34	0.31	0.32	0.23	0.01	–0.67	–0.67	–0.51	–0.29	–0.13	0.04
Average real wage and quarterly inflation rate												
(WIN/LNN)/PCD	0.25	–0.06	–0.12	–0.02	–0.13	–0.24	–0.73	0.43	0.31	0.26	0.10	0.12
INFQ	0.37	0.02	0.02	–0.07	0.07	0.10	0.44	–0.72	0.08	0.02	0.09	–0.04
Nominal exchange and interest rate												
EEN	3.28	–0.08	–0.01	–0.09	0.04	0.23	0.94	–0.09	–0.06	–0.11	–0.03	–0.12
STN	0.55	–0.16	–0.02	–0.03	0.01	0.11	0.64	–0.06	–0.07	–0.18	–0.58	0.16

Table 3.11 **Cyclical behaviour of key variables of artificial EDGE economy based on stochastic foreign demand shocks, deviations from trend**

		Cross-correlation of output with:										
Variable	**SD%**	**x(–5)**	**x(–4)**	**x(–3)**	**x(–2)**	**x(–1)**	**x**	**x(+1)**	**x(+2)**	**x(+3)**	**x(+4)**	**x(+5)**
Output component												
GDP	0.19	–0.25	–0.32	–0.18	0.16	0.58	1.00	0.58	0.16	–0.17	–0.31	–0.24
Private consumption												
C	0.36	–0.38	–0.52	–0.45	–0.15	0.28	0.81	0.53	0.29	0.09	–0.01	0.04
Fixed investment												
I	0.36	–0.25	–0.34	–0.41	–0.40	–0.27	–0.04	0.08	0.14	0.16	0.16	0.18
Exports and imports												
X	1.22	–0.42	–0.57	–0.54	–0.30	0.10	0.63	0.47	0.34	0.21	0.14	0.14
M	1.46	–0.43	–0.58	–0.57	–0.35	0.02	0.54	0.43	0.35	0.25	0.19	0.18
Labour supply, labour demand and unemployment												
N	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.00
L	0.04	–0.28	–0.38	–0.36	–0.13	0.26	0.78	0.83	0.63	0.31	0.04	–0.09
U	0.04	0.28	0.38	0.36	0.13	–0.26	–0.78	–0.83	–0.63	–0.31	–0.04	0.09
Average real wage and quarterly inflation rate												
(WIN/LNN)/PCD	0.15	–0.44	–0.58	–0.58	–0.36	0.01	0.54	0.49	0.41	0.30	0.22	0.18
INFQ	0.50	0.17	0.18	–0.05	–0.31	–0.50	–0.69	0.14	0.13	0.17	0.11	0.05
Nominal exchange and interest rate												
EEN	2.35	0.41	0.57	0.56	0.37	0.03	–0.47	–0.40	–0.35	–0.28	–0.23	–0.21
STN	0.30	0.14	0.18	0.15	–0.03	–0.34	–0.77	–0.68	–0.47	–0.12	0.31	0.26

The foreign demand shock, ε_t^{YWR}, is assumed to be an iid process distributed $N(0, \sigma^{YWR})$. We approximate the standard deviation by calculating the standard deviation of foreign demand from the data for 1997Q1–1999Q4, which equals 0.0266 per quarter. The cross-correlations are shown in table 3.11. Here, we note only that the time t correlation of output with the nominal exchange rate is now consistent with the data. However, as with the foreign price shock, the variance of real variables is far too low compared with the data, with the notable exception of imports and exports.

To sum up, we introduced three different stochastic shocks to the model and obtained three different correlation patterns. A supply side (technology) shock puts the correlations of the real variables into line with the actual data and two other shocks are needed to explain the cross-correlation between output and real wages, inflation, nominal interest and exchange rates. Thus, we note that there is a positive chance of finding a combination of these three shocks, or some other shocks, which give a cross-correlation structure that is observed in the data.

3.4 Diagnostic simulations

In analysing the success of calibration of the EDGE model, primary emphasis is placed on the results of diagnostic simulations. In this subsection the EDGE model is analysed through a series of diagnostic simulations. All simulations considered here are unanticipated. With this type of model it is also possible to simulate what is anticipated to happen in the future. Some of the diagnostic simulations are of a temporary nature while others are permanent. Even though in all the simulations presented here, both the interest rate and exchange rate are endogenous, most of the shocks have also been simulated with exogenous interest and exchange rates.

In general, the results show that the EDGE model adjusts quickly back to the long-run equilibrium after different shocks. Adjustment is especially fast for transitory shocks. For permanent shocks, the adjustment takes slightly longer, which is understandable since the long-run equilibrium has also changed. Nominal rigidities are surprisingly weak, which suggests that the EDGE model is more akin to the RBC models.

3.4.1 Permanent increase in public consumption

The effects of a permanent increase of 1% of GDP in public consumption are shown in figure 3.8 and table 3.12. In the very short run this has an expansionary effect on output, albeit very small and short-lived. In the long-run the adjustment of prices and wages works to adjust the economy towards an equilibrium output, which is defined by the supply side. A fiscal impulse leads to an increase in the demand for goods, which causes the real exchange rate to appreciate. The positive output effect is crowded out in the medium term, as real exchange rate appreciation reduces net exports through the foreign trade elasticities.

In this simulation the shift of resources from private sector to government sector yields a decrease in average productivity, which lowers marginally the output relative to baseline in the long run. Furthermore, private consumption is crowded out in the long run. The nominal interest rate increases about a quarter of a percentage point in the first year and starts to converge to baseline thereafter. The expected real interest falls immediately but then turns positive and starts to converge towards the baseline. The nominal exchange rate jumps immediately and appreciates more than 1%. In the long run the real exchange rate returns to baseline. The increase in output in the short run generates increases in real wages and the inflation rate. However, inflation and unemployment do return to baseline in the long run.

Figure 3.8 **Permanent increase of 1% of real GDP in public consumption, difference from baseline**

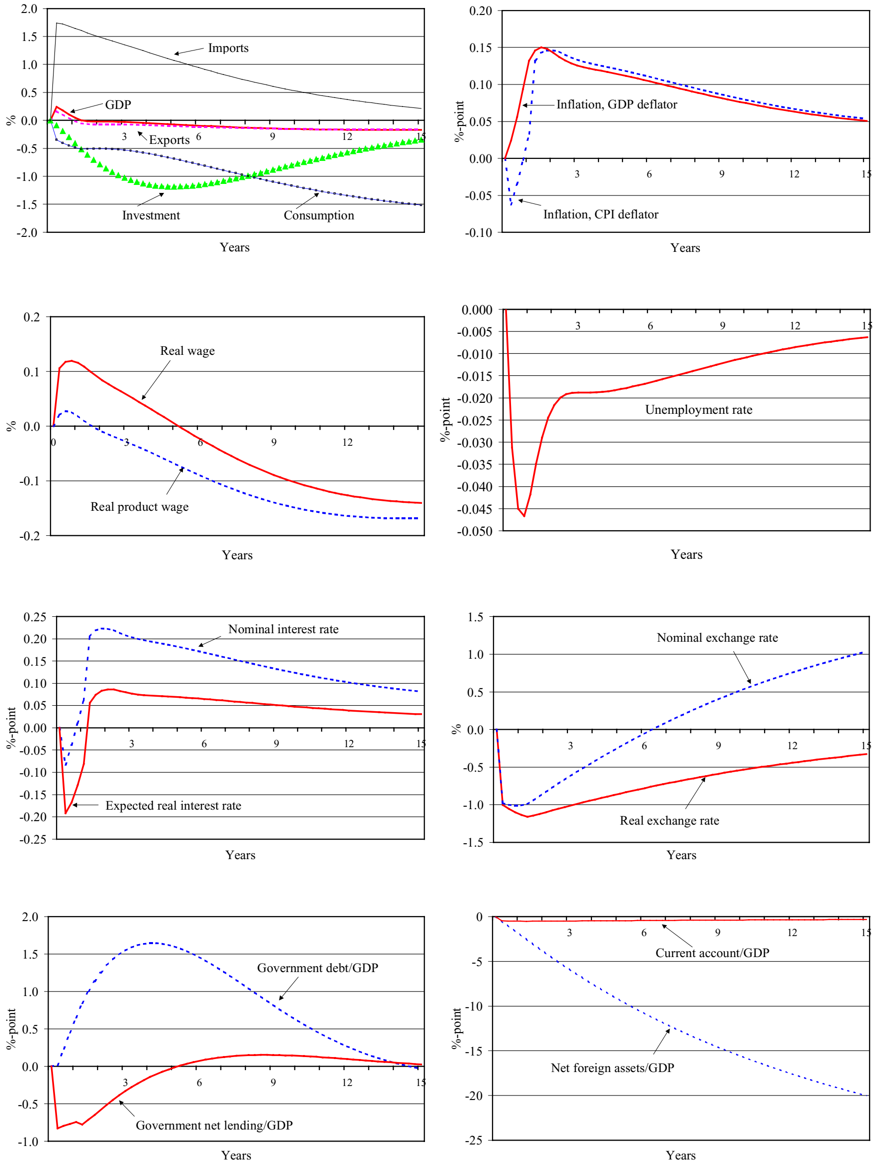

Table 3.12 **Permanent increase of 1% of real GDP in public consumption, difference from baseline**

Q/Y	Q1	Q2	Q3	Y1	Y2	Y3	Y5	Y10	Y50
GDP, %	0.24	0.18	0.11	0.05	–0.02	–0.03	–0.07	–0.15	–0.04
Imports, %	1.74	1.72	1.68	1.64	1.49	1.35	1.07	0.52	–0.28
Exports, %	0.16	0.11	0.04	–0.01	–0.07	–0.07	–0.10	–0.15	–0.04
Private consumption, %	–0.35	–0.40	–0.45	–0.49	–0.51	–0.53	–0.69	–1.19	–1.88
Private fixed investment, %	–0.09	–0.19	–0.30	–0.41	–0.79	–1.03	–1.18	–0.77	0.00
Inflation, GDP defl., %-pts	0.02	0.06	0.09	0.13	0.14	0.13	0.11	0.07	0.00
Inflation, consumpt. defl., %-pts	–0.06	–0.03	0.00	0.03	0.15	0.13	0.12	0.08	0.00
Real wage, %	0.11	0.12	0.12	0.12	0.08	0.06	0.00	–0.10	–0.05
Real product wage, %	0.02	0.03	0.03	0.02	–0.01	–0.03	–0.07	–0.15	–0.04
Unemployment, %-pts	–0.03	–0.05	–0.05	–0.04	–0.02	–0.02	–0.02	–0.01	0.00
Nominal interest rate, %-pts	–0.08	–0.04	0.01	0.06	0.22	0.20	0.18	0.12	0.00
Expected real interest rate, %-pts	–0.19	–0.17	–0.13	–0.08	0.09	0.08	0.07	0.05	0.00
Nominal exchange rate, %	–0.98	–1.00	–1.01	–1.01	–0.83	–0.62	–0.23	0.53	2.20
Real exchange rate, %	–1.00	–1.06	–1.10	–1.14	–1.10	–1.01	–0.85	–0.54	0.15
Government debt/GDP, %-pts	0.02	0.24	0.45	0.65	1.25	1.55	1.60	0.61	–0.01
Government net lending/GDP, %-pts	–0.83	–0.79	–0.77	–0.74	–0.58	–0.33	–0.01	0.14	0.00
Net foreign assets/GDP, %-pts	–0.53	–1.02	–1.52	–2.02	–4.03	–5.91	–9.29	–15.68	–29.28
Current account/GDP, %-pts	–0.48	–0.49	–0.50	–0.51	–0.51	–0.49	–0.45	–0.37	–0.23

Government finances the increase in public consumption by issuing new debt, which is shown by the immediate fall of the government net lending-to-nominal GDP ratio by nearly a percentage point. This increases the government debt-to-nominal GDP ratio, but there is no long-run effect as the increase in public consumption is financed via higher income taxes. The current account-to-nominal GDP ratio falls by a half percentage point permanently. The net foreign assets-to-nominal GDP ratio falls sharply to a new steady-state level, which is lower because consumption falls permanently.

3.4.2 Temporary depreciation of exchange rate

The shock to the nominal exchange rate is a one-off 10% depreciation in the first quarter (figure 3.9 and table 3.13). This shock can be interpreted as a temporary loss of confidence in euro-dominated assets.

In order to damp the inflationary effects, the central bank increases the nominal interest immediately by more than one percentage point. Because the initial shock to the exchange rate is only transitory and monetary policy is tightened accordingly, the inflationary effects are short-lived.

The real depreciation increases export demand by about 4% and decreases imports by some 8% immediately. The effects on investment and consumption are much smaller. The total effect is that output increases by about 3.5%. These real effects are only temporary; output returns to baseline in about one year. A sudden hike in inflation temporarily lowers real wages, which leads to a fall in unemployment. These effects are only transitory.

The government debt-to-nominal GDP ratio decreases due to inflationary peak, but this effect is transitory. As the trade balance improves in the first period, this is reflected to current account. As can be seen, all real variables converge back to baseline after a temporary shock.

Figure 3.9 **Temporary (one-quarter) 10% depreciation of exchange rate, difference from baseline**

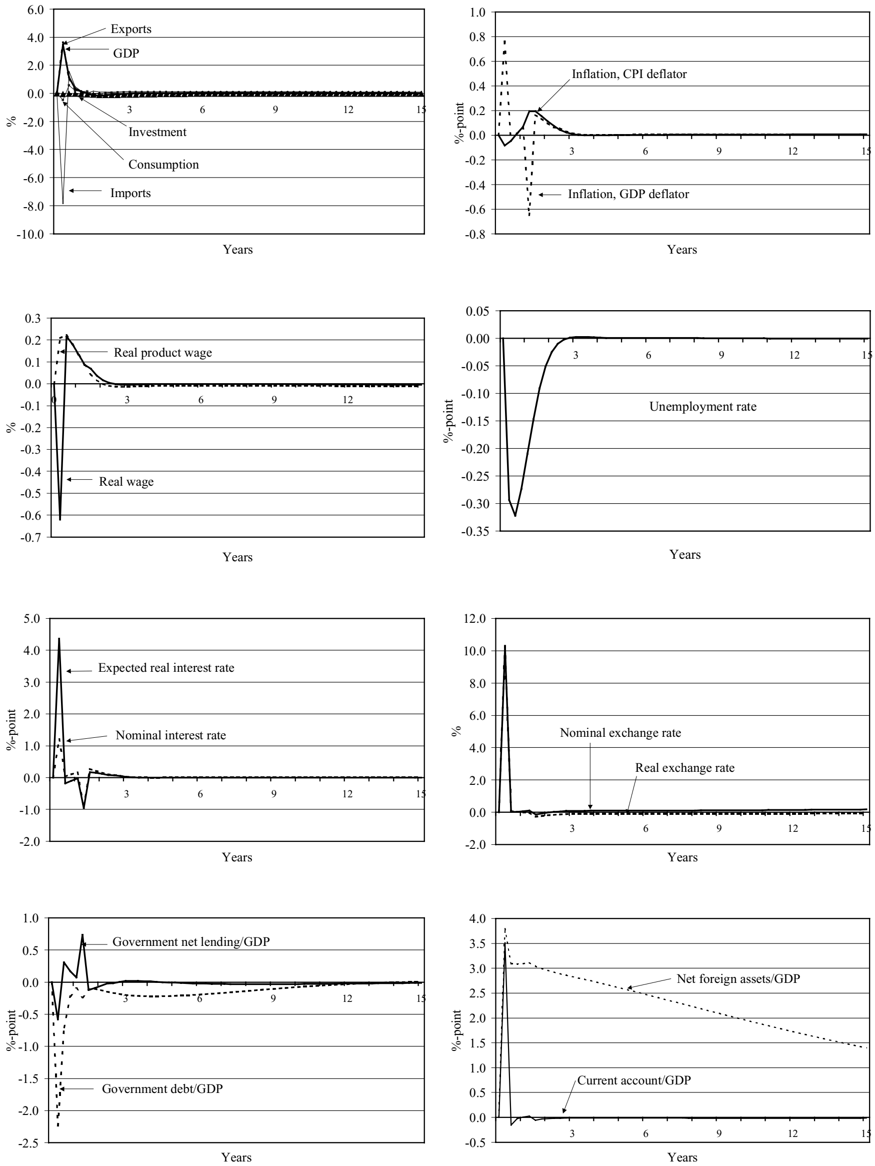

Table 3.13 **Temporary (one-quarter) 10% depreciation of exchange rate, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	3.47	1.15	0.35	0.11	–0.13	–0.02	–0.01	–0.01	0.00
Imports, %	–7.87	1.57	0.49	0.17	0.08	0.11	0.12	0.11	0.00
Exports, %	3.63	1.00	0.31	0.09	–0.12	–0.02	–0.01	–0.01	0.00
Private consumption, %	–0.49	0.58	0.17	0.14	0.02	0.09	0.08	0.07	0.00
Private fixed investment, %	–0.05	–0.04	–0.04	–0.05	–0.13	–0.11	–0.05	–0.04	0.00
Inflation, GDP defl., %-pts	–0.08	–0.05	0.01	0.07	0.11	0.01	0.00	0.01	0.00
Inflation, consumpt. defl., %-pts	0.76	–0.04	0.01	0.07	0.10	0.02	0.00	0.01	0.00
Real wage, %	–0.62	0.22	0.18	0.13	0.02	0.00	0.00	0.00	0.00
Real product wage, %	0.21	0.22	0.18	0.13	0.00	–0.01	–0.01	–0.01	0.00
Unemployment, %-pts	–0.29	–0.32	–0.27	–0.21	–0.02	0.00	0.00	0.00	0.00
Nominal interest rate, %-pts	1.21	0.03	0.10	0.16	0.15	0.02	0.00	0.01	0.00
Expected real interest rate, %-pts	4.36	–0.19	–0.11	–0.02	0.12	0.02	0.00	0.00	0.00
Nominal exchange rate, %	10.21	0.02	0.03	0.05	–0.01	0.08	0.09	0.12	0.34
Real exchange rate, %	10.30	0.07	0.02	–0.01	–0.19	–0.11	–0.10	–0.09	0.00
Government debt/GDP, %-pts	–2.23	–0.70	–0.22	–0.10	–0.12	–0.20	–0.21	–0.08	0.00
Government net lending/GDP, %-pts	–0.58	0.31	0.17	0.07	–0.06	0.02	–0.01	–0.03	0.00
Net foreign assets/GDP, %-pts	3.79	3.09	3.09	3.09	2.96	2.83	2.60	1.97	0.03
Current account/GDP, %-pts	3.51	–0.15	–0.03	0.01	–0.02	–0.01	–0.01	–0.02	0.00

3.4.3 Temporary increase in the interest rate

The nominal interest rate is increased by one percentage point from baseline level for two years, and thereafter the Taylor rule determines the nominal interest rate (figure 3.10 and table 3.14). The expected real interest rate increases immediately and reduces domestic demand through the wealth effect. Furthermore, an increase in interest rates leads to immediate appreciation of the real exchange rate, which reduces net trade through the foreign trade elasticities.

An increase in the nominal interest rate immediately results in appreciation of both nominal and real exchange rates. The real exchange rate returns to baseline after the shock is removed. The temporary increase in the nominal interest rate dampens inflation by less than a half percentage point and real wages by less than 0.5% during the next two years. This reduction in inflation rate yields accordingly a higher domestic real interest rate which peaks around 1.5 percentage points above baseline at the end of the first year.

The rise in the real interest rate causes a sharp but temporary fall in production. Consumption falls immediately by 1.7% while investment demand reacts more sluggishly, falling by 1.5% after one year. Exports fall by more than 2% as does output. The real effects are however only short-lived, and after three years the real variables are close to baseline. The sudden fall in output increases unemployment by 0.75 percentage point in the first year, despite the lower real wages. Unemployment also returns to baseline after three years.

The sudden increase in the nominal interest rate increases the government's borrowing cost and its debt is accumulated correspondingly. These are however temporary and fiscal balance is restored quickly as the interest rate returns to baseline. The current account deteriorates for two years as exports decline by more than imports. This feeds into net foreign assets, which decrease at first but then slowly start to converge toward the steady state.

Figure 3.10 **Temporary (two-years) 1%-pt increase in interest rates, difference from baseline**

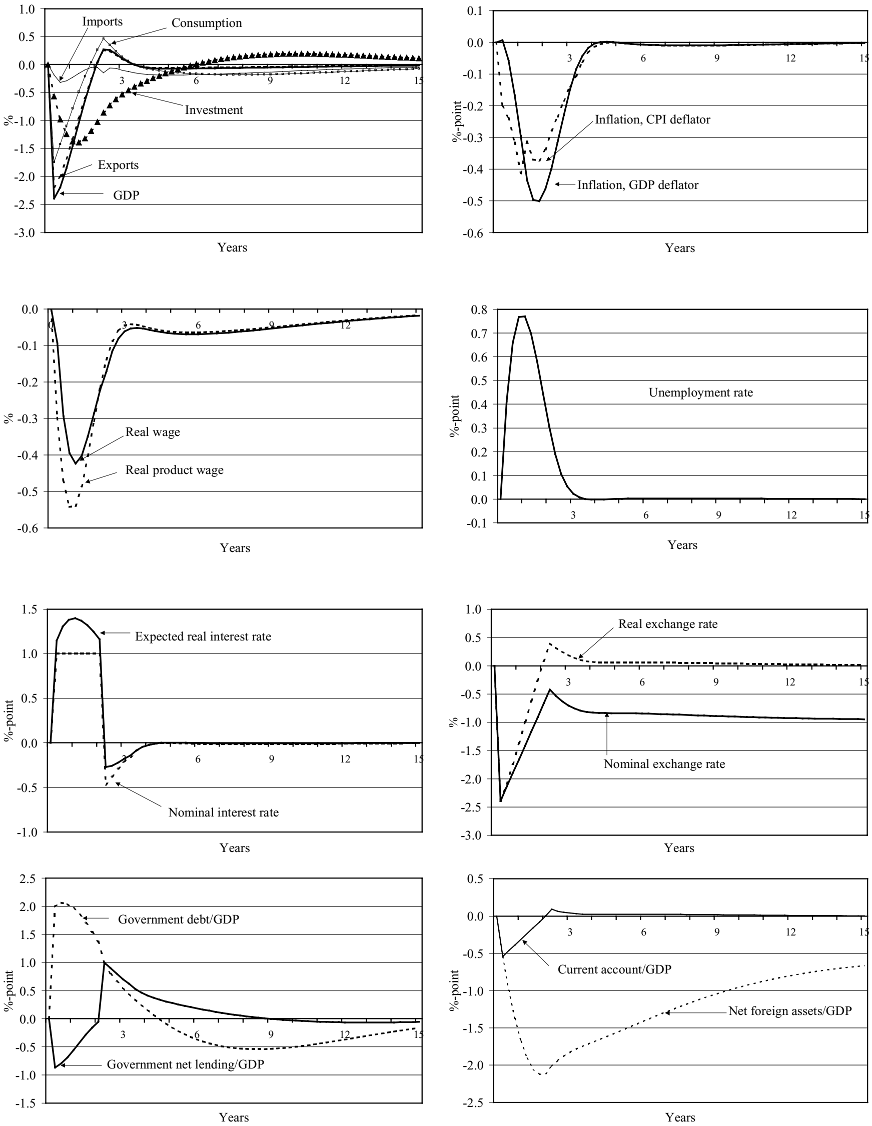

Table 3.14 **Temporary (two-years) 1%-pt increase in nominal interest rate, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–2.39	–2.19	–1.85	–1.45	0.04	0.11	–0.07	–0.04	0.00
Imports, %	–0.19	–0.31	–0.29	–0.23	–0.05	–0.10	–0.19	–0.11	0.00
Exports, %	–2.19	–2.00	–1.68	–1.32	0.04	0.11	–0.06	–0.04	0.00
Private consumption, %	–1.74	–1.42	–1.10	–0.78	0.27	0.14	–0.13	–0.16	0.00
Private fixed investment, %	–0.56	–0.98	–1.24	–1.37	–1.02	–0.53	–0.12	0.19	0.00
Inflation, GDP defl., %-pts	0.01	–0.06	–0.17	–0.30	–0.46	–0.15	0.00	–0.01	0.00
Inflation, consumpt. defl., %-pts	–0.20	–0.24	–0.32	–0.41	–0.34	–0.14	0.00	–0.01	0.00
Real wage, %	–0.09	–0.29	–0.39	–0.42	–0.22	–0.06	–0.07	–0.05	0.00
Real product wage, %	–0.30	–0.47	–0.54	–0.54	–0.21	–0.05	–0.06	–0.04	0.00
Unemployment, %-pts	0.41	0.66	0.77	0.77	0.31	0.02	0.00	0.00	0.00
Nominal interest rate, %-pts	1.00	1.00	1.00	1.00	1.00	–0.21	0.00	–0.01	0.00
Expected real interest rate, %-pts	1.15	1.30	1.38	1.40	1.16	–0.18	0.00	–0.01	0.00
Nominal exchange rate, %	–2.39	–2.15	–1.90	–1.66	–0.67	–0.70	–0.84	–0.90	–0.97
Real exchange rate, %	–2.40	–2.09	–1.74	–1.37	0.08	0.19	0.06	0.04	0.00
Government debt/GDP, %-pts	2.00	2.07	2.04	1.97	1.37	0.55	–0.15	–0.50	0.00
Government net lending/GDP, %-pts	–0.87	–0.80	–0.69	–0.56	–0.05	0.70	0.28	–0.03	0.00
Net foreign assets/GDP, %-pts	–0.54	–1.00	–1.38	–1.68	–2.11	–1.83	–1.55	–0.95	–0.08
Current account/GDP, %-pts	–0.54	–0.46	–0.39	–0.31	0.00	0.04	0.02	0.01	0.00

3.4.4 Permanent increase in labour force

The total labour force is increased by 1% permanently (figure 3.11 and table 3.15). This shock can be interpreted as a sudden impulse to the immigration rate.

The nominal interest rate falls by one-quarter percentage point. This is because most of the increase in labour force goes first into the unemployment rate. The real interest rate falls also in the first year after the shock but then starts to converge quite rapidly to baseline. Both the nominal and real exchange rates depreciate immediately, by roughly 0.4%. Depreciation of both the real and nominal exchange rates stabilises in the long run. The inflation rate falls immediately by 0.1 percentage point and then converges back to baseline. Real wages fall first, so that after three years this decrease is 0.3%, but thereafter real wages converge to baseline.

Consumption, exports, imports and GDP all increase immediately by 0.8% and then slowly converge toward 1% above baseline level. Investment increases at first more slowly, but after two years it's adjustment speed exceeds that of other real variables in convergening toward 1% above baseline level. The unemployment rate increases in the first period by 0.65 percentage point, which means that 35% of the labour force increase is employed in the first quarter. Convergence towards the NAIRU of the labour force increase is rapid, taking only about 3 years. We do not interpret this as indicating that the European labour market are functioning well. Rather, we note that the general equilibrium features of the EDGE model are particularly strong with respect to the labour market, ie the unemployment rate settles down quite rapidly to the 'high' NAIRU level. Furthermore, one can see that this rapid adjustment is the result of our calibration, where it was assumed that labour demand reacts considerably faster to imbalances than do prices and wages.

The government net lending-to-GDP ratio is boosted slightly by the higher taxes generated by accelerated economic activity in the first year but is then reversed and in the long-run this returns to baseline. The government debt-to-nominal GDP ratio decreases mainly because of the increase in output. The current account-to-GDP ratio remains in balance with this shock. The net foreign assets-to-nominal GDP ratio decreases by the amount of the increase in output in the long run.

Figure 3.11 **Permanent 1% increase in total labour force, difference from baseline**

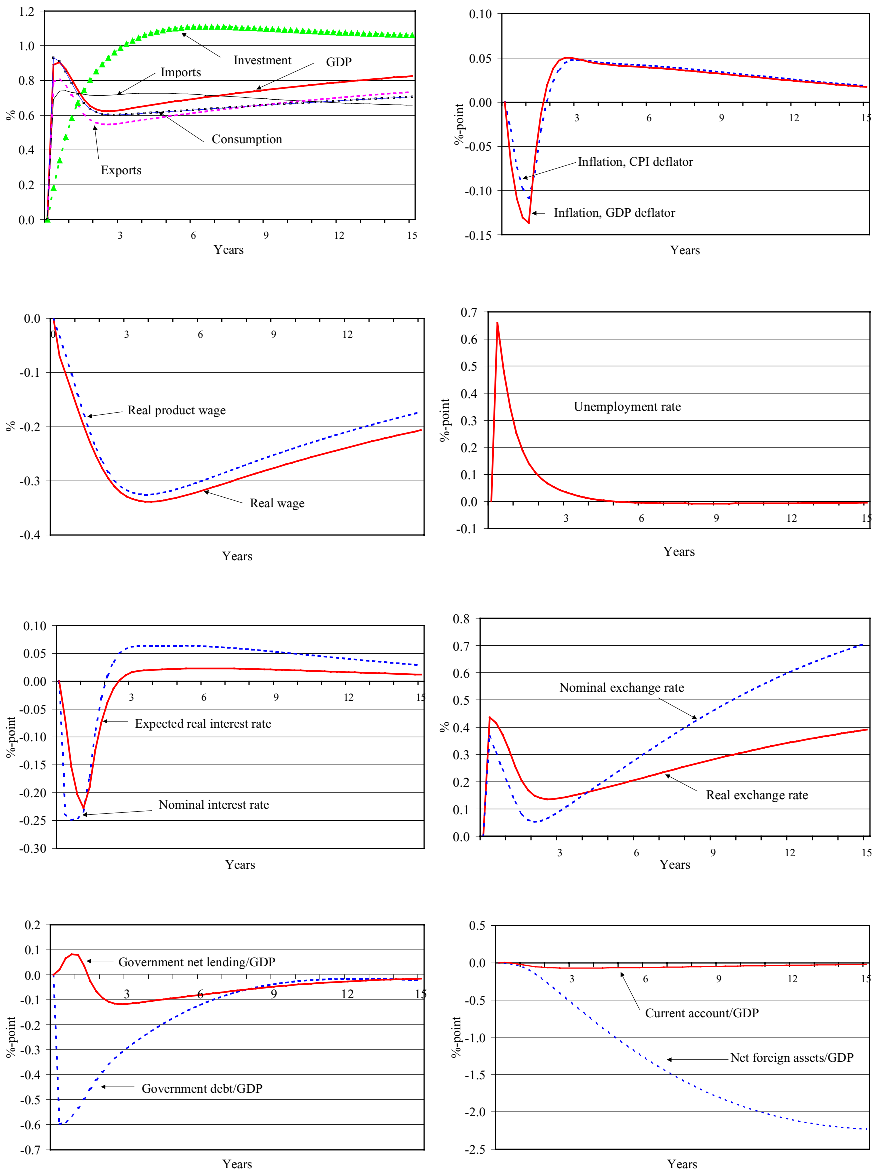

Table 3.15 **Permanent 1% increase in total labour force, difference from baseline**

Q/Y	Q1	Q2	Q3	Y1	Y2	Y3	Y5	Y10	Y50
GDP, %	0.89	0.91	0.87	0.81	0.63	0.63	0.67	0.76	0.96
Imports, %	0.69	0.74	0.74	0.73	0.71	0.72	0.73	0.69	0.75
Exports, %	0.79	0.80	0.77	0.71	0.56	0.55	0.59	0.68	0.85
Private consumption, %	0.93	0.91	0.85	0.79	0.62	0.60	0.62	0.67	0.90
Private fixed investment, %	0.18	0.34	0.47	0.58	0.85	0.99	1.10	1.09	0.93
Inflation, GDP defl., %-pts	–0.07	–0.11	–0.13	–0.14	0.04	0.05	0.04	0.03	0.00
Inflation, consumpt. defl., %-pts	–0.03	–0.07	–0.10	–0,11	0.02	0.05	0.04	0.03	0.00
Real wage, %	–0.07	–0.10	–0.13	–0,17	–0.28	–0.33	–0.33	–0.26	–0.08
Real product wage, %	–0.03	–0.07	–0.10	–0,14	–0.27	–0.32	–0.32	–0.24	–0.04
Unemployment, %-pts	0.66	0.48	0.35	0.25	0.08	0.03	0.00	–0.01	0.00
Nominal interest rate, %-pts	–0.24	–0.25	–0.25	–0.23	0.01	0.06	0.06	0.05	0.00
Expected real interest rate, %-pts	–0.07	–0.15	–0.20	–0.23	–0.04	0.02	0.02	0.02	0.00
Nominal exchange rate, %	0.37	0.31	0.25	0.18	0.05	0.09	0.22	0.51	0.84
Real exchange rate, %	0.44	0.42	0.37	0.32	0.15	0.14	0.18	0.30	0.46
Government debt/GDP, %-pts	–0.60	–0.59	–0.56	–0.53	–0.39	–0.30	–0.17	–0.03	0.00
Government net lending/GDP, %-pts	0.02	0.07	0.08	0.08	–0.09	–0.12	–0.09	–0.04	0.00
Net foreign assets/GDP, %-pts	–0.01	–0.02	–0.03	–0.06	–0.27	–0.54	–1.06	–1.93	–0.48
Current account/GDP, %-pts	0.01	0.00	–0.01	–0.03	–0.06	–0.07	–0.07	–0.04	0.01

3.4.5 Temporary increase in direct tax rate

The direct tax rate is increased by 1 percentage point for the next ten years (figure 3.12 and table 3.16). Hence, the immediate increase in the direct tax rate is unanticipated, but the decrease back to baseline levels after ten years is anticipated. This can be seen as a part of a temporary fiscal policy shock. Note, however, that the labour force is exogenous in the model, so that the tax shock does not have an effect on labour supply here.

Both nominal and real interest rate increase slightly in the first year to stop inflation, but remain constant for the next ten years, after which they fall again. After this second reaction, the real interest rate converges toward baseline. Both nominal and real exchange rate decrease by one-half percentage point immediately and thereafter decrease an additional half percentage point over the next ten years. However, after ten years the real exchange starts to converge toward the baseline. The inflation rate picks up in the first year but then starts to decline as the interest rate cools the economy. After ten years the inflation rate has fallen by some 0.25 percentage point relative to baseline. Thereafter the inflation rate converges towards the baseline. Real wages decrease somewhat in the first ten years, but after ten years real wages pick up sharply before falling back to baseline in the long run.

A depreciating exchange rate increases exports, which boosts output in the short run. Thereafter falling consumption and investment demand drag output down to baseline. Investment demand increases in advance of the decrease in the direct tax rate in year ten. After ten years investment demand starts to fall and consumption demand starts to increase towards baseline in the long run. Unemployment falls marginally for the first ten years but picks up thereafter and falls back to baseline in the long run.

Government net lending is boosted by higher tax receipts for the first ten years and reduced thereafter. This reflects declining government debt, which starts to increase again after ten years. For the first ten years, the current account is slightly positive, which cumulates in net foreign assets.

Figure 3.12 **Temporary (10-year) 1%-pt increase in direct tax rate, difference from baseline**

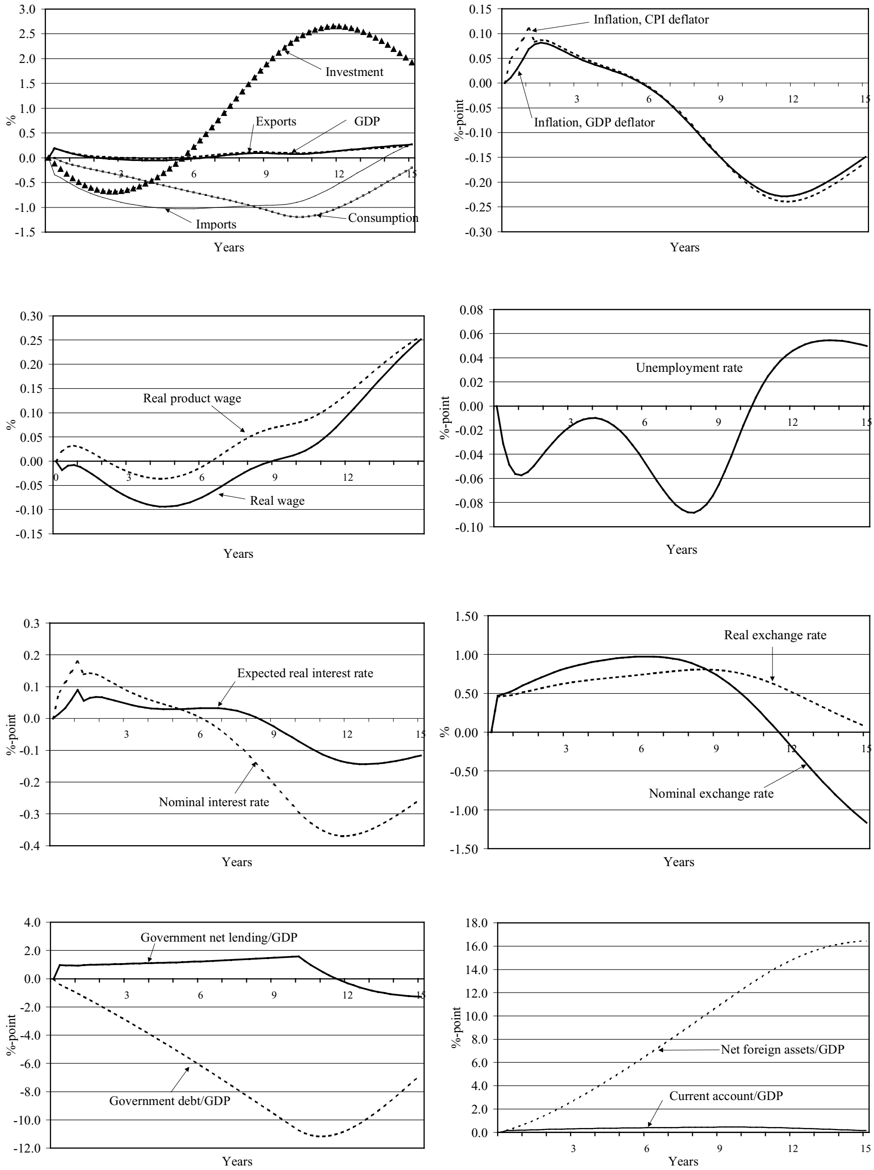

Table 3.16 **Temporarily (10-year) 1%-pt increase in direct tax rate, difference from baseline**

Q/Y	Q1	Q2	Q3	Y1	Y2	Y3	Y5	Y10	Y50
GDP, %	0.19	0.15	0.11	0.08	0.00	–0.03	–0.05	0.07	–0.02
Imports, %	–0.34	–0.40	–0.48	–0.55	–0.76	–0.90	–1.02	–0.93	0.13
Exports, %	0.19	0.16	0.12	0.09	0.03	0.00	–0.01	0.09	–0.02
Private consumption, %	–0.01	–0.07	–0.11	–0.15	–0.25	–0.36	–0.59	–1.19	0.09
Private fixed investment, %	–0.12	–0.22	–0.32	–0.41	–0.64	–0.67	–0.22	2.32	–0.07
Inflation, GDP defl., %-pts	0.01	0.03	0.05	0.07	0.08	0.05	0.02	–0.20	0.01
Inflation, consumpt. defl., %-pts	0.05	0.07	0.09	0.11	0.08	0.06	0.02	–0.20	0.01
Real wage, %	–0.02	–0.01	–0.01	–0.01	–0.04	–0.08	–0.09	0.02	–0.01
Real product wage, %	0.02	0.03	0.03	0.03	0.00	–0.02	–0.03	0.08	–0.02
Unemployment, %-pts	–0.03	–0.05	–0.06	–0.06	–0.04	–0.02	–0.02	–0.02	0.00
Nominal interest rate, %-pts	0.08	0.11	0.15	0.18	0.13	0.09	0.03	–0.29	0.02
Expected real interest rate, %-pts	0.02	0.03	0.06	0.09	0.07	0.05	0.03	–0.07	0.01
Nominal exchange rate, %	0.47	0.49	0.52	0.56	0.71	0.82	0.95	0.49	–1.23
Real exchange rate, %	0.46	0.46	0.47	0.49	0.56	0.63	0.71	0.75	–0.11
Government debt/GDP, %-pts	–0.39	–0.61	–0.82	–1.04	–1.98	–2.97	–5.04	–10.72	0.00
Government net lending/GDP, %-pts	0.96	0.95	0.94	0.93	1.00	1.06	1.16	1.57	–0.01
Net foreign assets/GDP, %-pts	0.17	0.33	0.51	0.71	1.63	2.73	5.25	12.39	2.31
Current account/GDP, %-pts	0.16	0.17	0.18	0.20	0.26	0.30	0.37	0.45	–0.03

3.4.6 Permanent increase in world demand

World demand is increased permanently by 1% (figure 3.13 and table 3.17). This means that the European export market expands. However, the exchange rate appreciates immediately and partly offsets the increase in foreign demand. The euro appreciation lowers the prices of import goods somewhat and hence consumption and investment demands also increase slightly.

The effect on the real side variables is marginal, except that imports jump directly by 0.4% from baseline due to falling import prices and exports by 0.3% due to increased foreign demand. Unemployment decreases marginally but this effect is almost zero. Thus, the appreciation of the exchange rate insulates the euro area economy in the sense that real activity, as well as unemployment, is almost unchanged.

Both the real and nominal interest rates fall marginally, by some 0.05 percentage point in the short run and then return to baseline in the long run. Both the nominal and real exchange rates appreciate immediately, by slightly less than 0.5% and then stabilise at these levels in the long run. CPI inflation decreases first marginally and then reverts to baseline. The real wage increases marginally and permanently, by about 0.04%.

The effect on government net lending and on government debt is virtually nil. There are, however, some changes in the short run, but these die out in the long run. The effect on the current account is marginally negative, which cumulates as a decrease in net foreign assets.

Figure 3.13 **Permanent 1% increase in world demand, difference from baseline**

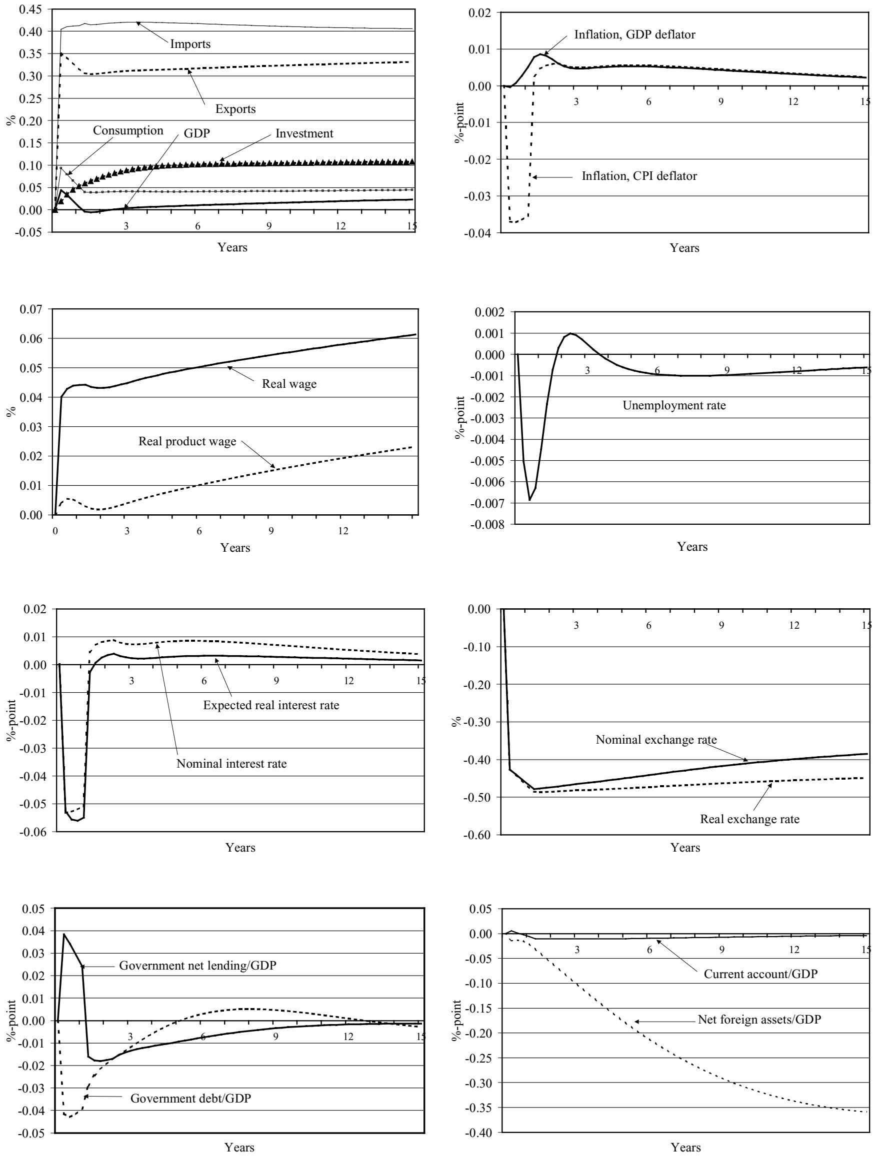

Table 3.17 **Permanent 1% increase in world demand, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	0.04	0.03	0.02	0.01	0.00	0.00	0.01	0.02	0.04
Imports, %	0.40	0.41	0.41	0.41	0.42	0.42	0.42	0.41	0.42
Exports, %	0.35	0.34	0.33	0.32	0.31	0.31	0.32	0.32	0.35
Private consumption, %	0.09	0.08	0.07	0.05	0.04	0.04	0.04	0.04	0.07
Private fixed investment, %	0.02	0.03	0.05	0.05	0.07	0.09	0.10	0.11	0.10
Inflation, GDP defl., %-pts	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
Inflation, consumpt. defl., %-pts	–0.04	–0.04	–0.04	–0.04	0.01	0.00	0.01	0.00	0.00
Real wage, %	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.08
Real product wage, %	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.04
Unemployment, %-pts	–0.01	–0.01	–0.01	0.00	0.00	0.00	0.00	0.00	0.00
Nominal interest rate, %-pts	–0.05	–0.05	–0.05	–0.05	0.01	0.01	0.01	0.01	0.00
Expected real interest rate, %-pts	–0.05	–0.06	–0.06	–0.06	0.00	0.00	0.00	0.00	0.00
Nominal exchange rate, %	–0.43	–0.44	–0.45	–0.47	–0.47	–0.47	–0.45	–0.41	–0.36
Real exchange rate, %	–0.43	–0.44	–0.46	–0.47	–0.49	–0.48	–0.48	–0.46	–0.44
Government debt/GDP, %-pts	–0.04	–0.04	–0.04	–0.04	–0.02	–0.01	0.00	0.00	0.00
Government net lending/GDP, %-pts	0.04	0.03	0.03	0.02	–0.02	–0.01	–0.01	0.00	0.00
Net foreign assets/GDP, %-pts	–0.01	–0.01	–0.02	–0.02	–0.06	–0.10	–0.18	–0.31	–0.16
Current account/GDP, %-pts	0.01	0.00	0.00	–0.01	–0.01	–0.01	–0.01	–0.01	0.00

3.4.7 Permanent increase in indirect tax rate

The indirect tax rate is increased by 1 percentage point permanently (figure 3.14 and table 3.18). This has potentially large effects since it changes relative prices.

Nominal and real interest rates increase to match the increase in the inflation rate. Inflation falls in the second year, which also allows the nominal interest rate to adjust to a lower level. The real interest also falls below baseline, but after three years it starts to converge towards the baseline. Both nominal and real exchange rates depreciate by 1% in the first period, after which the real exchange rate starts to converge towards the baseline. The real wage rate falls permanently by 1%.

The increase in the interest rate induced by inflation developments decreases consumption sharply, by over 1% in the short run. Output also falls, by 0.5% in the short run. Imports fall sharply, by over 2% in the short run. All real variables converge to baseline in the long run. The unemployment rate rises in the first year, by less than 0.2 percentage point, and then starts to converge back to baseline.

The increase in the indirect tax rate boosts tax revenue and thus government net lending increases in the first five years. This is reflected in government debt, which decreases during the first five years and then converges back to old levels. Depreciation of the exchange rate creates a small current account surplus, relative to baseline, and this cumulates to higher net foreign assets.

Figure 3.14 **Permanent 1%-pt increase in indirect tax rate, difference from baseline**

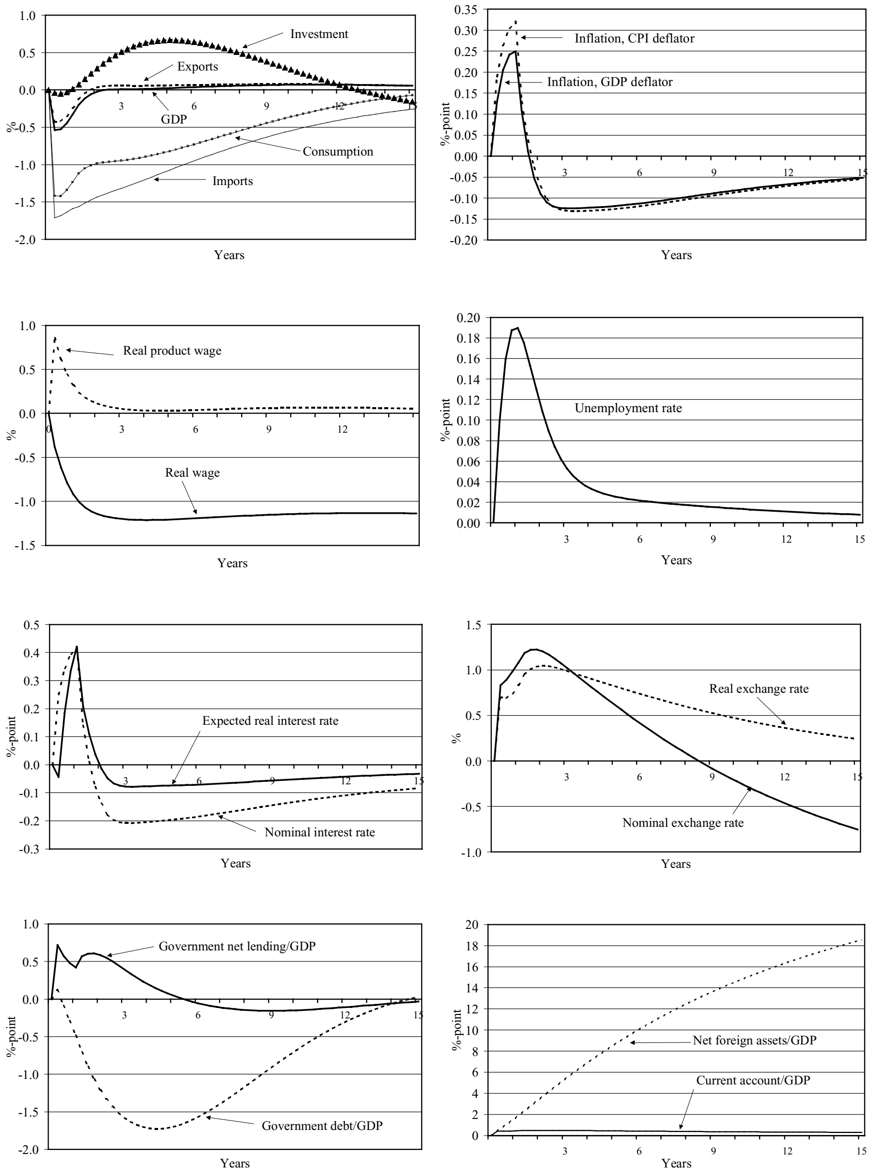

Table 3.18 **Permanent 1%-pt increase in indirect tax rate, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–0.54	–0.53	–0.44	–0.33	–0.02	0.01	0.02	0.07	–0.14
Imports, %	–1.71	–1.68	–1.64	–1.59	–1.44	–1.32	–1.07	–0.55	0.12
Exports, %	–0.43	–0.42	–0.35	–0.24	0.03	0.06	0.06	0.08	–0.12
Private consumption, %	–1.42	–1.42	–1.34	–1.24	–0.99	–0.95	–0.82	–0.36	0.11
Private fixed investment, %	–0.04	–0.05	–0.03	0.01	0.29	0.51	0.67	0.27	–0.41
Inflation, GDP defl., %-pts	0.13	0.21	0.24	0.25	–0.09	–0.12	–0.12	–0.08	0.00
Inflation, consumpt. defl., %-pts	0.19	0.26	0.31	0.32	–0.07	–0.13	–0.13	–0.09	0.00
Real wage, %	–0.38	–0.62	–0.79	–0.92	–1.14	–1.20	–1.21	–1.14	–1.29
Real product wage, %	0.86	0.62	0.44	0.32	0.11	0.05	0.03	0.06	–0.14
Unemployment, %-pts	0.10	0.16	0.19	0.19	0.11	0.05	0.03	0.01	0.00
Nominal interest rate, %-pts	0.25	0.34	0.39	0.42	–0.14	–0.21	–0.20	–0.13	0.00
Expected real interest rate, %-pts	–0.04	0.19	0.33	0.42	–0.01	–0.08	–0.07	–0.05	0.00
Nominal exchange rate, %	0.83	0.89	0.98	1.08	1.20	1.02	0.61	–0.22	–1.82
Real exchange rate, %	0.70	0.69	0.74	0.83	1.05	0.99	0.82	0.47	–0.21
Government debt/GDP, %-pts	0.12	–0.09	–0.29	–0.48	–1.21	–1.58	–1.70	–0.69	0.01
Government net lending/GDP, %-pts	0.72	0.57	0.48	0.42	0.59	0.39	0.04	–0.15	0.00
Net foreign assets/GDP, %-pts	0.46	0.85	1.26	1.69	3.54	5.36	8.63	14.66	25.97
Current account/GDP, %-pts	0.40	0.40	0.41	0.43	0.48	0.47	0.44	0.35	0.20

3.4.8 Permanent increase in equity premium

Equity premium is increased by 1 percentage point permanently (figure 3.15 and table 3.19). This can be seen as a negative wealth shock, caused by the increase in corporate risk.

The nominal interest rate increases in the first period, to match the corresponding increase in CPI inflation. Thereafter, inflation falls rapidly so that at the end of the first year inflation has decreased by 1.5 percentage points relative to baseline. The nominal interest rate also falls. The expected real interest rate rises in the first period, by more than 1.5 percentage points above baseline, after which it falls, and after two years, is one percentage point lower than baseline. Thereafter the real interest rate starts to converge towards the baseline level. The exchange rate depreciates immediately by 10% and the real exchange rate starts slowly to converge back to baseline. Real wages fall by 0.7% immediately and converge to a level lower than the steady-state level.

Consumption falls immediately by almost 8% but then starts move back to the baseline level. Investment falls slowly but steadily to lower levels. The sudden depreciation in the exchange rate induces higher exports and much lowers imports. All together, GDP falls by 2% in the long run. Despite lower real wages, dampened economic activity leads to an increase in the unemployment rate, by about 0.2 percentage point.

Government net lending increases as interest rates fall and this reduces the debt in the short run. However, in the long run the debt rises to a new steady-state level. A positive current account balance and negative consumption demand cumulate into net foreign assets, which balance at a new steady state.

To sum up, we find that the EDGE model fits the data reasonably well. In solving the model forward, we do not encounter convergence problems. If we look at the model's long run adjustment, we see that it is dynamically stable. It converges to the equilibrium represented by the steady-state solution in the long run. Furthermore, the diagnostic simulations indicate that the economic behaviour of the model is intuitive, although size and speed of adjustment are always controversial issues. All in all, we feel confident about using the model for demanding policy simulations.

Figure 3.15 **Permanent 1%-pt increase in equity premium, difference from baseline**

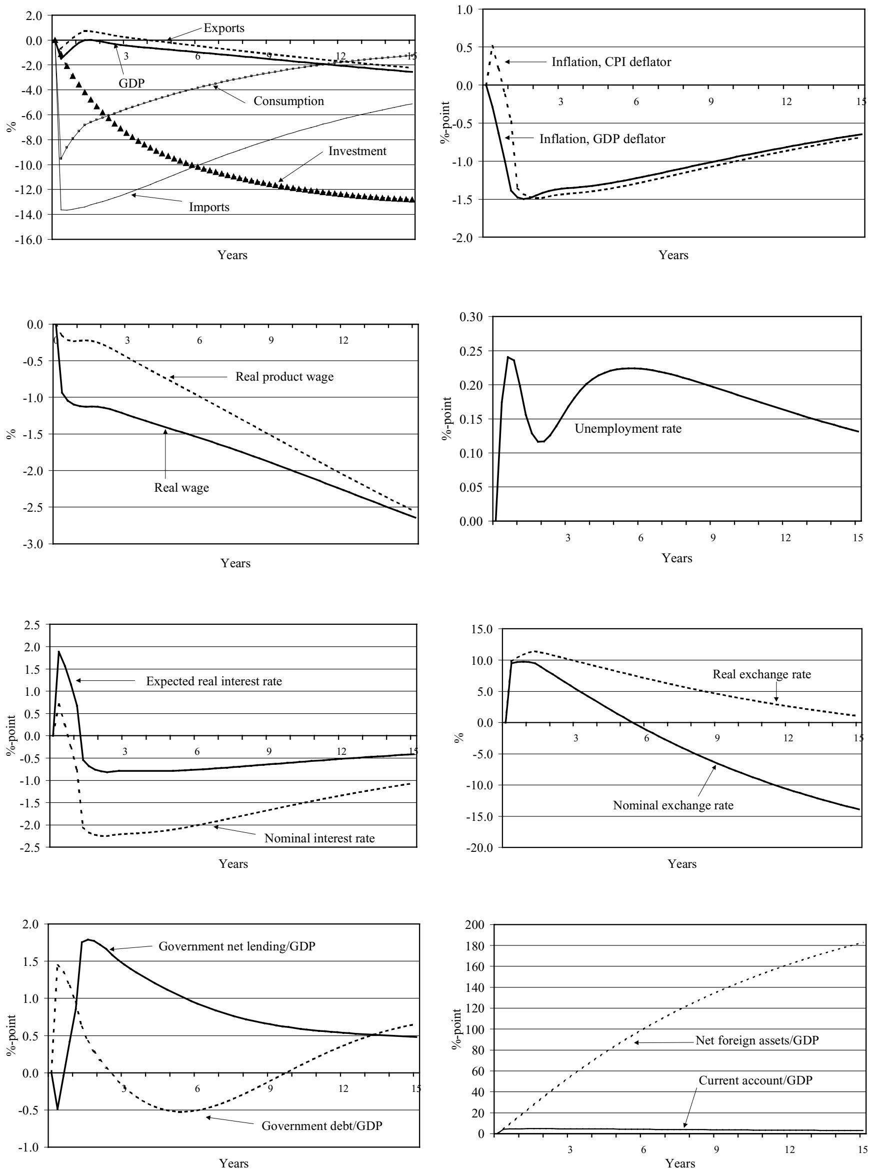

Table 3.19 **Permanent 1%-pt increase in equity premium, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–1.50	–1.06	–0.59	–0.22	–0.14	–0.44	–0.80	–1.70	–5.05
Imports, %	–13.63	–13.68	–13.60	–13.49	–12.96	–12.34	–10.83	–7.43	–1.94
Exports, %	–0.69	–0.28	0.15	0.50	0.55	0.22	–0.24	–1.32	–4.41
Private consumption, %	–9.52	–8.62	–7.91	–7.31	–6.22	–5.55	–4.34	–2.31	–0.98
Private fixed investment, %	–1.13	–2.08	–2.89	–3.58	–5.81	–7.46	–9.51	–11.88	–12.33
Inflation, GDP defl., %-pts	–0.29	–0.63	–1.01	–1.39	–1.45	–1.36	–1.29	–0.94	0.00
Inflation, consumpt. defl., %-pts	0.51	0.21	–0.12	–0.48	–1.48	–1.44	–1.36	–1.00	0.00
Real wage, %	–0.94	–1.05	–1.10	–1.12	–1.14	–1.24	–1.45	–2.02	–4.74
Real product wage, %	–0.15	–0.22	–0.23	–0.23	–0.28	–0.45	–0.81	–1.70	–5.05
Unemployment, %-pts	0.17	0.24	0.24	0.20	0.12	0.17	0.22	0.19	0.01
Nominal interest rate, %-pts	0.71	0.24	–0.25	–0.77	–2.24	–2.20	–2.11	–1.55	–0.01
Expected real interest rate, %-pts	1.89	1.57	1.15	0.67	–0.80	–0.78	–0.78	–0.60	–0.01
Nominal exchange rate, %	9.49	9.68	9.75	9.68	7.72	5.34	0.87	–8.05	–23.06
Real exchange rate, %	9.80	10.37	10.84	11.19	10.80	9.83	7.96	3.89	–3.78
Government debt/GDP, %-pts	1.44	1.35	1.17	0.95	0.17	–0.19	–0.52	0.06	0.08
Government net lending/GDP, %-pts	–0.49	–0.04	0.42	0.86	1.72	1.45	1.08	0.60	0.02
Net foreign assets/GDP, %-pts	4.77	9.20	13.76	18.43	37.10	54.75	86.33	145.05	239.84
Current account/GDP, %-pts	4.28	4.48	4.62	4.73	4.78	4.68	4.38	3.59	1.81

4 Heterogeneous expectations and monetary policy

In this chapter we analyse the interaction of expectations and monetary policy. In particular we are interested in the case where expectations can differ as between central bank and private sector. In order to examine these issues we first discuss the monetary policy rule in the EDGE model. In the EDGE model monetary policy is conducted through the Taylor rule. To make the notation convenient we transform the Taylor rule to the annual level:

$$R_t = r^* + \pi_t + 0.5 \cdot \left(\pi_t - \bar{\pi}_t\right) - 0.5 \cdot (1 - \beta) \cdot \left(U_t - \overline{U_t}\right)$$

ie the nominal interest rate is defined by the foreign real interest rate and domestic inflation rate as well as by the deviations of inflation from target and unemployment rate from NAIRU. We have assumed the conventional parameters for the inflation and activity gaps.

There are six different places in this rule where expectations of central bank and private sector may differ. First, as regards expectations of the inflation target, the private sector may not know or may not believe in the inflation target of the central bank. Second, central bank and private sector expectations may differ with respect to the equilibrium real interest rate. Furthermore, it is possible that both perceive an equilibrium interest rate which is different from what actually materialises. Third, central bank and private sector expectations may differ with respect to NAIRU, and the actual NAIRU may differ from the expectations of both. Fourth, the private sector may hold different expectations with respect to the parameters of the inflation and/or unemployment gap. Fifth, it is possible that private sector expectations of actual inflation and unemployment rates differ from those of the central bank. Finally, private sector may expect that the functional form of the reaction function of the central bank will be different from the simple Taylor rule.

Below, we concentrate our analysis on the first three possibilities. We proceed first by analysing the permanent expectational errors by assuming that the differences between central bank and private sector expectations are permanent. Next, we analyse temporary expectational errors by introducing some exogenous mechanism which removes the difference between the expectations of private sector and central bank. Finally, we analyse random expectational errors.

4.1 Permanent expectational errors

In order to describe the nature of the experiment we also make comparison simulations where the changes in the inflation target, equilibrium interest rate and NAIRU are fully understood by all agents and thus the expectations are formed rationally with perfect information.

In applying a monetary policy shock to the EDGE model we change the setup slightly. In the derivation of both nominal wages and prices, we used the nominal interest rate as the constant discount rate. Now, we shock the model by changing the inflation target, which assuming credibility amounts to a fall in the actual inflation rate. Thus, we have to make corresponding changes to the parameters of the wage and price equation, which are derived using constant nominal interest rates. We adjust the price equation as follows:

$$\begin{aligned}
P_t &= \frac{1}{1+a+\widetilde{\rho}} P_{t-1} + \frac{\widetilde{\rho}}{1+a+\widetilde{\rho}} E_t P_{t+1} \\
&\quad - \frac{1}{1+a+\widetilde{\rho}} \pi_t + \frac{\widetilde{\rho}}{1+a+\widetilde{\rho}} \pi_t \\
&\quad + \frac{a}{1+a+\widetilde{\rho}} \frac{WN_t \cdot L_t}{(1-\tau_t^{indirect})(1-\beta)Y_t} \\
&= \frac{1}{1+a+\widetilde{\rho}} P_{t-1} + \frac{\widetilde{\rho}}{1+a+\widetilde{\rho}} E_t P_{t+1} \\
&\quad + \frac{a}{1+a+\widetilde{\rho}} \frac{WN_t \cdot L_t}{(1-\tau_t^{indirect})(1-\beta)Y_t} \\
&\quad + \left(\frac{\widetilde{\rho}}{1+a+\widetilde{\rho}} - \frac{1}{1+a+\widetilde{\rho}} \right) \cdot \pi_t
\end{aligned}$$

The nominal wage equation is changed accordingly:

$$
\begin{aligned}
WN_t &= \frac{1-q}{1+(1-q)(1-q)\widetilde{\rho}} WN_{t-1} + \frac{(1-q)\widetilde{\rho}}{1+(1-q)(1-q)\widetilde{\rho}} E_t WN_{t+1} \\
&\quad - \frac{1-q}{1+(1-q)(1-q)\widetilde{\rho}} \pi_t + \frac{(1-q)\widetilde{\rho}}{1+(1-q)(1-q)\widetilde{\rho}} \pi_t \\
&\quad + \frac{q\left(1-(1-q)\widetilde{\rho}\right)}{1+(1-q)(1-q)\widetilde{\rho}} \left[p_t \frac{(1-\beta)Y_t}{N_t} \cdot \left(1-\eta \cdot (U_t - \overline{U_t})\right) \right] \\
&= \frac{1-q}{1+(1-q)(1-q)\widetilde{\rho}} WN_{t-1} + \frac{(1-q)\widetilde{\rho}}{1+(1-q)(1-q)\widetilde{\rho}} E_t WN_{t+1} \\
&\quad + \frac{q\left(1-(1-q)\widetilde{\rho}\right)}{1+(1-q)(1-q)\widetilde{\rho}} \left[p_t \frac{(1-\beta)Y_t}{N_t} \cdot \left(1-\eta \cdot (U_t - \overline{U_t})\right) \right] \\
&\quad + \left(\frac{(1-q)\widetilde{\rho}}{1+(1-q)(1-q)\widetilde{\rho}} - \frac{1-q}{1+(1-q)(1-q)\widetilde{\rho}} \right) \cdot \pi_t
\end{aligned}
$$

The reason for introducing these corrections is to correct the inflation bias in the nominal equations. This bias may arise because the parameters are fixed under a particular assumption concerning nominal interest rates. When the inflation rate changes considerably, it is possible that the nominal interest rate would also change. This cannot be taken into account since the parameters of the nominal wage and price equation are fixed. Thus, in order to account for large changes in the inflation rate, we add an extra term to these nominal equations, to which makes an inflation correction to the parameters. This inflation correction does not have a major impact on any other simulation. It has an effect only when there is a large change in the inflation rate.

We run the baseline simulation with these changed equations and then implement the monetary policy shocks.

4.1.1 Permanent increase in inflation target with full credibility

The inflation target is decreased unexpectedly and permanently by 1 percentage point (figure 4.1 and table 4.1). This may be interpreted as a monetary policy shock where the inflation target is lowered.

It is assumed that the policy change comes as a surprise to the private sector in the period in which it is effected and that it is completely credible. In subsequent periods private agents continue to believe in this new target.

The actual inflation rate decreases by 1 percentage point in the course of one year and remains stable thereafter. Because the model incorporates price stickiness a temporary increase in the nominal interest rate occurs. In the first quarter the short term interest rate is 6 basis points higher than the benchmark solutions, after which it return to its new equilibrium, which is one percentage point lower. Hence, the long-run equilibrium obeys 'Fishers equation' linking nominal interest rate to inflation. Accordingly, the expected real interest rate increases sharply, by about 1 percentage point in the short run but then returns to baseline.

As monetary policy is tightened the exchange rate appreciates. The nominal exchange rate appreciates by 0.8% immediately and the real exchange rate by 0.5%. After this impact effect, the nominal exchange rate remains permanently stronger than it would have been absent the disinflation episode. The real exchange rate converges to the baseline solution in the long run. The trend of the nominal exchange rate reflects the change in the inflation rate. Real wages zigzag (narrowly) around the baseline and return to baseline in the long run.

Private consumption and exports are the main demand components affected in the short run. Their reactions are caused by temporary policy effects on the expected real interest rate and real exchange rate. Consumption and exports decrease immediately by 0.5% but revert nearly to the baseline solution. Investment decreases slowly by 0.1% but it also returns to close to baseline. The unemployment rate rises immediately by less than 0.1 percentage point and then falls, but it remains above baseline in the long run.

The government net lending-to-nominal GDP ratio increases sharply and permanently by 0.7%, while the government debt-to-nominal GDP ratio returns to baseline. The former can be observed directly from the government net lending and debt equations in the steady-state model. The current account-to-nominal GDP ratio falls along with GDP in the first year but then returns to baseline. This cumulates to the net foreign assets-to-nominal GDP ratio, which falls first but then starts to converge towards baseline.

Figure 4.1 **Permanent 1%-pt decrease in inflation target with full credibility, difference from baseline**

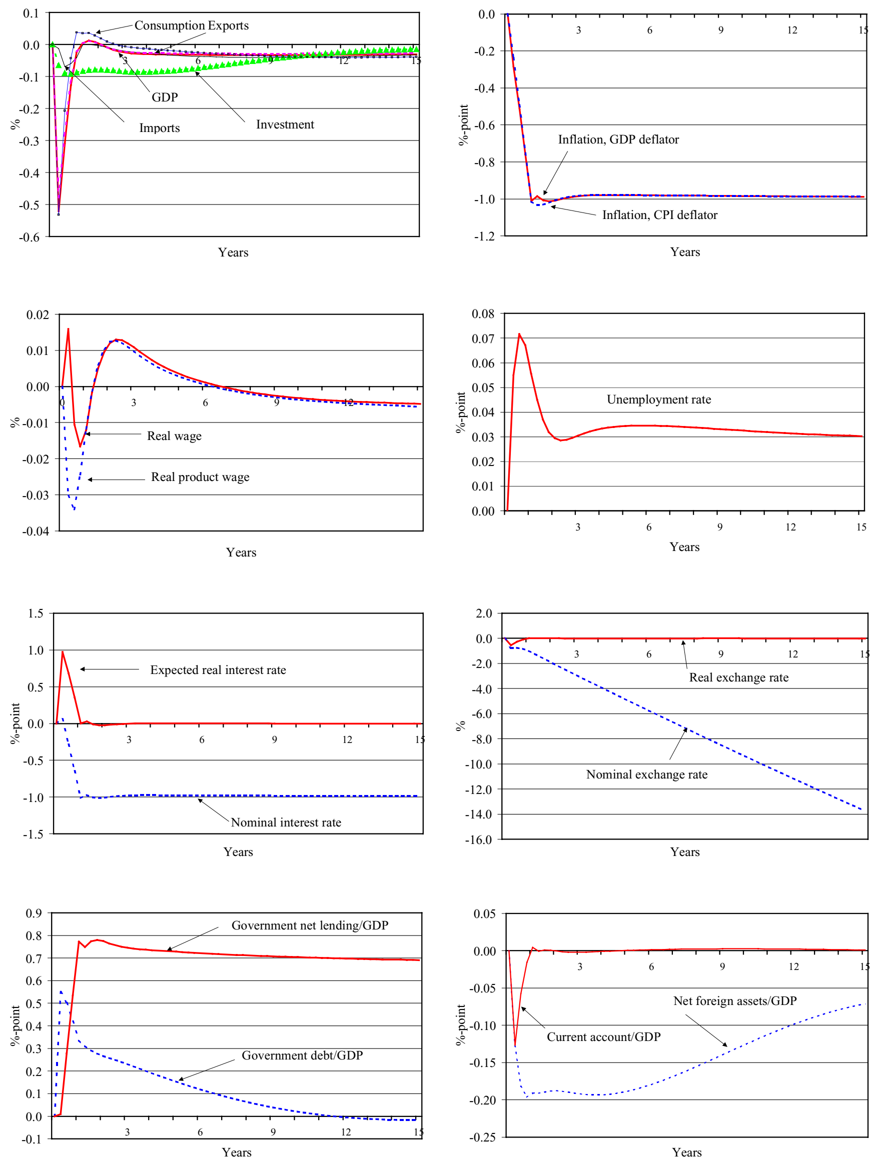

Table 4.1 **Permanent 1%-pt decrease in inflation target with full credibility, difference from baseline**

Q/Y	Q1	Q2	Q3	Y1	Y2	Y3	Y5	Y10	Y50
GDP, %	–0.52	–0.31	–0.13	–0.02	0.00	–0.03	–0.03	–0.03	–0.04
Imports, %	–0.01	–0.07	–0.06	–0.04	–0.01	–0.02	–0.03	–0.04	–0.03
Exports, %	–0.48	–0.28	–0.12	–0.02	0.00	–0.02	–0.03	–0.03	–0.04
Private consumption, %	–0.53	–0.21	–0.04	0.04	0.02	–0.01	–0.02	–0.04	–0.03
Private fixed investment, %	–0.06	–0.09	–0.09	–0.09	–0.08	–0.08	–0.08	–0.04	–0.04
Inflation, GDP defl., %-pts	–0.24	–0.49	–0.75	–1.01	–1.01	–0.98	–0.98	–0.98	–0.98
Inflation, consumpt. defl., %-pts	–0.28	–0.52	–0.76	–1.01	–1.01	–0.98	–0.98	–0.98	–0.98
Real wage, %	0.02	–0.01	–0.02	–0.01	0.01	0.01	0.00	0.00	–0.03
Real product wage, %	–0.03	–0.03	–0.02	–0.01	0.01	0.01	0.00	0.00	–0.03
Unemployment, %-pts	0.06	0.07	0.07	0.06	0.03	0.03	0.03	0.03	0.04
Nominal interest rate, %-pts	0.06	–0.28	–0.64	–1.01	–1.01	–0.98	–0.98	–0.98	–0.98
Expected real interest rate, %-pts	0.97	0.68	0.35	0.00	–0.03	0.00	0.00	0.00	0.00
Nominal exchange rate, %	–0.78	–0.76	–0.83	–0.99	–1.98	–2.94	–4.82	–9.37	–38.80
Real exchange rate, %	–0.54	–0.28	–0.09	0.00	0.00	–0.01	–0.01	–0.01	–0.02
Government debt/GDP, %-pts	0.55	0.50	0.42	0.34	0.27	0.23	0.15	0.02	–0.01
Government net lending/GDP, %-pts	0.01	0.28	0.53	0.77	0.78	0.74	0.73	0.70	0.68
Net foreign assets/GDP, %-pts	–0.13	–0.18	–0.20	–0.19	–0.19	–0.19	–0.19	–0.13	–0.64
Current account/GDP, %-pts	–0.13	–0.06	–0.02	0.00	0.00	0.00	0.00	0.00	–0.01

This simulation reveals an interesting feature of the EDGE model: it is not completely neutral. The observed non-neutrality, which is marginal but persistent, may arise because of the nominal rigidities. In our case, if the economy has no public debt and no net foreign assets, the decrease in the inflation rate would be quite neutral. In particular, when the interest rate on net foreign assets is measured by domestic interest rates, the steady-state model may become neutral for this shock. Moreover, if the labour supply is endogenised, then it is possible that the labour supply would fall in the face of a falling inflation rate, as suggested by the Lucas (1972) misperception model, and thus the non-neutrality effect might be further diminished. In particular, if in the wage formation process nominal wages react more strongly to dispcrepancies on the real side, this non-neutrality effect may vanish. An alternative interpretation of the latter effect is that the Calvo contracts, which make the nominal wages sticky, govern this non-neutrality effect, ie if the probability that wage contracts can be renegotiated approaches one, then the adjustment of wages becomes frictionless and thus discrepancies on the real side (unemployment gap) vanish almost immediately. As a result, the observed non-neutrality effect also vanishes.

Here we showed the effect of a 1 percentage point change in the inflation target by a credible central bank, ie a change that is believed. Next, we consider two cases in which the inflation target of the central bank differs from that expected by the private sector, ie the change is not believed. In the first case, the central bank and the private sector act simultaneously in each period. Thus the central bank is cognisant of private agents' disbelief in the new inflation target. In the second case, the central bank acts first on the information it has, assuming credibility, and sets the interest rate. After this the private sector takes the interest rate in the first period as given and optimises, assuming that the central bank will return to the old inflation target at the next period. We call the first case as the cognisant case and the second the naive case.

4.1.2 Cognisant case: central bank sets interest rates on basis of actual economic situation

In this first case we assume that the central bank sets the interest rate by the Taylor rule and that the private sector simultaneously optimises in each period. The private sector's belief about the central bank's future inflation target differs permanently from the central bank's actual inflation target. The private sector applies a 1 percentage point higher inflation target when it forms expectations on future monetary policy. This situation is repeated in every period. Thus, the private sector is always surprised by the tightness of monetary policy in the current period. Therefore, after the change, the economy is in a situation where monetary policy is persistently tighter than expected by the private sector, which is interpreted here as a situation of imperfect credibility.

Clearly we could run a more complex simulation where the private sector learns and comes to believe the new target. We will revert to the issue of learning in the next subsection. Our aim here, however, is to show what happens when this belief is absent, in order to measure the 'costs' of credibility. This also shows the costs of peso problems (see Vilmunen 1998 and Mattila 1998). The peso problem reflects distributional peculiarities associated with expectations of possible future policy shifts.

The simulation results for this case are presented in figure 4.2 and in table 4.2. The results with imperfect credibility are remarkably different from those of the credible case. First, inflation does not decline, even though monetary policy is tightened. This is due to the expectation effects that apparently dominate here. Real wages and inflation fall only marginally. Unemployment increases only marginally, which may be due to the fact that the labour demand equation is strongly forward looking. The negative labour productivity effects of the higher real interest rate that emerges seem to neutralise any negative price effects that might otherwise have derived from a real contraction. As a result, nominal and real interest rates rise permanently by a half percentage point above baseline. The nominal and real exchange rates appreciate immediately by 0.12% but thereafter the real exchange rate converges slowly to baseline while the nominal exchange rate appreciates in the long run.

The simulation results indicate that real GDP falls by 0.1% and that the main demand components affected are consumption and exports. Consumption and exports fall 0.1% relative to baseline. A notable feature of this simulation is that there is little immediate short-run variation compared to the above credible policy case. This can be explained by the fact that since expectations do not adjust, and the price level does not react much either, we do not get the immediate adjustment problems that would otherwise derive from existing wage contracts and price adjustment costs.

The government net lending-to-nominal GDP ratio falls by 0.3 percentage point immediately but then converges to baseline. The real contraction increases borrowing, and this leads to small increases in the government debt-to-nominal GDP ratio, but in the long run this also converges to baseline. The current account-to-nominal GDP ratio falls slightly at first but then converges to baseline. The net foreign assets-to-nominal GDP ratio falls as a result of the detoriorating current account but then balances and reverts to baseline in the long run.

Figure 4.2 **Permanent 1%-pt decrease in inflation target by cognisant central bank, difference from baseline**

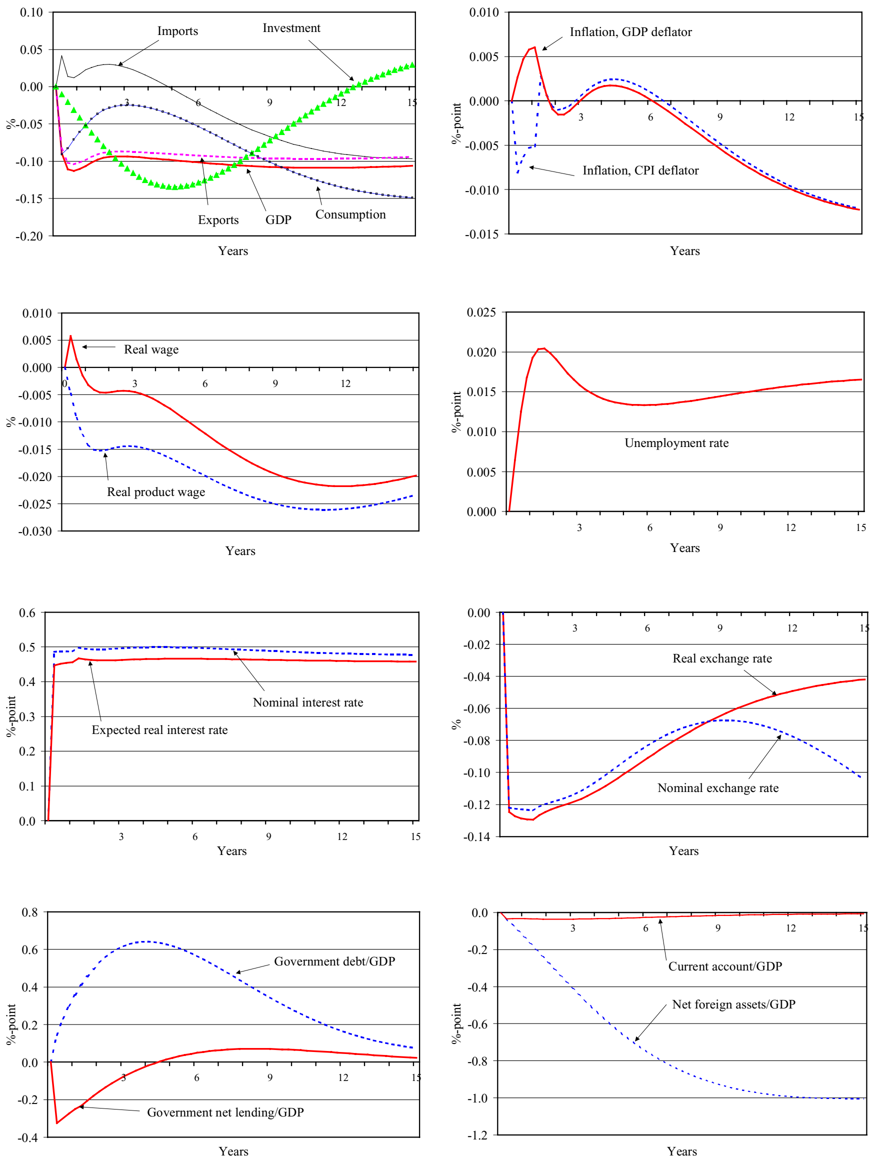

Table 4.2 **Permanent 1%-pt decrease in inflation target by cognisant central bank, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–0.09	–0.11	–0.11	–0.11	–0.10	–0.09	–0.10	–0.11	–0.09
Imports, %	0.04	0.01	0.01	0.02	0.03	0.03	0.00	–0.08	–0.08
Exports, %	–0.08	–0.10	–0.10	–0.10	–0.09	–0.09	–0.09	–0.10	–0.08
Private consumption, %	–0.09	–0.18	–0.07	–0.06	–0.03	–0.02	–0.04	–0.11	–0.13
Private fixed investment, %	–0.01	–0.02	–0.03	–0.04	–0.08	–0.11	–0.13	–0.05	0.02
Inflation, GDP defl., %-pts	0.00	0.00	0.01	0.01	0.00	0.00	0.00	–0.01	–0.01
Inflation, consumpt. defl., %-pts	–0.01	–0.01	–0.01	–0.01	0.00	0.00	0.00	–0.01	–0.01
Real wage, %	0.01	0.00	0.00	0.00	0.00	0.00	–0.01	–0.02	0.00
Real product wage, %	0.00	–0.01	–0.01	–0.01	–0.01	–0.01	–0.02	–0.03	0.00
Unemployment, %-pts	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.02
Nominal interest rate, %-pts	0.49	0.49	0.49	0.49	0.49	0.50	0.50	0.49	0.47
Expected real interest rate, %-pts	0.45	0.45	0.45	0.46	0.46	0.46	0.47	0.46	0.46
Nominal exchange rate, %	–0.12	–0.12	–0.12	–0.12	–0.12	–0.11	–0.09	–0.07	–0.59
Real exchange rate, %	–0.12	–0.13	–0.13	–0.13	–0.12	–0.12	–0.10	–0.06	–0.04
Government debt/GDP, %-pts	0.14	0.23	0.30	0.36	0.53	0.62	0.62	0.27	0.09
Government net lending/GDP, %-pts	–0.33	–0.30	–0.27	–0.25	–0.16	–0.08	0.02	0.07	0.01
Net foreign assets/GDP, %-pts	–0.04	–0.07	–0.10	–0.13	–0.27	–0.41	–0.65	–0.96	–0.93
Current account/GDP, %-pts	–0.04	–0.03	–0.03	–0.03	–0.04	–0.04	–0.03	–0.01	–0.01

4.1.3 Naive case: central bank sets interest rate on basis of its forecast and assumes credibility

We now assume that the central bank sets the interest rate by the Taylor rule, after which the private sector optimises in each period. Thus, the central bank forecasts the economy on the assumption of a lower inflation target and fixes the interest rate in the first period accordingly. Because the central bank has set interest rates with expectation that it will be believed, it anticipates a partly offsetting fall in output and hence raises interest rates by less than in the cognisant case. The private sector's belief in the central bank's inflation target is still assumed to differ permanently from the central bank's actual inflation target. Thus, in each period, the private sector optimises with a fixed interest rate in the first period but uses a 1 percentage point higher inflation target when it forms expectations on future monetary policy. In this case the central bank always makes forecast errors in the first period. Hence, we call this the naive case. This situation is repeated in every period.

The simulation results for this case, which are presented in figure 4.3 and in table 4.3, indicate that this type of solution looks similar to that for the previous case. Nevertheless, for most of the variables, the size of the effect is about one-fifth of that of the previous case.

In both the cognisant and naive cases, the cost of a lack of credibility is a permanently higher real interest rate and hence an output loss, but in the naive case the effect is considerably smaller. Note that neither in the cognisant nor in the naive case is monetary policy credible; hence inflation does not change. As a result there are no non-neutrality effects here, and the cost incurred comes from the lack of credibility through the higher real interest rate.

The cumulative quadratic losses of different cases are presented in figure 4.4. The quadratic loss is calculated as

$$Quadratic\, Loss = 0.5 \cdot \left(\pi_t - \bar{\pi}_t\right)^2 + 0.5 \cdot \left((1-\beta) \cdot \left(U_t - \overline{U_t}\right)\right)^2$$

The credible case involves much lower losses in terms of social welfare than do the cognisant and naive cases in the long run. However, credible changes in monetary policy mean larger sacrifices in the short run.

Figure 4.3 **Permanent 1%-pt decrease in inflation target by naive central bank, difference from baseline**

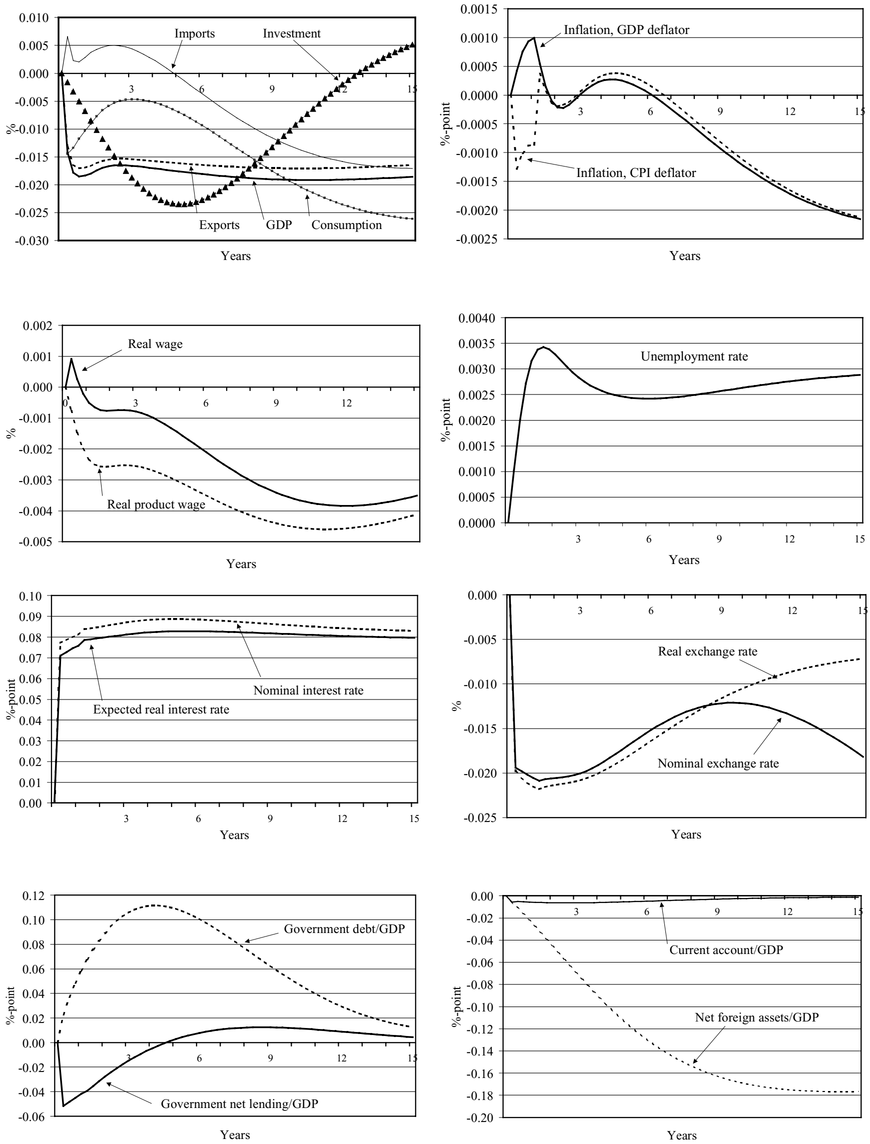

Table 4.3 **Permanent 1%-pt decrease in inflation target by naive central bank, difference from baseline**

Q/Y	Q1	Q2	Q3	Y1	Y2	Y3	Y5	Y10	Y50
GDP, %	–0.01	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02
Imports, %	0.01	0.00	0.00	0.00	0.00	0.00	0.00	–0.01	–0.01
Exports, %	–0.01	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.01
Private consumption, %	–0.01	–0.01	–0.01	–0.01	–0.01	0.00	–0.01	–0.02	–0.02
Private fixed investment, %	0.00	0.00	–0.01	–0.01	–0.01	–0.02	–0.02	–0.01	0.00
Inflation, GDP defl., %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inflation, consumpt. defl., %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Real wage, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Real product wage, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unemployment, %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nominal interest rate, %-pts	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.08
Expected real interest rate, %-pts	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08
Nominal exchange rate, %	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.01	–0.10
Real exchange rate, %	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.01	–0.01
Government debt/GDP, %-pts	0.02	0.04	0.05	0.06	0.09	0.11	0.11	0.05	0.02
Government net lending/GDP, %-pts	–0.05	–0.05	–0.05	–0.04	–0.03	–0.01	0.00	0.01	0.00
Net foreign assets/GDP, %-pts	–0.01	–0.01	–0.02	–0.02	–0.05	–0.07	–0.11	–0.17	–0.16
Current account/GDP, %-pts	–0.01	–0.01	–0.01	–0.01	–0.01	–0.01	–0.01	0.00	0.00

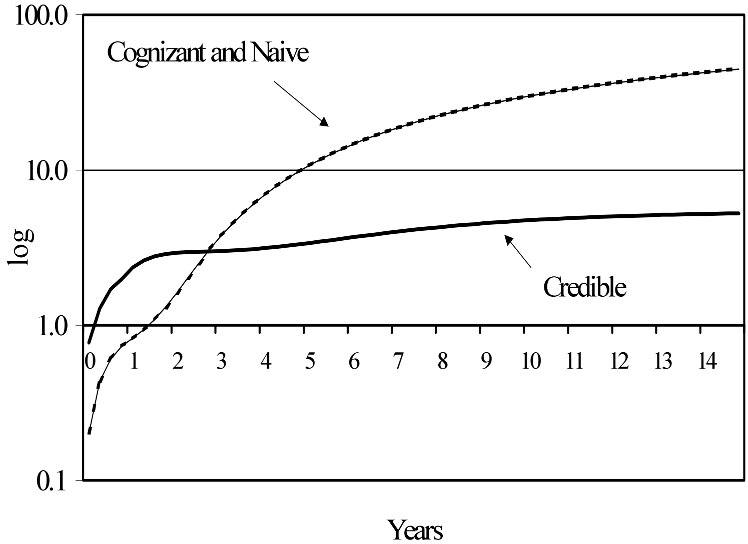

Figure 4.4 Cumulative quadratic loss
1/2*(infy-inft)**2+1/2*(U-NAIRU)**2

4.1.4 Permanent decrease in NAIRU

The non-accelerating inflation rate of unemployment (NAIRU), ie equilibrium unemployment rate, is currently exogenous in the EDGE model. Furthermore, monetary policy (Taylor) rule is written so that it reacts to differences between actual unemployment rate and NAIRU. It would be interesting to see how the model reacts if NAIRU is changed. As NAIRU is exogenous, the ultimate reason for the change must come from outside of the model (preferences and technology). The change in NAIRU could possibly happen because of legislative changes that change the labour supply.

We implement a change in NAIRU in the EDGE model as follows. We use the same baseline as above. Next, we assume that the NAIRU decreases by 1 percentage point permanently and that this is not anticipated. The results are shown in figure 4.5. These are identical (as expected) to the earlier results of the permanent and unanticipated 1% shock in the labour force.

As these result have been already dealt with the labour supply shock we move on to separate the beliefs of the level of NAIRU.

Figure 4.5 **Permanent 1%-pt decrease inNairu, difference from baseline**

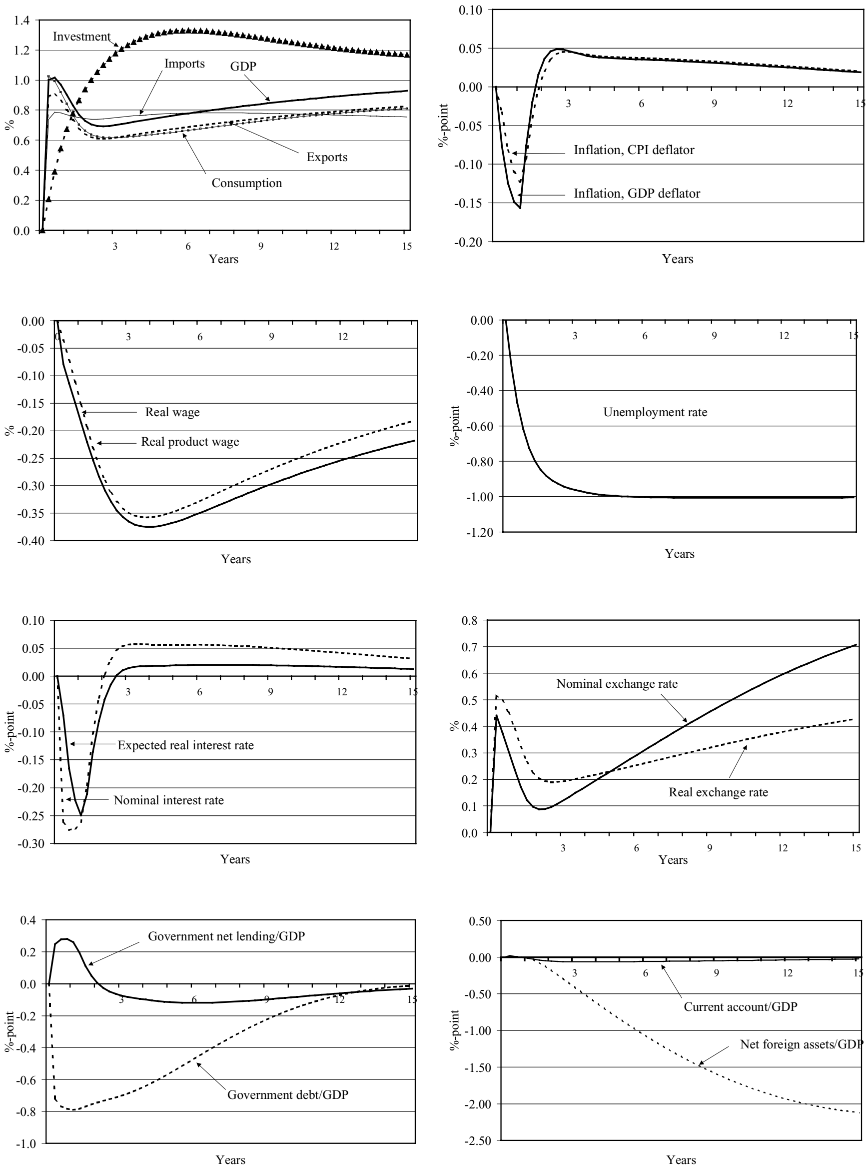

Table 4.4 **Permanent 1%-pt decrease in NAIRU, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	1.00	1.02	0.97	0.90	0.70	0.70	0.75	0.86	1.07
Imports, %	0.74	0.79	0.78	0.77	0.74	0.75	0.77	0.78	0.83
Exports, %	0.89	0.90	0.86	0.80	0.62	0.62	0.67	0.76	0.95
Private consumption, %	1.02	0.99	0.92	0.84	0.64	0.62	0.64	0.75	1.00
Private fixed investment, %	0.21	0.39	0.55	0.67	1.00	1.18	1.32	1.26	1.03
Inflation, GDP defl., %-pts	–0.08	–0.12	–0.15	–0.16	0.04	0.05	0.04	0.03	0.00
Inflation, consumpt. defl., %-pts	–0.03	–0.08	–0.11	–0.12	0.02	0.05	0.04	0.03	0.00
Real wage, %	–0.08	–0.11	–0.15	–0.19	–0.31	–0.37	–0.37	–0.28	–0.08
Real product wage, %	–0.04	–0.07	–0.11	–0.15	–0.29	–0.35	–0.35	–0.25	–0.04
Unemployment, %-pts	–0.27	–0.47	–0.62	–0.73	–0.91	–0.96	–1.00	–1.01	–1.00
Nominal interest rate, %-pts	–0.26	–0.28	–0.27	–0.26	0.00	0.06	0.06	0.05	0.00
Expected real interest rate, %-pts	–0.07	–0.17	–0.22	–0.25	–0.04	0.01	0.02	0.02	0.00
Nominal exchange rate, %	0.44	0.37	0.31	0.24	0.09	0.12	0.23	0.51	0.87
Real exchange rate, %	0.52	0.50	0.45	0.39	0.21	0.19	0.23	0.34	0.51
Government debt/GDP, %-pts	–0.73	–0.77	–0.78	–0.79	–0.74	–0.70	–0.56	–0.16	0.00
Government net lending/GDP, %-pts	0.25	0.28	0.28	0.26	0.01	–0.07	–0.11	–0.09	0.00
Net foreign assets/GDP, %-pts	0.00	0.01	0.01	–0.01	–0.18	–0.41	–0.86	–1.73	–0.47
Current account/GDP, %-pts	0.02	0.01	0.00	–0.01	–0.05	–0.06	–0.06	–0.04	0.01

4.1.5 Myopic central bank perceives permanent increase in NAIRU

Here, we analyse the case where the central bank expects to see an increase in the NAIRU while the private sector believes correctly that NAIRU is not changing. In each period the central bank reacts to the actual situation in the economy but has a distorted view of the level of the NAIRU whereas the private sector is able to forecast the level of NAIRU correctly. Furthermore, the private sector in each period expects that the central bank will correct its view of NAIRU in the future (next period). There is no learning here, and thus the central bank expects to see the increase in the NAIRU also in the next period. In other words, due to the heterogeneity in information sets and the assumption of no learning, this situation is repeated infinitely. As a result, the simulation is executed recursively starting from the first period and rolling over to the fixed end-point.

The results of this simulation are shown in figure 4.6 and in table 4.5. Quantitatively and qualitatively these are close to the case of a 1 percentage point reduction in the central bank's inflation target and this is not believed by the private sector, ie the cognisant case. Here, the inflation rate hardy changes at all. The same applies to real wages. As the activity also changes only marginally, we see immediately from the Taylor rule that the increase in the nominal interest rate should be approximately as $\Delta\left[-0.5\cdot(1-\beta)\cdot\left(U_t-\overline{U_t}\right)\right] \approx 0.5\cdot 0.6\cdot\Delta\overline{U_t}$ ie +0.3 percentage point. The expected real interest rate increases accordingly as the inflation rate is close to zero. The nominal and real exchange rates depreciate somewhat.

Real GDP falls by only 0.06% due to declines in exports and consumption, which are affected by the expected real interest rate and real exchange rate. Here the effects are about half of those of the 1 percentage point reduction in the interest rate target by the cognisant central bank. One may however wonder if it is reasonable to assume that the central bank will permanently forecast the NAIRU incorrectly.

4.1.6 Myopic private sector perceives that central bank perceives a permanent increase in NAIRU

Here, we analyse the case where the private sector expects that the central bank perceives an increase in NAIRU. However, in each period, the central bank reacts to the actual situation in the economy and has a correct view of the actual level of NAIRU. The private sector has also a correct view of the level of the NAIRU. Nevertheless, the private sector unfortunately perceives that the central bank has a higher estimate of the NAIRU. As a result, the private sector permanently expects in each period that the central bank will perceive a higher level of NAIRU in the future.

Results from this simulation are shown in figure 4.7 and in table 4.6. This case differs quite much from the previous one since now the inflation rate falls permanently by over 0.5 percentage point. Here the myopic private sector has a misperception of the central bank's estimate of the level of NAIRU. As a result the private sector foresees tighter monetary policy in the future. However, this does not happen, and as the inflation rate falls the nominal interest rate and expected real interest rate also fall permanently. Note however, that a small decline in the expected real interest rate generates only a small increase in output via an increase in consumption. The real exchange rate remains stable and thus the changes in exports are quite modest. There is a slight boosting effect on real activity but this vanishes in the long run.

Figure 4.6 **Myopic central bank perceives a 1%-pt increase in NAIRU, difference from baseline**

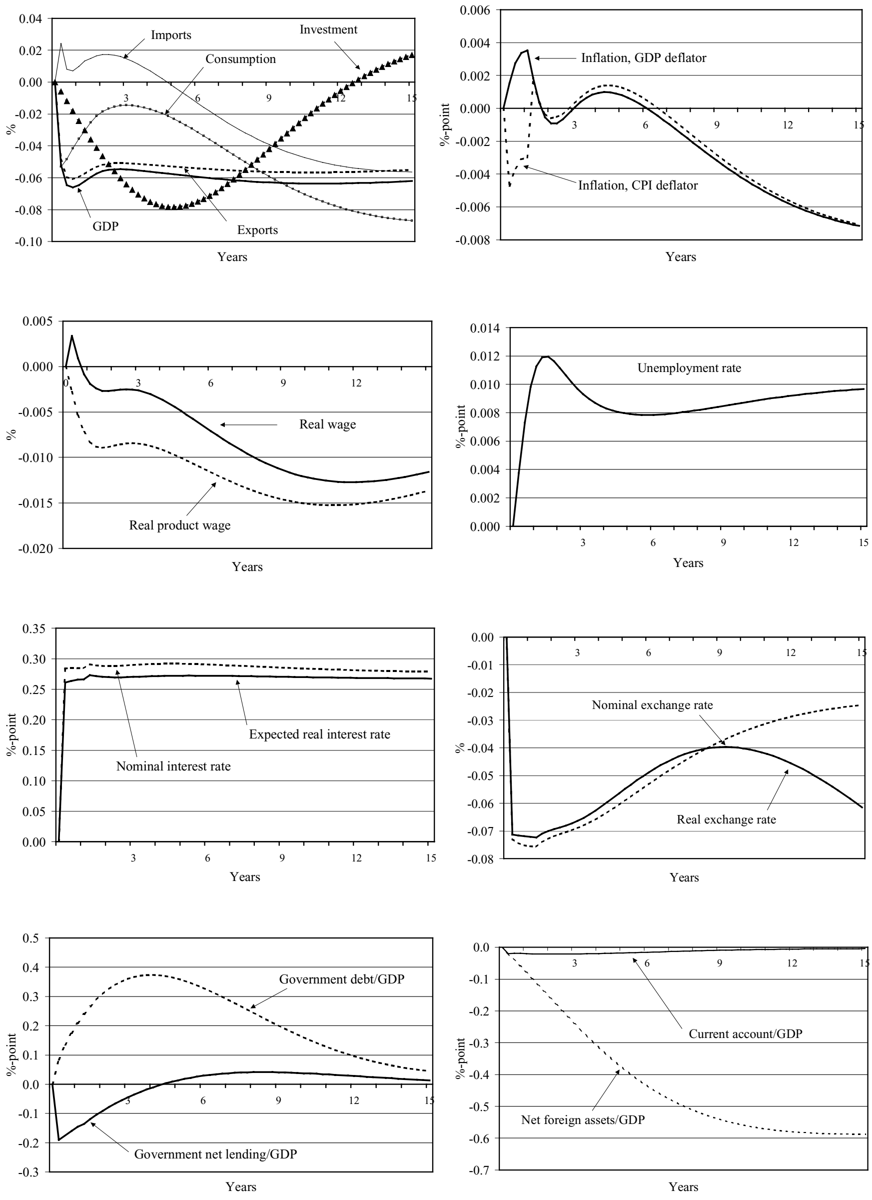

Table 4.5 **Myopic central bank perceives at 1%-pt increase in NAIRU, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–0.05	–0.06	–0.07	–0.06	–0.06	–0.05	–0.06	–0.06	–0.05
Imports, %	0.02	0.01	0.01	0.01	0.02	0.01	0.00	–0.05	–0.05
Exports, %	–0.05	–0.06	–0.06	–0.06	–0.05	–0.05	–0.05	–0.06	–0.05
Private consumption, %	–0.05	–0.05	–0.04	–0.04	–0.02	–0.01	–0.02	–0.07	–0.08
Private fixed investment, %	–0.01	–0.01	–0.02	–0.02	–0.05	–0.06	–0.08	–0.03	0.01
Inflation, GDP defl., %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–0.01
Inflation, consumpt. defl., %-pts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–0.01
Real wage, %	0.00	0.00	0.00	0.00	0.00	0.00	–0.01	–0.01	0.00
Real product wage, %	0.00	–0.01	–0.01	–0.01	–0.01	–0.01	–0.01	–0.02	0.00
Unemployment, %-pts	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Nominal interest rate, %-pts	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.28	0.28
Expected real interest rate, %-pts	0.26	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Nominal exchange rate, %	–0.07	–0.07	–0.07	–0.07	–0.07	–0.07	–0.05	–0.04	–0.34
Real exchange rate, %	–0.07	–0.07	–0.08	–0.08	–0.07	–0.07	–0.06	–0.03	–0.02
Government debt/GDP, %-pts	0.08	0.14	0.17	0.21	0.31	0.36	0.36	0.16	0.06
Government net lending/GDP, %-pts	–0.19	–0.17	–0.16	–0.15	–0.09	–0.04	0.01	0.04	0.00
Net foreign assets/GDP, %-pts	–0.02	–0.04	–0.06	–0.08	–0.16	–0.24	–0.38	–0.56	–0.54
Current account/GDP, %-pts	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02	–0.01	0.00

Figure 4.7 **Myopic private sector perceives that central bank perceives a 1%-pt increase in NAIRU, difference from baseline**

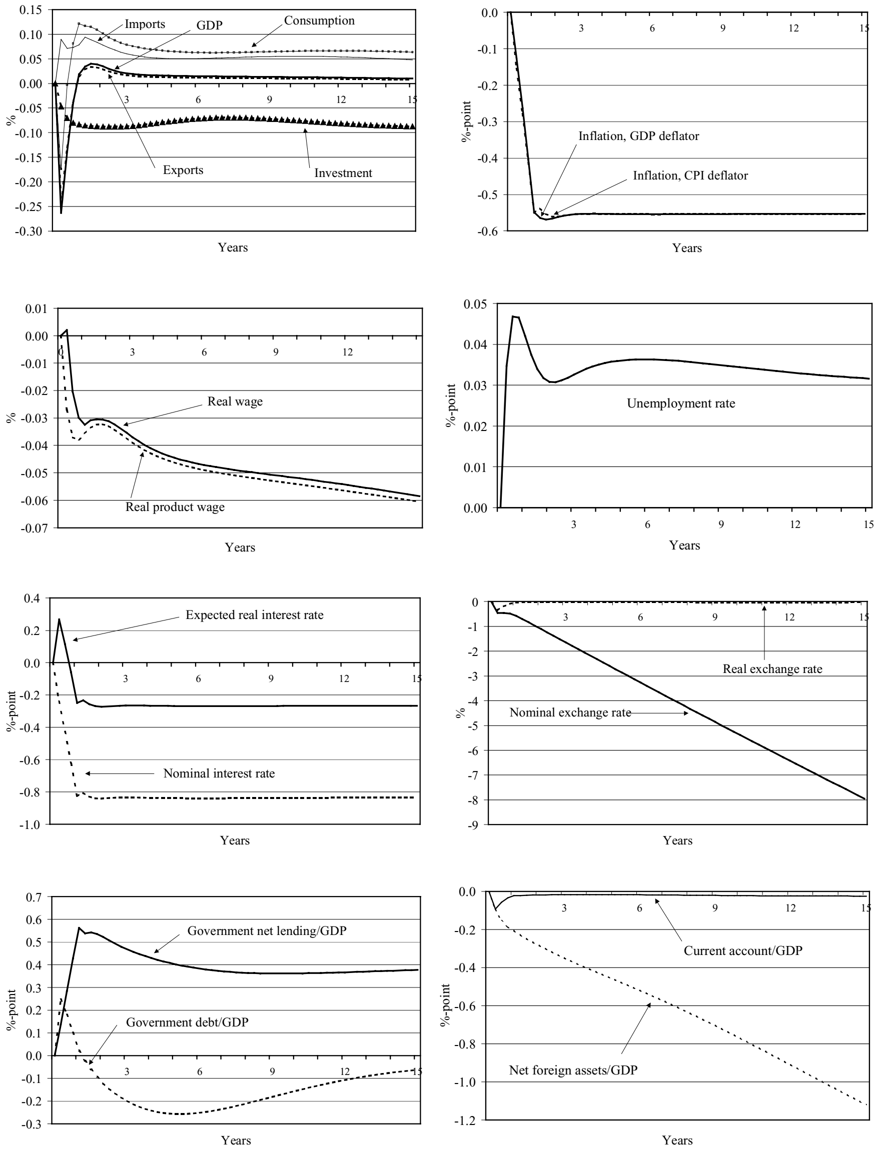

Table 4.6 **Myopic private sector perceives that central bank perceives a 1%-pt increase in NAIRU, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–0.26	–0.14	–0.04	0.02	0.03	0.02	0.02	0.01	0.00
Imports, %	0.09	0.07	0.07	0.08	0.08	0.06	0.05	0.06	–0.01
Exports, %	–0.24	–0.13	–0.04	0.01	0.03	0.02	0.01	0.01	0.00
Private consumption, %	–0.17	0.00	0.08	0.12	0.10	0.08	0.06	0.07	0.01
Private fixed investment, %	–0.05	–0.07	–0.08	–0.08	–0.09	–0.09	–0.08	–0.07	–0.06
Inflation, GDP defl., %-pts	–0.13	–0.26	–0.40	–0.55	–0.56	–0.55	–0.55	–0.55	–0.55
Inflation, consumpt. defl., %-pts	–0.16	–0.28	–0.41	–0.55	–0.56	–0.55	–0.55	–0.55	–0.55
Real wage, %	0.00	–0.02	–0.03	–0.03	–0.03	–0.04	–0.05	–0.05	–0.08
Real product wage, %	–0.03	–0.04	–0.04	–0.04	–0.03	–0.04	–0.05	–0.05	–0.08
Unemployment, %-pts	0.03	0.05	0.05	0.04	0.03	0.03	0.04	0.03	0.03
Nominal interest rate, %-pts	–0.24	–0.43	–0.62	–0.83	–0.84	–0.83	–0.84	–0.84	–0.83
Expected real interest rate, %-pts	0.27	0.12	–0.06	–0.25	–0.27	–0.27	–0.27	–0.27	–0.27
Nominal exchange rate, %	–0.47	–0.46	–0.49	–0.57	–1.11	–1.65	–2.73	–5.38	–24.04
Real exchange rate, %	–0.34	–0.20	–0.09	–0.04	–0.02	–0.02	–0.02	–0.03	0.01
Government debt/GDP, %-pts	0.25	0.18	0.10	0.02	–0.12	–0.20	–0.26	–0.16	–0.07
Government net lending/GDP, %-pts	0.14	0.28	0.43	0.56	0.52	0.47	0.40	0.36	0.38
Net foreign assets/GDP, %-pts	–0.10	–0.15	–0.19	–0.21	–0.28	–0.35	–0.46	–0.77	–2.41
Current account/GDP, %-pts	–0.09	–0.06	–0.03	–0.02	–0.02	–0.02	–0.02	–0.02	–0.02

4.1.7 Permanent increase in foreign real interest rate

The equilibrium real interest rate is the exogenous foreign real interest rate in the EDGE model and is also included in the Taylor rule. Thus possible variations in it are of some interest. A change in the equilibrium real interest rate is assumed to occur due to changes in the external economic environment.

We implement the change in the equilibrium real interest rate in the EDGE model as follows. We assume that the equilibrium real interest rate increases by 1 percentage point annually and permanently and that this is unanticipated. We introduce this change first in the steady-state and then run a new baseline with the dynamic model using the new steady-state and new equilibrium real interest rate. The results of this rise in the foreign interest rate are shown in figure 4.8.

The inflation falls immediately by 1.5 percentage points and then starts to converge back to baseline. The expected real interest rate as well as the nominal interest rate increase immediately but fall as sharply in about one year's time. In the long run both the nominal and expected real interest rate increase by 1 percentage point. This increase in expected real interest rate drags down investment in the long run, which also drags down output in the long run. Real wages follow output in the long run while unemployment returns to baseline. The government net lending-to-nominal GDP ratio, as well as the government debt to-nominal GDP ratio return to baseline in the long run. The current account to-nominal GDP and net foreign assets to-nominal GDP ratios return to baseline, at a much slower pace.

4.1.8 Myopic central bank perceives a permanent increase in foreign real interest rate

We do a simulation in which we assume that the information sets are heterogeneous. In particular, we analyse the case where the central bank fails to see the actual level of the equilibrium real interest rate. In each period the central bank perceives that the equilibrium real interest rate increases by 1 percentage point annually. The private sector in each period expects that the central bank will correct its view of the equilibrium real interest rate in the future (next period). We assume no learning here. Thus, the central bank perceives a hike in the equilibrium real interest rate also in the next period. In other words, due to heterogeneity of information sets and the no learning assumption, this situation is repeated infinitely.

The figure 4.9 and table 4.8 describe a situation in which there is a 1 percentage point rise in the equilibrium real interest rate, which the central bank perceives, while the actual foreign real interest rate remains unchanged. The inflation rate remains almost unchanged. Real wages fall slightly and unemployment rises slightly. The nominal interest rate, as well as the expected real interest rate, rises almost 1 percentage point, which drags output down by 0.2% permanently. The government and foreign sectors return to baseline in the long run.

Note that this shock assumes that the central bank permanently perceives a higher-than-actual foreign interest rate rule. This assumption is purely ad hoc, and it may well be more reasonable to assume that such a difference between fact and central bank perceptions is only temporary in nature.

Figure 4.8 **Permanent 1%-pt increase in foreign real interest rate, difference from baseline**

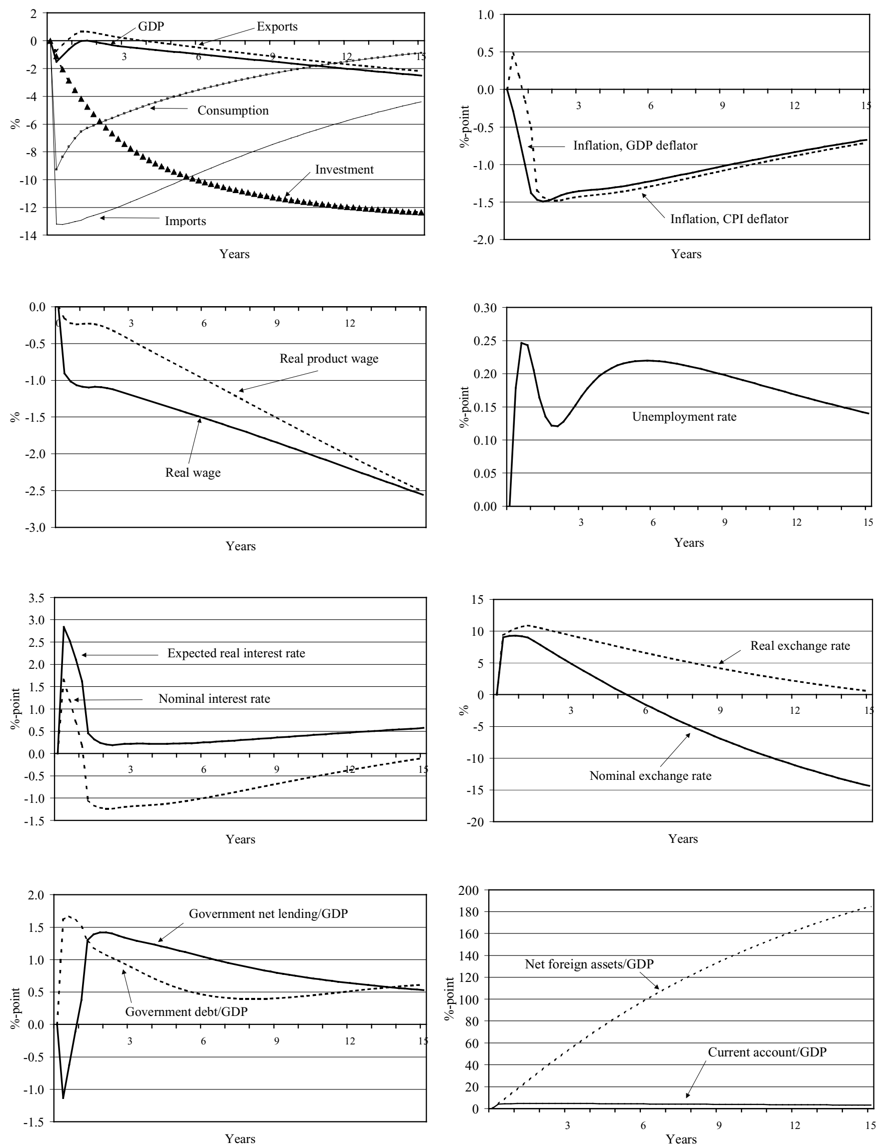

Table 4.7 **Permanent 1%-pt increase in foreign real interest rate, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–1.52	–1.08	–0.61	–0.24	–0.14	–0.44	–0.79	–1.67	–4.99
Imports, %	–13.21	–13.24	–13.13	–13.01	–12.44	–11.80	–10.29	–6.86	–0.66
Exports, %	–0.75	–0.33	0.10	0.44	0.51	0.19	–0.27	–1.32	–4.32
Private consumption, %	–9.27	–8.36	–7.63	–7.02	–5.91	–5.23	–4.04	–2.04	–0.08
Private fixed investment, %	–1.12	–2.06	–2.86	–3.55	–5.78	–7.43	–9.43	–11.54	–12.26
Inflation, GDP defl., %-pts	–0.29	–0.63	–1.00	–1.38	–1.45	–1.36	–1.28	–0.96	0.01
Inflation, consumpt. defl., %-pts	0.48	0.18	–0.16	–0.51	–1.48	–1.43	–1.35	–1.02	0.00
Real wage, %	–0.91	–1.02	–1.07	–1.09	–1.11	–1.20	–1.41	–1.96	–4.62
Real product wage, %	–0.15	–0.22	–0.24	–0.23	–0.28	–0.45	–0.81	–1.68	–5.00
Unemployment, %-pts	0.18	0.25	0.24	0.21	0.12	0.17	0.22	0.19	0.01
Nominal interest rate, %-pts	1.66	1.20	0.70	0.18	–1.24	–1.19	–1.09	–0.57	1.00
Expected real interest rate, %-pts	2.84	2.52	2.10	1.62	0.20	0.22	0.22	0.40	1.00
Nominal exchange rate, %	9.05	9.23	9.28	9.20	7.24	4.88	0.46	–8.43	–23.91
Real exchange rate, %	9.36	9.91	10.37	10.70	10.29	9.33	7.48	3.44	–4.53
Government debt/GDP, %-pts	1.62	1.67	1.61	1.51	1.08	0.90	0.56	0.43	0.09
Government net lending/GDP, %-pts	–1.13	–0.62	–0.11	0.38	1.42	1.31	1.14	0.74	0.01
Net foreign assets/GDP, %-pts	4.60	8.86	13.27	17.78	35.86	53.06	84.24	144.21	253.39
Current account/GDP, %-pts	4.12	4.32	4.46	4.57	4.64	4.57	4.34	3.69	1.92

Figure 4.9 **Myopic central bank perceives 1%-pt rise in foreign real interest rate, difference from baseline**

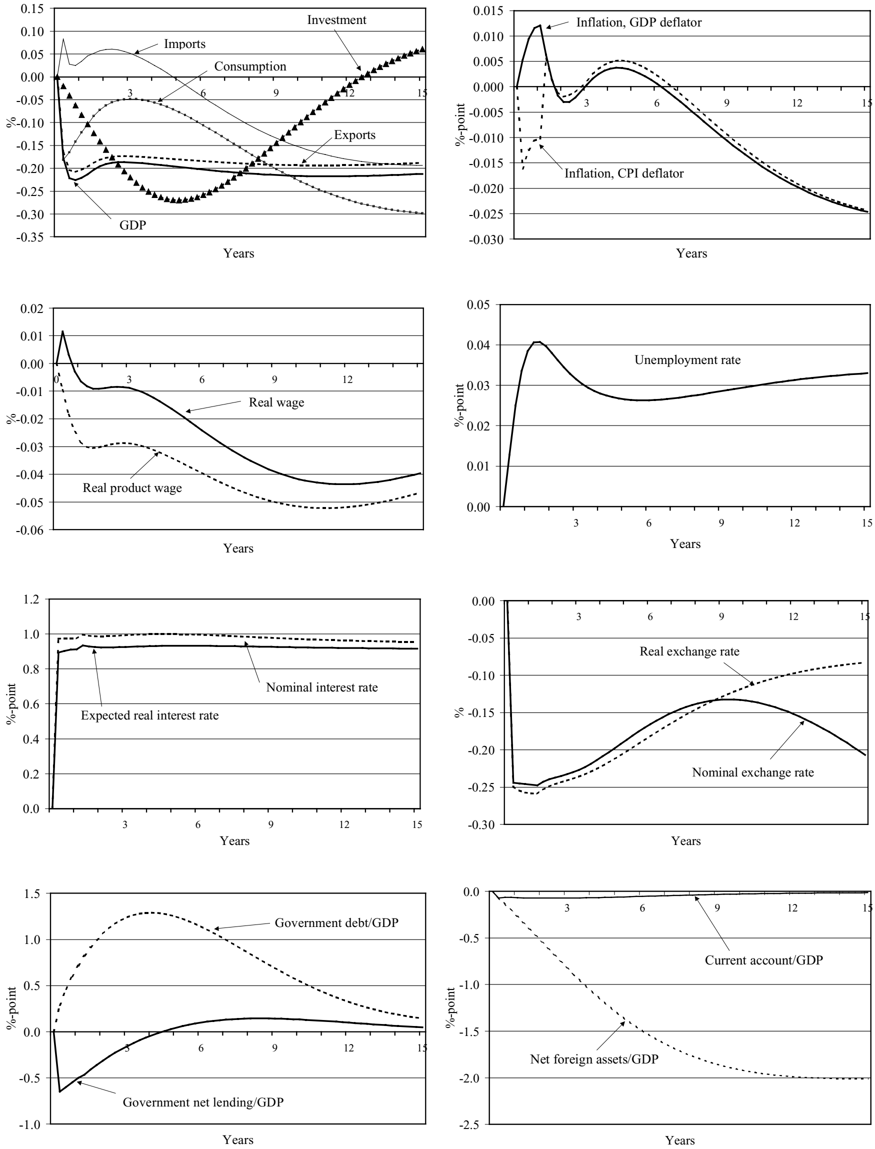

Table 4.8 **Myopic central bank perceives 1%-pt rise in foreign real interest rate, difference from baseline**

Q/Y	**Q1**	**Q2**	**Q3**	**Y1**	**Y2**	**Y3**	**Y5**	**Y10**	**Y50**
GDP, %	–0.18	–0.22	–0.23	–0.22	–0.19	–0.19	–0.20	–0.22	–0.18
Imports, %	0.08	0.03	0.02	0.03	0.06	0.05	–0.01	–0.15	–0.16
Exports, %	–0.17	–0.20	–0.21	–0.20	–0.18	–0.17	–0.18	–0.19	–0.16
Private consumption, %	–0.18	–0.17	–0.14	–0.12	–0.06	–0.05	–0.08	–0.23	–0.26
Private fixed investment, %	–0.02	–0.04	–0.06	–0.08	–0.16	–0.22	–0.27	–0.10	0.04
Inflation, GDP defl., %-pts	0.01	0.01	0.01	0.01	0.00	0.00	0.00	–0.01	–0.03
Inflation, consumpt. defl., %-pts	–0.02	–0.01	–0.01	–0.01	0.00	0.00	0.00	–0.01	–0.03
Real wage, %	0.01	0.00	0.00	–0.01	–0.01	–0.01	–0.02	–0.04	0.00
Real product wage, %	–0.01	–0.02	–0.02	–0.03	–0.03	–0.03	–0.04	–0.05	–0.01
Unemployment, %-pts	0.01	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.04
Nominal interest rate, %-pts	0.97	0.97	0.97	0.97	0.99	0.99	1.00	0.97	0.95
Expected real interest rate, %-pts	0.89	0.90	0.91	0.91	0.92	0.93	0.93	0.92	0.91
Nominal exchange rate, %	–0.24	–0.25	–0.25	–0.25	–0.24	–0.23	–0.19	–0.13	–1.17
Real exchange rate, %	–0.25	–0.25	–0.26	–0.26	–0.25	–0.24	–0.20	–0.12	–0.07
Government debt/GDP, %-pts	0.29	0.46	0.60	0.72	1.06	1.24	1.25	0.55	0.19
Government net lending/GDP, %-pts	–0.65	–0.60	–0.55	–0.50	–0.31	–0.16	0.04	0.13	0.01
Net foreign assets/GDP, %-pts	–0.07	–0.14	–0.20	–0.27	–0.55	–0.82	–1.31	–1.92	–1.85
Current account/GDP, %-pts	–0.07	–0.06	–0.07	–0.07	–0.07	–0.07	–0.06	–0.03	–0.01

4.2 Temporary expectational errors

The above cases where the expectations of central bank and private sector differ generate real costs to economy. However, it may be hard to accept that the central bank and private sector could be so ignorant of this difference in expectations in the long run. It is therefore possible that either the central bank or the private sector or both change their behaviour as time goes by. We approach this issue by introducing some learning mechanisms into the model which render these differences in expectations transitory. What this amounts to is that the expectation formation mechanism in the model is changed from fully rational to adaptive. This enables us to analyse different kinds of interesting dynamic processes. However, it also changes the fundamental behaviour of the model and so is not an innocent adjustment. In particular, the case where the central bank learns may entail a serious undermining of its to commit to its ex ante policy. Therefore, a more natural place for learning to take place is in private sector expectations. We examine both cases for completeness shake, but the latter case is probably the more interesting.

We analyse two different cases involving a cognisant central bank that lowers the inflation target. First, we impose an exogenous decay process which removes the difference between the expectations. Second, we add a simple adaptive process which also results in convergence of expectations in the long run.

4.2.1 Exogenous decay process

Below we show in one case what happens if the expectational difference disappears exogenously. We consider a case where a cognisant central bank lowers the inflation target by 1 percentage point initially. However, after the first period, exogenous forces force the central bank to adjust its inflation target by the decay rule $e^{-t/10}$. The result is that the simulation returns to baseline, as expected.

The initial reaction to the change in inflation target follows the pattern seen above for the cognisant central bank case without learning. In this case, we assume that the some exogenous process forces the central bank to shift its inflation

Figure 4.10 **Cognisant central bank lowers inflation target by 1%-pt, learns exogenously that it is not credible, difference from baseline**

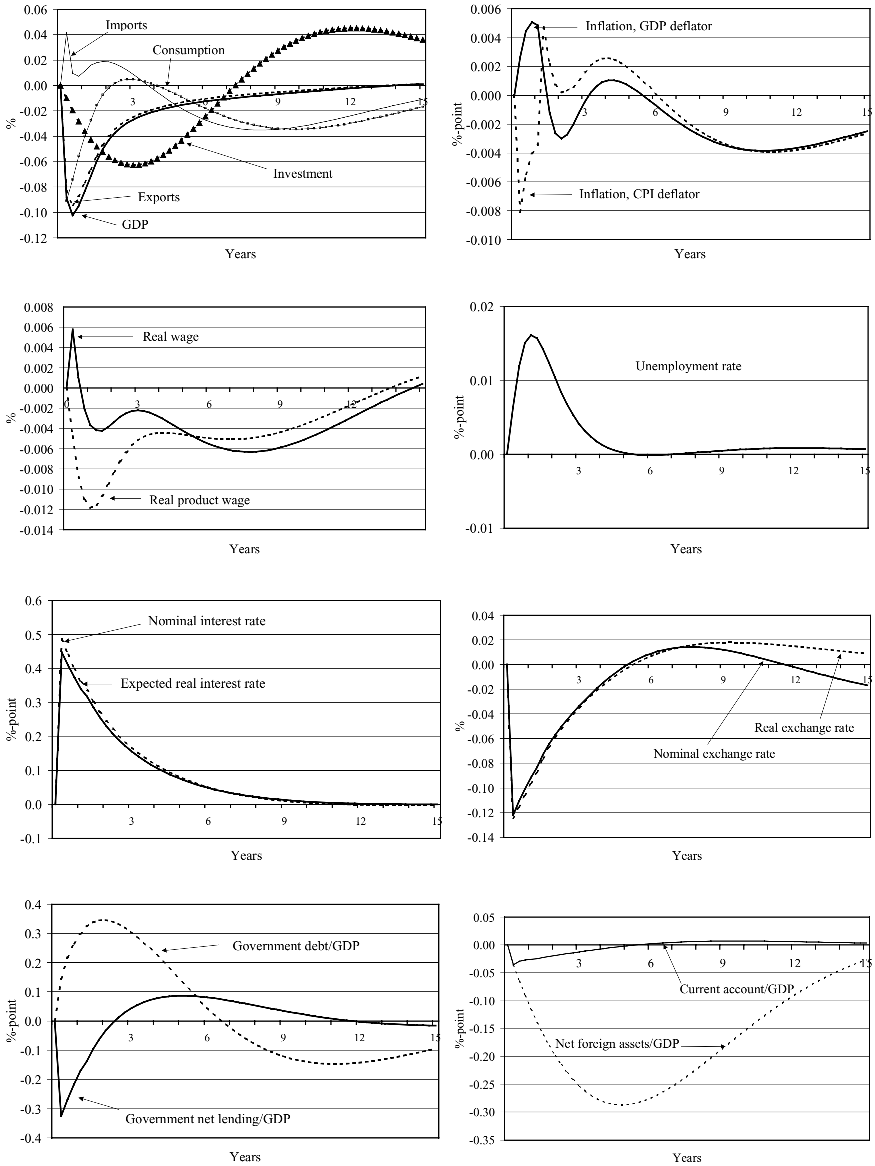

Table 4.9 **Cognisant central bank lowers inflation target by 1%-pt, learns exogenously that it is not credible, difference from baseline**

Q/Y	Q1	Q2	Q3	Y1	Y2	Y3	Y5	Y10	Y50
GDP, %	–0.09	–0.10	–0.09	–0.08	–0.04	–0.03	–0.02	–0.01	0.00
Imports, %	0.04	0.01	0.01	0.01	0.02	0.01	–0.02	–0.03	0.00
Exports, %	–0.08	–0.09	–0.09	–0.08	–0.04	–0.03	–0.01	0.00	0.00
Private consumption, %	–0.09	–0.07	–0.06	–0.04	0.00	0.00	–0.01	–0.03	0.00
Private fixed investment, %	–0.01	–0.02	–0.03	–0.04	–0.06	–0.06	–0.04	0.04	0.00
Inflation, GDP defl., %-pts	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Inflation, consumpt. defl., %-pts	–0.01	–0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Real wage, %	0.01	0.00	0.00	0.00	0.00	0.00	0.00	–0.01	0.00
Real product wage, %	0.00	–0.01	–0.01	–0.01	–0.01	–0.01	0.00	0.00	0.00
Unemployment, %-pts	0.01	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.00
Nominal interest rate, %-pts	0.49	0.44	0.40	0.36	0.25	0.17	0.08	0.00	0.00
Expected real interest rate, %-pts	0.45	0.41	0.37	0.34	0.23	0.16	0.07	0.01	0.00
Nominal exchange rate, %	–0.12	–0.11	–0.10	–0.09	–0.06	–0.03	0.00	0.01	–0.04
Real exchange rate, %	–0.12	–0.12	–0.11	–0.10	–0.06	–0.04	0.00	0.02	0.00
Government debt/GDP, %-pts	0.14	0.22	0.27	0.30	0.35	0.31	0.13	–0.14	0.00
Government net lending/GDP, %-pts	–0.33	–0.27	–0.22	–0.17	–0.03	0.04	0.09	0.02	0.00
Net foreign assets/GDP, %-pts	–0.04	–0.06	–0.09	–0.12	–0.20	–0.25	–0.29	–0.15	0.01
Current account/GDP, %-pts	–0.04	–0.03	–0.03	–0.03	–0.02	–0.01	0.00	0.01	0.00

target back to the original level, which in the case of no credibility, also minimises the real costs to the economy in the long run.

This form of learning mechanism does not reveal the source of learning, but it does allow for the possibility that expectational errors cause only temporary deviations from baseline.

4.2.2 Endogenous learning through adaptive expectations

Private sector learning from past behaviour could be modelled by adaptive expectations. We do this in such a way that the private sector gradually learns the new inflation target set by the central bank. Note that we use the term endogenous here to mean that the learning follows a certain adaptive process rather than that the learning comes from a dynamic optimisation problem.

We assume that the aggregate expectations of x_t at time t-1 can be expressed by $E(x_t|I_{t-1}) = E_{t-1}(x_t)$, where $I_{t-1} = \{x_{t-1}, x_{t-2}, x_{t-3}, ...\}$ is the information set at time t-1. x_t is the set of variables, including all endogenous and exogenous variables at time t. We assume that when expectations are formed at time t-1 all the variable values for time t-1 are known. We further define private sector and central bank time t-1 expectations of x_t to be $\widehat{E}_{t-1}(x_t)$ and $\widehat{\widehat{E}}_{t-1}(x_t)$ respectively.

Assume that in the initial period t-1 there is a common belief in the central bank's inflation target, ie $E_{t-1}(\overline{\pi}_t) = \widehat{E}_{t-1}(\overline{\pi}_t) = \widehat{\widehat{E}}_{t-1}(\overline{\pi}_t)$. The central bank knows the future inflation target: $\widehat{E}_{t-1}(\overline{\pi}_t) = \overline{\pi}_t$. Furthermore, the central bank has a constant inflation target for t-1 and forward, ie $\overline{\pi}_{t-1} = \overline{\pi}_t = \overline{\pi}_{t+1} = ... = \overline{\pi}$.

Next, assume that in period t the central bank sets a new constant inflation target, ie $\overline{\pi}_{t-1} + \varepsilon = \overline{\overline{\pi}}_t = \overline{\overline{\pi}}_{t+1} = ... = \overline{\overline{\pi}}$, where $\overline{\pi}_t$ is the old inflation target, ε is the difference between new and old inflation targets and $\overline{\overline{\pi}}$ is the new inflation target. In period t the private sector either does not believe or does not know the new inflation target of the central bank. Thus, the private sector expectation of the inflation target is the same as before, $\widehat{E}_{t-1}(\overline{\pi}_t)$.

Agents optimise at time t (the model is solved) with the cognisant central bank pursuing its new inflation target and the private sector holding its flawed expectations of the old inflation target. Now the private sector observes that the nominal interest rate is not consistent with its inflation target expectations, ie $\widehat{E}_{t-1}(R_t) \neq R_t$. The private sector can calculate the actual inflation target that the central bank had at time t: $\overline{\overline{\pi}}_t = \pi_t - 2 \cdot \left(R_t - (r_t^* + \pi_t) + 0.5 \cdot (1-\beta) \cdot \left(U_t - \overline{U}\right)\right)$. Next, we assume that the private sector adapts this information on past expectational errors by shifting its expectations of the future inflation target by the rule $\widehat{E}_t(\overline{\pi}_{t+1}) = \widehat{E}_{t-1}(\overline{\pi}_t) - \phi\left(\widehat{E}_{t-1}(\overline{\pi}_t) - \overline{\overline{\pi}}_t\right)$, where ϕ is a parameter that describes the disbelief of the private sector as regards the new inflation target of the cognisant central bank. Note that if $\phi = 1$, then the central bank has full credibility and private sector expectations of the inflation target are rational. If $\phi = 0$, the central bank is not credible at all and private sector expectations of the inflation target are static. If $0 < \phi < 1$, the central bank is partly credible and private sector expectations of the inflation target are adaptive.

An alternative way of modelling the adaptive expectations would be to have the central bank learn from past behaviour. In this case we would have to assume that the central bank sees it as socially optimal to reset its inflation target to the old level. The learning could happen via the actual inflation process, which does not change much if the central bank is not credible. Finally, both central bank and private sector learning could happen via past behaviour. These cases could generate interesting dynamics in the model. Below, we however concentrate on the case where only the private sector learns.

The private sector learns adaptively as explained above. We set $\phi = 0.05$, which generate learning in a little more than 20 periods (five years). The results are shown in figure 4.11 and in table 4.10.

In this case the inflation rate falls immediately by about half of the change in the inflation target and then gradually by the rest. The peak for the expected real interest rate is short lived and the rate converges to baseline in the long run. This yields an immediate fall in output, but after this initial shock GDP increases above the baseline in one year's time. In the long run, output falls slightly below baseline as the credible case without learning shows above.

Figure 4.11 **Cognisant central bank lowers inflation target by 1%-pt, private sector learns adaptively the new inflation terget, difference from baseline**

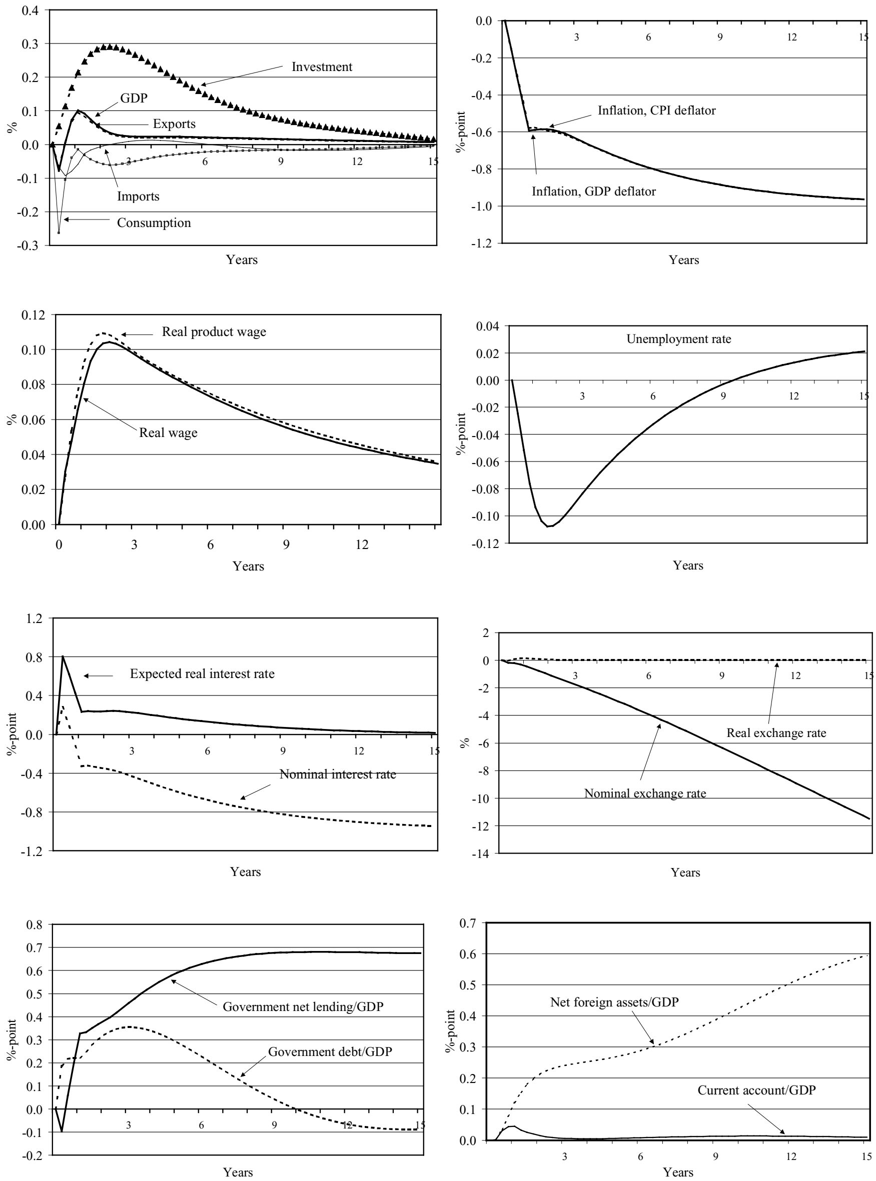

Table 4.10 **Cognisant central bank lowers inflation target by 1%-pt, private sector learns adaptively the new inflation target, difference from baseline**

Q/Y	Q1	Q2	Q3	Y1	Y2	Y3	Y5	Y10	Y50
GDP, %	–0.08	0.00	0.07	0.10	0.04	0.02	0.02	0.01	–0.04
Imports, %	–0.07	–0.09	–0.08	–0.06	0.00	0.01	0.01	–0.02	–0.02
Exports, %	–0.07	0.01	0.07	0.10	0.04	0.02	0.02	0.01	–0.04
Private consumption, %	–0.26	–0.11	–0.04	–0.02	–0.06	–0.05	–0.03	–0.02	–0.02
Private fixed investment, %	0.05	0.11	0.17	0.21	0.29	0.28	0.19	0.06	–0.05
Inflation, GDP defl., %-pts	–0.15	–0.30	–0.45	–0.59	–0.59	–0.64	–0.75	–0.91	–0.98
Inflation, consumpt. defl., %-pts	–0.15	–0.29	–0.43	–0.58	–0.60	–0.64	–0.75	–0.91	–0.98
Real wage, %	0.03	0.05	0.07	0.08	0.10	0.10	0.08	0.05	–0.03
Real product wage, %	0.03	0.05	0.08	0.09	0.11	0.10	0.08	0.05	–0.03
Unemployment, %-pts	–0.02	–0.05	–0.08	–0.09	–0.10	–0.08	–0.05	0.00	0.04
Nominal interest rate, %-pts	0.28	0.08	–0.12	–0.33	–0.36	–0.43	–0.60	–0.86	–0.98
Expected real interest rate, %-pts	0.80	0.62	0.43	0.23	0.24	0.23	0.16	0.05	0.00
Nominal exchange rate, %	–0.18	–0.22	–0.30	–0.43	–1.11	–1.76	–3.17	–7.20	–37.16
Real exchange rate, %	–0.03	0.07	0.14	0.15	0.05	0.02	0.02	0.03	–0.03
Government debt/GDP, %-pts	0.19	0.22	0.22	0.22	0.32	0.36	0.29	0.00	–0.01
Government net lending/GDP, %-pts	–0.10	0.06	0.20	0.33	0.38	0.46	0.59	0.68	0.68
Net foreign assets/GDP, %-pts	0.00	0.03	0.08	0.12	0.21	0.24	0.27	0.43	–0.44
Current account/GDP, %-pts	0.00	0.03	0.04	0.04	0.01	0.01	0.01	0.01	–0.01

4.3 Random expectational errors

Finally, we consider the case where private sector expectation of the future inflation target is shocked randomly. In each period, the cognisant central bank sets the interest rate. However, the central bank has no control over private sector expectations. In each period, the random shock shifts the private sector expectation of the future inflation target. These shifts are permanent in the sense that the private sector assumes that its expectation of the inflation target will hold in all future periods. But as each new period unfolds, a new random shock hits the actual inflation target of the cognisant central bank and the private sector again assumes that its expectation of the new inflation target will be permanent. Since private sector expectations revolve around the actual target, the expected value of the private sector's perceived inflation target is the actual one.

Thus, in each period the private sector expectation of the future inflation target is shocked by a random error, $\varepsilon_t^{\overline{\pi}}$, which we assume to be an iid process distributed $N(0, \sigma^{\overline{\pi}})$. We assume a standard deviation of 0.00125, ie 0.5 percentage point pa. Next, we simulate the model with this stochastic shock over the next 50 years, compare the results to baseline, and calculate the appropriate deviations from baseline. The standard deviations of deviations from baseline are shown in table 4.11

Table 4.11. **Standard deviations of differences from baseline**

Variable	Standard Deviation
GDP	0.28
Expected quarterly inflation rate	0.0011
Nominal interest rate	0.36
Nominal exchange rate	0.57

These figures imply that the standard deviation of GDP deviation from baseline is one-quarter of 1%. The standard deviation of the deviation of expected quarterly inflation rate from baseline is approximately 0.5 percentage point. The standard deviation of the deviation of nominal interest rate from baseline is 36 basis points, and the standard deviation of the nominal exchange rate from baseline is roughly 0.5%.

All in all, these results clearly show that whenever there are random expectational errors there is variation in both the real and nominal variables. Furthermore, if we assume that the cognisant central bank prefers smoother paths of variables, then these variations are undesirable. Thus, the random shifts in private sector expectations induce costs in the form of higher variability. One way of interpreting these random shifts in private sector expectations is as a lack of transparency.

5 Conclusions

In this paper, we first built a DGE model to characterise economic behaviour in the euro area. Second, we calibrated this model to publicly available euro area data. Third, we analysed monetary policy credibility with respect to heterogeneous expectations. Our results from the credibility analysis show that permanent expectational errors cause permanent real costs to the economy. If the expectational errors are transitory, as a result of some learning process, then the real costs too are temporary. Finally if there are random expectational errors, which may arise from a lack of transparency, then there are costs in the form of higher variability.

The EDGE model is built on well known economic theories. Thus it should be easy to approach. The EDGE model can provide answers to many economic questions that might be posed. Furthermore, these answers are quantitatively intuitive and consistent with the economic theory. This way of modelling the economy entails both advantages and disadvantages, which we discuss below. Finally, we summarise the main results of the study.

5.1 Possible development of the model

Calibration is not satisfactory with respect to the consumption function: The deep parameters are clearly outside of the acceptable range in parameter space. This failure is not unknown to the literature. In our judgement, this failure does not entitle one to add ac hoc features such as liquidity constraints or myopic behaviour into the model. Furthermore, our chosen form of consumption function seems to provide intuitively correct results when the model is exposed to various types of shocks. Hence, even though the Blanchard -type consumption has its faults, we choose to stick with it.

A minor source of concern is the division of the problem of the firm into separate problems. This is not satisfactory from the general equilibrium perspective However, relaxing this assumption leads to the very burdensome task of deriving the appropriate Euler equations. This can be done under certain assumptions. Our shortcut approach is to assume that these are separable problems. An alternative approach, used eg by Wouters and Dombrecht (2000), is to assume a differentiated structure of firms, and this yields a similar result. The model would thus become more elegant, but the basic results would be hardly changed.

Introduction of the unemployment gap into the wage equation (Phillips-curve) is currently not motivated by microeconomic optimisation decisions. Even though the inclusion of the unemployment gap in the Phillips curve is currently ad hoc it is possible that such a relationship exists, as shown by the Lucas (1972) misperception model. Finding the proper microeconomic structure behind the model would make the model even more elegant, ie the parameter η, which ties the nominal and real sides of the economy together, would have microfoundations. Assuming that the solution would provide a functionally equivalent optimal real wage equation, the model would need no changes and the results would not change.

The EDGE model is reasonably well adapted to policy analysis, judging by the diagnostic simulations. Furthermore, it is possible to use the model in forecasting, albeit this was not the aim of the project. Moreover, the foundations of the EDGE model are explicitly specified by rational expectations, optimisation and general equilibrium. Thus, this model is well suited for educational use.

In addition, the model is constructed so as to enable differentiation between different agents' expectations or information sets and can thus be fairly flexible used in a number of interesting applications. The latter property may be of importance if the model is used in forecasting, since it could help to pin down the immediate jump in the exchange rate.

Currently the EDGE model is a combination of well known economic theories. However, it is amenable to several enlargements:

The trade sector is not yet modelled in a satisfactory way. If it is possible to model this via optimising behaviour, this should be done. If this dynamic optimisation results long-run equations similar to the current static foreign trade equation, the extra dynamics would probably generate extra adjustments around the current baseline. This would mean more parameters and more calibration and more complex dynamics of the model.

A CES production function could replace the Cobb-Douglas technology. This would yield richer dynamics. Note that it would lead to more a complex model structure, as the marginal product of capital and labour function would be more complex. Therefore, the clear structure rendered by the Cobb-Douglas production function might be lost.

Money currently has no role. This is a deliberate choice, and it shows that the model is perfectly capable of explaining economic behaviour and answering several questions without money. It is possible to introduce money into this environment through utility maximisation. One advantage of modelling money is that it would give us an alternative monetary policy rule, which could be tested against other monetary policy rules. The introduction of money may not generate new results and might render the model more difficult to understand.

Labour supply is currently exogenous. Thus, some interesting dynamics are still missing from the model. It is possible to endogenise the labour supply through consumers' utility maximisation. This might be especially important when considering the fiscal policy. Furthermore, endogenisation of labour supply and population are crucial into the long-run simulation, where we can no longer be sure about unchanging population and labour market structure. The downside of these additions is of course that the model becomes more cumbersome and more parameters are introduced.

The government sector is currently modelled as a budget constraint, tax rule and interest rate rule. In the future, it might be interesting to model the behaviour of public consumption and investment as well as to derive tax and interest rate rules from optimising behaviour, ie to more or less endogenise the whole government sector.

Perfect competition is assumed in the model. Many recent models include some form of imperfect competition such as monopolistic competition, as in Obstfeld and Rogoff (1995) and Goodfriend and King (1997). Assuming imperfect competition introduces quite different dynamics, and it would be interesting to explore these in the context of EDGE model.

One very nice property of the EDGE model is that the dynamic structure is tied to economic theory. This dynamic structure is largely governed by the adjustment cost structure in the model. This lead/lag structure is determined by economic theory and is not changed to justify the calibration of the model to data. An additional advantage of the EDGE model is that its parsimonious structure means that only a few parameters need be calibrated/estimated. The latter property is of considerable importance.

The above mentioned additions would make the model more complex in structure and increase the number of parameters to be calibrated/estimated. Therefore, if anything, I would prefer to introduce the labour supply decision/population growth assumption and imperfect competition. The change in labour supply and population structure would perhaps not improve model considerably but it would provide a better foundation for the long-run simulations. The imperfect competition assumption would probably generate different types of dynamic responses, but this assumption might after all be more consistent with actual behaviour.

5.2 Results

We combine some well established economic theories and label this mixture the Euro area Dynamic General Equilibrium (EDGE) model. The advantage of this strategy is that the model should be easy to understand. This model is tightly bound to modern economic theory. The key features of the model include optimising behaviour of representative agents, nominal rigidities in prices and wages and explicit modelling of the expectation formation mechanism via the rational expectation paradigm.

We calibrate the model to publicly available euro area data and, using stochastic simulations, find that the model is capable of explaining the past cross correlation structure in the data. We also find that the model's responses to different diagnostic simulations with historical data period make sense in economic terms. Therefore, we feel confident that the EDGE model, even in its current form, is helpful for monetary policy simulations.

Lack of credibility is analysed in three different ways. First, we analyse permanent expectational error in two cases. In both cases it is assumed that private sector perception of the central bank's inflation target is stronger than in actual fact. In the first case, it is assumed that the central bank sets the interest rate on the basis of the actual economic situation. In the second case, the central bank sets the interest rate on the basis of its forecast and assumes that it is credible.

In both simulations the cost of a lack of credibility is a permanently higher real interest rate and hence an output loss.

This line of analysis is extended to heterogeneous expectations of the equilibrium interest rate and NAIRU. These yield results quantitatively similar to those of inflation target analysis: heterogeneous expectations generate real costs to the economy.

The second line of analysis concentrates on the possibility that agents learn from past behaviour. We are able to show that if this is the case, these temporary expectational errors also yield only transitory costs to the economy. The third line of analysis shows that if the private sector randomly changes its expectations of the inflation target, which we interpret as a result of a lack of transparency, then there are costs to the economy in the form of higher variability.

Finally, we note that the model at hand opens rich possibilities to experiment with different expectation formation mechanisms, of which only some have been explored here. One could easily consider other aspects of the assumed monetary policy rule such as differences in expectations of parameters or functional form of monetary policy rule. One could also calculate the optimal monetary policy rule. Note that we have used only one agent (central bank) that has expectations that differ from those of the private sector. We could also apply this theory to other agents or groups of agents, eg fiscal authority vs private sector or consumers vs firms etc, which would make the model more complicated but also more rewarding.

References

[1] Armstrong, J. – Black, R. – Laxton, D. – Rose, D. (1995) **A Robust Method for Simulating Forward-Looking Models.** The Bank of Canada's New Quarterly Projection Model, Part 2, Technical report No. 73, Ottawa: Bank of Canada.

[2] Bank of England (1999) **Economic models at the Bank of England.**

[3] Black, R. – Laxton, D. – Rose, D. – Tetlow, R. (1994) **The Steady-State Model: SSQPM.** The Bank of Canada's New Quarterly Projection Model, Part 1, Technical report No. 72, Ottawa: Bank of Canada.

[4] Blanchard, O (1985) **Debt deficits and finite horizons.** Journal of Political Economy, Vol. 93, No. 2, 223–247.

[5] Blanchard, O. – Fischer, S. (1988). **Lectures on Macroeconomics.** The MIT Press.

[6] Brayton, F. – Tinsley, P. (1996) **A Guide to FRB/US: A Macroeconometric Model of the United States.** FEDS 96-42, Board of Governors of the Federal Reserve System.

[7] Calvo, G. (1983) **Staggered prices in a utility-maximizing framework.** Journal of Monetary Economics, Vol. 12, No. 3, 383–398.

[8] Chirinko, R. (1993) **Business Fixed Investment Spending Modeling Strategies, Empirical Results, and Policy Implications.** Journal of Economic Literature, Vol. 31, No. 4, 1875–1911.

[9] Coenen, G. – Wieland, V. (2000) **A small estimated model of the euro area economy with rational expectations and nominal rigidities.** European Central Bank, Working Paper No. 30.

[10] Coletti, D. – Hunt, B. – Rose, D. – Tetlow, R. (1996) **The Dynamic Model: QPM.** The Bank of Canada's New Quarterly Projection Model, Part 3, Technical report No. 75, Ottawa: Bank of Canada.

[11] Cooley, T., ed. (1995) **Frontiers of Business Cycle Research.** Princeton, NJ, Princeton University Press.

[12] Cooley, T. (1997) **Calibrated Models.** Oxford Review of Economic Policy, Vol. 13, No. 3, 55–69.

[13] Cooley, T. – Prescott, E. (1995) **Economic Gowth and Business Cycles.** In Cooley, T. ed., Frontiers of Business Cycle Research, Princeton, NJ, Princeton University Press.

[14] Cooley, T. – Hansen, G. (1995) **Money and the Business Cycle.** In Cooley, T. ed., Frontiers of Business Cycle Research, Princeton, NJ, Princeton University Press.

[15] Danthine, J.-P. (1997) **In the Search of a Successor to IS-LM.** Oxford Review of Economic Policy, Vol. 13, No. 3, 135–144.

[16] Dimitz, M. (2001) **Output gaps and technological progress in European.** Bank of Finland, Discussion Papers 20/2001.

[17] Evans, G. – Honkapohja, S. (2001) **Learning and Expectations in Macroeconomics.** Princeton University Press.

[18] Fagan, G. – Henry, J. – Mestre, R. (2001) **An Area-Wide Model for the EU11.** European Central Bank, Working Paper No. 42.

[19] Fischer, S. (1977) **Long-Term Contracts, Rational Expectations and the Optimal Money Supply Rule.** Journal of Political Economy, Vol. 85, No. 1, 191–205.

[20] Frenkel, J. – Razin, A. (1992) **Fiscal Policies and the World Economy.** 2nd ed. MIT Press.

[21] Friedman, M. (1968) **The Role of Monetary Policy.** American Economic Review, Vol. 58, No. 1, 1–17.

[22] Fuhrer, J. – Moore, G. (1995a) **Inflation Persistence.** The Quarterly Journal of Economics, Vol. 110, No. 1, 127–159.

[23] Fuhrer, J. – Moore, G. (1995b) **Monetary Policy Trade-offs and the Correlation between Nominal Interest Rates and Real Output.** The American Economic Review, Vol. 85, No. 1, 219–239.

[24] Galí, J. – Gertler, M. (1999) **Inflation Dynamics: A Structural Econometric Analysis.** CEPR, Discussion Papers No. 2246.

[25] Goodfriend, M. – King, R. (1997) **The New Neoclassical Synthesis and the Role of the Monetary Policy.** In Bernanke, B. and Rotemberg, J., eds., NBER Macroeconomics Annual *1997.*

[26] Goodfriend, M. – King, R. (2001) **The Case for Price Stability.** Federal Reserve Bank of Richmond, Working Paper No. 01–02.

[27] Hollinger, P. (1996) **The Stacked-Time Simulator in TROLL: A Robust Algorithm for Solving Forward-Looking Models.** Presented at the Second International Conference on Computing in Economics and Finance, Geneva, Switzerland, 26–28 June 1996, Intex Solutions, Inc., Needham, MA.

[28] Hubbard, R. – Kashyap, A. – Whited, T. (1993) **Internal Finance and Firm Investment.** National Bureau of Economic Research, Working Paper No. 4392.

[29] Juillard, M. (1996) **DYNARE: A program for the resolution and simulation of dynamic models with forward looking variables through the use of a relaxation algorithm.** CEPREMAP, Working paper No. 9602, Paris.

[30] Kim, K. – Pagan, A. (1995) **The Econometric Analysis of Calibrated Macroeconomic Models.** In Pesaran, M. and Wickens, M., eds., Handbook of Applied Econometrics: Macroeconomics, Blackwell Publishers Ltd.

[31] Kollmann, R. (1997) **The Exchange Rate in a Dynamic-Optimizing Current Account Model with Nominal Rigidities: A Quantitative Investigation.** IMF Working Paper, WP/97/7.

[32] Kollmann, R. (1999) **Explaining International Comovements of Output and Asset Returns: The Role of Money and Nominal Rigidities.** IMF Working Paper, WP/99/84.

[33] Kortelainen, M. (2001) **Actual and perceived monetary policy rules in a dynamic general equilibrium model of the euro area.** Bank of Finland, Discussion Papers 3/2001.

[34] Kortelainen, M. – Mayes, D. (2002) **Using EDGE – A Dynamic General Equilibrium Model of the Euro Area.** The conference volume to the RWI/Project LINK Euro meeting, forthcoming.

[35] Kydland, F. – Prescott, E. (1982) **Time to Build and Aggregate Fluctuations.** Econometrica, Vol. 50, No. 6, 1345–1370.

[36] Lucas, R. (1972) **Expectations and Neutrality of Money.** Journal of Economic Theory, Vol. 4, No. 2, 103–124.

[37] Lucas, R. (1976) **Econometric Policy Evaluation: A Critique.** Carnegie-Rochester Conference Series on Public Policy, Vol. 1, 19–46.

[38] Mankiw, N.G. (1990) **A Quick Refresher Course in Macroeconomics.** Journal of Economic Literature, Vol. 28, No. 4, 1645–1660.

[39] Mattila, V.-M. (1998) **Simulating the Effects of Imperfect Credibility: How does the Peso Problem Affect the Real Economy.** Bank of Finland, Discussion Papers 24/98.

[40] McCallum, B.T. – Nelson, E. (1999) **Performance of Operational Policy Rules in an Estimated Semiclassical Structural Model.** In Taylor, J., ed., Monetary Policy Rules, National Bureau of Economic Research, The University of Chicago Press.

[41] Muth, J. (1961) **Rational Expectations and the Theory of Price Movements.** Econometrica, Vol. 29, No. 3, 315–335.

[42] Nerlove, M. (1958) **Adaptive Expectations and Cobweb Phenomena.** Quarterly Journal of Economics, Vol. 72, No. 2, 227–240.

[43] Obstfeld, M. – Rogoff, K. (1995) **Exchange Rate Dynamic Redux.** Journal of Political Economy, Vol. 103, No. 3, 624–660.

[44] Phelps, E. (1967) **Phillips Curves, Expectations of Inflation and Optimal Unemployment Over Time.** Economica, Vol. 34, 254–281.

[45] Reifschneider, D. – Stockton, D. – Wilcox, D. (1997) **Econometric models and the monetary policy process.** Carnegie-Rochester Conference Series on Public Policy, Vol. 47, 1–38.

[46] Ripatti, A. – Vilmunen, J. (2001) **Declining labour share – Evidence of a change in underlying production technology?** Bank of Finland, Discussion Papers 10/2001.

[47] Roberts, J. (1995) **New Keynesian Economics and the Phillips Curve.** Journal of Money, Credit and Banking, Vol. 27, No. 4, 975–984.

[48] Roberts, J. (1997) **Is Inflation Sticky?** Journal of Monetary Economics, Vol. 39, No. 2, 173–196.

[49] Rotemberg, J. (1982) **Monopolistic Price Adjustment and Aggregate Output.** Review of Economic Studies, October, Vol. 49, No. 158, 517–531.

[50] Rotemberg, J. (1987) **The New Keynesian Microfoundations.** In Fischer, S., ed., NBER Macroecnomics Annual *1987.*

[51] Rotemberg, J. – Woodford, M. (1999) **Interest rate rules in an Estimated Sticky Price Model.** In Taylor, J., ed., Monetary Policy Rules, National Bureau of Economic Research, The University of Chicago Press.

[52] Rudebusch, G. (2000) **Term Structure Evidence on Interest Rate Smoothing and Monetary Policy Inertia.** CEPR/ESI 2000 Conference.

[53] Sargent, T. (1993) **Bounded Rationality in Macroeconomics.** Clarendon Press – Oxford.

[54] Sargent, T. (1999) **Conquest of American Inflation.** Princeton University Press.

[55] Sargent, T. – Wallace, N. (1975) **Rational Expectations, the Optimal Monetary Instrument, and the Optimal Money Supply Rule.** Journal of Political Economy, Vol. 83, No. 2, 241–254.

[56] Sefton, J. – in't Veld, J. (1999) **Consumption and Wealth: An International Comparison.** The Manchester School, Vol. 67, No. 4, 525–544.

[57] Siegel, J. (1992) **The real rate of interest from 1800–1990.** Journal of Monetary Economics, Vol. 29, No. 2, 227–252.

[58] Sims, C. (1980) **Macroeconomics and Reality.** Econometrica, Vol. 48, No. 1, 1–48.

[59] Solow, R. (1956) **A Contribution to the Theory of Economic Growth.** Quarterly Journal of Economics, Vol. 70, No. 1, 65–94.

[60] Swan, T. (1956) **Economic Growth and Capital Accumulation.** Economic Record, Vol. 32, 334–361.

[61] Tarkka, J. – Kortelainen, M. (2001) **Analysing monetary policy credibility with a model of the euro area.** Bank of Finland Bulletin, Vol. 75, No. 3, 18–23.

[62] Tarkka, J. – Willman, A. – Männistö, H.-L. (1990a) **Private Consumption and Investment.** The BOF4 Quarterly Model of Finnish Economy, Bank of Finland, D:73.

[63] Tarkka, J. – Willman, A. – Rasi, C.-M. (1990b) **Production and Employment.** The BOF4 Quarterly Model of Finnish Economy, Bank of Finland, D:73.

[64] Taylor, J. (1978) **Staggered Wage Setting in a Macro Model.** American Economic Review, Vol. 69, No. 2, 108–113.

[65] Taylor, J. (1993) **Discretion versus policy rules in practice.** Carnegie-Rochester Conference Series on Public Policy, Vol. 39, 195–214.

[66] Turnovsky, S. (1995) Methods of Macroeconomic Dynamics, The MIT Press.

[67] Vilmunen, J. (1998) **Macroeconomic Effects of Looming Policy Shifts: Non-falsified Expectations and Peso Problems.** Bank of Finland, Discussion Papers 13/98.

[68] Walsh, C. (1998) **Monetary Theory and Policy.** The MIT Press.

[69] Whited, T. (1998) **Why Do Investment Euler Equations Fail?** Journal of Business and Economic Statistics, Vol. 16, No. 4, 479–488.

[70] Willman, A. – Kortelainen, M. – Männistö, H.-L. – Tujula, M. (2000) **The BOF5 Macroeconomic Model of Finland, Structure and Dynamic Microfoundations,** Economic Modelling, Vol. 17, 275–303. A previous version can be found in (1998), The BOF5 Macroeconomic Model of Finland, Structure and equations, Bank of Finland, Discussion Papers 10/98.

[71] Wouters, R. – Dombrecht, M. (2000) **Model-based inflation forecasts and monetary policy rules.** The National Bank of Belgium, Working Paper No. 1.

A Equations of the EDGE model

Labour demand:

$$L_t = 0.483 \cdot E_t L_{t+1} + 0.492 \cdot L_{t-1} + 0.025 \cdot \left(\frac{Y_t}{TK_t^{0.41}} \right)^{1.69}$$

Capital stock:

$$\begin{aligned} \Delta \log K_t &= -0.324 \cdot E_t \Delta \log K_{t+2} + 0.986 \cdot E_t \Delta \log K_{t+1} \\ &\quad +0.3378 \cdot \Delta \log K_{t-1} \\ &\quad +0.0005 \cdot \left(\frac{PF_t}{PC_t} \cdot \left(\frac{0.41 \cdot Y_t}{K_t} \right) \right. \\ &\quad \left. - \left(\frac{r_t + \chi + 0.01}{1 + r_t + \chi} \right) \cdot \frac{PI_t}{PC_t} \right) \end{aligned}$$

Nominal wages:

$$\begin{aligned} WN_t &= 0.49 \cdot E_t WN_{t+1} + 0.5 \cdot WN_{t-1} \\ &\quad +0.01 \cdot \left[0.59 \cdot Y_t / N_t \cdot PF_t \cdot \left(1 - 3 \cdot \left(U_t - \overline{U_t} \right) \right) \right] \end{aligned}$$

GDP deflator:

$$P_t = 0.495 \cdot P_{t-1} + 0.485 \cdot E_t P_{t+1} + 0.02 \cdot \left(\frac{WN_t}{1 - \tau_t^{indirect}} \cdot \frac{L_t}{0.59 \cdot Y_t} \right)$$

Consumption:

$$C_t = 0.6 \cdot \frac{1}{1 + r_t + \chi} \cdot E_t C_{t+1} + 0.015 \cdot \left((1 + \zeta_t) \cdot \frac{A_{t-1}}{PC_t} + \frac{YDN_t}{PC_t} \right)$$

Windfall gain:

$$\zeta_t = \frac{A_t}{A_{t-1}} - 1 - \frac{YDN_t - C_t \cdot PC_t}{A_{t-1}} - \pi_{t-1}$$

Wealth:

$$\begin{aligned} A_t &= \frac{1}{1 + R_t/400 + \chi} E_t \left(A_{t+1} - GDN_{t+1} - NFA_{t+1} \right) \\ &\quad +PF_t \cdot Y_t - WN_t \cdot L_t - 0.01 \cdot PI_t \cdot K_{t-1} - 0.33 \cdot GOY_t \\ &\quad +GDN_t + NFA_t \end{aligned}$$

Inventories:

$$\begin{aligned} KI_t &= 0.88 \cdot T \cdot L_t^{0.59} K_t^{0.41} - 0.5 \cdot (Y_t - T \cdot L_t^{0.59} K_t^{0.41}) \\ &\quad +0.494 \cdot E_t(Y_{t+1} - T \cdot L_{t+1}^{0.59} K_{t+1}^{0.41}) \end{aligned}$$

Exports:

$$\log X_t = 0.48 \cdot \log Y_t^* + 0.72 \cdot \log DD_t - 0.41 \cdot \log \left(\frac{PX_t}{P_t^* \cdot e_t} \right) + 0.63$$

Imports:

$$\log M_t = 1.2 \cdot \log DD_t - 0.9 \cdot \log \left(\frac{PM_t}{P_t} \right) - 3.9$$

Export prices:

$$\log PX_t = 0.32 \cdot \log P_t + 0.68 \cdot \log(P_t^* \cdot e_t) - 0.05$$

Import prices:

$$\log PM_t = 0.48 \cdot \log PX_t + 0.38 \cdot \log(P_t^* \cdot e_t) + 0.14 \cdot \log(PC_t^* \cdot e_t) - 0.65$$

Consumer price deflator:

$$\log PC_t = 0.90 \cdot \log P_t + 0.10 \cdot \log PM_t + 0.01$$

Investment deflator:

$$\log PI_t = 0.85 \cdot \log PF_t + 0.15 \cdot \log PM_t + 0.10$$

IDENTITIES:

Private nominal disposable income:

$$YDN_t = YFN_t - TAX_t + INN_t + TRF_t - GOY_t + NFN_t - 0.01 \cdot PI_t \cdot K_{t-1}$$

Real GDP:

$$Y_t = C_t + CG_t + I_t + X_t - M_t + \Delta KI_t$$

Capital accumulation equation:

$$I_t = K_t - 0.99 \cdot K_{t-1}$$

Indirect taxes:

$$TIN_t = \tau_t^{indirect} \cdot YEN_t$$

Direct taxes.

$$TAX_t = \tau_t^{direct} \cdot YEN_t$$

Public disposable income:

$$GYN_t = TAX_t + TIN_t + GOY_t - TRF_t - INN_t$$

Interest outlays of government:

$$INN_t = R_t/400 \cdot GDN_{t-1}$$

Net foreign assets:

$$NFA_t = NFA_{t-1} \cdot (e_t/e_{t-1}) + CA_t$$

Net factor income from abroad:

$$NFN_t = R_t^*/400 \cdot NFA_{t-1}$$

Current account:

$$CA_t = X_t \cdot PX_t - M_t \cdot PM_t + NFN_t$$

Public debt:

$$GDN_t = GDN_{t-1} - GLN_t$$

Public net lending:

$$GLN_t = -GCN_t - GIN_t + GYN_t$$

Domestic demand:

$$DD_t = C_t + CG_t + I_t + \Delta KI_t$$

Nominal GDP at factor cost:

$$YFN_t = Y_t \cdot PF_t$$

Nominal GDP:

$$YEN_t = Y_t \cdot P_t$$

GDP deflator at factor price:

$$PF_t = P_t \cdot (1 - \tau_t^{indirect})$$

Expected inflation rate, quarterly:

$$\pi_t = \log PC_{t+1} - \log PC_t$$

Expected real interest rate:

$$r_t = R_t/400 - \pi_t$$

Effective exchange rate (UIRP):

$$\log e_t = \log e_{t+1} + (R_t^* - R_t)/400$$

Unemployment rate:

$$U_t = (N_t - L_t)/N_t$$

Public nominal consumption:

$$GCN_t = CG_t \cdot P_t$$

Public nominal investment:

$$GIN_t = IG_t \cdot PI_t$$

Public other income

$$GOY_t = 0.20 \cdot YEN_t$$

Public real consumption

$$CG_t = \gamma \cdot Y_t$$

Policy parameters

Transfers:

$$TRF_t/YEN_t = 0.25 \cdot U_t + 0.20$$

Direct tax rate:

$$\begin{aligned}\Delta\tau_t^{direct} &= 0.05 \cdot (GDN_t/YEN_t - \psi) \\ &\quad -0.1 \cdot (GLN_t/YEN_t + \psi \cdot (\pi_{t-1} + g))\end{aligned}$$

Inflation rate target:

$$\bar{\pi}_t = 0.0027$$

Taylor rule:

$$\begin{aligned} R_t &= (1-\Omega) \cdot R_{t-1} \\ &+\Omega \cdot \begin{bmatrix} 400 \cdot r^* + 100 \cdot \log\left(PC_t/PC_{t-4}\right) \\ +50 \cdot \left[\log\left(PC_t/PC_{t-4}\right) - 4 \cdot \bar{\pi}_t\right] \\ -50 \cdot 0.59 \cdot \left(U_t - \overline{U_t}\right) \end{bmatrix} \end{aligned}$$

List of variable names

Symbol	Explanation
A	Asset wealth
C	Consumption
CA	Current account
CG	Public consumption, real
DD	Domestic demand
e	Effective exchange rate
g	Real growth rate in steady-state
GCN	Public consumption, nominal
GDN	Public debt, nominal
GIN	Public investment, nominal
GLN	Public net lending
GOY	Public other income, nominal
GYN	Public disposable income, nominal
I	Investment, real
IG	Public investment, real
INN	Public interest outlays, nominal
K	Capital stock
ΔKI	Change in inventories
KI	Inventories
N	Labour force
L	Labour demand
M	Imports
NFA	Net foreign assets
NFN	Net factor income from abroad
P	GDP deflator
PC	Consumer price deflator
PC^*	World commodity prices
PF	GDP deflator at factor price

List of variable names

Symbol	Explanation
P^*	Foreign prices
PM	Import prices
PI	Gross investment deflator
PX	Export prices
π	Inflation rate
$\bar{\pi}$	Inflation target
r	Real interest rate, domestic
r^*	Real interest rate, foreign
R	Nominal interest rate, domestic
R^*	Nominal interest rate, foreign
T	Technical progress
TAX	Direct taxes
τ^{direct}	Direct tax rate
$\tau^{indirect}$	Indirect tax rate
TIN	Indirect taxes
TRF	Public transfers
U	Unemployment rate
$\overline{U}$	NAIRU
W	Real wages
WN	Nominal wages per employee
χ	Equity premium
X	Exports
Y	Real GDP
Y^*	World GDP, real
YDN	Private disposable income, nominal
YEN	Nominal GDP
YFN	Nominal GDP at factor cost
ζ	Windfall gain

List of parameters

Symbol	Explanation
β	Factor share of capital in production
ψ	Steady-state government debt-to-nominal GDP ratio
ω_1 and ω_2	Steady-state transfers equation parameters
ξ	Steady-state government real investments-to-GDP ratio
γ	Steady-state government real consumption-to-GDP ratio
Ω	Smoothing parameter for interest rate

B Equations of steady state of the EDGE model

Output:

$$Y = TK^{0.41}L^{0.59}$$

Capital stock:

$$K = (PF/PI) \cdot 0.41 \cdot Y/(r + \chi + 0.01)$$

Wages:

$$WN = 0.59 \cdot PF \cdot Y/L$$

Consumption:

$$C = \left(\frac{1 + r + \chi - 0.6 \cdot (1 + g)}{1 + r + \chi}\right)^{-1} \cdot 0.015 \cdot (A + YDN)/PC$$

Private wealth:

$$\begin{aligned} A &= (r + \chi - g)^{-1} \cdot (PF \cdot 0.41 \cdot Y - 0.01 \cdot PI \cdot K - 0.33 \cdot GOY) \\ &\quad + GDN + NFA \end{aligned}$$

Change in inventories:

$$\Delta KI = 0.88 \cdot g \cdot Y$$

Exports:

$$\begin{aligned} \log X &= 0.48 \cdot \log Y^* + 0.72 \cdot \log(C + CG + I + \Delta KI) \\ &\quad - 0.41 \cdot \log(PX/(P^* \cdot e)) + 0.63 \end{aligned}$$

Imports:

$$\log M = 1.2 \cdot \log(C + CG + I + \Delta KI) - 0.64 \cdot \log(PM/P) - 3.9$$

Export prices:

$$\log PX = 0.32 \cdot \log P + 0.68 \cdot \log(P^* \cdot e) - 0.05$$

Import prices:

$$\log PM = 0.48 \cdot \log PX + 0.38 \cdot \log(P^* \cdot e) + 0.14 \cdot \log(PC^* \cdot e) - 0.65$$

Consumer price deflator:

$$\log PC = 0.90 \cdot \log P + 0.10 \cdot \log PM + 0.01$$

Investment deflator:

$$\log PI = 0.85 \cdot \log PF + 0.15 \cdot \log PM + 0.10$$

IDENTITIES:

Employment:

$$L = N \cdot (1 - U)$$

Technical progress:

$$\log T = \log T_{-1} + g \cdot 0.59$$

Public interest outlays:

$$INN = R/400 \cdot GDN$$

Net factor income from abroad:

$$NFN = R^*/400 \cdot NFA$$

Government other income:

$$GOY = 0.20 \cdot YEN$$

Government budget constraint:

$$TAX = GLN - TIN - GOY + GCN + GIN + TRF + INN$$

Private nominal disposable income:

$$YDN = YFN - TAX + TRF + INN - GOY + NFN - 0.01 \cdot PI \cdot K$$

GDP identity:

$$Y = C + CG + I + X - M + \Delta KI$$

Current Account:

$$CA = X \cdot PX - M \cdot PM + NFN$$

Nominal GDP at factor cost:

$$YFN = Y \cdot PF$$

Nominal GDP:

$$YEN = Y \cdot P$$

Government nominal consumption:

$$GCN = CG \cdot P$$

Government nominal investment:

$$GIN = IG \cdot PI$$

GDP deflator at factor price:

$$PF = P \cdot (1 - \tau^{indirect})$$

Domestic real interest rate:

$$r = R/400 - \pi$$

Inflation rate:

$$\log PC = \log PC_{-1} + \pi$$

POLICY VARIABLES:

Indirect taxes:

$$TIN = \tau^{indirect} \cdot YEN$$

Transfers:

$$TRF/YEN = \omega_1 \cdot U + \omega_2$$

Government real consumption:

$$CG = \gamma \cdot Y$$

Government real investment:

$$IG = \xi \cdot Y$$

STEADY-STATE CONDITIONS:

Unemployment rate:

$$U = \overline{U}$$

Investment:

$$I = (0.01 + g) \cdot K$$

Government net lending:

$$GLN = -GDN \cdot (g + \pi)$$

Government debt :

$$GDN = \psi \cdot YEN$$

Net foreign assets:

$$NFA = CA/(g + \pi)$$

Domestic nominal interest rate:

$$R = 100 \cdot \log\left(PC/PC_{-4}\right) + 400 \cdot r^{*}$$

Inflation rate:

$$\pi = \bar{\pi}$$

Publications of the Bank of Finland

Series E (ISSN 1238-1691, print) (ISSN 1456-5951, online)

(Series E replaces the Bank of Finland's research publications series B, C and D.)

E:1 Jukka Vesala **Testing for Competition in Banking: Behavioral Evidence from Finland**. 1995. 206 p. ISBN 951-686-447-3.

E:2 Juha Tarkka **Approaches to Deposit Pricing: A Study in the Determination of Deposit Interest and Bank Service Charges.** 1995. 166 p. ISBN 951-686-457-0.

E:3 Timo Tyrväinen **Wage Determination, Taxes, and Employment: Evidence from Finland.** 1995. 212 p. ISBN 951-686-459-7.

E:4 Sinimaaria Ranki **Realignment Expectations in the ERM: Causes and Measurement.** 1996. 164 p. ISBN 951-686-507-0.

E:5 Juhana Hukkinen **Kilpailukyky, ulkomaankaupan rakenne ja taloudellinen kasvu** (Competitiveness, structure of foreign trade and economic growth). 1996. 134 p. ISBN 951-686-512-7.

E:6 Eelis Hein **Deposit Insurance: Pricing and Incentives.** 1996. 120 p. ISBN 951-686-517-8.

E:7 Vesa Vihriälä **Banks and the Finnish Credit Cycle 1986–1995.** 1997. 200 p. ISBN 951-686-537-2.

E:8 Anne Brunila **Fiscal Policy and Private Consumption-Saving Decisions: European Evidence.** 1997. 147 p. ISBN 951-686-558-5. (Published also as A-131, Helsinki School of Economics and Business Administration, ISBN 951-791-225-0, ISSN 1237-556X)

E:9 Sinimaaria Ranki **Exchange Rates in European Monetary Integration**. 1998. 221 p. ISBN 951-686-564-X.

E:10 Kimmo Virolainen **Tax Incentives and Corporate Borrowing: Evidence from Finnish Company Panel Data**. 1998. 151 p. ISBN 951-686-573-9. (Published also as A-137, Helsinki School of Economics and Business Administration, ISBN 951-791-290-0, ISSN 1237-556X)

E:11 Monica Ahlstedt **Analysis of Financial Risks in a GARCH Framework**. 1998. 181 p. ISBN 951-686-575-5.

E:12 Olli Castrén **Fiscal-Monetary Policy Coordination and Central Bank Independence**. 1998. 153 p. ISBN 951-686-580-1.

E:13 Antti Ripatti **Demand for Money in Inflation-Targeting Monetary Policy**. 1998. 136 p. ISBN 951-686-581-X.

E:14 Risto Koponen – Kimmo Soramäki **Intraday Liquidity Needs in a Modern Interbank Payment System. A Simulation Approach**. 1998. 135 p. ISBN 951-686-601-8.

E:15 Liisa Halme **Pankkisääntely ja valvonta. Oikeuspoliittinen tutkimus säästöpankkien riskinotosta** (Banking regulation and supervision: A legal policy study of risk taking by savings banks). 1999. XLIV + 560 p. ISBN 951-686-606-9, print; ISBN 951-686-607-7, online.

E:16 Juha Kasanen **Ilmoitusvelvollisten osakeomistus ja -kaupat Helsingin Pörssissä** (Corporate insiders shareholdings and trading on the HEX Helsinki Exchanges). 1999. 146 p. ISBN 951-686-630-1, print; ISBN 951-686-631-X, online.

E:17 Mikko Spolander **Measuring Exchange Market Pressure and Central Bank Intervention.** 1999. 118 p. ISBN 951-686-645-X, print; ISBN 951-686-646-8, online.

E:18 Karlo Kauko **The Microeconomics of Innovation: Oligopoly Theoretic Analyses with Applications to Banking and Patenting**. 2000. 193 p. ISBN 951-686-651-4, print; ISBN 951-686-652-2, online.
(Published also as A-166, Helsinki School of Economics and Business Administration, ISBN 951-791-442-3, ISSN 1237-556X)

E:19 Juha Kilponen **The Political Economy of Monetary Policy and Wage Bargaining. Theory and Econometric Evidence**. 2000. 180 p. ISBN 951-686-665-4, print; ISBN 951-686-666-2, online.

E:20 Jukka Vesala **Technological Transformation and Retail Banking Competition: Implications and Measurement**. 2000. 211 p. ISBN 951-686-695-6, print; ISBN 951-686-696-4, online.
(Published also as A-184, Helsinki School of Economics and Business Administration, ISBN 951-791-518-7, ISSN 1237-556X)

E:21 Jian-Guang Shen **Models of Currency Crises with Banking Sector and Imperfectly Competitive Labor Markets**. 2001. 159 p. ISBN 951-686-711-1, print; ISBN 951-686-712-X, online.

E:22 Kari Takala **Studies in Time Series Analysis of Consumption, Asset Prices and Forecasting**. 2001. 300 p. ISBN 951-686-759-6, print; ISBN 951-686-760-X, online.

E:23 Mika Kortelainen **Edge: a model of the euro area with applications to monetary policy**. 2002. 166 p. ISBN 952-462-001-4, print; ISBN 952-462-002-2, online.
(Published also as A-204, Helsinki School of Economics and Business Administration, ISBN 951-791-715-5, ISSN 1237-556X)

Edge: a model of the euro area with applications to monetary policy

Bank of Finland Studies E:23 • 2002

ISBN 952-462-001-4
ISSN 1238-1691

Vammalan Kirjapaino Oy
Vammala 2002