An area-wide model for the euro area

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Accepted 4 April 2004  

Abstract  

This paper presents a \textit{quarterly estimated structural macroeconomic model for the euro area}, the AWM, which is a medium-sized model that treats the euro area as a single economy. The model is designed to have a long-run equilibrium consistent with neo-classical economic theory while the short-run dynamics are largely demand-driven. The current version of the AWM is mostly backward-looking and is largely estimated rather than calibrated. A general overview of the structure of the model and of its long-run and short-run properties is given, with particular emphasis on the steady state properties, and a review of key equations. Results from two illustrative simulations are provided: a fiscal expenditure shock and a change in interest rates, with and without policy responses, respectively.  

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\textit{JEL classification:} C3; C5; E2  

\textit{Keywords:} European monetary union; Macroeconometric modelling; Euro area  

1. Introduction  

Prior to the move to monetary union it was widely recognised that “the ESCB will need to have at its disposal analysis capacities, including a broad range of econometric tools” \cite{EMI1997}. It was envisaged that, as in most central banks, the econometric toolbox would include traditional estimated structural models, smaller scale reduced form models,
calibrated theoretical models and various time-series tools such as VARs. In addition, given the specific circumstances of the euro area, the need for both an area-wide as well as cross-country approaches was also recognised.

The present paper presents one element in this toolbox, namely a quarterly structural macroeconomic model for the euro area. This model has been developed with four uses in mind. First, the model can assist in the assessment of current economic and monetary conditions in the euro area since it provides a means of assessing the impact of various shocks hitting the economy. Second, by providing a coherent analytical framework which takes into account the behaviour of economic agents as estimated from historical data, the model is used for producing forecasts of future economic developments in the euro area. Third, the model can be used to assess effects of policy actions on the economy (e.g. “the transmission mechanism”). Finally, by treating the euro area as a single economy, an area-wide model can help to develop an understanding of how the economy of the area as a whole functions and to focus attention on area-wide conditions. In this regard, given the absence of a well established body of empirical evidence regarding the behaviour of the euro area economy per se, the estimation of a range of key behavioural equations and the development of the necessary database can provide a valuable starting point for further empirical analysis.

However, the development of an econometric model for the euro area poses formidable challenges. Even in ‘normal’ circumstances a number of difficulties arise, since there is, for example, no consensus on the theoretical framework or on the empirical methodology. These standard obstacles are supplemented with at least two major problems which are euro-area specific in some sense. First, the euro area comprises a group of individual countries with—at least to some extent—different historical experiences, different economic structures and different institutional arrangements (e.g. financial systems, wage formation processes, roles of governments, etc.). This implies potential difficulties in identifying meaningful ‘aggregate’ behaviour from the data. Second, since econometric inference depends crucially on the estimation of parameters on the basis of historical data, specific difficulties arise in estimating an area-wide model. To the extent that the creation of the monetary union involves a major structural change in terms of monetary policy, this may also lead to changes in other aspects of economic behaviour. There is therefore a risk that the estimated equations could be subject to the Lucas (1976) critique. Moreover, there are significant problems in obtaining sufficient spans of historical data for the area.

Despite these difficulties, the advantages of developing an area-wide model are compelling, although the current version of the model should be seen as a first step in this direction, which clearly could be improved in a number of respects. In any case, the model has been found to be extremely useful in practice, for e.g. forecasting and simulation tasks. In addition, the AWM is only one model in a range of possible tools. Alternative approaches include multi-country models (see, for example, De Bondt et al., 1997; Deutsche Bundesbank, 2000), very small-scale models (such as Coenen and Wieland, 2000) as well as time-series approaches (such as Angelini et al., 2001).

The remainder of this paper is structured as follows. Section 2 identifies the key features of the model. An overview of the model structure is provided in Section 3, with also some details on specific key equations. Section 4 focuses on the long-run properties of
the model and recalls the main adjustment mechanisms at work. In Section 5, the dynamic properties of the model as a whole are described and illustrated by simulation results. Section 6 concludes.

2. Key features of the area-wide model

The AWM is characterised by a number of key features, related to its scope, its structure and its empirical content, which are worth listing before going into more details.

2.1. The euro area modelled as a single economy

First and foremost, all equations involve area-wide variables only. The model thus extends in a substantial way the tradition of area-wide econometric analysis within Europe, which up to now has been largely confined to studies of area-wide money demand.3

2.2. A limited degree of sectoral disaggregation

Another key feature of the AWM is that it is a relatively small scale model which, while giving some detail on the main components of aggregate demand and the corresponding prices, remains nonetheless sufficiently small to be manageable in the context of forecasting and simulation exercises. This is in line with current practice in academic macroeconomics4 and increasingly also the modelling practice among central banks in both Europe and in other industrialised countries. The current version of the model thus contains a total of 84 equations of which 15 are estimated behavioural equations.

2.3. The desired economic properties

In line with most current mainstream macro-models, the AWM has been specified to ensure that a set of given structural economic relationships hold in the long run. These relationships are, e.g., constrained to be consistent with a basic neo-classical steady state, in which in long-run output is determined by technological progress and the available factors of production. The model comprises a ‘vertical’ Phillips curve, so that there is no inflation-unemployment trade-off in the long run. The long run of the model has been designed to ensure that money is both ‘neutral’ and ‘superneutral’ with respect to output. In addition, the long-term levels of prices and wages are determined by the particular nominal anchor used in simulating the model.

3 See, for example, Browne et al. (1997) for a comprehensive survey and Fagan and Henry (1998) and Coenen and Vega (2001) for pre-EMU contributions to this literature. On the combination of an area-wide approach with the multi-country one and the specific issues implied, see Henry (1999).

4 Indeed by the standard of the current macroeconomic literature (e.g. Fuhrer and Moore, 1995a; McCallum and Nelson, 1999), the AWM could be considered as a large-scale model, although this not the case when specifically comparing with models used at central banks (e.g. at the Us Fed FRB US, Brayton and Tinsley, 1996, or at the Bank of Canada QPM, Coletti et al., 1996).
In the short-run, however, because of sluggish adjustment of prices and wages, output is demand-determined. While the long-run properties are closely linked to the underlying theory, the short-run dynamics are not explicitly derived from an optimisation framework but instead specified in a more traditional ‘ad-hoc’ form and estimated on the basis of historical data. The dynamics, however, are constrained by the need to fulfil long-run steady-state properties via the use of ECM terms and of appropriate homogeneity properties. Finally, another (unrelated) aspect is that the model does not include equations for the ‘rest of the world’ variables, which are therefore treated as exogenous in simulations.5

2.4. The treatment of expectations

The reported version is mostly backward-looking, i.e. expectations are represented by lagged values of the variables (i.e. adaptive expectations). For the purpose of generating short-term forecasts—which are usually produced conditional on exogenous interest rates and exchange rates—such an approach is usually considered adequate (cf. ECB, 2001). However, for other purposes, including simulation exercises, especially those involving policy changes, or the assessment of alternative policy rules, the backward-looking approach may be unsatisfactory and for many variables (especially financial variables such as long-term interest rates and exchange rates) is inherently implausible. In this document, the forward-looking elements are limited to financial variables, specifically the exchange rate and the long-term interest rate, using respectively an Uncovered Interest Parity (UIP) condition and the expectations theory of the term structure.

2.5. A summary view of transmission mechanisms

The model as it stands now does not comprise all of the elements that are necessary to comprehensively describe the transmission mechanism of monetary policy. The latter is simply summarised by a direct influence of short-term interest rates on demand components. As a result, a number of standard channels are not explicitly modelled, such as the financial quantity and price channels. There is, e.g., no explicit role of credit variables in shaping liquidity constraints, nor is there any description of the pass-through of the short-term interest rates directly affected by monetary policy decisions to retail rates affecting households and corporate behaviour.6

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5 Given the share of the euro area in the global economy, it is likely that shocks to the euro area economy will have some impact on ‘foreign variables’ and these ‘spillovers’ are found in some multi-country models to be potentially sizeable (see Douven and Peeters, 1997). The spillovers in turn will imply further impacts on the euro area itself. By treating foreign variables as exogenous, these effects are not taken into account in the AWM. However, it should be noted that the available evidence for the US (see, for example, Fair, 1994) suggests that these additional impacts are relatively small compared to the effect of the initial shock. These impacts could, in principle, be taken into account in simulations by supplementing the AWM with some equations for ‘foreign variables’.

6 For an exhaustive description of the various mechanisms at play, see ECB (1999).
2.6. A data-oriented approach

The final feature worth pointing out relates to the data and empirical approach that has been followed. Regarding data, a decision has been made to develop a quarterly model, since it allows for a richer treatment of the short-run dynamics of the economy than would be allowed by lower frequency data. This feature particularly enhances the usefulness of the model for forecasting purposes. However, while the situation is improving continuously, severe data availability problems arise with respect to the euro area, especially regarding longer spans of data, as necessary for estimation. There are currently no satisfactory databanks with long spans of area-wide time-series that could be readily accessed. Thus, the model variables were created using a range of national and international sources. The data extends back for most variables to the first quarter of 1970. In order to ensure maximum consistency in the data used across the ECB and within the Eurosystem, the older series have been linked to the series contained in the ECB Monthly Bulletin, where available.7

As regards the empirical approach, the determination of the parameters of the various equations comprised in the AWM has mostly been based on estimation. When developing econometric tools for a new economic entity such as the euro area, the need for striking the appropriate balance between ‘fitting’ the historical data, on the one hand, and ensuring that the model as a whole has appropriate economic properties, on the other, is especially acute. In particular, estimation is more delicate and questionable than when developing models for individual countries, so that calibration techniques could be envisaged to play a more prominent role. Calibration, as used, e.g., extensively in Black et al. (1994), on the other hand, needs a very comprehensive understanding of the modelled economy, which is of course not yet available at the euro area level. Estimation has therefore been the preferred option, with a view to getting some initial benchmark estimates for key economic area-wide behaviour, on the basis of standard specifications.

3. Model structure and key equations

This section provides a summary overview of the model structure, followed by a short presentation of the equations for some key variables (details on the estimated long-run and short-run parameters can be found in Fagan et al., 2001).

3.1. The structure of the model

The model comprises blocks of equations for aggregate supply, wages and prices, aggregate demand, monetary and financial variables and policy behaviour.

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7 Further details on data definition and construction can be found in Annex 2 to Fagan et al. (2001). The mentioned document, together with the model’s database, can be downloaded from the ECB’s website, see www.ecb.int/pub/wp/ecbwp042.pdf.
As described in the previous section, the model has been designed to specifically incorporate some particular economic properties. In line with this, the supply side of the model comprises a whole-economy production function, according to which potential output depends on technical progress, the capital stock and the effective labour supply. The structural unemployment rate—which together with the actual labour force determines effective labour supply—is an exogenous variable. Employment and investment are determined by the inversion of the production function and profit maximisation, respectively, under the assumption of competitive markets.

There is a wage-price block in which prices are a function of unit labour costs while wages are determined by a Phillips curve in levels. Some restrictions have been imposed on the dynamics of the equations, e.g. dynamic homogeneity\textsuperscript{8} in the price equation, to ensure that the resulting long-run Phillips curve is vertical. Long-run inflation and price levels are pinned down by a nominal anchor, which can be defined in alternative ways, involving different monetary policy specifications.

In the short run, actual output is determined by aggregate demand. The model contains standard equations for the main components of demand—private consumption, stockbuilding and exports and imports—while government consumption is exogenous and investment is determined in the supply-side block. The model comprises in addition simplified accounts for both households and the public sector, the policy reaction of the latter being also modelled. Finally, the model contains equations for money demand, the exchange rate and long-term interest rates.

3.2. Key empirical features of the estimated equations

For all behavioural equations, ECM specifications à la Engle and Granger (1987) have been systematically estimated. They were generally found to fit the euro area data reasonably well over the last 25 years. Some summary features resulting from the estimation conducted, such as key long and short-run elasticities, are reported in Table 1 below, along with the corresponding $t$-ECM statistics. The reported $t$-ECMs can be seen as a test for cointegration.\textsuperscript{9} In view of the results, it appears that most of the long-run restrictions imposed are roughly consistent with the data used, although, in many cases, the speed of adjustment to equilibrium values is relatively low.

Bearing in mind the potential occurrence of structural breaks following the move to monetary union, some aspects of the euro area economy that appear in view of the econometric estimates are still worth highlighting. There is, e.g., a significant short-run negative impact of real wages on employment, or a relatively high short-run elasticity of consumption with respect to income—which may reflect a high proportion of liquidity-constrained households. The price elasticity of exports is much higher than that of imports, presumably reflecting a quite different product composition in both trade flows. Of course, such observations should be taken with caution, to the extent that euro area econometric modelling is in its infancy and mostly relies, de facto, on pre-EMU data.

\textsuperscript{8} Dynamic homogeneity is a standard concept, the definition of which can be found, e.g., in Jensen (1994).

\textsuperscript{9} As proposed in Banerjee et al. (1998).
Given the risk that some of the equations might not be statistically stable, further attention should be paid in the future to the detecting and modelling of structural breaks. An appropriate modelling of structural changes may also increase the size of the ECM coefficients, thereby speeding up convergence to the implied long-run equilibrium of the model.

3.3. The specification of the main equations of the model

3.3.1. The production function and factor demands

The model includes a description of technology in which potential output is assumed to be given by a constant-returns-to-scale Cobb-Douglas production function with

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10 Once the functional form of any given behavioural equation is deemed robust enough on the basis of past observations, the model could be adjusted to accommodate for structural change. A number of methods could be used, such as time-varying parameters or non-linear transition models (cf. Hall, 1993; Granger and Terasvirta, 1993, respectively).

11 A comprehensive and detailed account of all equations in the models, including estimation and single-equation simulation results are available in Annex 1 to Fagan et al. (2001).
calibrated factor-share parameters (see Eq. (3.1)). The parameter $\beta$ has been set as one minus the average wage income share in the sample and is thus not estimated.

$$\text{YPOT} = \text{TFT} \ KSR^\beta \ LNN^{1-\beta} \quad (3.1)$$

Trend total factor productivity TFT has been estimated within the sample by applying the Hodrick-Prescott filter to the Solow Residual derived from this production function. This production function is used to derive theoretically consistent first-order conditions that enter other equations in the model, e.g. investment. It also provides the measure of potential output, which combined with actual output, determines the output gap.

The factor demand equations of the model—specifically for investment and employment—are specified so as to be consistent in the long run with the underlying theoretical framework of the supply side. The corresponding ECM terms embody, respectively, the marginal productivity condition for capital and the production function (3.1) for employment. In the short run, however, investment and employment are driven by other factors, such as changes in demand.

In view of the well-known difficulties in estimating satisfactory aggregate investment equations (see, e.g., Chirinko, 1993), little emphasis has been put on the statistical significance of parameters. The investment specification is consistent with the long-run capital stock (see Section 4.1), supplemented with some accelerator effect in the short run, with unit elasticity imposed, i.e. it is a specification in terms of the investment to output ratio. This equation, via the cost of capital variable, provides the main channel through which interest rates affect aggregate demand in the model.

Employment growth in the short run depends on real wages and output growth (both adjusted for trend productivity). In the longer term, in line with a number of models (e.g., Bank of England, 2000), employment adjusts to a level implied by the inversion of the production function (3.1).

### 3.3.2. Components of aggregate demand

Expenditure on real GDP is split into six separate components:

- private consumption
- government consumption
- investment
- inventories

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12 This restriction is not rejected by formal tests on the unrestricted version of the equation.

13 There are a number of possible ways in which the long-run condition for employment consistent with the theoretical framework of the model could be specified, apart from the inverted production function condition currently used. On the one hand, solving a profit maximisation problem would lead to an expression for the long-run level of employment as a function of output and the real wage. Alternatively, cost-minimisation subject to a given capital stock would lead to an expression in which long-run employment would be a function of output, technical progress and relative factor prices. It can be easily shown, in the context of the current model as a whole, that each of these formulations leads in the long run to the same level of employment. The decision to adopt an inverse production function approach has been motivated by better ‘fitting’ and simulation properties of this approach.
exports of goods and services and
imports of goods and services

Starting with domestic demand, the consumption function is standard (see, e.g.,
Muellbauer, 1994 for a survey of commonly used specifications and Church et al.,
1994 for a review of estimates of specifications involving wealth and income for a number
of UK models). Private Consumption is a function of both disposable income—comprising compensation,\textsuperscript{14} transfers net of taxes and other income—and of wealth. The latter is
defined as cumulated savings, under the assumption that households own all of the assets
in the economy (i.e. public debt, net foreign assets and the capital stock). Inventories
respond to short-run demand fluctuations, while the long-run ratio cumulated inventories
to GDP is constant.

On the external side, it is worth stressing that exports and imports comprise both intra-
and extra-area flows, i.e. they are not based on trade only with countries outside the area,
due to data limitations. The modelling approach is otherwise in line with, e.g., Goldstein
and Kahn (1985) or the more recent review by Sawyer and Sprinkle (1996). Namely,
market shares—in terms of export and import demand—are a function of competitiveness.
Export demand and competitors’ prices are computed as a weighted average of both extra-
and intra-area variables. For both imports and exports, deterministic trends were intro-
duced to ensure cointegration between market shares and the corresponding relative prices.
These could capture the time-varying openness of both the euro area and the rest of the
world.

3.3.3. Prices and costs

The model contains equations for a number of price and cost indicators. This system of
prices has been estimated under the assumption that some law of one price should hold, i.e.
imposing static homogeneity to all price equations, which is equivalent to express the long
run ECM component of each of those equations in terms of relative prices only.
Specifically, the main equations in the price/cost block are the following:

- GDP (basic prices) deflator
- GDP (Market Prices deflator, i.e. including indirect taxes and subsidies)
- Whole-economy compensation per head
- Private consumption deflator
- HICP
- Import and Export deflators
- Investment deflator

The key price index used in the model is YFD, the deflator for real GDP at basic prices
(i.e. excluding the effect of indirect taxes and subsidies). This deflator is modelled as a
function of trend unit labour costs. In the short-run, import prices also have some effect.

\textsuperscript{14} Nominal GDP YEN is decomposed on the income side into total compensation WIN, indirect taxes TIN
and Gross Operating Surplus GON, the latter being computed as a residual.
The GDP deflator at market prices YED in turn is derived by using the accounting identity linking market prices to basic prices, through an exogenous ratio in GDP terms for indirect taxes and subsidies. Dynamic homogeneity is strongly rejected by the data, i.e. the estimated coefficient on unit labour cost inflation differs from one, which implies that in principle the long-run mark-up would depend on steady state inflation.\footnote{See \cite{Price1992} for a similar approach estimating forward-looking price ECM equations under the constraint of dynamic homogeneity, an hypothesis which cannot be rejected using the UK data, contrary to what our findings suggest for the euro area.} The intercept of the equation is however set to ensure that the long-run equilibrium of the model coincides with its theoretical steady state, thereby restoring for out-of-sample simulations the dynamic homogeneity condition. In the short-run, the mark-up depends on the output gap, a feature that increases the response of the nominal side of the model to real shocks. In addition, a term in inflation expectations enters the short-run dynamics, the coefficient of which has been calibrated following simulation experiments. This expectational term may be viewed as a proxy for forward-looking behaviour (inflation expectations being set exogenously).\footnote{Accounting for such expectational components is clearly crucial for policy analysis (see, e.g., \cite{FuhrerMoore1995b,Clarida2000}). The current setup is a modified version of \cite{GerlachSvensson2003}.} In a forward-looking setting the expectations term can, e.g., be either the inflation objective of the monetary authority or future inflation, which at steady state converges to the central bank’s objective.

Wages, measured by compensation per head, are modelled as a Phillips curve in levels, with wage growth depending on productivity, current and lagged inflation—in terms of consumer prices—and the deviation of unemployment from its structural level (in a NAIRU sense). This latter variable is exogenous in the model, although it is time-varying in sample, having been estimated using the \cite{Gordon1997} approach. Since dynamic homogeneity holds, the long-run Phillips curve is vertical in the model. The short-run dynamics include a calibrated term in inflation similar to that used for the price equation.\footnote{In case expectations would represent a 1-year ahead forecast, the calibration used would be consistent with empirical estimates for the US, as documented, e.g., in \cite{Rudebusch2002} where forward-looking price-price Phillips curves are estimated. In practice, having expectational terms in both equations is tantamount to having such a term in only one of them, albeit with a higher coefficient. However, in the absence of reliable estimates for such effects in the euro area, it has been deemed appropriate to treat potential effects of expectations on both wage and price formation symmetrically.}

The long-run equilibrium for both wages and prices is pinned down by the pre-determined trend real unit labour costs or, equivalently, by the long-run labour share, in turn equal to the labour elasticity \((1 - \beta)\) in the production function (3.1). This obviously establishes a unique relation between real wages and productivity.

The specification of the wage and the key price equations implies that demand pressure can affect inflation in the short-run through two channels.\footnote{Both terms have been calibrated, so as to have tensions affecting both prices and wages in a symmetric and balanced manner. The output gap term was borderline significant but kept in the equation, whereas the estimated Phillips curve impact has been rescaled to half of its point estimate. Without such a calibration, demand shock would have led to some short-run overreaction of real wages.} The first channel is standard and appears in the wage equation, via the unemployment gap term. The second channel has two components. The first one is standard, namely the output gap term entering the
price equation. The other one is less immediate, coming from the fact that inflationary pressures affect prices and wages asymmetrically because of the differing measures of productivity involved, with respectively trend productivity in prices and actual productivity in wages. In the reduced form of the price system, i.e. eliminating the wage equation, this would result in the inclusion of a productivity gap as an additional measure of inflationary pressure, next to the unemployment and output gaps.

There are two equations for consumption prices, one for the National Account deflator PCD, another one for the Harmonised Index for Consumption Prices (HICP). The roles played by the corresponding equations are quite different. While the consumption deflator is a key price indicator within the model’s accounting framework and has a strong feedback on the model, the HICP is in contrast recursive to the rest of the model. The consumption deflator is a function of the GDP and import deflators, supplemented with some transitory effect of commodity prices. The equation for HICP expresses the gap between this variable and the consumption deflator as a function of unit labour costs and import deflator.

Import prices are a function of euro area export prices (to account for intra-area trade), of foreign prices and of commodity prices (measured by the HWWA index, a weighted average of oil and non-oil commodity prices), all expressed in euros. Export prices similarly have two driving components, intra-area and extra-area, i.e. the GDP deflator and foreign prices, respectively.

3.3.4. Fiscal and external accounts

The fiscal block is very simplified, with a limited number of revenue and expenditure categories, generally being exogenous in terms of ratios to GDP, with two exceptions however. First, real government consumption is exogenous in levels. Second, transfers to households (in GDP percentage points) are a function of the unemployment rate, the coefficient being calibrated to be consistent with country estimates. The version used for long-run simulation purposes also incorporates a calibrated fiscal rule in which the direct apparent tax rate—i.e. the direct taxes paid by households to GDP ratio—responds to the fiscal deficit to GDP ratio, as observed four quarters earlier. Apparent direct tax rates are changed with a view to reaching some given deficit ratio, with a fraction of the deviations from target being absorbed each period. The postulated lagged fiscal reaction allows for some realistic inertia in the fiscal policy process.19

As regards the external accounts, the nominal trade balance is clearly a function of trade volumes and prices. Net factor income (including international transfers) is determined by a calibrated equation, linking it to lagged values of the stock of net foreign assets. The sum of the trade balance and net factor income gives the current account balance, which in turn is cumulated to generate the stock of net foreign assets.

3.3.5. Monetary and financial sector

Two equations are included in the financial sector: money demand and a yield curve. The money demand equation is a fairly standard dynamic ECM equations for the new M3

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19 This fiscal rule is only one of the possible ways to model such a necessary closure rule (see, e.g., Mitchell et al., 2000 for a comparative analysis of alternative specifications).
aggregate, which expresses real money balances as a function of real income, short- and long-term interest rates and inflation. The yield curve links the long-term interest rate to the short-term rate. Two versions of the equation are currently available, a purely backward-looking and a purely forward-looking version (using the Fuhrer and Moore, 1995a linear approximation).

4. The long-run properties of the model

4.1. The long-run supply equilibrium

The starting point for the supply side specification is the above-mentioned two-factor Cobb-Douglas production function. Factor markets are competitive by assumption and therefore the following marginal productivity conditions hold in the long run:

\[
F_{KSR} (KSR, LNN) = \beta \frac{YER}{KSR} = (r + \delta + \lambda)
\]

\[
F'_{LNN} (KSR, LNN) = (1 - \beta) \frac{YER}{LNN} = \frac{WRN}{YFD}
\]

i.e. in Eq. (4.1) the marginal product of capital (KSR) equals the user cost (comprising the sum of the real interest rate \(r\) and the depreciation rate \(\delta\) plus a risk premium \(\lambda\)), while in Eq. (4.2) the marginal product of labour (LNN) is equal to the real product wage \(WRN/YFD\), where \(WRN\) is the whole-economy nominal wage rate and \(YFD\) the output price. Therefore, Eq. (4.1) pins down the steady-state capital-output ratio, while Eq. (4.2) can be interpreted as a labour demand equation or, as done in the model, as an expression of the steady-state real wage consistent with a constant labour income share in GDP.

At steady state, the unemployment rate is equal to the natural rate (URT) which is also the NAIRU. Under this assumption, inserting the first order condition for capital (4.1) into the production function (3.1) yields the following expression for steady-state output:

\[
YER^* = TFT^1/(1-\beta) (\beta/(r^* + \delta + \lambda))^{\beta/(1-\beta)} LNT
\]

where \(TFT\) is trend total factor productivity and \(LNT\) is the effective labour supply, i.e. the labour force multiplied by \((1 - URT)\). The marginal productivity condition for labour (4.2) enters the long run of the wage equation and the capital to output ratio is given by Eq. (4.1). Since capital stock adjusts sluggishly to its steady-state level, the level of potential

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20 See Coenen and Vega (2001) for further details.

21 Consistent with the construction of the area-wide capital stock, the depreciation rate is a constant 4% per annum. The size of the risk premium is calibrated to ensure that the marginal productivity condition holds, on average, over the sample 1980–1997.

22 In order to ensure that the model has indeed a steady state which satisfies these conditions, the long-run terms of the employment, investment, wage and output price equations have been defined to incorporate these long-run conditions. In addition, the wage, output price and factor demand equations incorporate some dynamic homogeneity, to ensure that the resulting long-run solution does not depend on arbitrary constants. Without dynamic homogeneity, the steady state of the model, while well-defined, would not necessarily correspond to the conditions set out above. In particular, unemployment might not equal URT and the steady-state output could differ from that given by (3.4) by an arbitrary constant.
output (YET)—i.e. the level of output which can be produced at any given point in time by the available factors—will be given by:

\[
Y_{ET,t} = TFT_t K_{SR,t}^{1-\beta} \text{LNT}_t^{\beta} \tag{4.4}
\]

As the capital stock adjusts gradually to its steady-state value, YET will converge to YER*.

The long-run system formed by Eqs. (4.1)–(4.2), the long-run employment equation (the production function (3.1), inverted) plus the condition that unemployment equals the equilibrium rate is embodied as ECM (long-run) terms in four of the model’s equations. First, the marginal productivity condition for capital (4.1) enters the investment equation. Second, the marginal productivity condition for labour (4.2) is incorporated in both the wage and the price equation. Third, the production function enters the employment equation. Finally, the condition on the labour force is incorporated in the wage equation. The long-run solution of these four equations is thus given by four theoretical steady-state conditions, ensuring that output in the long run is given by the supply side of the model. The precise steady-state level of output will depend on the steady-state real interest rate entering the user cost of capital in Eq. (4.1). The steady-state real interest rate is exogenous and has been calibrated on the basis of an historical average.

**4.2. The long-run demand and the equilibrium real exchange rate**

In order to complete the real long-run equilibrium it is necessary that the components of aggregate demand, in the long run, sum to YER* as given in Eq. (4.3), which involves some additional hypotheses regarding, e.g., consumption and inventory accumulation behaviour and public finance.

\[
Y_{ER,*} = PCR + GCR + ITR + XTR - MTR + SCR \tag{4.5}
\]

Where: PCR real private consumption depends on real income and real wealth, the components of which are real public debt, real capital stock and net foreign assets NFA; GCR public consumption is exogenously given, assumed to represent a constant share of GDP; ITR is investment, the dynamics of which is consistent with that of the capital stock KSR; XTR and MTR real exports and imports respectively depend on the real exchange rate and demand terms, world demand and GDP, respectively; SCR change in inventories consistent with a constant stock to GDP ratio, conditional on the (given) real interest rate.

The equality between demand and supply in Eq. (4.5) is achieved by means of a stock-flow interaction delivering an equilibrium value for the real effective exchange rate (EER*). To see this, it is helpful to go through the various components in Eq. (4.5) one by one, expressed in GDP terms. The long-run investment to GDP ratio is already determined by the dynamics of the capital stock, i.e. by the supply side. In addition, inventories are proportional to GDP in the long run, while Public Consumption is given exogenously. The two remaining components, namely private consumption and real net trade (XTR – MTR), should then be consistent with each other, ensuring that Eq. (4.5)
holds. Since private consumption in GDP terms is proportional to the wealth to GDP ratio, the adding-up constraint on demand components results in a relation linking wealth and net trade. Under the additional assumption of an effective fiscal rule, the debt to GDP ratio is pinned down in the long run. Since the capital to GDP ratio is given by the supply side, the only free component of wealth is net foreign assets. Defining those as cumulated net trade, the adding-up condition boils down to a dynamic equation for the real exchange rate.

4.3. Determination of prices in the long run

The model includes equations for a number of price indices, which determine relative prices but not the overall level of prices. A nominal anchor is required in order to pin down the long-run level and growth rate of the price system. Technically, a number of possibilities can be employed for this purpose. For instance, under strict monetary targeting, the long-run price level would be given by the equilibrium condition for the demand for real money balances, conditional on the money demand function, with an exogenously fixed nominal money supply. Alternatively, if short-term interest rates were to depend on deviations of inflation or the price level from a given central bank’s objective, the price level would be pinned down in the long run by the price objective.

4.4. Adjustment to equilibrium and the involved short-run mechanisms

The theoretical equilibrium holds only for the long-run behaviour of the model. In the short-run, prices and wages do not adjust instantaneously to shocks. As a result, transitory disequilibria appear in both goods and labour markets, namely a deviation of output from potential level as well as a deviation of actual unemployment from the NAIRU. In order to restore equilibrium, a number of mechanisms have to operate. These involve adjustments stemming from disequilibrium terms (from goods and labour markets) entering the price and wage equations as well as policy responses.

The type of adjustment mechanisms depends on the simulation environment, particularly the exchange rate regime and the specification of the interest rate setting equation and of the fiscal rule. The simulations reported below, for illustrative purposes, have been carried out in an environment where the exchange rate fulfils the Uncovered Interest Parity (UIP) condition whereas short-term interest rates are determined by a standard Taylor (1993) rule. Tax rates are adjusted so as to ensure that a targeted deficit to GDP ratio is met. Obviously, because of the UIP condition, this setting is only compatible with forward-looking simulations and therefore requires the use of special solution techniques to solve the model, in the case at hand, the Julliard and Laxton (1996) algorithm in Troll.

It is worth pointing out moreover that the plausibility or policy relevance of those otherwise relatively standard three relationships—i.e. the UIP condition, the calibrated

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23 See Bryant et al. (1993) for such policy modelling and some empirical assessment of various types of rules.
Taylor rule and the fiscal reaction—is not at stake as such. In fact, these supplementary equations are used primarily because they are necessary elements to close the model as a full system, which would otherwise not converge to some steady-state path.

In such a configuration the main adjustment mechanisms are as follows, taking the example of a positive aggregate demand shock:

- First, the shock mechanically increases output and employment, leading therefore to an increase in inflation via the Phillips curve. This triggers a rise in real short-term interest rates, since both arguments in the Taylor rule are deviating from their equilibrium values. This puts downward pressure on domestic demand, arising from weakening investment and therefore aggregate demand.
- Second, some external channel will operate too, although the impacts remain somewhat limited for a relatively closed economy such as the euro area. In line with the expected change in interest rates, the UIP condition would lead to an initial jump in the nominal exchange rate followed by a sustained but gradual depreciation. There would be ceteris paribus an initial appreciation of the real exchange rate, therefore downward pressures on both prices (via diminished imported inflation) and demand (via lower net trade and also lower net foreign assets).
- Third, this initial nominal and real appreciation is reinforced by some further “crowding-out”, via an external channel. First, the additional inflation induces a real appreciation of the exchange rate, which would tend to weaken net trade and, in part, offset the initial increase in output. Second, increased demand would boost imports, leading to a further weakening of trade contribution to growth.
- Fourth, the ‘automatic stabilisers’ of fiscal policy imply in the case at hand that transfers to households should fall on foot of lower unemployment, helping to further dampen the growth of disposable income. In addition, in the case where the shock emanated from a fiscal expansion, the fiscal solvency rule gradually ‘kicks-in’ and the associated rise in direct taxes also dampens demand.

The adjustment process would continue until inflation rate and output growth rates return to their baseline values.

5. Some standard simulation results

To get some flavour of the model properties, this section presents two standard simulation exercises. The first one introduces an unexpected and permanent increase in real Government consumption by 1% of GDP, and the second, an unexpected and temporary 100 basis points increase in the short-term interest rate. The first simulation is run over a very long-horizon since such a variant typically aims at assessing the extent to which a permanent shock would affect the model’s long-run equilibrium. The second simulation, in turn, is analysed only over a shorter horizon, since the experiment conducted assumes that interest rates will remain exogenous, therefore not using the fully fledged model. Of course a wide range of additional experiments have been conducted so as to assess further the model properties, the choice being made here however to only
report in detail those simulations with significant illustrative elements underlying the
dynamics of the model.\textsuperscript{24}

5.1. Shock to government consumption by 1\% of GDP (ex-ante), permanent

The fiscal shock implemented is a permanent raise in real Government Consumption by
1\% of GDP. The shock is a textbook-like test for any macroeconomic model. As
documented above, on theoretical grounds, a return to the pre-shock level of activity is
expected, to the extent that total supply should not be affected by this shock. An obvious
further element worth analysing in the context of such a permanent shock is the speed at
which the model goes back to a new equilibrium and the extent to which inflation rises
above its steady-state level before returning to base.

Prices respond to the expansionary shock quite progressively (see Fig. 1). The
deflationary impact of the initial appreciation of the exchange rate (3.4 \%) counteracts the inflationary effect of additional activity. The increase in demand,
however, pushes up both key deflators—consumption and GDP—inflation being
higher than baseline for 9 years. After 20 years, both inflation and price levels are
close to baseline. The final equilibrium reached by the economy following this
permanent demand shock implies a real appreciation of the euro of around 2.5\%.
The latter is needed to ensure a permanent reallocation of supply across demand
components which is consistent with a permanently higher GDP share for Govern-
ment consumption.

As to real activity (see Fig. 2), the outcome is in line with expectations, i.e. the
initial expansion is quickly crowded out with the result that the impact on GDP is less
than one-to-one at all horizons. The initial expansion of exogenous output results in a
rise in employment and lower unemployment, which in turn generates a pick-up in

\textsuperscript{24} In line with the above mentioned discussion on adjustments, the simulations were carried out with a
forward-looking UIP condition for the exchange rate, a fiscal solvency rule and with short-term interest rates
being determined by a standard Taylor rule.
wage growth. This leads to an increase in consumption while accelerator effects boost investment. The deviation of GDP from baseline on the first year amounts however to only 0.9%, i.e. less than the shock itself, with Government consumption accounting for most of the initial reaction. After the initial expansion of output the above mentioned demand dampening mechanisms kick in, as expected. Real interest rates rise exerting downward pressure on investment. In addition, the real exchange rate appreciation—induced initially by higher interest rates and later by higher domestic prices—leads to weaker net trade. After the second year, the deterioration of public finance moreover triggers a necessary adjustment of direct taxes to restore fiscal solvency, which in turn dampens consumption. The debt to GDP ratio is higher than baseline for about a dozen years, but this result is of course sensible to the calibration chosen for the fiscal rule.

The output reaction is remarkably smooth in terms of the return to steady state, which is reached after around 20 years. No hump shape is observed in annual terms as the highest impact on activity is reached the first year, a shallow monotonic decline following afterwards. As to the speed of the response, the initial impact takes only 3 years to be halved and 3 further years to cross again the baseline.

5.2. Interest rate increase of 100 basis point, sustained for 2 years

Interest rate shocks form also part of the basic tool-kit of the macro-modeller. The simulated shock in the case at hand is an increase of 100 basis points in the short-term interest rate, spanning 2 years, assuming moreover that the interest rate goes back to baseline after the shock. Such a variant is typically a short-run experiment, which can, e.g., be conducted in the context of conditional forecasts, to the extent that one of the key equilibrating mechanisms—the interest rate setting equation—does not intervene over the simulation horizon.

The inflation response (see Fig. 3) is a mix of the depressing effect of lower activity and the initial appreciation of the exchange rate. Inflation, on the basis of the consumption deflator, drops immediately by around 0.2 percentage point, mainly because
of lower imported inflation, whereas the output gap effect on GDP deflator can be felt only after one quarter. In the ensuing quarters, the initial exchange rate appreciation unwinds completely, as expected to the extent that interest rates are back to their baseline value, so that after a couple of years the gap between the two measures of inflation (consumption deflator and GDP deflator) tends to vanish. On the basis of additional simulations without an endogenous response of the exchange rate, it appears that the exchange rate contributes to two-thirds of the first year effect, this contribution dying out after 3 years.

As to activity, the outcome of higher interest rates is a lagged and gradual negative impact on GDP growth (see Fig. 4), with a maximum deviation from baseline of around 0.15%. As a result, the level of GDP is below its steady-state value by around 1 percentage point after 3 years. The main factor underlying these developments is the direct and strongly negative impact of higher interest rates on investment. This effect is supplemented with the consequences of the initial appreciation of the nominal exchange rate (of about 2%, reflecting the changes in short-term rates over the whole horizon). Both trade—via competitiveness—and consumption—through the foreign asset terms entering wealth—are negatively affected by the initial appreciation. The contribution of the exchange rate
channel to this pattern for output is of the order of one third and remains more or less stable over the whole simulation horizon, contrary to what has just been mentioned for inflation.

6. Conclusions

The work undertaken around the AWM has been doubly fruitful: firstly, and obviously, because of the model that has resulted once the tool had been finalised, but also because of the lessons learned as regards the features and behaviour of the euro area economy as a whole.

The model and all the accompanying data and software infrastructure has now been designed, tested and routinely implemented. The resulting model has been found to be useful for practical purposes, in particular as a tool used in the context of forecasting and simulation exercises.25

However, model development is a continuous process and no model can ever be considered to be ‘final’ in the sense that further improvements could and even should be envisaged. The AWM is no exception to that rule: sooner or later, it will have to be improved or replaced altogether by more advanced alternatives. In the meantime, it is hoped that the AWM will become a hard-to-beat benchmark, having set a milestone in the empirical analysis of euro-area wide macroeconomics.

Acknowledgements

Opinions expressed in the paper are those of the authors and do not necessarily reflect those of the European Central Bank. The authors thank Alistair Dieppe and Elena Angelini for excellent research assistance, in particular for their contribution to the construction of the historical database, which permitted estimation work to be conducted. We greatly benefited from discussions at various stages of the project with S. Siviero, F. Smets, D. Terlizzese and J. Williams. Comments from colleagues from the ECB and National Central Banks of the European System of Central Banks, from seminar participants at Warwick, Bank of Canada, INSEE, Bocconi and Bielefeld as well as from two ECB Working Paper Series referees, are also gratefully acknowledged. Remaining errors are the sole responsibility of the authors.

References


EMI, 1997. The single monetary policy in Stage Three: elements of the monetary policy strategy of the ESCB European Monetary Institute, Frankfurt.


