Update and Re-estimation of NAWM II (Version 1.2.3)

Günter Coenen, José-Emilio Gumiel, Carlos Montes-Galdón and Anders Warne

January 18, 2022

Abstract

This note describes an updated and re-estimated version of the New Area-Wide Model with a financial sector (NAWM II).[1] This version reflects the adoption of a 2% inflation target by the ECB following the completion of its strategy review against the backdrop of the downward trend in the equilibrium real interest rate over the past decades and makes use of an extension of the model database to 2019Q4. Most notably, the downward trend in the real rate is now captured by a newly introduced highly persistent discount-rate shock, which generates, as intended, co-movement among the model's interest rates, along with a re-calibration of the model's steady-state real interest rate to 1.25%. Compared to the previous version, the salient properties of NAWM II are preserved, including the responses to key structural shocks (reflecting broadly unchanged estimates of the model's parameters), the historical decomposition of real GDP growth during the financial and sovereign debt crises, and the effects of central bank asset purchases.

[1] For a detailed description of the previous model version 1.2, see Coenen, G., P. Karadi, S. Schmidt and A. Warne (2018), "The New Area-Wide Model II: An extended version of the ECB's micro-founded model for forecasting and policy analysis with a financial sector", ECB Working Paper No. 2200.

Table of contents

List of tables

List of figures

1 Adaptations in the light of the ECB's strategy review

The adoption of a 2% inflation target by the ECB following the completion of its strategy review in July 2021 reflects the need for maintaining a sufficient inflation buffer in order not to compound the distortions resulting from the effective lower bound on nominal interest rates in the low-interest-rate environment brought about by the secular downward trend in the equilibrium real interest rate over the past decades. To adapt the financial-sector extension of the New Area-Wide Model (NAWM II) to these circumstances, the model has been modified in two distinct, but complementary ways.

1.1 Re-calibration of the inflation objective and the steady-state real rate

To align NAWM II with the outcome of the ECB's strategy review, the central bank's gross inflation objective, $\bar{\Pi}$, has been raised from a value of 1.00475 to 1.005, in line with the ECB's new inflation target of 2% per annum. In the absence of the effective lower bound, this objective determines the value of gross inflation in the intended steady state of the model, with $\Pi = \bar{\Pi}$. In addition, to partly accommodate the documented fall in the equilibrium real interest rate, the steady-state value of the short-term gross real interest rate, $R^r = g_z/\beta$, has been lowered from a value of 1.005 to 1.003125, corresponding to a steady-state real rate of 1.25% per annum in net terms. This re-calibration ensures that the households' discount rate β remains below unity, given the maintained value of 1.003 for gross trend (labour) productivity growth, g_z. At the same time, the re-calibration of R^r is broadly consistent with the average value of the short-term real interest rate over the extended sample period used for the estimation of the model.

1.2 Introduction of a serially correlated discount-rate shock

In the modified model, a new stochastic discount-rate shock has been introduced which is intended to capture the secular downward trend in real interest rates, over and above the effect due to the re-calibration of the model's steady-state real interest rate itself. In particular, this shock is intended to capture the fall in interest rates which can be attributed to the increase in the premium for safe and liquid assets required by investors.[2]

[2] See, e.g., Del Negro, M., D. Giannone, M. Giannoni, and A. Tambalotti (2017), "Safety, liquidity, and the natural rate of interest", *Brookings Papers on Economic Activity*, 48(1), pp. 235-316, and Fahri, E. and

Let Υ_t denote a possibly non-stationary shock to households' discount factor β^t and assume that the transformation $\upsilon_t = \Upsilon_t / \Upsilon_{t-1}$, which hereafter is referred to as a *discount-rate shock*, follows a serially correlated, but stationary process.[3] We then obtain for households' marginal utility of consumption Λ_t the following expression:

$$\Lambda_t \;=\; \frac{\Upsilon_t}{C_t - \kappa\, C_{t-1}}, \tag{1}$$

whereas the standard first-order condition (FOC) for households' holdings of short-term risk-free government bonds, i.e. the consumption Euler equation, is given by:

$$1 \;=\; \beta\, \epsilon_t^{RP} R_t\, \mathrm{E}_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \frac{P_{C,t}}{P_{C,t+1}} \right]. \tag{2}$$

For details on the households' decision problem and the notation used, see Coenen et al. (2018), Section 2.2.1, noting that, for the sake of simplicity, household-specific indices as well as consumption taxes have been dropped.

Taking into account the presence of an additional non-stationary shock to the level of (labour) productivity, z_t, which determines the model's balanced growth path, we can transform households' marginal utility of consumption as follows: $\lambda_t = z_t\, \Lambda_t / \Upsilon_t$, and obtain the following re-scaled equations in stationary form:

$$\lambda_t \;=\; \frac{1}{c_t - \kappa\, c_{t-1}\, g_{z,t}}, \tag{3}$$

$$1 \;=\; \beta\, \epsilon_t^{RP} R_t\, \mathrm{E}_t \left[\upsilon_{t+1} \frac{\lambda_{t+1}}{\lambda_t}\, g_{z,t+1}^{-1}\, \Pi_{C,t+1}^{-1} \right], \tag{4}$$

where $c_t = C_t / z_t$, $g_{z,t+1} = z_{t+1} / z_t$ and $\Pi_{C,t+1} = P_{C,t+1} / P_{C,t}$.

Log-linearising these two equations, and indicating the logarithmic deviation of a variable from its steady-state value by a hat ('$\widehat{\ }$'), we get:

$$\widehat{\lambda}_t \;=\; -\frac{1}{1-\kappa\, g_z^{-1}}\, \widehat{c}_t + \frac{\kappa\, g_z^{-1}}{1-\kappa\, g_z^{-1}}\, \widehat{c}_{t-1} - \frac{\kappa\, g_z^{-1}}{1-\kappa\, g_z^{-1}}\, \widehat{g}_{z,t}, \tag{5}$$

$$0 \;=\; \widehat{\epsilon}_t^{RP} + \widehat{R}_t + \mathrm{E}_t\left[\widehat{\upsilon}_{t+1}\right] + \mathrm{E}_t\left[\widehat{\lambda}_{t+1}\right] - \widehat{\lambda}_t - \mathrm{E}_t\left[\widehat{g}_{z,t+1}\right] - \mathrm{E}_t\left[\widehat{\pi}_{C,t+1}\right]. \tag{6}$$

F. Gourio (2018), "Accounting for macro-finance trends: Market power, intangibles, and risk premia", *Brookings Papers on Economic Activity*, 49(2), pp. 147-250.

[3] Note that shocks which relate to the level of Υ_t are commonly referred to as preference shocks in the macroeconomic literature. The shock υ_t relates to the discount rate β itself and is more widely used in the finance literature.

We can finally combine these two equations to obtain a hybrid log-linear consumption equation:

$$
\begin{aligned}
c_t \quad = \quad & \frac{1}{1+\kappa\, g_z^{-1}}\, \mathrm{E}_t\left[\widehat{c}_{t+1}\right] + \frac{\kappa\, g_z^{-1}}{1+\kappa\, g_z^{-1}}\, \widehat{c}_{t-1} - \frac{1}{1+\kappa\, g_z^{-1}} \left(\mathrm{E}_t\left[\widehat{g}_{z,t+1}\right] - \kappa\, g_z^{-1}\, \widehat{g}_{z,t}\right) \\
& - \frac{1-\kappa\, g_z^{-1}}{1+\kappa\, g_z^{-1}} \left(\widehat{R}_t + \widehat{\epsilon}_t^{RP} + \mathrm{E}_t\left[\widehat{\upsilon}_{t+1}\right] - \mathrm{E}_t\left[\widehat{\pi}_{C,t+1}\right]\right), \qquad (7)
\end{aligned}
$$

where the expected discount-rate shock $\mathrm{E}_t[\widehat{\upsilon}_{t+1}]$ enters as a wedge between the risk-free short-term interest rate $\widehat{R}_t$, which is controlled by the central bank, and the *effective* interest rate faced by households, over and above the wedge created by the domestic risk premium shock $\widehat{\epsilon}_t^{RP}$. As argued previously, this shock can be interpreted as a liquidity premium reflecting the distinct liquidity services provided by central bank reserves versus short-term government bonds, see Coenen et al. (2018), Section 2.2.1.

The stochastic discount factors entering other intertemporal equations of the model, notably the FOCs concerning households' demand for investment loans and their holdings of long-term government bonds (see equations (11) and (12) in Coenen et al. (2018), Section 2.2.1), along with the standard equation determining Tobin's Q, and the expression determining the wholesale banks' leverage limit (see equation (32) in Coenen et al. (2018), Section 2.2.3), are amended accordingly, resulting in similar modifications of the respective log-linearised equations:[4]

Demand for investment loans:

$$
\widehat{\mathcal{Q}}_{I,t} + \widehat{\Sigma}_t \quad = \quad \mathrm{E}_t\left[\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \upsilon_{t+1} - \widehat{\Pi}_{C,t+1} - \widehat{g}_{z,t+1} + \beta\, \varrho_I\, \bar{\Pi}^{-1} g_z^{-1} \left(\widehat{\mathcal{Q}}_{I,t+1} + \widehat{\Sigma}_{t+1}\right)\right] \qquad (8)
$$

Holdings of long-term government bonds:

$$
\begin{aligned}
b_{L,h}\, \widehat{b}_{L,h,t+1} \quad = \quad & \bar{b}_{L,h}\, \widehat{\bar{b}}_{L,h,t+1} \\
& + \bar{b}_{L,h}\, \gamma_L^{h^{-1}} \beta\, \bar{\Pi}^{-1} g_z^{-1} \mathrm{E}_t\left[(R_L - R)\left(\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \upsilon_{t+1} - \widehat{\Pi}_{C,t+1} - \widehat{g}_{z,t+1}\right)\right. \\
& \left. + R_L\, \widehat{R}_{L,t+1} - R\left(\widehat{R}_t + \widehat{\epsilon}_t^{RP}\right)\right] \qquad (9)
\end{aligned}
$$

[4]Note that the discount factors entering the FOCs for the capital producers' production decision and for the price-setting decisions by intermediate-good firms and retail banks drop out when being log-linearised, with the original log-linearised equations remaining unchanged. Similarly, the log-linearised FOCs governing the portfolio choices of the wholesale banks regarding their holdings of different types of long-term assets remain unaffected.

Tobin's Q:

$$\widehat{Q}_t = \beta\,(1-\delta)\,g_z^{-1}\,\mathrm{E}_t\left[\widehat{Q}_{t+1}\right] + \mathrm{E}_t\left[\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \upsilon_{t+1} - \widehat{g}_{z,t+1}\right]$$
$$+\,\beta\,(1-\tau^K)\,r_K\,g_z^{-1}\,\mathrm{E}_t\left[\widehat{r}_{K,t+1}\right] + \beta\,\delta\,\tau^K\,p_I\,g_z^{-1}\,\mathrm{E}_t\left[\widehat{p}_{I,t+1}\right] \tag{10}$$

Leverage limit:

$$\widehat{\Phi}_t = \left(1 + \left(\tilde{R}_I - R\right)R^{-1}\Phi\right)\mathrm{E}_t\left[\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \upsilon_{t+1} - \widehat{\Pi}_{C,t+1} - \widehat{g}_{z,t+1} + \widehat{\Omega}_{t+1} - \widehat{\Psi}_t\right]$$
$$+\,\Phi\,R^{-1}\mathrm{E}_t\left[\tilde{R}_I\,\widehat{\tilde{R}}_{I,t+1} - R\left(\widehat{R}_t + \widehat{\epsilon}_t^{RP}\right)\right] + \left(\widehat{R}_t + \widehat{\epsilon}_t^{RP}\right) \tag{11}$$

2 Re-calibration of other steady-state parameters

Besides the re-calibration of the central bank's inflation objective and the steady-state real interest rate, the model's other steady-state parameters have been revisited as well. Changes primarily concern the updating of the expenditure shares for the different demand components in the model using the longer sample of the extended model database, which is described in the following section, and data from more recent input-output tables. Additional changes concern the updating of the tax rates in the model using more timely data on national VAT rates and more recent OECD estimates of tax wedges in the euro area. Changes in the calibrated financial-sector parameters are related to the re-calibration of the inflation objective and the steady-state real rate, but remain very limited. Details on the updated steady-state parameters are provided in Tables 1 to 3, with general information on the employed calibration strategy being provided in Coenen et al. (2018), Section 3.2.1.

3 Extension of the database

3.1 Changes in measurement

The database used for the re-estimation of the model extends the previous database from 2014Q4 to 2019Q4. The extension follows past practices, keeping the same definitions and sources for the series with two exceptions, namely the nominal effective exchange rate and the foreign GDP deflator. Regarding the nominal effective exchange rate, we have employed the broadest definition of the time series with 42 trading partners for the data post 1993, instead of previously 38. The pre-1993 data account for 19 trading partners. Concerning the foreign GDP deflator, it was compiled using the aggregation of trading partners's GDP deflators in the previous version of the database. In the new database it is computed using the implicit foreign GDP deflator of the real effective exchange rate series, relying on the expertise of colleagues in the ECB's DG Statistics on the compilation of the foreign prices series. Finally, a smaller change in the compilation of the database is that the annual series of the euro area working population has been smoothed using a centered 3-period moving average of the series to remove some volatility towards the end of the sample.

3.2 Treatment of outliers and breaks

In the extension of the estimation sample, two of the observed variables have been given special attention with regard to the existence of potential irregularities. First, the time series of total investment growth appears to display a number of outliers, which are related to investment data from the Netherlands and Ireland.[5] The time periods in question cover Q2 and Q3 in the years 2015, 2017 and 2019, as well as Q4 in 2019. The (Q2, Q3) pairs are such that there seems to be a large positive outlier in Q2 and a large offsetting negative outlier in Q3, while the possible outlier in 2019Q4 is positive. The positive outliers are all above 6% per quarter and the negative ones below -4% so that these quarters indeed display extreme values.[6]

Three alternative methods for dealing with the outliers have been considered. The first method simply treats the investment variable as having missing observations for these quarters. The second approach replaces the observations of the same quarters with average investment growth, while the third approach takes into account that we have information about the sources of the outliers at the country level and corrects the investment data since 2015Q1 based on the country data.[7] Overall, the empirical results are robust with respect to the selected correction method and we have therefore opted to use the first approach of treating the seven outliers as missing data.

[5] In general these outliers are related to the accounting for the allocation of foreign multinationals' headquarters and do not reflect tangible developments in real economic activity.

[6] If the outliers are treated as missing data in the sample since 1985Q1, average quarterly investment growth per capita is 0.4% while the standard deviation is estimated at 1.5; see Table 7.

[7] The outliers were identified at the country level for real GDP, real total investment and real extra imports, and the contribution of the respective countries to the euro area aggregate was adjusted to the average contribution of the other countries.

Second, the government consumption series around a (log-)linear trend (with a coefficient calibrated to equal the model's steady-state growth rate) appears to have a gradually shifting mean in connection with the sovereign debt crisis. We have modelled this shift by assuming that the mean around the linear trend is constant until 2010Q1, before falling linearly until 2013Q4. From then onwards the mean remains constant at a new level. This time period covers the years during and shortly after the sovereign debt crisis from 2010 until 2014.[8]

3.3 The transformed data

Figure 1 depicts the transformed data for the observed variables used in the re-estimation of NAWM II, taking into account the corrections outlined above.[9] The data incorporate both revisions to the series pre-2014 and new data for the period 2015-2019. The period 2015-2019 is characterised by interest rates at very low levels, reflecting the impact of the ECB's standard and non-standard policy measures and with the short-term rate seemingly close to its effective lower bound, a drifting down of long-term inflation and GDP growth expectations, rather positive developments in employment and a closing of the output gap, becoming even positive at the end of the sample.

4 Parameter estimates

Tables 4 to 6 report the posterior mode estimates of the model's parameters, comparing the estimates obtained for the updated model using the extended database (version 1.2.3) with those obtained for the original model (version 1.2). In the estimation of the updated model, the new discount-rate shock replaces the previous survival-rate shock, with the estimated degree of persistence of the discount-rate shock being very high.[10] Overall, the estimates of the updated model are broadly unchanged. Some notable differences concern the estimated degree of habit formation in consumption, which is somewhat higher in the re-estimated model, and the estimated investment adjustment cost parameter, which is somewhat lower.

[8] Figure 1 in Coenen et al. (2018) shows the government consumption series until 2014Q4, for which a possible shift in the trend since 2010 can be observed, but the levelling out around 2014 is not yet discernible.

[9] For general details on the data transformations, see Coenen et al. (2018), Section 3.1.1.

[10] The survival-rate shock is not reliably identified and quantitatively unimportant when included jointly with the discount-rate shock.

It is worth noting that the capital share parameter in the updated model is now estimated, with a posterior mode noticeably lower than the previously calibrated value.[11] Given its central role for the implied inflation-output trade-off and hence the stabilisation properties of monetary policy, it is also noteworthy that the estimated slope parameter of the domestic price Phillips curve remains virtually unchanged.

For the updated and re-estimated model, the smoothed estimates of its structural shocks are shown in Figure 2. Over the pre-2015 sample, the time series of the estimated shocks reveal broad similarities with the shocks of the previous model version; see Figure A.3 in Coenen et al. (2018). Notable exceptions relate to the replacement of the survival-rate shock with the discount-rate shock in the updated version of the model. The estimated time series of the discount-rate shock displays a pronounced upward trend. This trend absorbs the upward trend that was previously captured by the survival-rate shock, but it also absorbs the upward trend previously displayed by the model's domestic risk-premium shock. This lends support to the view that the discount-rate shock is a potential source of persistent co-movement in the model's interest-rate variables.

To assess whether the newly introduced discount-rate shock helps the updated and re-estimated model to fit the data, a model variant has been estimated for which the discount-rate shock is replaced again with the original survival-rate shock. It turns out that the Laplace approximation of the log marginal likelihood for the model variant with the survival-rate shock is about 8 units lower than for the variant with the discount-rate shock. This suggests that the data indeed prefer the model with the discount-rate shock and its ability to create co-movement among short and long-term interest rates.

5 Model properties

5.1 Model and sample moments

Table 7 reports the population means and standard deviations of the observed variables based on the model and the posterior mode estimates of its parameters, along with the data-based estimates of these moments for the sample period 1985Q1-2019Q4. The results

[11] A lower capital share parameter can help to mitigate the impact of fluctuations in the rental rate of capital on marginal cost and hence inflation, which is an inherent feature of the propagation of supply-side shocks in NAWM II, but it may also help dampen the medium-term disinflationary effects of asset purchases in the model.

suggest that the NAWM II-based means are broadly in line with the data-based means. In particular, for the real variables the data-based means are close to the model-based means, with the exception of long-term growth expectations. This was already noted in Coenen et al. (2018), where the difference was in fact somewhat larger. For the nominal variables, the data-based means are greater than the model-based means, with the exception of the import price deflator. When compared with the results from the sample used in Coenen et al. (2018), the data-based means are lower when using data until 2019Q4. Turning to the standard deviations, the data-based estimates are typically lower than the model-based measures. Exceptions are the employment and the three interest-rate variables, broadly consistent with the findings in Coenen et al. (2018).

5.2 Impulse responses

In order to shed some light on possible changes in the monetary policy transmission mechanism due to the updating and re-estimation of the model, Figure 3 shows the impulse responses of selected variables to a standardised interest-rate shock for both the updated model (version 1.2.3) and the original model (version 1.2).[12] Overall, the two sets of impulse responses are strikingly similar. The only notable differences concern a somewhat larger amplitude of investment and a marginally more persistent response of consumption, consistent with the small differences in the parameter estimates for the investment adjustment cost parameter and for the strength of habit formation, as detailed above.

Figures 4 and 5 depict the impulse responses to a discount-rate shock and to a survival-rate shock for the updated and the original model, respectively. The key takeaway from these figures is that, as intended, the discount-rate shock gives rise to unidirectional movements in the short and the long-term interest rate, whereas the survival-rate shock leads to movements in opposite directions. Because of the very high persistence of the discount-rate shock, its effects are long-lived, with the implied fall in consumption in the shorter term and the long-lasting increase in productive capacity owing to the strong increase in investment causing visible disinflationary pressures. Such disinflationary effects are less pronounced for the survival-rate shock and limited to the medium term.

[12] Figures with the model's impulse responses to the full set of structural shocks are available in an accompanying document.

5.3 Historical decompositions

Figure 6 shows the historical decomposition of annual real GDP growth into the contributions of different groups of structural shocks for the updated model, along with the contributions of the individual financial-sector shocks, including the discount-rate shock. For the pre-2015 period, covering the years of the financial and sovereign debt crises, the pattern of the decomposition is broadly similar to the one for the original model; see Coenen et al. (2018), Section 4.3. In particular, the contribution pattern of the discount-rate shock is broadly comparable to the pattern of the survival-rate shock.

To demonstrate the role of the discount-rate shock more concretely, Figures 7 and 8 depict the decompositions of the short and the long-term nominal interest rate. As can be seen, for both the short and the long rate, the discount-rate shock accounts for the largest part of the downward trend in interest rates over the past decades.[13] Yet over more recent years, the impact of the discount-rate shock on the short-term interest rate has been partly offset by the domestic risk-premium shock. Economically, this may reflect that the effective lower bound on nominal interest rates, together with the ECB's asset purchases, has hindered the short-term interest rate to decline as much as the long-term rate.

5.4 Effects of asset purchases

Figure 9 shows the effects of central bank asset purchases on selected variables for the updated and for the original model.[14] The figure suggests that, overall, the effects of asset purchases are quite similar across both model versions. Yet in the updated model, most real variables, including GDP and investment, exhibit somewhat stronger effects,[15] while the impacts on inflation as well as on the 10-year government bond yield are more muted. Figure 10 illustrates the effects of asset purchases in the updated model under an interest-rate peg according to which the central bank promises to keep the short-term nominal interest rate unchanged for the initial eight quarters. In this case, it is assumed that only

[13]The important role of the discount-rate shock for explaining low-frequency movements in interest rates is confirmed by the large contributions of the shock in the long-run forecast-error variances of the short and the long-term interest rate, with values of around 35% and 70%, respectively.

[14]As in Coenen et al. (2018), Section 5.1, asset purchases are modelled as a second-order autoregressive process with parameters set equal to 1.7 and -0.71.

[15]The effects on imports are even more noticeable, albeit still contained in size, most likely because of the changes in the steady-state calibration of the model's expenditure and import shares.

a fraction of households and firms believe in the central bank's announcement, which helps to mitigate the forward guidance puzzle rooted in simulating the model under an interest-rate peg. Compared to the case when the interest rate adjusts endogenously, real GDP and inflation increase more strongly, along with a larger depreciation of the exchange rate. These findings are again in line with those obtained for the original model.

Table 1: Calibrated expenditure shares

Share	Description	Value
s_C	Private consumption	57.5
s_I	Investment	22.0
s_G	Government consumption	20.5
s_X	Exports	16.5
s_{IM}	Imports	16.5
<u>of which:</u>		
s_{IM^C}	Import share of pr. consumption	7.0
s_{IM^I}	Import share of investment	4.5
s_{IM^G}	Import share of gov. consumption	0.0
s_{IM^X}	Import share of exports	5.0

Note: This table provides information on the calibration of the steady-state ratios for the different expenditure categories in NAWM II, version 1.2.3, expressed as a share of GDP. The expenditure shares are computed using national accounts data and data from input-output tables, with the import shares being obtained by appropriately adjusting the quasi-share parameters ν^C, ν^I, ν^G, and ν^X in the respective final and intermediate-good aggregators of the model.

Table 2: Calibrated non-financial-sector parameters

Parameter	Description	Value
A. Preferences		
$\beta^{\dagger}$	Discount factor	0.999875
ζ	Inverse Frisch elasticity	2.0
B. Technology		
δ	Depreciation rate	0.025
$\psi^{\ddagger}$	Fixed cost in production	0.687
g_z	Gross labour productivity growth	1.003
C. Employment		
g_E	Gross labour force growth	1.00075
D. Wage and price setting		
φ^W	Wage mark-up	1.30
$\varphi^H, \varphi^X, \varphi^*$	Price mark-up	1.35
η_H, η_X, η^*	Slope of demand elasticity	10.0
E. Tax rates		
τ^C	Consumption tax	0.205
τ^N	Labour income tax	0.146
τ^{W_h}	Employees' social security contr.	0.108
τ^{W_f}	Employers' social security contr.	0.203
τ^K	Capital income tax	0.30
τ^D	Profit income tax	0.0
F. Monetary policy		
$\bar{\Pi}$	Gross inflation objective	1.005
R	Gross short-term nom. interest rate	1.008125

Note: This table provides information on the calibrated non-financial-sector parameters of NAWM II, version 1.2.3. The superscript '$\dagger$' indicates that the discount factor is calibrated so that it is consistent with a steady-state net real interest rate of 1.25% per annum and with steady-state net labour productivity growth of 1.2% per annum, while the superscript '$\ddagger$' indicates that the fixed cost in production is calibrated such that the intermediate-good firms' profits are zero in steady state.

Table 3: Calibrated financial-sector parameters

Parameter	Description	Value
A. Wholesale banks		
$\Psi^{\dagger}$	Absconding rate	0.381
$\vartheta^{\dagger}$	Start-up funds	0.048
θ	Survival rate	0.950
B. Retail banks		
$\varphi^{I\,\ddagger}$	Mark-down parameter	0.987
C. Duration of assets $(= 1/(4(1 - \varrho/R))$		
$\varrho_I{}^{\sharp}$	Decay parameter: inv. loans	0.973
$\varrho_L{}^{\sharp}$	Decay parameter: dom. gov. bonds	0.975
$\varrho_L^{*\,\sharp}$	Decay parameter: foreign gov. bonds	0.975
D. Long-term government bonds		
$\mathcal{Q}_L\, s_{B_L}$	Supply of bonds over GDP	0.7
$\overline{B}_{L,h}/B_L$	Share of household bond holdings	0.75
E. Cost of asset purchases		
$\vartheta_I, \vartheta_L, \vartheta_L^*$	Cost of asset purchases	0.0

Note: This table provides information on the calibrated financial-sector parameters of NAWM II, version 1.2.3. The superscript '$\dagger$' indicates that the absconding rate and the start-up funds are calibrated so that the steady-state leverage ratio Φ equals 6, and the retail lending rate spread over the deposit rate, $R_I - R$, equals 2.17 percentage points on an annualised basis. The superscript '$\ddagger$' indicates that the retail banks' mark-down parameter is calibrated to generate a 10% mark-up in the excess return in the retail lending rate relative to the excess return in the wholesale lending rate. The superscript '$\sharp$' indicates that the decay parameters of the loans and bonds are calibrated to reflect assets with 10-year maturity.

Table 4: Prior distributions and posterior mode estimates of financial-sector parameters

Parameter	Description	Prior distribution	Posterior mode	
			v1.2.3	v1.2
A. Wholesale banks				
ω_L	Absconding of dom. bonds	gamma(0.72,0.05)	0.71	0.85
$\tilde{\omega}_L^*$	Absconding of foreign bonds	gamma(1.00,0.05)	0.98	0.97
B. Retail banks				
ξ_I	Calvo: price of inv. loans	beta(0.75,0.0375)	0.73	0.74
C. Portfolio adjustment costs				
γ_L^h	Households	gamma(0.01,0.0025)	0.008	0.009
γ_L^*	Wholesale banks	gamma(0.01,0.0025)	0.002	0.004
D. Autoregressive parameters of shock processes				
ρ_υ	Discount rate	beta(0.75,0.1)	0.99	–
ρ_θ	Survival rate	beta(0.75,0.05)	–	0.80
ρ_{φ^I}	Mark-down parameter	beta(0.75,0.05)	0.75	0.71
E. Scaling parameters of shock processes				
σ_υ	Discount rate	invgamma(0.1,2)	0.05	–
σ_θ	Survival rate	invgamma(0.1,2)	–	5.08
σ_{φ^I}	Mark-down parameter	invgamma(0.1,2)	0.97	1.24

Note: This table provides information on the marginal prior distributions and the posterior mode estimates of the financial-sector parameters for versions 1.2.3 and 1.2 of NAWM II. The prior distributions are characterised by the parameters determining their respective means and variances, except for the inverse gamma prior distributions for which the mode and the degrees of freedom are reported. The posterior mode columns show the estimates obtained by numerically maximising the posterior distribution. In Coenen et al. (2018), the corresponding table shows the modes of the marginal posterior distributions obtained from applying Markov-Chain Monte-Carlo methods.

Table 5: Prior distributions and posterior mode estimates of non-financial-sector parameters: Model structure

Parameter	Description	Prior distribution	Posterior mode v1.2.3	Posterior mode v1.2
A. Preferences				
κ	Habit formation	beta(0.75,0.10)	0.69	0.62
B. Wage and price setting				
ξ_W	Calvo scheme: wages	beta(0.75,0.0375)	0.77	0.77
χ_W	Indexation to inflation: wages	beta(0.75,0.10)	0.36	0.38
$\tilde{\chi}_W$	Indexation to productivity: wages	beta(0.75,0.10)	0.67	0.65
ξ_H	Calvo scheme: domestic prices	beta(0.75,0.0375)	0.83	0.82
χ_H	Indexation: domestic prices	beta(0.75,0.10)	0.21	0.23
ξ_X	Calvo scheme: export prices	beta(0.75,0.0375)	0.80	0.75
χ_X	Indexation: export prices	beta(0.75,0.10)	0.28	0.32
ξ^*	Calvo scheme: import prices	beta(0.75,0.0375)	0.58	0.58
χ^*	Indexation: import prices	beta(0.75,0.10)	0.27	0.38
o^*	Oil import share	beta(0.15,0.05)	0.26	0.30
C. Final and intermediate-good production				
α	Capital share	beta(0.36,0.10)	0.31	–
μ_C	Subst. elasticity: consumption	gamma(1.50,0.25)	2.99	2.79
μ_I	Subst. elasticity: investment	gamma(1.50,0.25)	1.33	1.38
μ_X	Subst. elasticity: exports	gamma(1.50,0.25)	0.78	0.86
μ^*	Price elasticity: exports	gamma(1.50,0.25)	1.41	1.18
D. Adjustment costs				
γ_I	Investment	gamma(6.00,1.50)	9.30	11.23
$\gamma_{u,2}$	Capital utilisation	gamma(1.00,0.25)	0.82	0.97
γ_{IM^C}	Import content: consumption	gamma(2.50,1.00)	6.80	6.48
γ_{IM^I}	Import content: investment	gamma(2.50,1.00)	0.61	0.85
γ^*	Export market share	gamma(2.50,1.00)	2.76	2.47
E. Interest-rate rule				
ϕ_R	Interest-rate smoothing	beta(0.90,0.05)	0.93	0.92
ϕ_Π	Response to inflation	gamma(1.70,0.575)	2.93	2.75
$\phi_{\Delta\Pi}$	Response to change in inflation	gamma(0.30,0.125)	0.04	0.04
ϕ_Y	Response to output gap	gamma(0.14,0.05)	0.03	0.03
$\phi_{\Delta Y}$	Response to change in output gap	gamma(0.07,0.025)	0.09	0.10
F. Perception updating equations				
$\varpi_{\bar{\Pi}^p}$	Sens. of perc. inflation objective	gamma(0.10,0.25)	0.05	0.06
$\varpi_{g_Y^p}$	Sens. of perc. trend growth rate	gamma(0.10,0.25)	0.06	0.06
G. Employment (bridge) equation				
ξ_E	Calvo-style weighing scheme	beta(0.50,0.15)	0.85	0.86
H. Domestic price Phillips curve				
sl^{PC}	Slope parameter	system prior	0.007	0.007

Note: See Table 4.

Table 6: Prior distributions and posterior mode estimates of non-financial-sector parameters: Shock processes

Parameter	Description	Prior distribution	Posterior mode	
			v1.2.3	v1.2
A. Autoregressive parameters				
ρ_{RP}	Domestic risk premium shock	beta(0.75,0.10)	0.91	0.97
ρ_{RP^*}	External risk premium shock	beta(0.75,0.10)	0.99	0.99
$\rho_{g_z^p}$	Perm. techn. shock: pers. comp.	beta(0.75,0.10)	0.93	0.94
ρ_{ε}	Transitory technology shock	beta(0.75,0.10)	0.88	0.92
ρ_I	Investment-specific techn. shock	beta(0.75,0.10)	0.91	0.91
ρ_{φ^W}	Wage mark-up shock	beta(0.50,0.05)	0.72	0.68
ρ_{φ^H}	Domestic price mark-up shock	beta(0.50,0.05)	0.59	0.59
ρ_{φ^X}	Export price mark-up shock	beta(0.50,0.05)	0.40	0.40
ρ_{φ^*}	Import price mark-up shock	beta(0.50,0.05)	0.49	0.51
ρ_{IM}	Import demand shock	beta(0.75,0.10)	0.91	0.84
ρ_{ν^*}	Export preference shock	beta(0.75,0.10)	0.90	0.86
B. Scaling parameters				
σ_{RP}	Domestic risk premium shock	invgamma(0.122474,2)	0.20	0.14
σ_{RP^*}	External risk premium shock	invgamma(0.122474,2)	0.12	0.14
$\sigma_{g_z^p}$	Perm. techn. shock: pers. comp.	invgamma(0.122474,2)	0.07	0.07
σ_{ε}	Transitory technology shock	invgamma(0.122474,2)	1.18	1.01
σ_I	Investment-specific techn. shock	invgamma(0.122474,2)	0.26	0.25
σ_{φ^W}	Wage mark-up shock	invgamma(0.122474,2)	0.08	0.10
σ_{φ^H}	Domestic price mark-up shock	invgamma(0.122474,2)	0.13	0.13
σ_{φ^X}	Export price mark-up shock	invgamma(0.122474,2)	0.77	0.91
σ_{φ^*}	Import price mark-up shock	invgamma(0.122474,2)	1.26	1.08
σ_{IM}	Import demand shock	invgamma(0.122474,2)	6.52	6.69
σ_{ν^*}	Export preference shock	invgamma(0.122474,2)	9.75	8.81
σ_R	Interest rate shock	invgamma(0.122474,2)	0.10	0.11
$\sigma_{\bar{\Pi}^p}$	Perc. inflation objective shock	invgamma(0.122474,2)	0.02	0.03
$\sigma_{g_Y^p}$	Perc. trend growth rate shock	invgamma(0.122474,2)	0.02	0.03
C. Signal-to-noise ratio				
$\sigma^2_{g_z^p}/\sigma^2_{g_z^{tr}}$	Permanent technology shock	gamma(0.05,0.005)	0.06	0.06

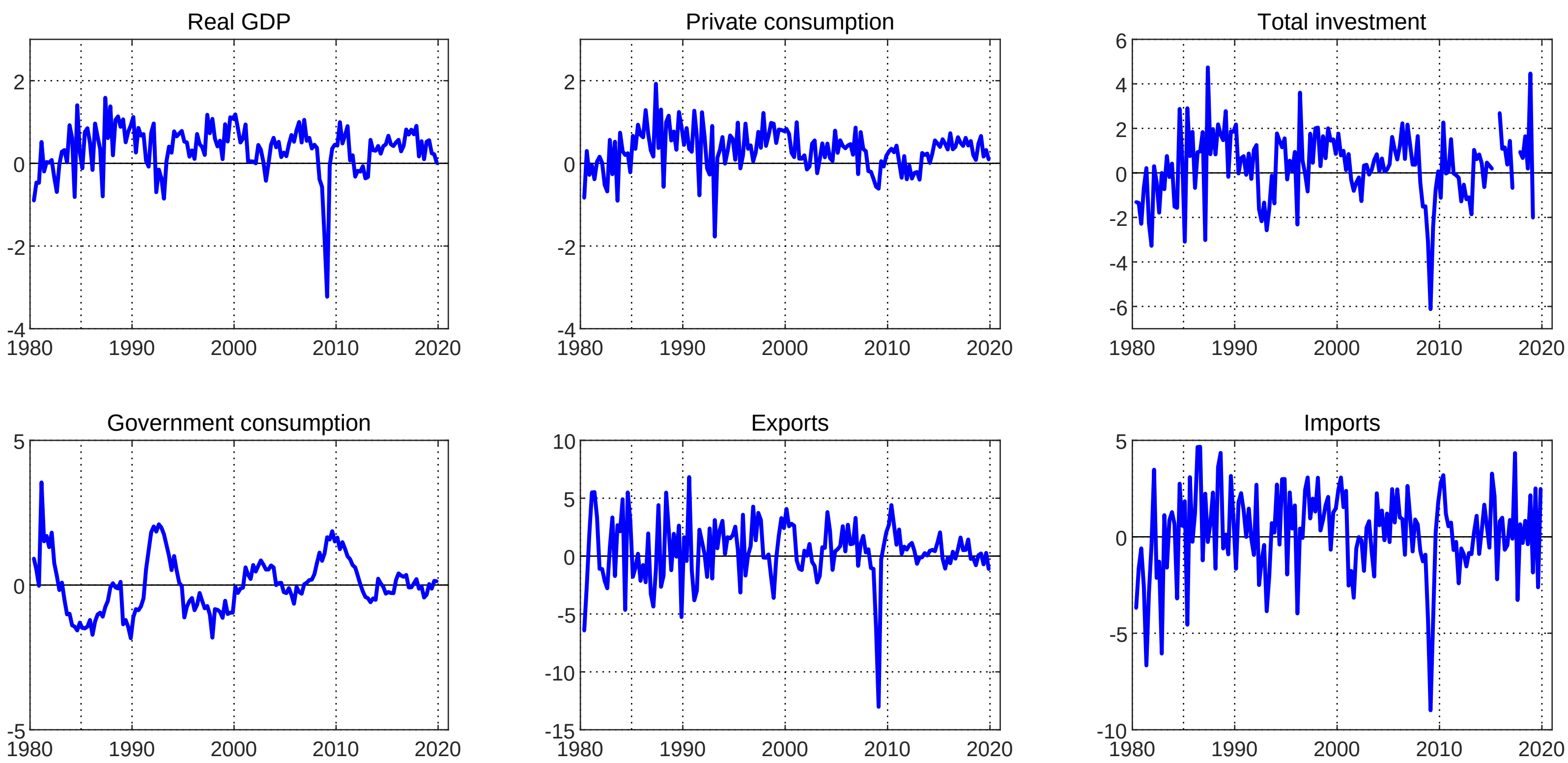
Note: See Table 4.

Table 7: Means and standard deviations of observed variables

Variable	Mean		Standard deviation	
	NAWM II	Data	NAWM II	Data
Real GDP	0.375	0.40	0.85	0.56
Consumption	0.375	0.37	0.88	0.47
Investment	0.375	0.41	3.26	1.50
Exports	0.375	0.40	4.24	2.32
Imports	0.375	0.40	3.05	2.06
GDP defl. inflation	0.50	0.55	0.60	0.33
Consumption defl. inflation	0.50	0.52	0.53	0.37
Import defl. inflation	0.50	0.01	2.96	2.48
Employment	0.00	0.00	2.31	2.85
Wage inflation	0.80	0.77	0.76	0.50
Short-term nom. interest rate	3.25	4.26	2.52	3.67
Real effective exchange rate	0.00	0.00	18.28	12.28
10-year gov't bond yield	4.64	4.51	1.58	2.46
Comp. long-term lending rate	5.41	3.45	1.58	1.15
Long-term inflation expect's	2.00	1.89	1.03	0.07
Long-term growth expect's	1.50	1.97	0.51	0.34
Output gap	0.00	−0.26	7.94	1.81

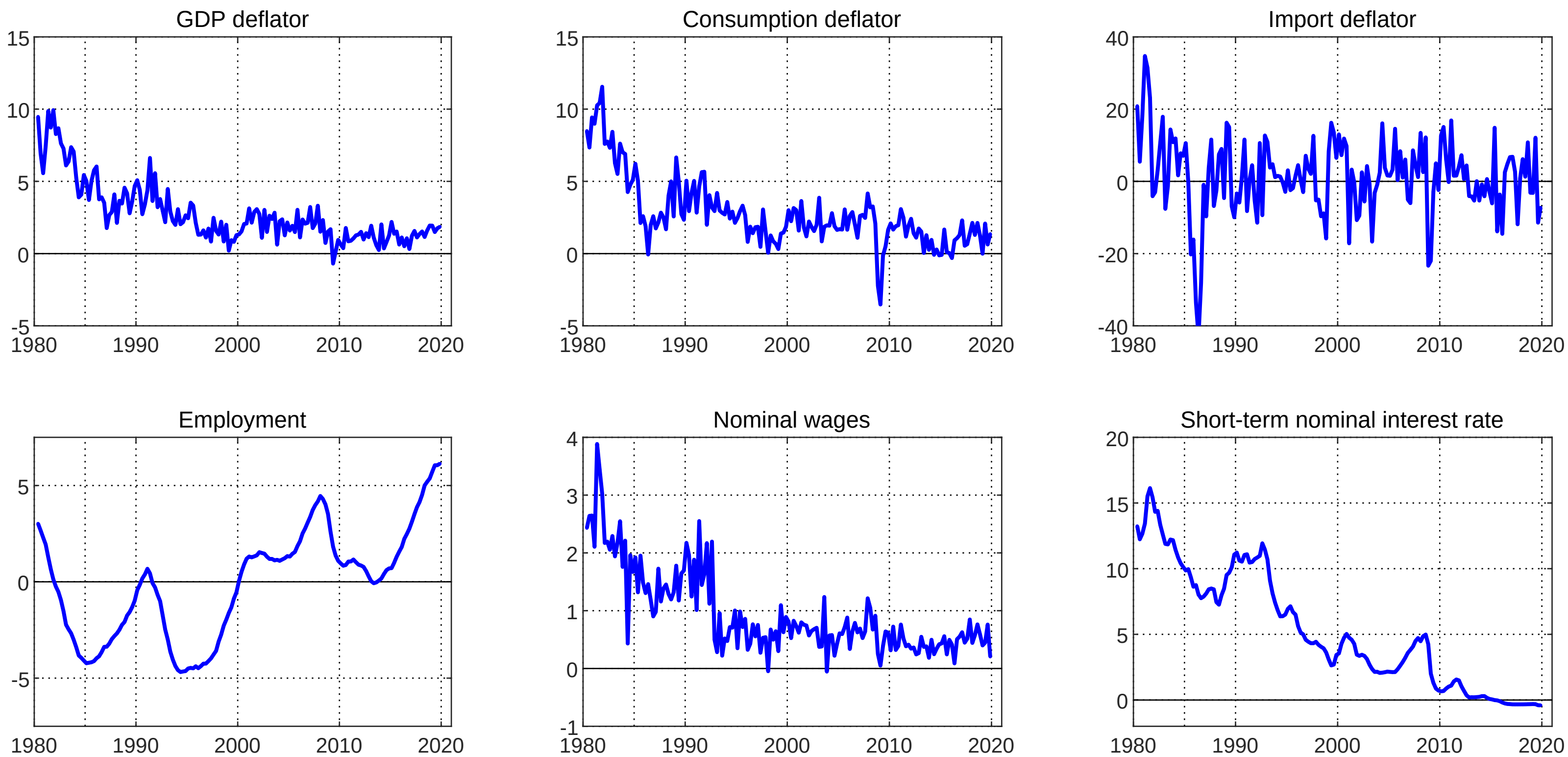
Note: This table reports population means and standard deviations at the posterior mode estimates of NAWM II, version 1.2.3, for the observed variables used in its Bayesian estimation, along with the corresponding sample moments based on the data covering the period 1985Q1–2019Q4.

Figure 1: The transformed data



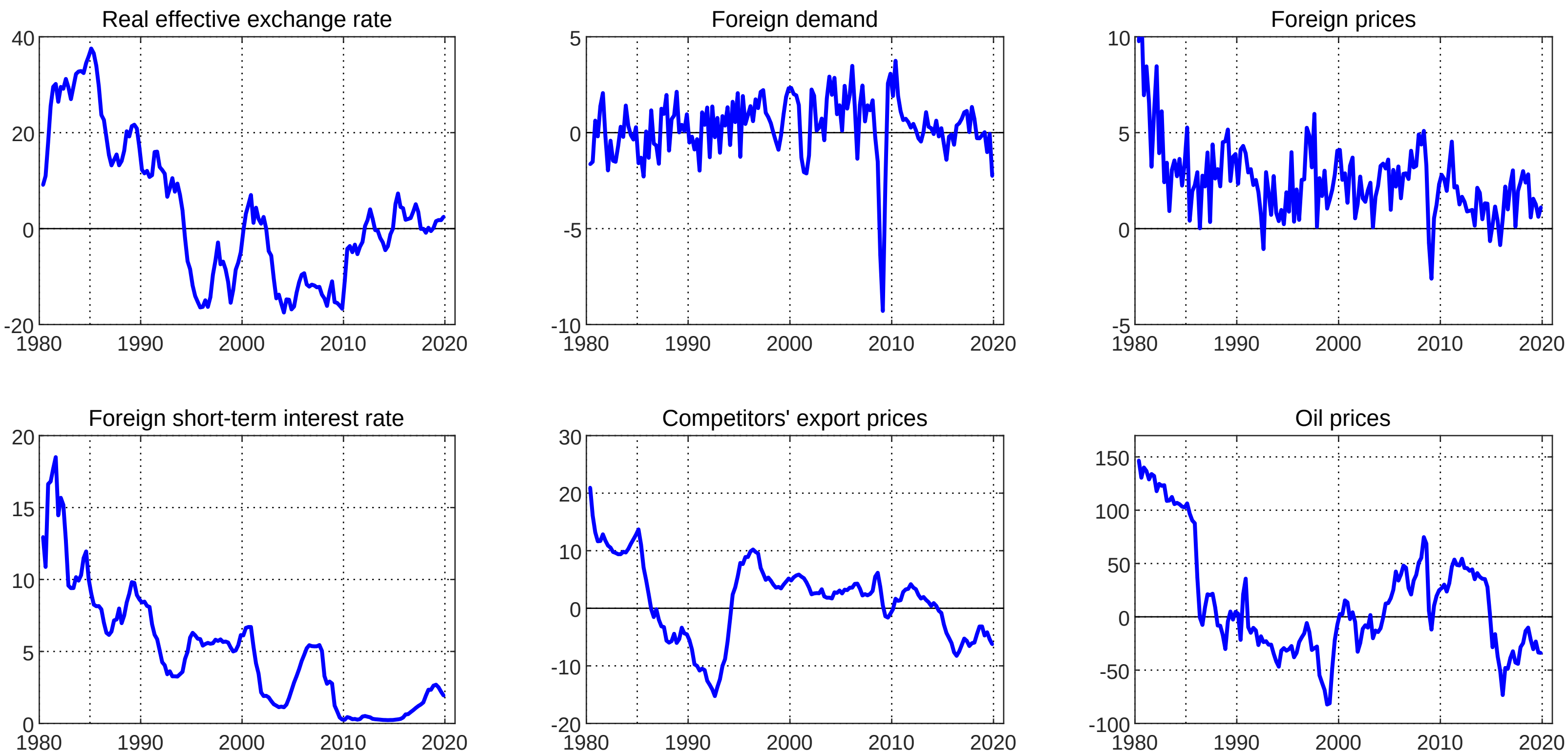
Note: This figure shows the updated and extended time series of the observed variables used in the estimation of NAWM II, version 1.2.3. Inflation and interest rates are reported in annualised percentage terms. The euro area 10-year government bond yield series (AAA) is available from 2004Q3 onwards, while the earlier observations concern the German 10-year government bond yield. The euro area long-term lending rate is available from 2003Q1 onwards and covers (new business) lending with an original maturity of over 1 year to households for house purchases and to non-financial corporations.

Figure 1: The transformed data (continued)



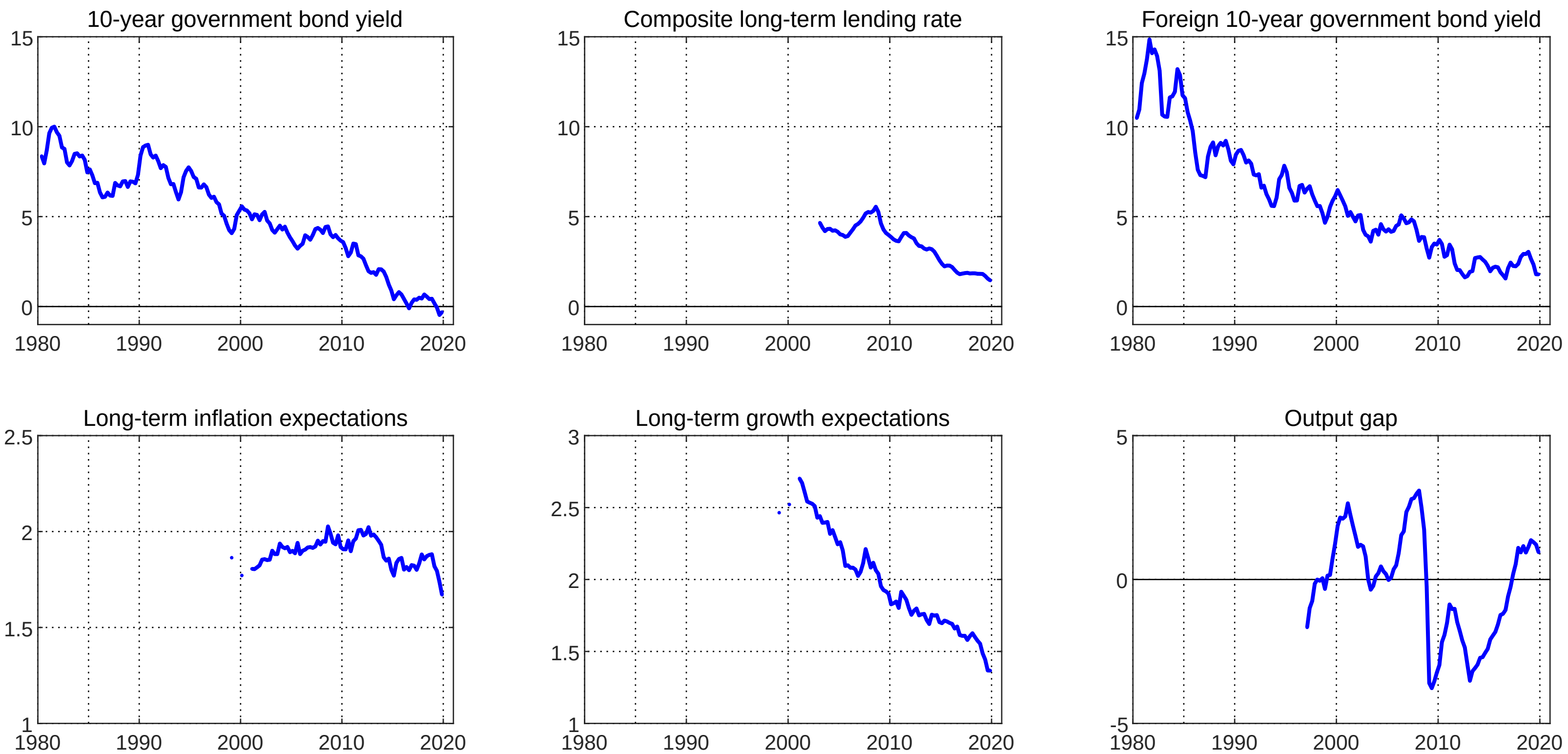
Note: See above.

Figure 1: The transformed data (continued)



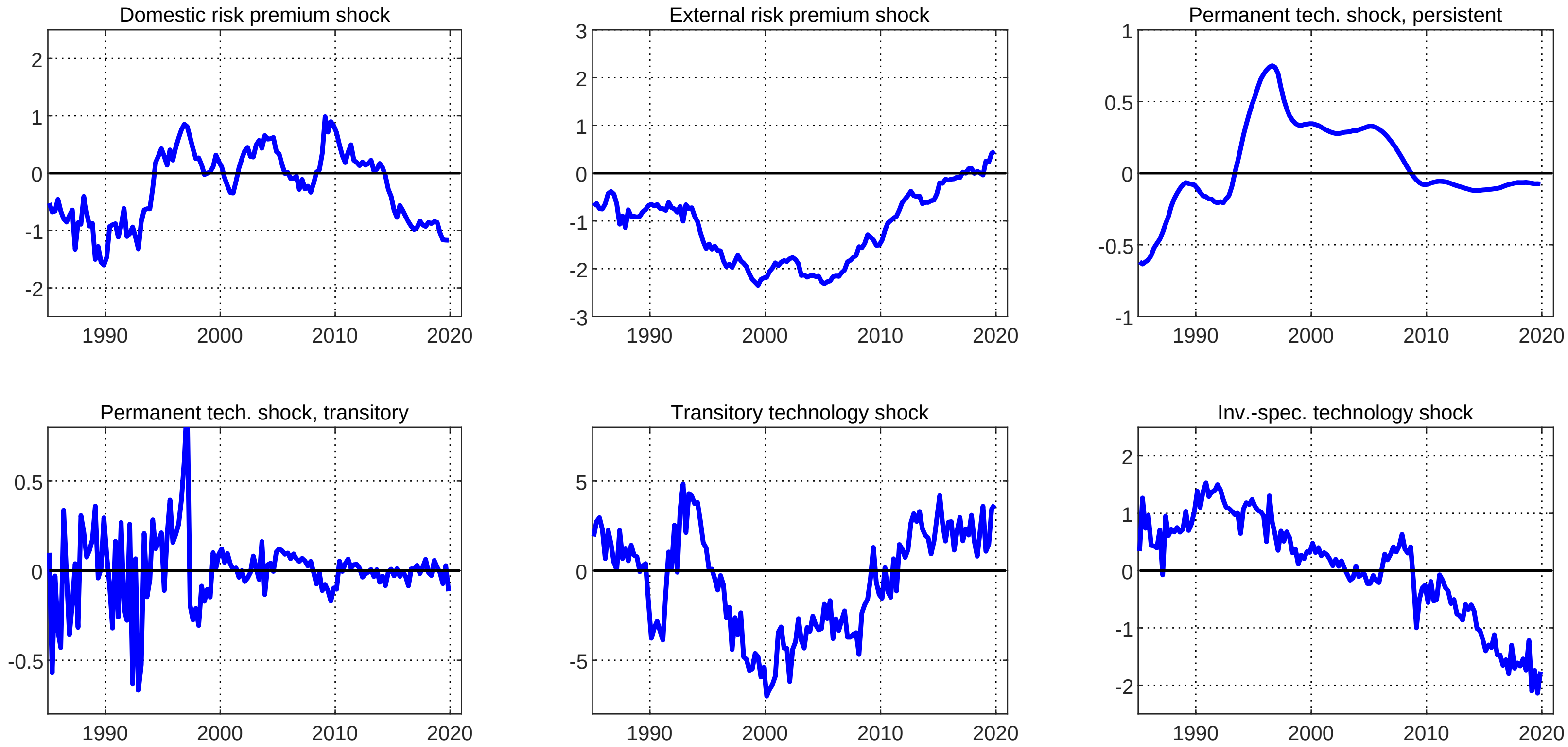
Note: See above.

Figure 1: The transformed data (continued)



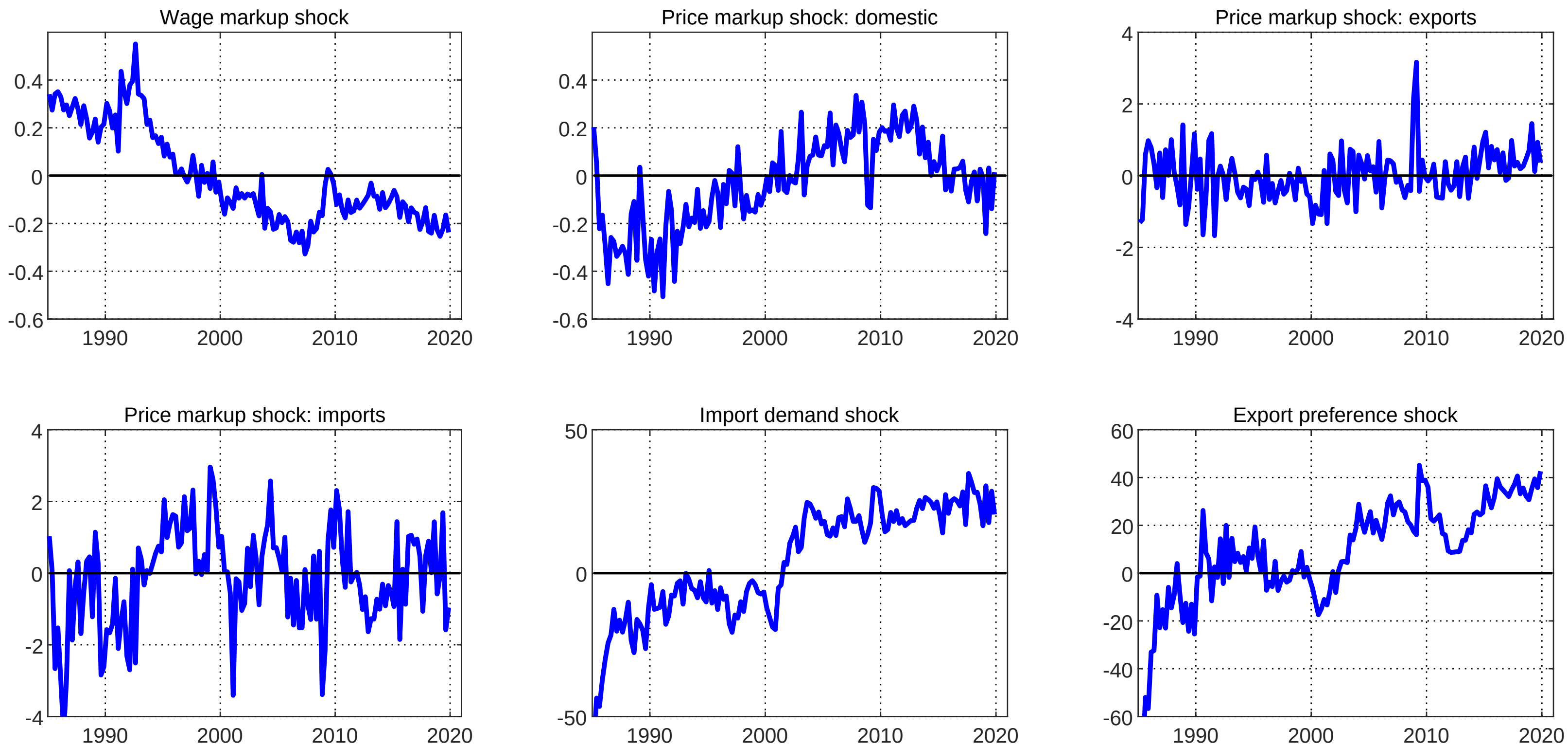
Note: See above.

Figure 2: Smoothed estimates of shocks



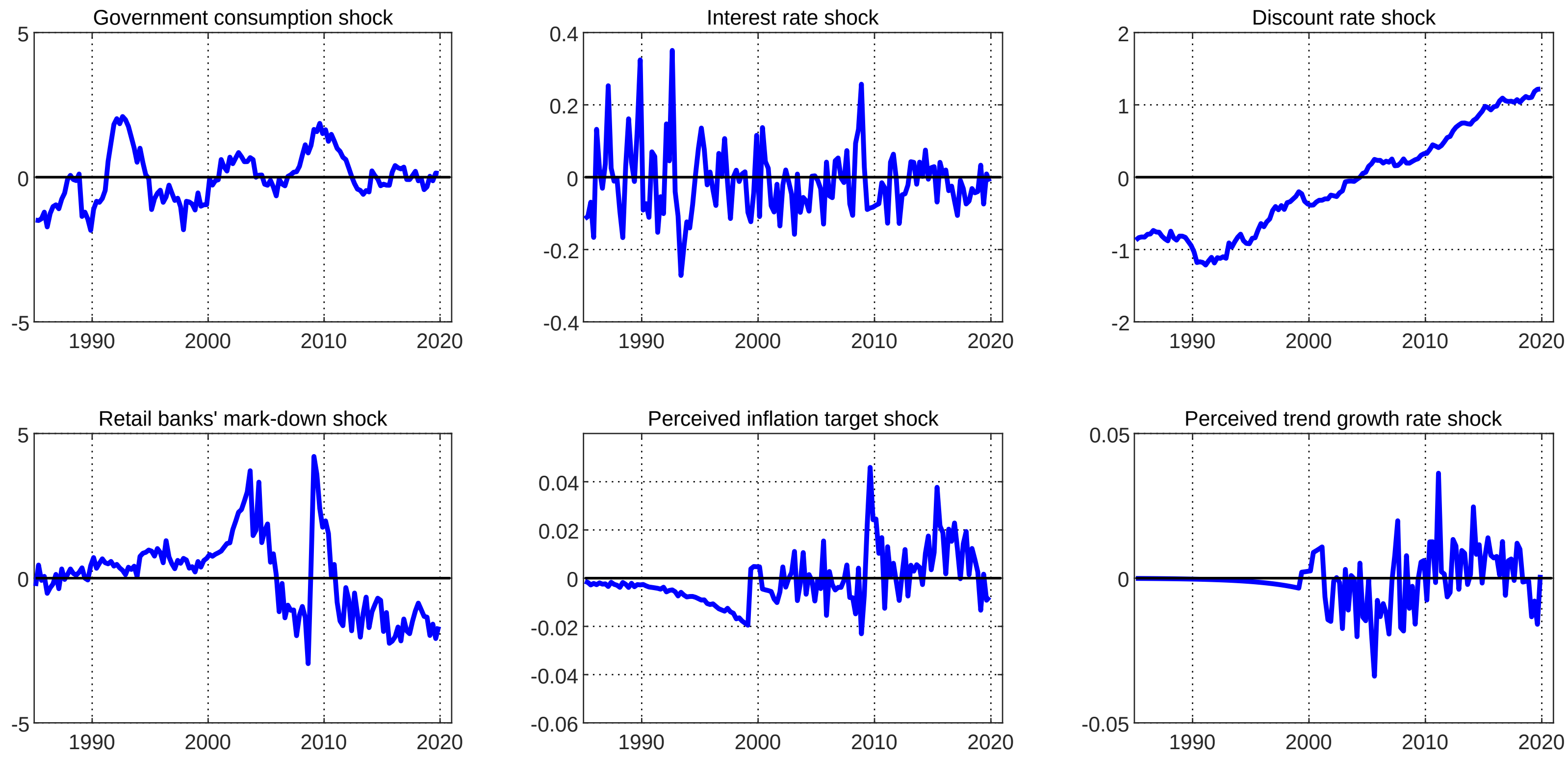
Note: This figure shows the smoothed estimates of the structural shocks of NAWM II, version 1.2.3, conditional on the posterior mode estimates of its parameters.

Figure 2: Smoothed estimates of shocks (continued)



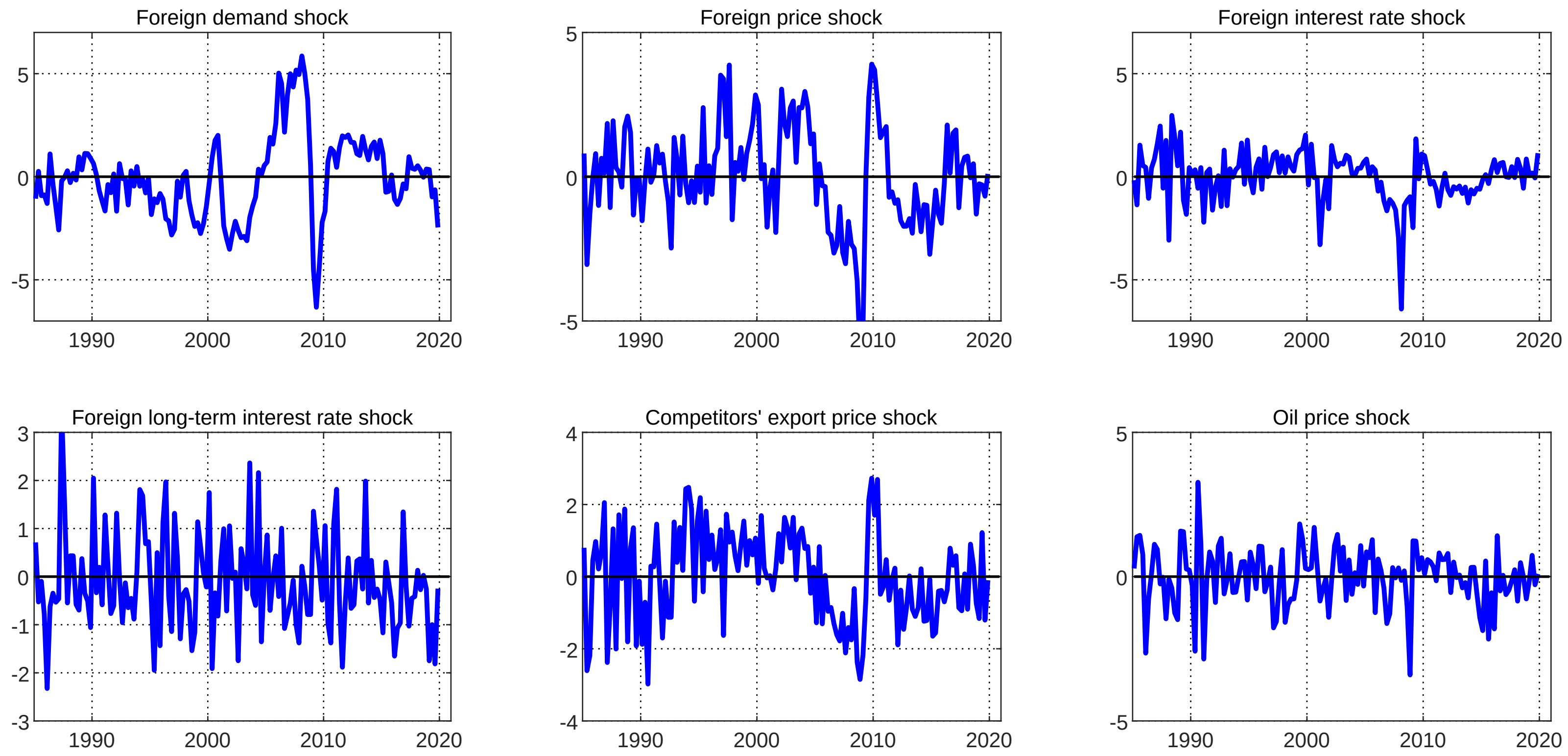
Note: See above.

Figure 2: Smoothed estimates of shocks (continued)



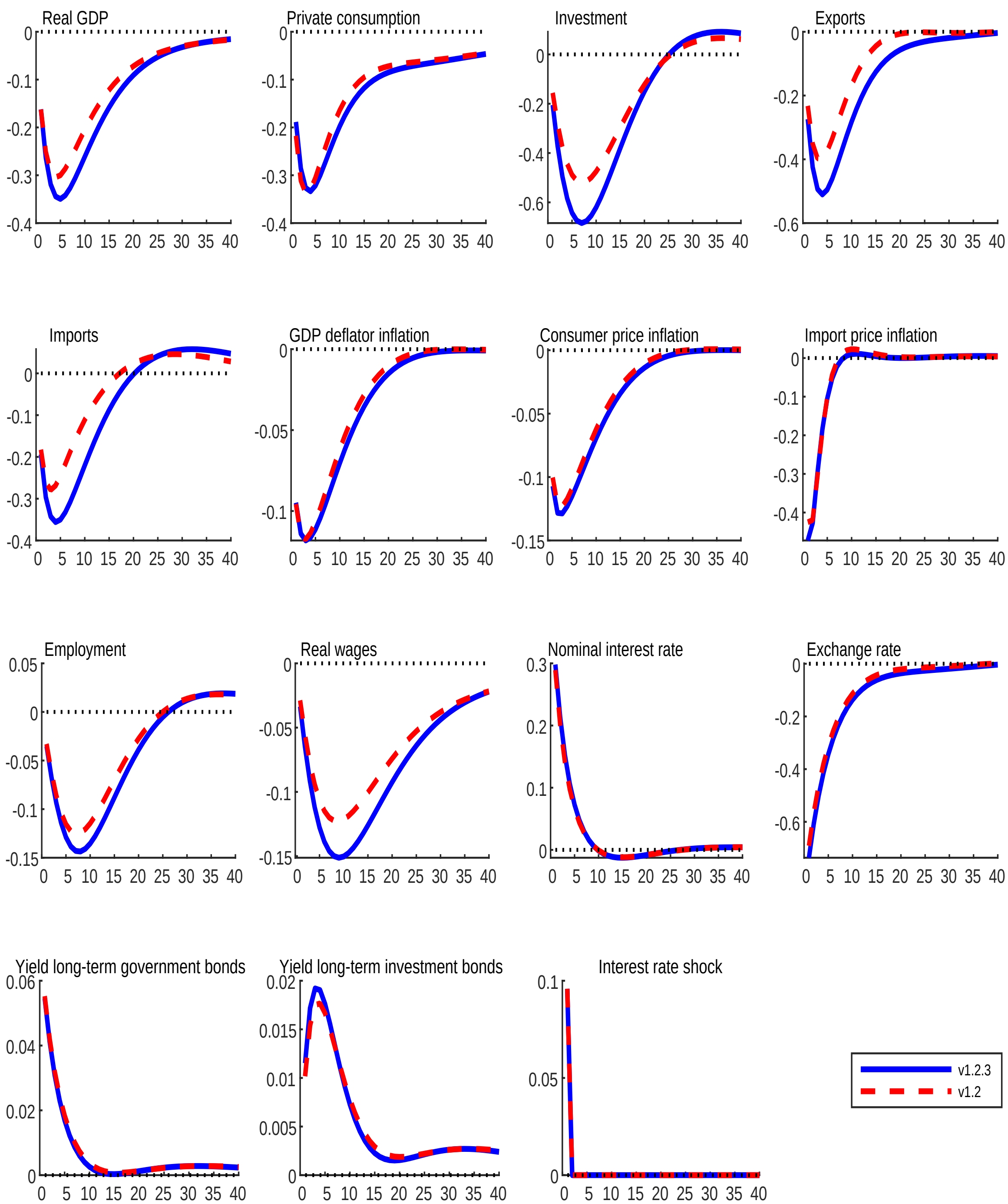
Note: See above.

Figure 2: Smoothed estimates of shocks (continued)



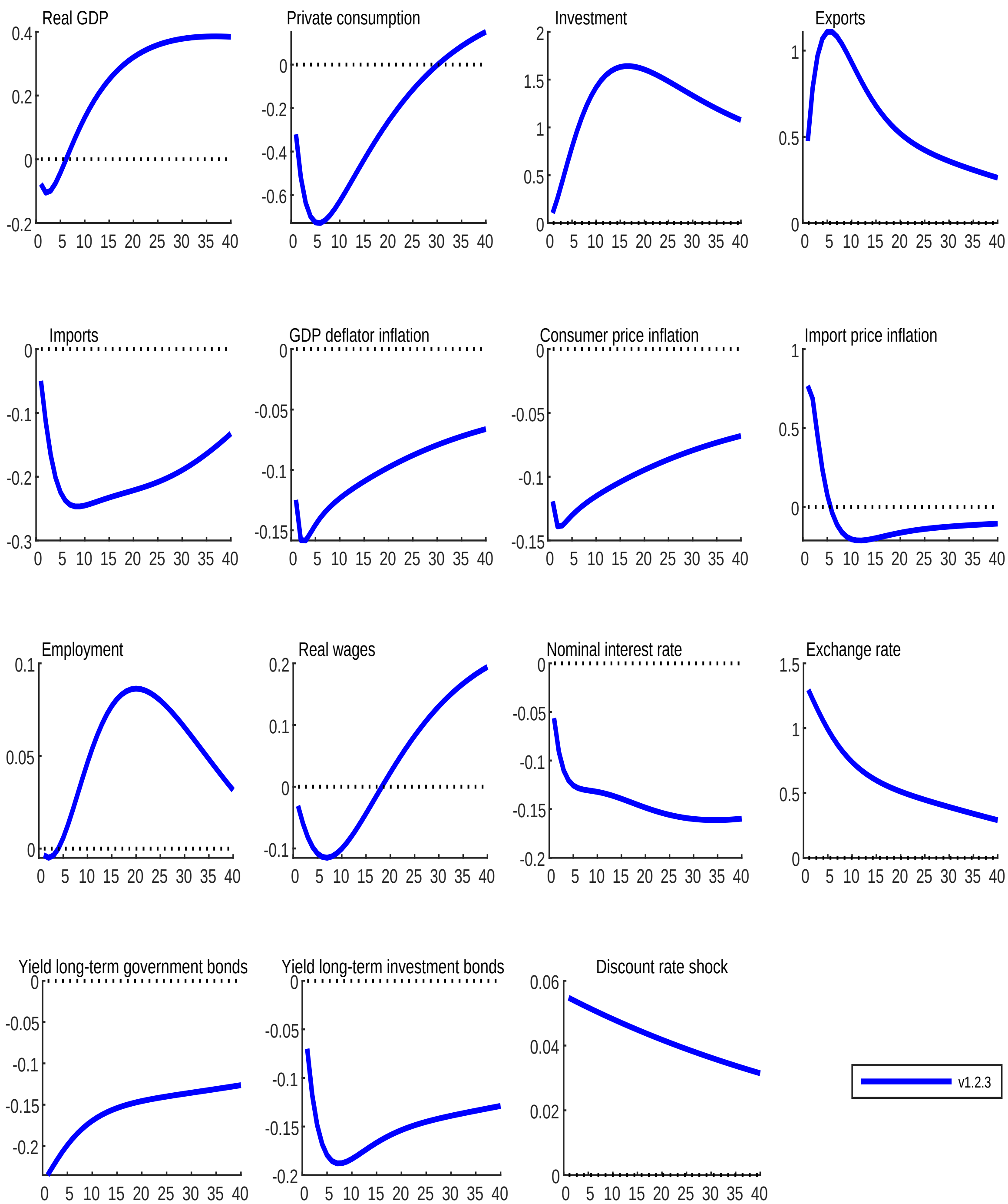
Note: See above.

Figure 3: Impulse responses to an interest-rate shock



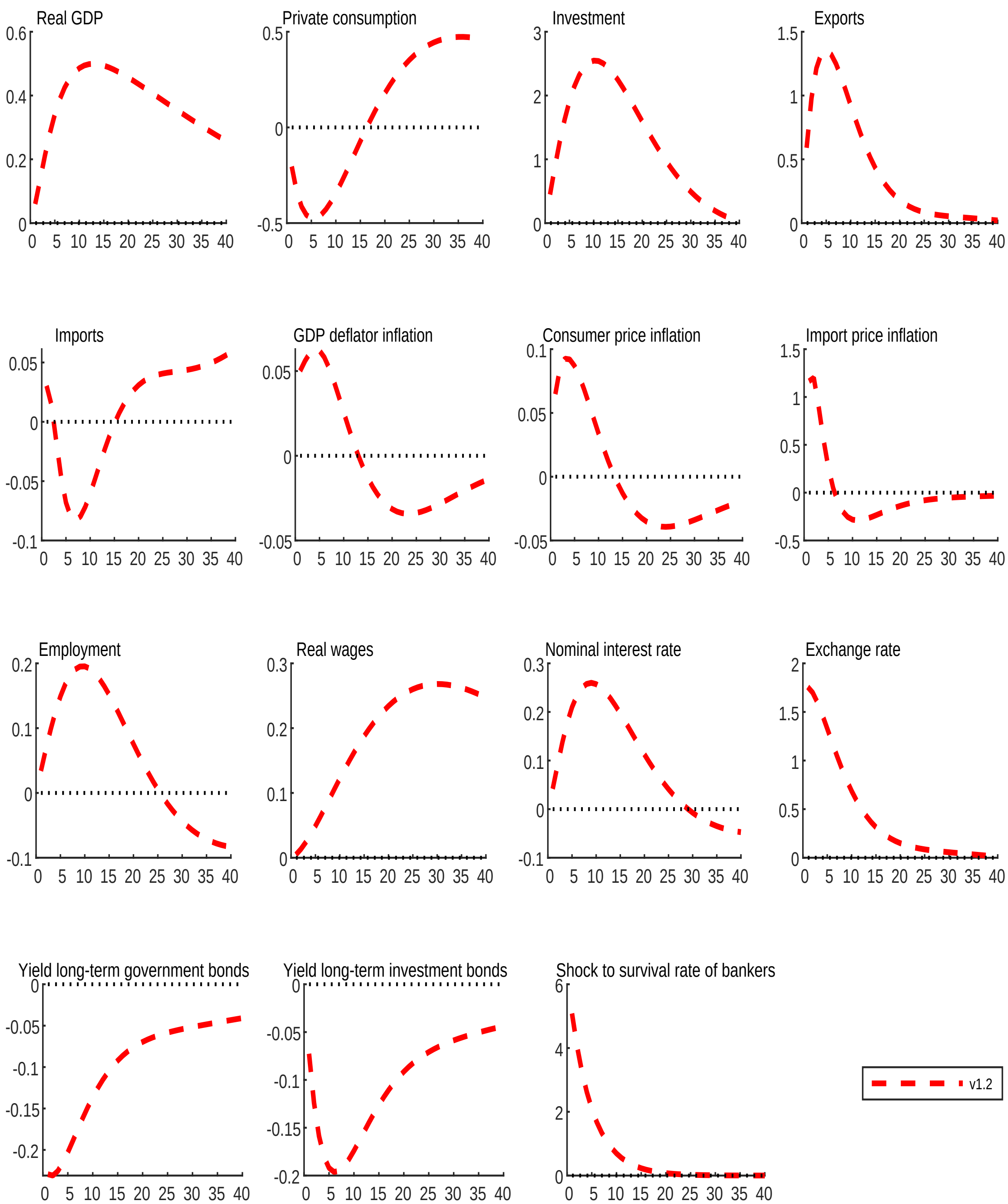
Note: For versions 1.2.3 and 1.2 of NAWM II, this figure depicts the impulse responses of selected domestic variables to an interest-rate shock equal to one standard deviation. All impulse responses are reported as percentage deviations from the non-stochastic balanced growth path, except for the impulse responses of the inflation and interest rates which are reported as annualised percentage-point deviations.

Figure 4: Impulse responses to a discount-rate shock



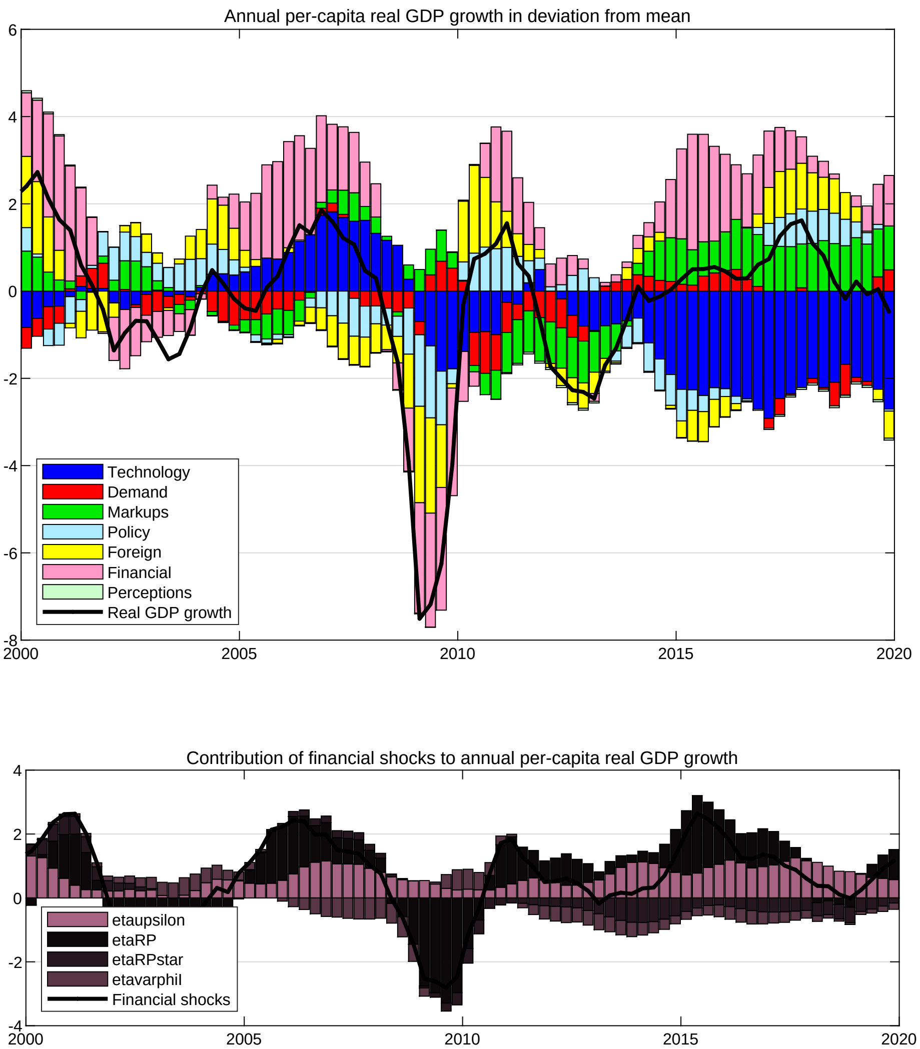
Note: For version 1.2.3 of NAWM II, this figure depicts the impulse responses of selected domestic variables to a discount-rate shock equal to one standard deviation. All impulse responses are reported as percentage deviations from the non-stochastic balanced growth path, except for the impulse responses of the inflation and interest rates which are reported as annualised percentage-point deviations.

Figure 5: Impulse responses to a banker's survival rate shock



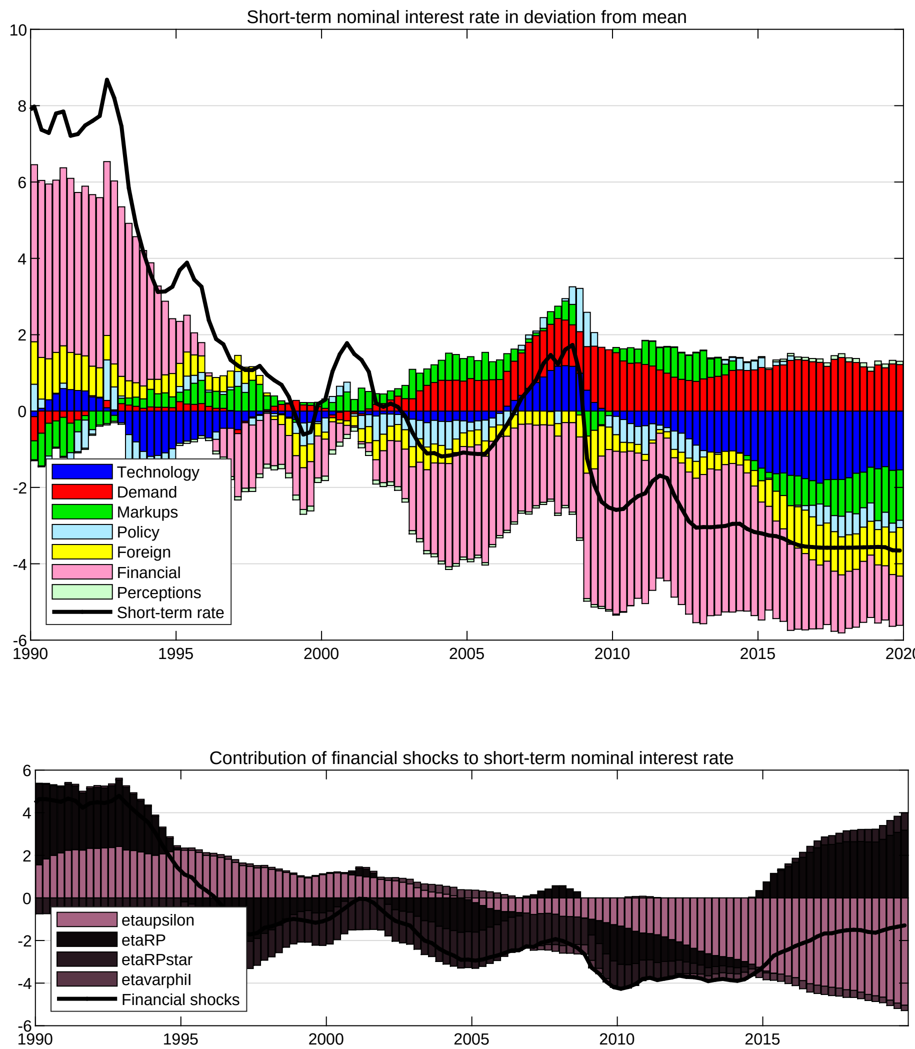
Note: For version 1.2 of NAWM II, this figure depicts the impulse responses of selected domestic variables to a banker's survival rate shock equal to one standard deviation. All impulse responses are reported as percentage deviations from the non-stochastic balanced growth path, except for the impulse responses of the inflation and interest rates which are reported as annualised percentage-point deviations.

Figure 6: Historical decomposition of real GDP growth



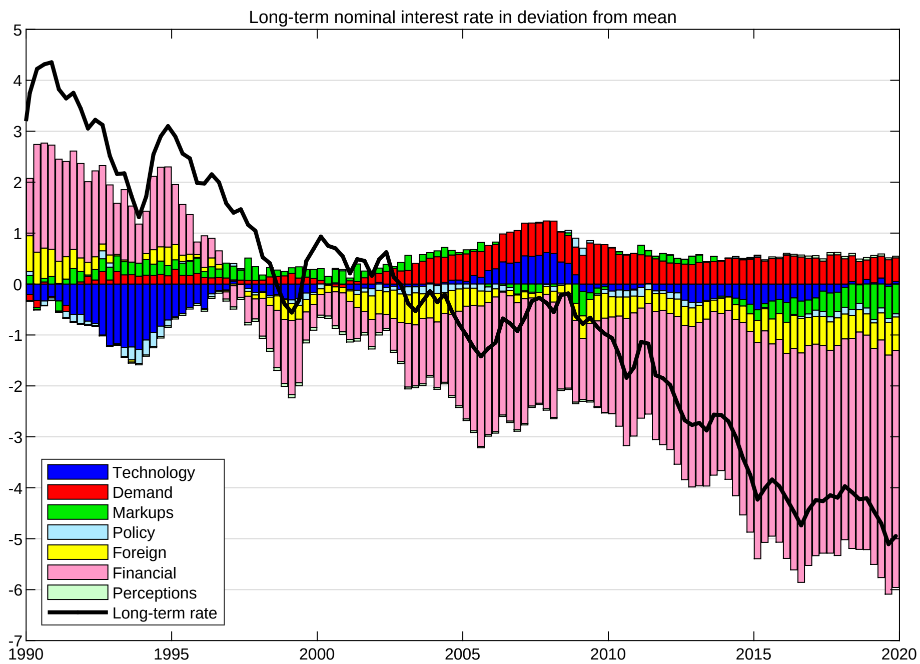
Note: The upper panel in this figure depicts the decomposition of annual per-capita real GDP growth into the contributions of the structural shocks of NAWM II, version 1.2.3, over the period 2000 to 2019. The shocks are bundled into seven groups: technology, demand, mark-up, foreign, financial and perception shocks, plus a monetary policy shock. The decomposition is computed in deviation from the model-implied mean real GDP growth rate using the posterior mode estimates of the model's estimated parameters. The lower panel shows the contributions of the individual financial sector shocks in the real GDP growth decomposition.

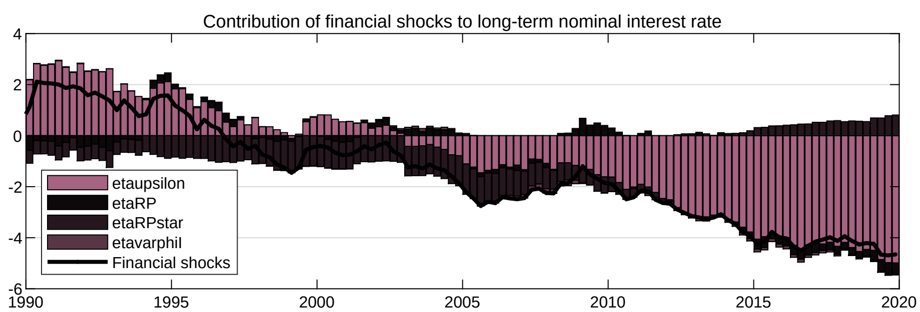
Figure 7: Historical decomposition of short-term nominal interest rate



Note: The upper panel in this figure depicts the decomposition of the short-term nominal interest rate into the contributions of the structural shocks of NAWM II, version 1.2.3, over the period 1990 to 2019. The shocks are bundled into seven groups: technology, demand, mark-up, foreign, financial and perception shocks, plus a monetary policy shock. The decomposition is computed in deviation from the model-implied mean short-term nominal interest rate using the posterior mode estimates of the model's estimated parameters. The lower panel shows the contributions of the individual financial sector shocks in the short-term nominal interest rate decomposition.

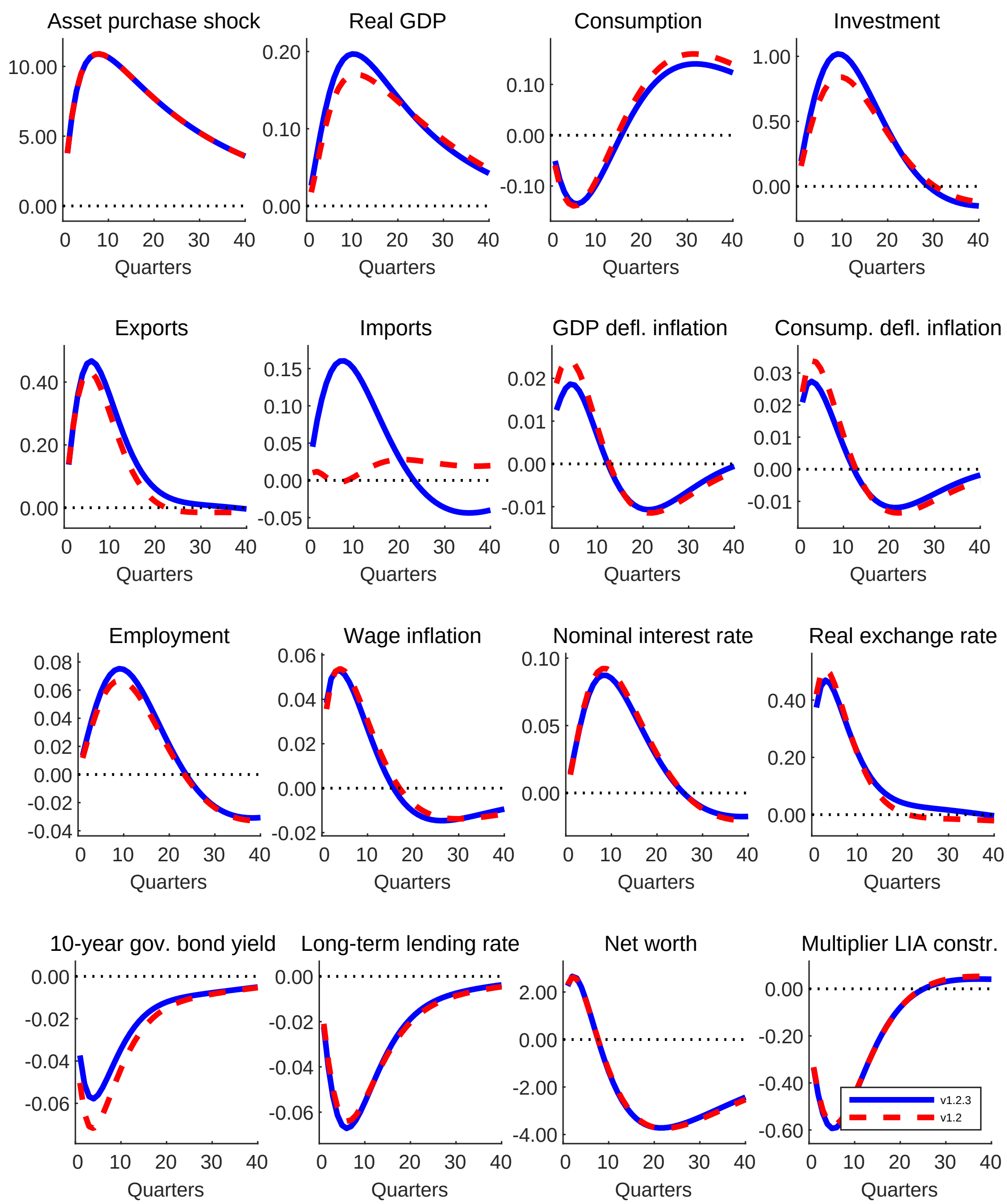
Figure 8: Historical decomposition of long-term nominal interest rate





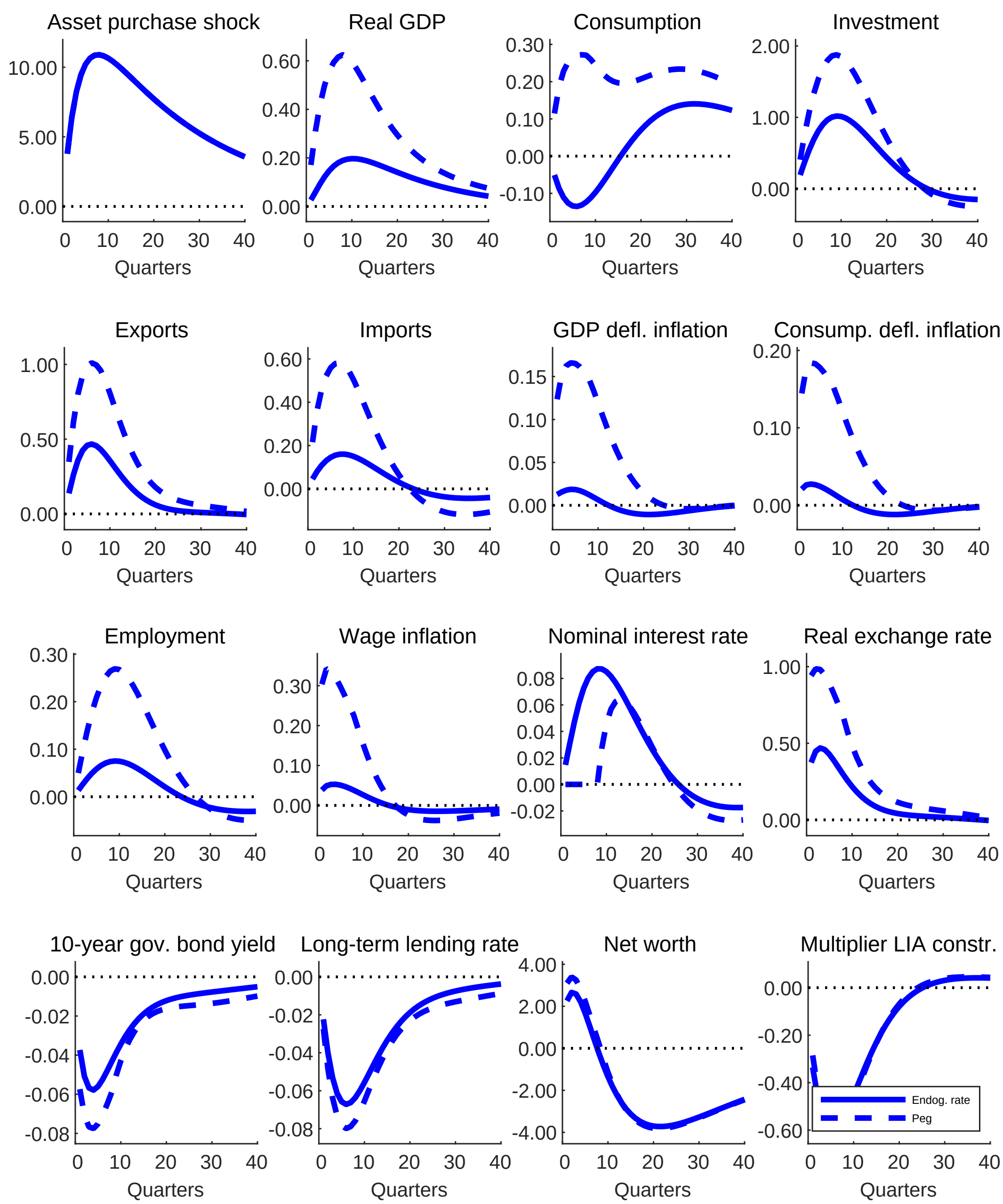
Note: The upper panel in this figure depicts the decomposition of the long-term nominal interest rate into the contributions of the structural shocks of NAWM II, version 1.2.3, over the period 1990 to 2019. The shocks are bundled into seven groups: technology, demand, mark-up, foreign, financial and perception shocks, plus a monetary policy shock. The decomposition is computed in deviation from the model-implied mean long-term nominal interest rate using the posterior mode estimates of the model's estimated parameters. The lower panel shows the contributions of the individual financial sector shocks in the long-term nominal interest rate decomposition.

Figure 9: Effects of central bank asset purchases



Note: For versions 1.2.3 and 1.2 of NAWM II, this figure shows the impulse responses to a central bank asset-purchase shock with a total size of 11% of GDP. All impulse responses are reported as percentage deviations from the model's non-stochastic balanced-growth path, except for the impulse responses of the inflation and interest rates which are reported as annualised percentage-point deviations. They are computed using the posterior mode estimates of the model's parameters.

Figure 10: Effects of central bank asset purchases under an interest-rate peg



Note: For version 1.2.3 of NAWM II, this figure shows the impulse responses to a central bank asset-purchase shock with a total size of 11% of GDP when the interest rate adjusts endogenously according to the model's interest-rate rule and when the nominal interest rate is pegged for eight quarters and with imperfect credibility of the central bank's announcement thereof. All impulse responses are reported as percentage deviations from the model's non-stochastic balanced-growth path, except for the impulse responses of the inflation and interest rates which are reported as annualised percentage-point deviations. They are computed using the posterior mode estimates of the model's parameters.