Update and Re-estimation of NAWM II (Version 1.5)

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Abstract

This note provides a technical description of an updated version of NAWM II, which has been re-estimated using an extended sample period that includes the COVID-19 pandemic. It starts by outlining the modifications made to the specification of the model to address the extreme volatility in economic activity observed during the pandemic. It then presents the estimation results and highlights selected properties of the updated and re-estimated model.[1] In addition, the note details the incorporation of a time-varying long-run real interest rate into the model's interest rate rule, enabling the rule to better capture the secular downward trend in interest rates observed over recent decades. In this context, it also documents the effects of tightening the intrinsic inertia of the interest rate rule, a modification which has been implemented to reduce the strength of monetary policy transmission within the model.

[1] In terms of notation and as a source for supplementary analytical derivations, the note builds on the following ECB Working Papers and mimeos:

- Christoffel, K., G. Coenen and A. Warne, 2008, "The New Area-Wide Model of the euro area: A micro-founded open-economy model for forecasting and policy analysis", ECB Working Paper No. 944.
- 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.
- Coenen, G., J.-E. Gumiel, C. Montes-Galdón and A. Warne, 2022, "Update and re-estimation of NAWM II (Version 1.2.3)", ECB mimeo.
- Coenen, G., J.-E. Gumiel, C. Montes-Galdón and A. Warne, 2024, "Update and re-estimation of NAWM II (Version 1.4)", ECB mimeo.

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1 Overview

This note documents an updated and re-estimated version of NAWM II, hereafter referred to as model version 1.5, focusing on the implemented enhancements and the resulting changes relative to the previous model version 1.4. The enhancements are made in two areas. First, we re-estimate the model using an extended estimation period that includes the COVID-19 pandemic, which caused exceptionally high volatility in economic activity, particularly during its initial phase in 2020. This required careful treatment in the estimation process, which we therefore split in two steps.[2] In the first step, we establish interim benchmark estimates of the model's structural parameters by replacing the actual observations of the variables most heavily affected by the pandemic with missing values. This approach reflects our maintained assumption that the pandemic was a transient episode that has not permanently altered the basic economic relationships, including the transmission mechanism of monetary policy. In the second step, we estimate an augmented model with a limited number of additional transitory shocks introduced to structurally capture the extraordinary fluctuations caused by the pandemic. Ideally, the resulting parameter estimates, as well as the implied impulse responses to key economic shocks, including the short-term nominal interest rate, should closely align with the benchmark estimates obtained when using missing values for the variables most affected by the pandemic. However, since the selection of pandemic shocks is limited and arguably imperfect, the matching of parameters and impulse responses is less precise than expected under our assumption of merely transitory pandemic effects. For this reason, we adjust the prior distributions of a few key model parameters in the estimation to more closely match the impulse responses to an interest rate shock. The resulting estimated model effectively captures the volatile quarterly profile of economic activity during the early phase of the pandemic, with a significant role for the added pandemic shocks, while otherwise broadly preserving the established properties of the model, notably the effects of monetary policy.

Second, we introduce a time-varying long-run real interest rate into the model's interest rate rule linked to its permanent productivity shock and its highly persistent discount rate

[2] In response to the inflation surge in 2021-22, driven to a significant extent by exceptionally large spikes in energy prices, model version 1.4 was augmented with a direct energy price propagation channel. However its estimation sample was restricted to the period up to 2019Q4.

shock. This enables the model to better track the secular downward trend in interest rates observed over recent decades, while avoiding excessively strong and economically implausible reversals to its higher steady-state interest rate out of sample. The estimated path of the model-based measure of the long-run real rate falls well within the range of estimates produced by Eurosystem staff. As part of re-specifying the interest rate rule, we also revisit the strength of monetary policy transmission within the model, as reflected in its impulse responses to an interest rate shock. In particular, to address economic concerns about the model's overly strong monetary policy effects related to the working of the expectations channel, we tighten the prior on the parameter governing the intrinsic inertia of the interest rate rule. As a result, the peak effects of monetary policy on real GDP and inflation are reduced in absolute terms by about 20% and 25%, respectively.

2 Dealing with the COVID-19 pandemic

To account for the exceptional volatility of private domestic demand and hours worked during the pandemic in a structural way, we augment NAWM II with three transitory shocks related to the COVID-19 pandemic: (i) "forced saving" shocks, (ii) "labour hoarding" shocks and (iii) supply-side shocks, drawing on Cardani et al. (2022).[3] We restrict these shocks, which we will denote by the superscript "$^{(C)}$", to the initial quarters of the pandemic, leveraging the fact that the timing of its outbreak is known. Technically, this approach amounts to introducing a subset of shocks that display exogenous deterministic heteroskedasticity, similar to the approach by Lenza and Primiceri (2022).[4] As we will demonstrate below, the additional shocks effectively capture the volatile quarterly profile of economic activity during the early phase of the pandemic. However, they have little impact on inflation due to the high degree of price rigidities in the model.

Forced saving shocks

To capture the sharp contraction in consumption caused by social distancing measures and lockdowns at the onset of the pandemic, we introduce a transitory "forced saving" shock,

[3]See Cardani, R., O. Croitorov, M. Giovannini, P. Pfeiffer, M. Ratto and L. Vogel (2022), "The euro area's pandemic recession: A DSGE-based interpretation", *Journal of Economic Dynamics and Control*, 143, 104512.

[4]See Lenza, M. and G. Primiceri (2022), "How to estimate a vector autoregression after March 2020", *Journal of Applied Econometrics*, 37, 688-699.

$\epsilon_t^{C,(C)}$, which enters the consumption component of households' utility, including its habit formation element,

$$u(C_{h,t}) \;=\; \ln\Big((1-\epsilon_t^{C,(C)})\, C_{h,t} - \kappa\,(1-\epsilon_{t-1}^{C,(C)})\, C_{t-1}\Big)\,,$$

where the subscript h denotes an individual household. A positive shock effectively curtails consumption and raises savings.

Households' marginal utility of consumption is given by

$$\Lambda_{h,t} \;=\; \Big((1-\epsilon_t^{C,(C)})\, C_{h,t} - \kappa\,(1-\epsilon_{t-1}^{C,(C)})\, C_{t-1}\Big)^{-1}$$

and, after standard transformations,

$$\lambda_{h,t} \;=\; \Big((1-\epsilon_t^{C,(C)})\, c_{h,t} - \kappa\, g_{z,t}^{-1}\,(1-\epsilon_{t-1}^{C,(C)})\, c_{t-1}\Big)^{-1}\,,$$

where $\lambda_t = \Lambda_t/z_t$, $c_{h,t} = C_{h,t}/z_t$, $c_t = C_t/z_t$ and $g_{z,t} = z_t/z_{t-1}$.

Log-linearisation around a symmetric equilibrium (so that we can drop the subscript h) then yields:

$$\widehat{\lambda}_t \;=\; -\frac{1}{1-\kappa\, g_z^{-1}}\,(\widehat{c}_t - \widehat{\epsilon}_t^{C,(C)}) + \frac{\kappa\, g_z^{-1}}{1-\kappa\, g_z^{-1}}\,(\widehat{c}_{t-1} - \widehat{\epsilon}_{t-1}^{C,(C)}) - \frac{\kappa\, g_z^{-1}}{1-\kappa\, g_z^{-1}}\,\widehat{g}_{z,t},$$

where a hat ("$\widehat{\ }$") denotes the logarithmic deviation of a variable from its steady-state value.

Labour hoarding shocks

In light of the restrictions on the ability to work during the pandemic, we introduce a transitory "labour hoarding" shock, $\epsilon_t^{N,(C)}$. This shock captures temporary short-time work (i.e., the use of job retention schemes), where employees work fewer hours while remaining employed, and it enters the model as a transitory shock to hours. By altering the labour intensity of production at the intensive margin, this shock introduces a wedge between effective hours worked, N_t (production function), and hours paid, $(1+\epsilon_t^{N,(C)})\, N_t$ (labour cost and wage income). On the firms' side, the labour hoarding shock gives rise to a modification of the first-order conditions of their cost minimisation problem with respect to labour and capital inputs, as well as the associated marginal cost term (see Christoffel et al. (2008), equations (20), (21), and (23)). On the households' side, it affects the first-order condition characterising their optimal wage setting decision (see Christoffel et al. (2008), equation (14)) and, hence, the model's wage Phillips curve. It can be shown that the respective expressions remain unchanged apart from a modification of the wage rate in the desired labour/capital ratio, the marginal cost term and the households' desired wage rate, which now enters the (log-linearised) model equations taking into account the labour hoarding shock, $\widehat{w}_t + \widehat{\epsilon}_t^{N,(C)}$.

Supply-side shocks

To capture pandemic-related supply-side shocks, including shortages and disruptions, we add another transitory component, $g_{z,t}^{tr,(C)}$, to the model's composite permanent productivity shock, $g_{z,t}$ (see Coenen et al. (2018), Section 2.3.3). For simplicity, this additional component is not included in the signal extraction problem regarding the nature of the permanent productivity shock that economic agents in the model need to solve.

3 Introducing an augmented time-varying long-run real interest rate

While in previous versions of NAWM II some time variation in the long-run real interest rate, $\bar{R}^r = \beta^{-1} g_z$, has already been accounted for, specifically related to persistent fluctuations in perceived trend (labour) productivity growth, $g_{z,t|t}^p$,[5] the updated model further endogenises $\bar{R}^r$ by also linking it to a time-varying premium for safe and liquid assets, which corresponds to the model's highly persistent discount rate shock, υ_t:[6]

$$\bar{R}_t^r \quad = \quad \beta^{-1} g_{z,t|t}^p \, \upsilon_t^{\varpi_\upsilon}.$$

Here, ϖ_υ is a free "loading" parameter that will be empirically estimated using the data.

The time-varying $\bar{R}^r$ measure enters the model's log-linearised interest rate rule as a time-varying "mean":

$$\begin{aligned}\widehat{r}_t \quad = \quad & \phi_R \, \widehat{r}_{t-1} + (1-\phi_R) \left(\widehat{\bar{r}}_t^r + \widehat{\bar{\pi}}_t + \phi_\Pi \, (\widehat{\pi}_{C,t} - \widehat{\bar{\pi}}_t) + \phi_Y \, \widehat{y}_t \right) \\ & + \phi_{\Delta\Pi} \, (\widehat{\pi}_{C,t} - \widehat{\pi}_{C,t-1}) + \phi_{\Delta Y} \, (\widehat{y}_t - \widehat{y}_{t-1}) + \widehat{\eta}_t^R,\end{aligned}$$

where $\widehat{\bar{r}}_t^r = \widehat{g}_{z,t|t}^p + \varpi_\upsilon \, \widehat{\upsilon}_t$.

Accordingly, the strong mean reversion in the nominal interest rate, R_t, that would otherwise result from the model's relatively high steady-state nominal interest rate of 3.25%

[5]For details, see Coenen et al. (2018), Section 2.3.4.

[6]For details regarding the introduction of the discount rate shock, see Coenen et al. (2024), Section 1.2.

per annum (composed of the steady-state real rate of 1.25% and the central bank's medium-term 2% inflation target) can be mitigated by accounting for the persistent dynamics of the time-varying $\bar{R}^r_t$ measure.

It should be noted that, in addition to capturing time variation in $\bar{R}^r$, the augmented model setup also allows for simulations of alternative scenarios for monetary policy normalisation in an environment of heightened uncertainty about the long-run nominal interest rate by conditioning on alternative paths for $\bar{R}^r_t$. This would add a realistic and relevant element to monetary policy simulations.

4 Model estimation

4.1 Data

Compared to the estimation of the previous version of the model, the database has been extended from 2019Q4 to 2024Q2. Accordingly, it now covers the sample period from 1985Q1 to 2024Q2 (using the period from 1980Q2 to 1984Q4 as a training sample).[7] The data transformations follow the practices used in the previous re-estimation of the model. The only change concerns the treatment of the oil import deflator, which has been replaced by the Synthetic Energy Price Index (SECPI, in euro) from 2020Q1 onward. This change allows us to capture the impact of developments in gas prices that are not always highly correlated with oil prices, as observed during the initial phase of the Russian invasion of Ukraine. Figure 1 shows the time series for the observed variables used in the estimation.

4.2 Parameter estimates and monetary policy transmission

Tables 1 and 2 present the prior distributions and the posterior mode estimates of the model parameters. The estimates obtained for the updated model using the extended sample (model version 1.5) are compared with those for the previous version (1.4) as well as two interim benchmark versions, which are used step-by-step to help account for the extreme observations for key real and nominal variables during the early phase of the COVID-19 pandemic. The first benchmark version treats the observations during the first three quarters of 2020 as missing ("NA") for real GDP, private consumption, total investment, government consumption, exports, imports, GDP deflator inflation, employment, nominal

[7] The database now also includes Croatia as an additional member state of the euro area.

wages, foreign demand and the output gap. The second benchmark version incorporates the three transitory ("iid") COVID-19 shocks discussed in Section 2 for these three quarters while retaining the missing values assumption for foreign demand and the output gap. In addition, the foreign SVAR model that was introduced in version 1.4 has been re-estimated over the extended sample period. The re-estimated VAR model is used in both benchmark versions and in version 1.5.[8]

Turning first to the NA benchmark version (see the columns labelled "NA" in Tables 1 and 2), the prior distributions correspond to those of the previous model version 1.4. Notable impacts on the posterior mode estimates of the structural parameters from extending the sample include changes to the habit persistence parameter, κ, the investment adjustment cost parameter, γ_I, and the interest rate smoothing parameter, ϕ_R. Regarding the impulse responses to an interest rate shock, which are displayed in Figure 2, the decrease in κ strengthens, in absolute terms, the interest rate effect on consumption, while the increase in γ_I dampens, in absolute terms, the interest rate effect on investment. The increase in ϕ_R in general amplifies the effects of the interest rate shock. Overall, however, the impulse responses for the NA benchmark version (represented by the green dash-dotted lines) remain close to those for version 1.4 (represented by the black dotted lines), with the exception of the consumption response, which is noticeably stronger.

In the iid benchmark version, the three COVID shocks are introduced by restricting them to equal zero in all quarters except for the first three quarters of the pandemic in 2020. At the same time, the innovations to the model's discount rate shock, the wage markup shock and the transitory component of the permanent technology shock, which are closely related to the COVID shocks both economically and in the way they enter the model, are restricted to zero during these quarters to facilitate the identification of the COVID shocks. For the transitory technology shock component this restriction implies that the shock's standard deviation becomes time-varying, while the introduction of the other two COVID shocks serves similar purposes, but it should be noted that the discount rate and wage markup shock processes are autoregressive. For all COVID shocks, we adopt a more impactful and diffuse prior compared to the other structural shocks in the model.

[8]For methodological reasons, the foreign demand observations during 2020Q1-Q3 are used as data when estimating the SVAR, but are instead cancelled via dummy variables prior to the actual estimation of the SVAR parameters.

This reflects the unprecedented and uncertain nature of the pandemic, allowing the model to account for the significant economic disruptions during this period.

Since the number of COVID shocks is small compared to the number of variables that display extreme fluctuations in 2020, it is not surprising that additional changes to the model setup are necessary to improve the matching of the interest rate impulse responses to those of the NA benchmark, which is the guiding principle of our estimation strategy outlined in Section 1. Specifically, the prior standard deviation of the habit persistence parameter is lowered from 0.10 to 0.025, while the investment adjustment cost prior standard deviation is halved from the very diffuse value of 1.5 to 0.75. Furthermore, the prior mean and standard deviation of the interest rate smoothing parameter are lowered from 0.9 to 0.75 and from 0.05 to 0.025, respectively. The modified priors and the resulting parameter estimates are shown in the "iid" columns of Tables 1 and 2, and the implied impulse responses to an interest rate shock are represented by the dashed red lines in Figure 2. Overall, the impulse responses are quite close to those for the NA benchmark, as intended. This also holds for the consumption response despite the fact that the estimate of the habit persistence parameter is now slightly lower than for the NA benchmark.

When introducing the time-varying long-run real interest rate into the model's interest rate rule we have opted to further lower the prior standard deviation of the interest rate smoothing parameter, reducing it from 0.025 to 0.015. This adjustment reflects the objective of reducing the overall strength of monetary transmission in the model, as explained in Section 1. For the resulting new model version 1.5, the primary effect of this change in prior is to lower the responses of the observed variables to an interest rate shock, reflecting the smaller estimated degree of interest rate smoothing. However, there is little impact on the estimates of the model parameters outside the interest rate rule.[9] The implied impulse responses are depicted by the blue solid lines in Figure 2. Not only are the real effects substantially weaker, with the peak effect on real GDP being diminished by about 20%, but also the nominal peak effects, with an approximate reduction of 25% for inflation.[10]

[9]The estimated degree of interest rate smoothing, as well as the estimated inflation coefficient, are now close to the corresponding values in the inertial Taylor (1999) rule, which is widely used as a benchmark rule in monetary policy evaluations. See Taylor, J.B.'(1999), "A historical analysis of monetary policy rules", in: J.B. Taylor (ed.), *Monetary Policy Rules*, Chicago: University of Chicago Press, 319-341.

[10]Note that introducing a time-varying long-run interest rate in the model, in isolation, does not have any material effect on either the parameter estimates or the impulse responses to an interest rate shock.

For model version 1.5, Figure 3 presents the smoothed estimates of both the standard and the COVID shocks. The estimates of the latter exhibit significant fluctuations, reflecting the collapse in economic activity and the subsequent swift rebound during the initial quarters of the pandemic.

4.3 Estimate of the long-run real interest rate

As outlined in Section 3, the time-varying long-run real interest rate appears in the NAWM's log-linearised interest rate rule as a time-varying "mean" and is given by the sum of the perceived persistent component of the model's permanent productivity shock and its highly persistent discount rate shock, with the latter scaled by a free parameter, ϖ_υ. The posterior mode estimate of this parameter, which is assigned a standard uniform marginal prior on the unit interval, is 0.38.

The model-based estimate of the time-varying long-run real interest rate is plotted in Figure 4, along with equal-tails uncertainty bands. The estimated path is overall downward-sloping. In particular, it declines from the model-based steady-state value of 1.25% per annum to values close to zero at the onset of the Great Recession, and it drops more sharply into negative territory during the early phase of the COVID-19 pandemic. From early 2022 onward, it rises toward zero and levels out by late 2023.[11] Overall, the estimated long-run real interest rate path lies well within the range of estimates produced by Eurosystem staff using a broader set of alternative approaches.[12]

5 Additional model properties

5.1 Model and sample moments

Table 3 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 data-based estimates of these moments for the sample period from 1985Q1 to 2024Q2. The population moments are provided not only for model version 1.5 but also for the previous

[11] It should be noted that the posterior mode estimate of the scaling parameter ϖ_υ is negatively related to the choice of prior standard deviation for the smoothing parameter ϕ_R in the model's interest rate rule. If ϖ_υ is smaller (larger), the amplitude of the estimated path of the time-varying long-run real rate is dampened (increased) and the level of the path shifts slightly upward (downward).

[12] See ECB Occasional Paper No 371 (2025), "A strategic view on the economic and inflation environment in the euro area", Section 3.6.1.

version 1.4 and the two interim benchmark versions which apply alternative methods for handling the outliers during the initial COVID-19 phase from 2020Q1 to 2020Q3. The moments of version 1.4 and the NA benchmark version can be compared with the estimated moments in the “NA Data” columns, where the outliers are treated as missing values. The moments of version 1.5 and the iid benchmark version can instead be compared with the estimates in the “Data” columns, which account for the outliers.

Focusing on the population moments of model version 1.5, the results indicate that the model-based means are broadly consistent with the data-based estimates. In particular, the data-based means for the real variables are close to the model-based means, except for long-term growth expectations and the output gap. For the inflation measures, the data-based means are moderately higher than the model-based means, except for the two import price deflators, for which the data-based means are lower. These findings are consistent with the results for model version 1.4.

Turning to the standard deviations, the data-based estimates are generally lower than the model-based values, with exceptions for real GDP, private consumption and employment. The data-based estimates for real GDP and consumption more than double when accounting for the COVID-related outliers in 2020. These changes are largely captured by model version 1.5 through the three COVID shocks. Compared with the previous model version 1.4, the model-based standard deviations are generally aligned with the relevant data-based estimates. However, for the real effective exchange rate and the composite long-term lending rate, the model-based estimates of version 1.5 deteriorate relative to version 1.4, while improvements are observed for the short-term nominal interest rate and the 10-year government bond yield. In summary, for the standard deviations, there are both improvements and deteriorations. Nevertheless, given that it accounts for the extreme data fluctuations during 2020, the new model version 1.5 matches the data-based moments at least as well as the previous version 1.4.

5.2 Historical decompositions

Figure 5 provides the historical decompositions of the drivers of quarterly real GDP and private consumption growth for the period from 2019Q1 to 2024Q2. Focusing on the COVID-specific shock contributions, these shocks are identified as the dominant drivers of the 2020 recession. They caused a sharp contraction in 2020Q2, followed by a strong rebound in 2020Q3, related to the re-opening of the economy, and a relatively quick fading of their contributions thereafter. Among the individual COVID shock contributions (not shown), the forced saving and supply-side shocks dominate the decompositions, whereas the labour hoarding shock plays only a minor role in GDP and consumption dynamics.[13] Overall, the decompositions show that the new version of the model, augmented with a small number of COVID-specific shocks, effectively captures the volatile quarterly profile of economic activity during the early phase of the pandemic.

Figure 6 presents the historical decompositions of annual consumer price inflation and wage growth, measured in terms of the private consumption deflator and compensation per head, respectively. The COVID shocks, particularly the labour-hoarding shock, account for a significant portion of the decline in wage growth during the early quarters of the pandemic. This reflects the widespread use of job retention schemes during the pandemic, which put downward pressure on wages as employees retained their employment status but faced pay cuts while enrolled in these schemes.[14] However, the initial negative contribution is reversed rather swiftly. Regarding inflation, the decomposition suggests that the COVID shocks have had little impact. This is due to the high degree of price rigidities in the model, which limit the pass-through of wage reductions to prices.

[13]For investment growth, the COVID shocks account for a considerably smaller portion of the dynamics during the pandemic. Among the other shocks, the far largest contribution is made by the model's investment-specific technology shock.

[14]The model-based decompositions of employment and hours worked reveal an interesting contrast. Hours worked, an unobserved state variable, fell considerably more than the observed employment variable during the pandemic. The decompositions show that a significant portion of the decline in hours worked is attributed to the COVID shocks, while the decline in employment is only modestly affected by these shocks. This finding is aligned with the view that labour adjustment via the "intensive margin" was facilitated by the widespread use of job retention schemes.

Table 1: Prior distributions and posterior mode estimates of the structural parameters

Parameter	Description	Prior distribution	Posterior mode			
			v1.4	NA	iid	v1.5
A. Preferences						
κ	Habit formation	beta(0.75,0.10)	0.63	0.58	—	—
		beta(0.75,0.025)	—	—	0.52	0.52
B. Wage and price setting						
ξ_W	Calvo scheme: wages	beta(0.75,0.0375)	0.79	0.80	0.79	0.79
χ_W	Indexation to inflation: wages	beta(0.75,0.10)	0.32	0.29	0.26	0.24
$\tilde{\chi}_W$	Indexation to productivity: wages	beta(0.75,0.10)	0.78	0.76	0.96	0.96
ξ_H	Calvo scheme: domestic prices	beta(0.75,0.0375)	0.81	0.81	0.81	0.81
χ_H	Indexation: domestic prices	beta(0.75,0.10)	0.33	0.25	0.31	0.27
ξ_X	Calvo scheme: export prices	beta(0.75,0.0375)	0.77	0.76	0.75	0.74
χ_X	Indexation: export prices	beta(0.75,0.10)	0.35	0.26	0.23	0.23
ξ^*_O	Calvo scheme: import prices	beta(0.25,0.0375)	0.06	0.09	0.09	0.09
ξ^*_{XO}	Calvo scheme: import prices	beta(0.75,0.0375)	0.69	0.68	0.66	0.65
χ^*_O	Indexation: import prices	beta(0.25,0.10)	0.18	0.14	0.13	0.13
χ^*_{XO}	Indexation: import prices	beta(0.75,0.10)	0.34	0.32	0.32	0.31
o^*	Oil import price weight	beta(0.15,0.05)	0.13	0.12	0.12	0.12
C. Wage and domestic price Phillips curves						
$100 \cdot sl^W$	Slope parameter	gamma(0.50,0.10)	0.29	0.27	0.28	0.29
$100 \cdot sl^H$	Slope parameter	gamma(1.00,0.15)	0.74	0.80	0.77	0.75
D. Final and intermediate-good production						
μ_C	Subst. elasticity: consumption	gamma(0.40,0.10)	0.40	0.53	0.50	0.49
μ_{CXO}	Subst. elasticity: consumption	gamma(1.50,0.25)	2.12	2.37	2.62	2.51
μ_I	Subst. elasticity: investment	gamma(1.50,0.25)	1.39	1.33	1.97	1.88
μ_X	Subst. elasticity: exports	gamma(1.50,0.25)	0.86	1.07	1.35	1.35
μ^*	Price elasticity: exports	gamma(1.50,0.25)	1.20	1.31	1.17	0.98
α	Capital share	beta(0.36,0.10)	0.35	0.27	0.43	0.34
E. Wholesale and retail banks						
ω_L	Absconding of domestic bonds	gamma(0.72,0.05)	0.72	0.69	0.78	0.73
$\tilde{\omega}^*_L$	Absconding of foreign bonds	gamma(1.00,0.05)	1.00	1.00	0.99	0.99
ξ_I	Calvo scheme: price of loans	beta(0.75,0.0375)	0.71	0.70	0.67	0.66

Note: This table provides information on the marginal prior distributions and the posterior mode estimates of the structural parameters for versions 1.4 and 1.5 of NAWM II, as well as of two interim versions where the sample has been extended to 2024Q2 with the COVID quarters 2020Q1-2020Q3 being treated as missing observations for some variables (NA version), and using iid COVID structural shocks (iid version). The prior distributions are characterised by the parameters determining their respective means and standard deviations. The posterior mode columns show the estimates obtained by numerically maximising the posterior distribution.

Table 1: Prior distributions and posterior mode estimates of the structural parameters (cont'd)

Parameter	Description	Prior distribution	Posterior mode			
			v1.4	NA	iid	v1.5
F. Adjustment costs						
γ_I	Investment	gamma(6.00,1.50)	6.19	11.72	—	—
		gamma(6.00,0.75)	—	—	8.59	9.24
$\gamma_{u,2}$	Capital utilisation	gamma(1.00,0.25)	0.72	0.90	1.28	0.98
$\gamma_{IM^{CO}}$	Import content: consumption	gamma(5.00,1.00)	3.81	5.62	5.44	5.64
$\gamma_{IM^{CXO}}$	Import content: consumption	gamma(2.50,1.00)	5.75	5.02	6.35	6.80
γ_{IM^I}	Import content: investment	gamma(2.50,1.00)	0.73	0.81	4.98	4.93
γ^*	Export market share	gamma(2.50,1.00)	1.65	2.43	1.42	1.14
γ_L^h	Portfolio: households	gamma(0.01,0.0025)	0.009	0.009	0.009	0.008
γ_L^*	Portfolio: wholesale banks	gamma(0.01,0.0025)	0.004	0.003	0.001	0.001
G. Interest-rate rule						
ϕ_R	Interest-rate smoothing	beta(0.90,0.05)	0.93	0.95	—	—
		beta(0.75,0.025)	—	—	0.92	—
		beta(0.75,0.015)	—	—	—	0.87
ϕ_Π	Response to inflation	gamma(1.70,0.575)	2.52	2.87	2.32	1.68
$\phi_{\Delta\Pi}$	Response to change in inflation	gamma(0.30,0.125)	0.04	0.03	0.03	0.03
ϕ_Y	Response to output gap	gamma(0.14,0.05)	0.04	0.05	0.01	0.01
$\phi_{\Delta Y}$	Response to change in output gap	gamma(0.07,0.025)	0.12	0.11	0.09	0.12
ϖ_υ	$r^\star$ response to discount rate shock	uniform(0,1)	—	—	—	0.38
H. Employment (bridge) equation						
ξ_E	Calvo-style weighing scheme	beta(0.50,0.15)	0.85	0.82	0.79	0.75
I. Perception updating equations						
$\varpi_{\bar{\Pi}^p}$	Sens. of perc. inflation objective	gamma(0.10,0.25)	0.05	0.02	0.02	0.02
$\varpi_{g_Y^p}$	Sens. of perc. trend growth rate	gamma(0.10,0.25)	0.06	0.06	0.05	0.05

Note: See above.

Table 2: Prior distributions and posterior mode estimates of the parameters of the shock processes

Parameter	Description	Prior distribution	Posterior mode			
			v1.4	NA	iid	v1.5
A. Autoregressive parameters						
ρ_{RP}	Domestic risk premium shock	beta(0.75,0.10)	0.86	0.91	0.92	0.87
ρ_{RP^*}	External risk premium shock	beta(0.75,0.10)	0.94	0.97	0.99	0.92
$\rho_{g_z^p}$	Perm. techn. shock: pers. comp.	beta(0.75,0.10)	0.97	0.96	0.99	0.99
ρ_{ε}	Transitory technology shock	beta(0.75,0.10)	0.83	0.86	0.83	0.82
ρ_I	Investment-specific techn. shock	beta(0.75,0.10)	0.91	0.86	0.71	0.62
ρ_{φ^W}	Wage mark-up shock	beta(0.50,0.05)	0.67	0.65	0.62	0.61
ρ_{φ^H}	Domestic price mark-up shock	beta(0.50,0.05)	0.53	0.46	0.44	0.44
ρ_{φ^X}	Export price mark-up shock	beta(0.50,0.05)	0.44	0.42	0.39	0.39
$\rho_{\varphi^*_O}$	Import price mark-up shock	beta(0.50,0.05)	0.47	0.58	0.58	0.60
$\rho_{\varphi^*_{XO}}$	Import price mark-up shock	beta(0.50,0.05)	0.46	0.45	0.44	0.43
ρ_{IM}	Import demand shock	beta(0.75,0.10)	0.84	0.87	0.60	0.58
ρ_{ν^*}	Export preference shock	beta(0.75,0.10)	0.89	0.88	0.94	0.95
ρ_{υ}	Discount rate shock	beta(0.75,0.10)	0.99	0.99	0.99	0.99
ρ_{φ^I}	Loan rate mark-down shock	beta(0.75,0.05)	0.78	0.81	0.89	0.90
B. Scaling parameters						
σ_{RP}	Domestic risk premium shock	invgamma(0.122474,2)	0.23	0.18	0.19	0.20
σ_{RP^*}	External risk premium shock	invgamma(0.122474,2)	0.24	0.14	0.08	0.26
$\sigma_{g_z^p}$	Perm. techn. shock: pers. comp.	invgamma(0.122474,2)	0.04	0.03	0.04	0.04
σ_{ε}	Transitory technology shock	invgamma(0.122474,2)	1.17	0.95	0.72	0.67
σ_I	Investment-specific techn. shock	invgamma(0.122474,2)	0.32	0.30	0.60	0.70
σ_{φ^W}	Wage mark-up shock	invgamma(0.122474,2)	0.09	0.09	0.10	0.10
σ_{φ^H}	Domestic price mark-up shock	invgamma(0.122474,2)	0.11	0.14	0.15	0.15
σ_{φ^X}	Export price mark-up shock	invgamma(0.122474,2)	0.91	1.17	1.38	1.38
$\sigma_{\varphi^*_O}$	Import price mark-up shock	invgamma(0.122474,2)	13.31	21.22	21.44	21.45
$\sigma_{\varphi^*_{XO}}$	Import price mark-up shock	invgamma(0.122474,2)	0.99	1.29	1.35	1.35
σ_{IM}	Import demand shock	invgamma(0.122474,2)	6.63	8.00	18.70	19.05
σ_{ν^*}	Export preference shock	invgamma(0.122474,2)	6.58	8.97	6.71	5.68
σ_R	Interest rate shock	invgamma(0.122474,2)	0.10	0.11	0.13	0.16
σ_{υ}	Discount rate shock	invgamma(0.122474,2)	0.04	0.05	0.04	0.04
σ_{φ^I}	Loan rate mark-down shock	invgamma(0.122474,2)	0.92	0.85	0.79	0.81
$\sigma_{\bar{\Pi}^p}$	Perc. inflation objective shock	invgamma(0.122474,2)	0.02	0.02	0.02	0.02
$\sigma_{g_Y^p}$	Perc. trend growth rate shock	invgamma(0.122474,2)	0.02	0.02	0.02	0.02
$\sigma_{C,(C)}$	Forced savings shock (COVID)	invgamma(2,4)	—	—	0.63	0.71
$\sigma_{N,(C)}$	Labour hoarding shock (COVID)	invgamma(2,4)	—	—	0.32	0.32
$\sigma_{g_z^{tr},(C)}$	Perm. tech. shock: trans. (COVID)	invgamma(2,4)	—	—	0.56	0.58
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	0.06	0.07

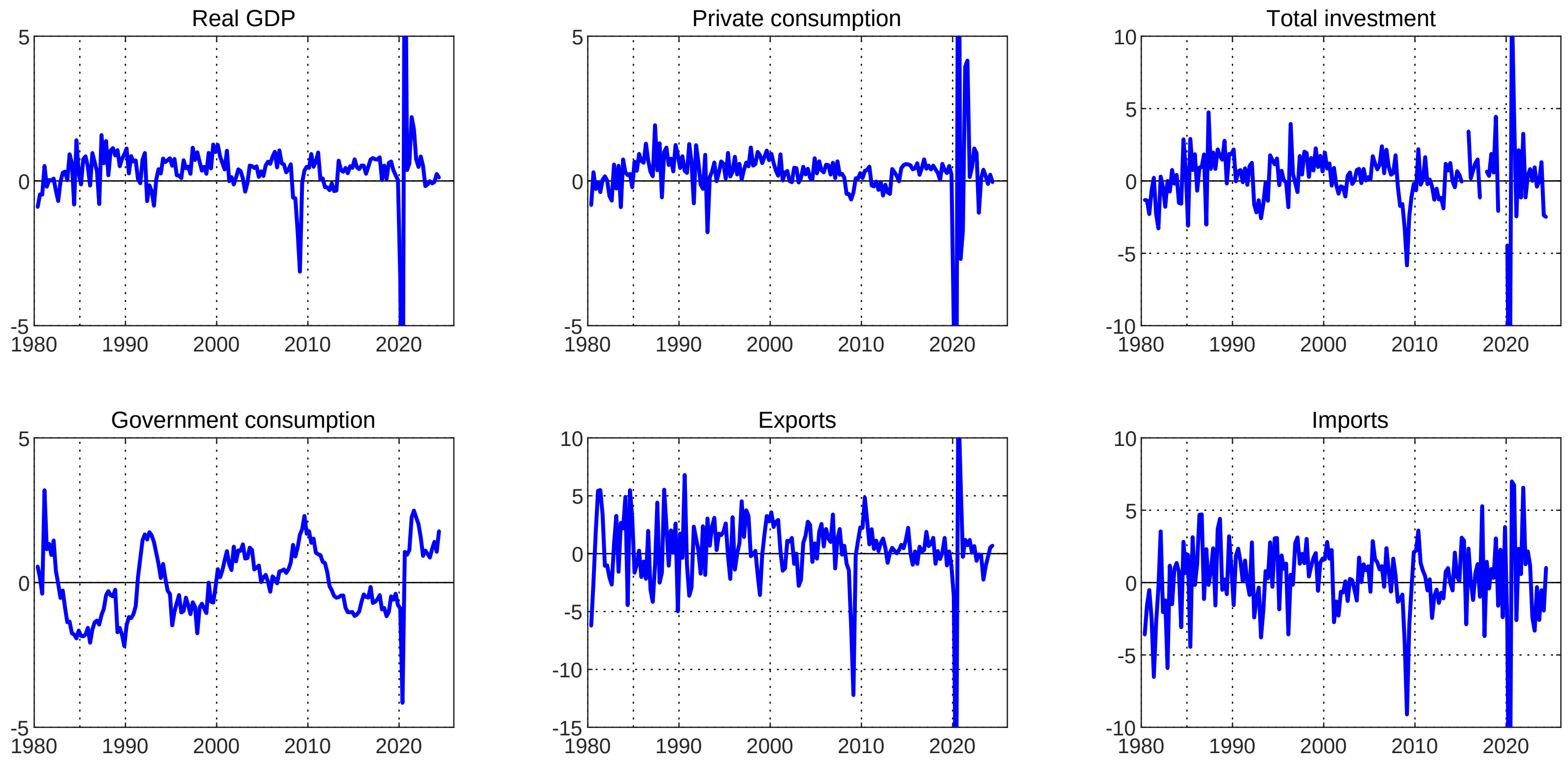
Note: See Table 1. The inverse gamma prior distributions are parameterised in terms of their mode and their degrees of freedom.

Table 3: Means and standard deviations of the observed variables

Variable	Mean						Standard deviation					
	v1.4	NA	iid	v1.5	NA Data	Data	v1.4	NA	iid	v1.5	NA Data	Data
Real GDP	0.375	0.375	0.375	0.375	0.41	0.38	0.73	0.74	1.17	1.18	0.58	1.44
Consumption	0.375	0.375	0.375	0.375	0.38	0.34	0.82	0.98	1.53	1.56	0.70	1.67
Investment	0.375	0.375	0.375	0.375	0.39	0.30	3.06	3.05	3.67	3.61	1.57	2.51
Gov't consumption	0.00	0.00	0.00	0.00	0.02	0.00	0.82	0.82	0.82	0.82	1.08	1.12
Exports	0.375	0.375	0.375	0.375	0.47	0.38	4.04	4.40	4.71	4.46	2.23	3.10
Imports	0.375	0.375	0.375	0.375	0.50	0.38	2.84	3.29	3.54	3.35	2.16	2.83
GDP defl. inflation	0.50	0.50	0.50	0.50	0.60	0.59	0.55	0.58	0.63	0.63	0.37	0.39
Consumption defl. inflation	0.50	0.50	0.50	0.50	0.57	0.57	0.56	0.55	0.60	0.61	0.46	0.46
Import defl. inflation	0.50	0.50	0.50	0.50	0.11	0.11	2.81	3.18	3.30	3.22	2.68	2.68
Oil import defl. inflation	0.50	0.50	0.50	0.50	0.34	0.34	13.26	14.68	14.69	14.67	16.41	16.41
Employment	0.00	0.00	0.00	0.00	−0.07	0.00	1.90	1.99	3.47	3.39	3.56	3.57
Wage inflation	0.80	0.80	0.80	0.80	0.81	0.80	0.66	0.66	0.98	1.08	0.50	0.77
Short-term nom. interest rate	3.25	3.25	3.25	3.25	3.89	3.89	2.24	2.21	3.27	3.72	3.66	3.66
Real effective exchange rate	0.00	0.00	0.00	0.00	0.00	0.00	13.42	15.19	18.98	17.85	11.43	11.43
10-year gov't bond yield	4.66	4.60	4.77	4.67	4.10	4.10	1.47	1.38	2.50	3.10	2.61	2.61
Comp. long-term lending rate	5.41	5.41	5.41	5.41	3.23	3.23	1.48	1.40	2.57	3.20	1.22	1.22
Long-term inflation expect's	2.00	2.00	2.00	2.00	1.90	1.90	1.05	0.90	1.16	1.32	0.11	0.11
Long-term growth expect's	1.50	1.50	1.50	1.50	1.86	1.86	0.53	0.39	1.45	2.06	0.37	0.37
Output gap	0.00	0.00	0.00	0.00	−0.34	−0.34	6.44	5.86	10.00	9.82	1.76	1.76

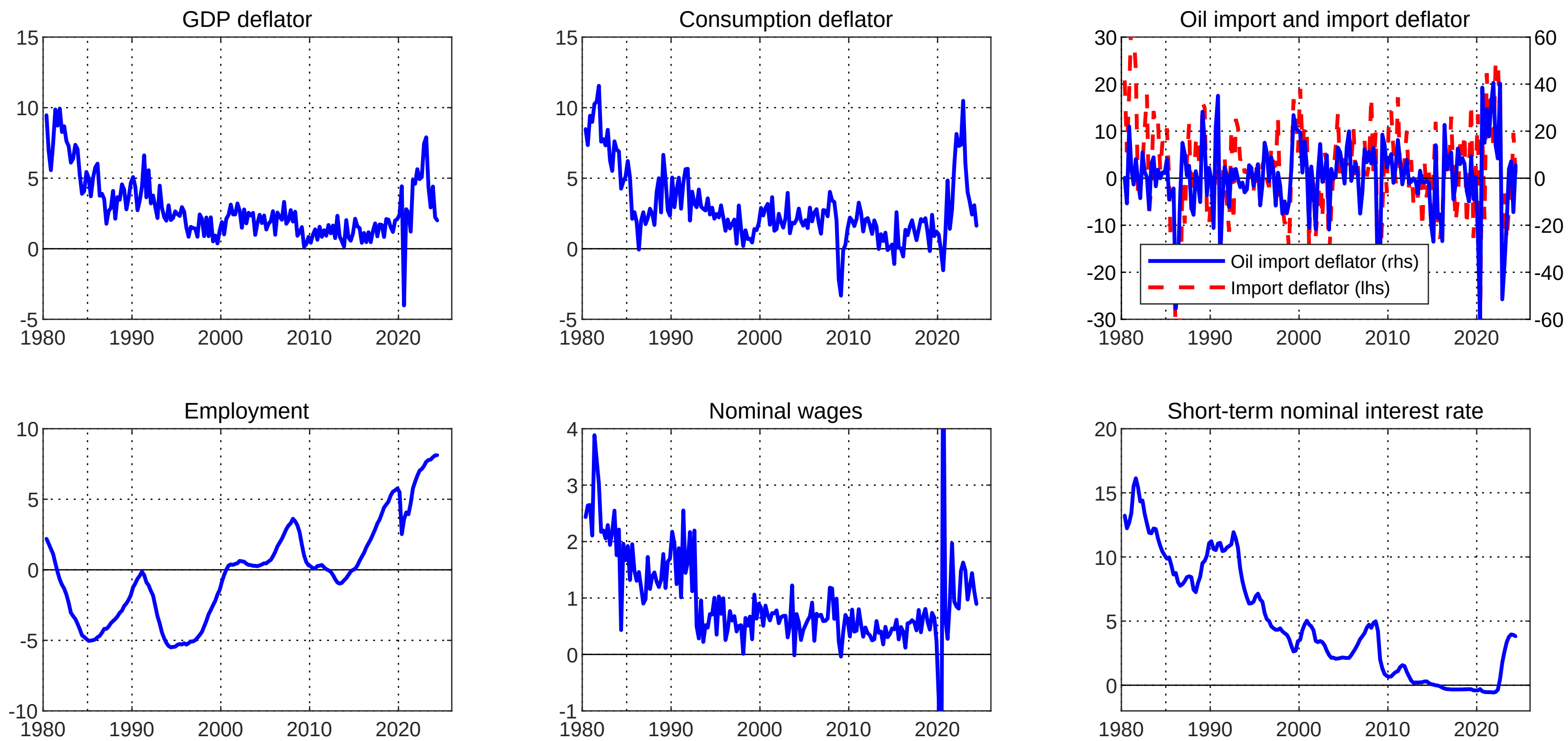
Note: This table reports population means and standard deviations at the posterior mode estimates of NAWM II, version 1.4, two interim versions taking the COVID outliers into account (with "NA" being the missing observations version and "iid" the iid shock version) and version 1.5, for the observed variables used in its Bayesian estimation, along with the corresponding sample moments based on the data covering the period 1985Q1-2024Q2. The "NA Data" moments can be compared with version 1.4 and the NA version, while the "Data" moments can be compared with version 1.5 and the iid version. The differences between the two data moments follow from the use of data from 2020Q1-Q3.

Figure 1: The transformed data



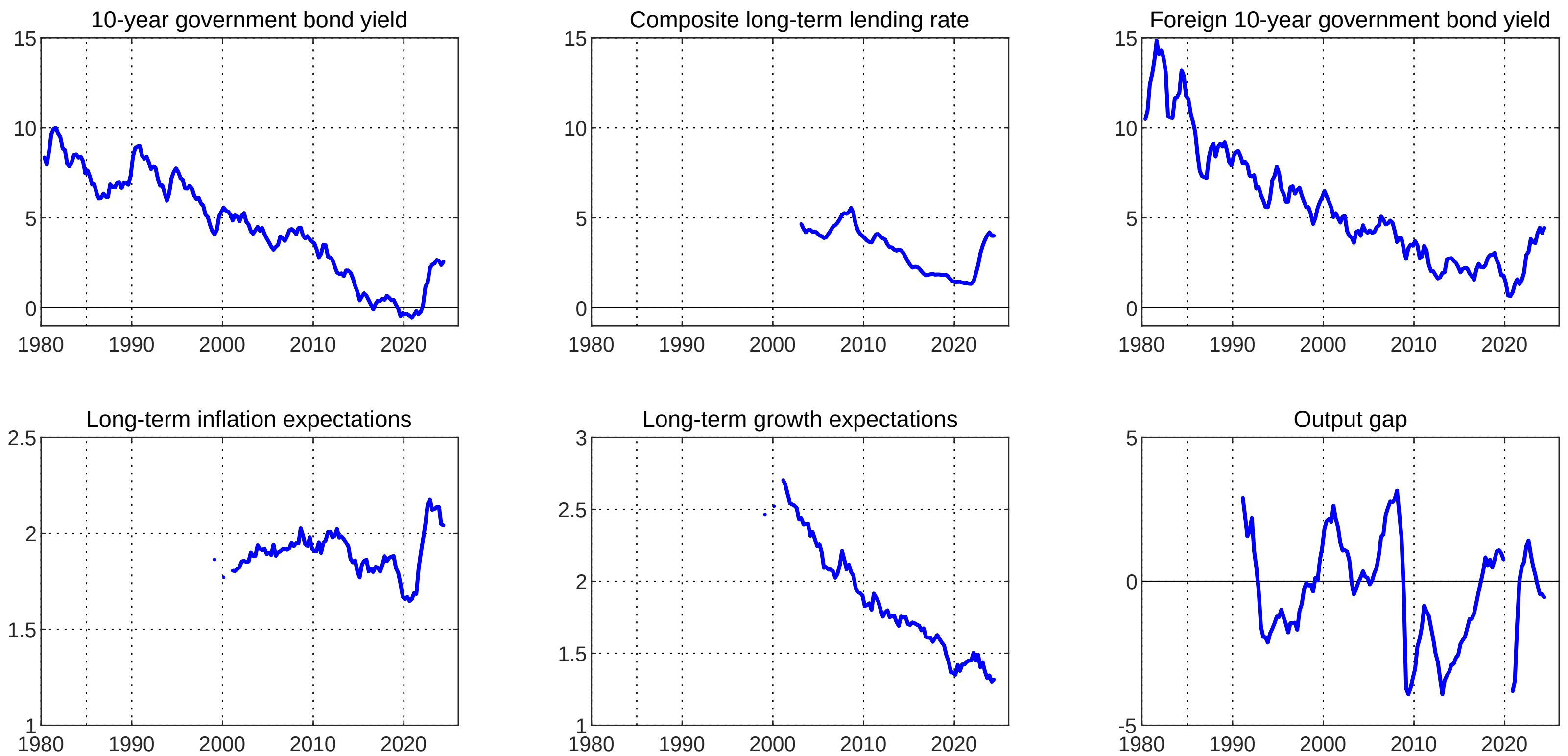
Note: This figure shows the updated and extended time series of the observed variables used in the estimation of NAWM II, version 1.5. Inflation and interest rates are reported in annualised percentage terms. The euro area 10-year government bond yield series (AAA) is available from 2004Q3 onwards, while 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)



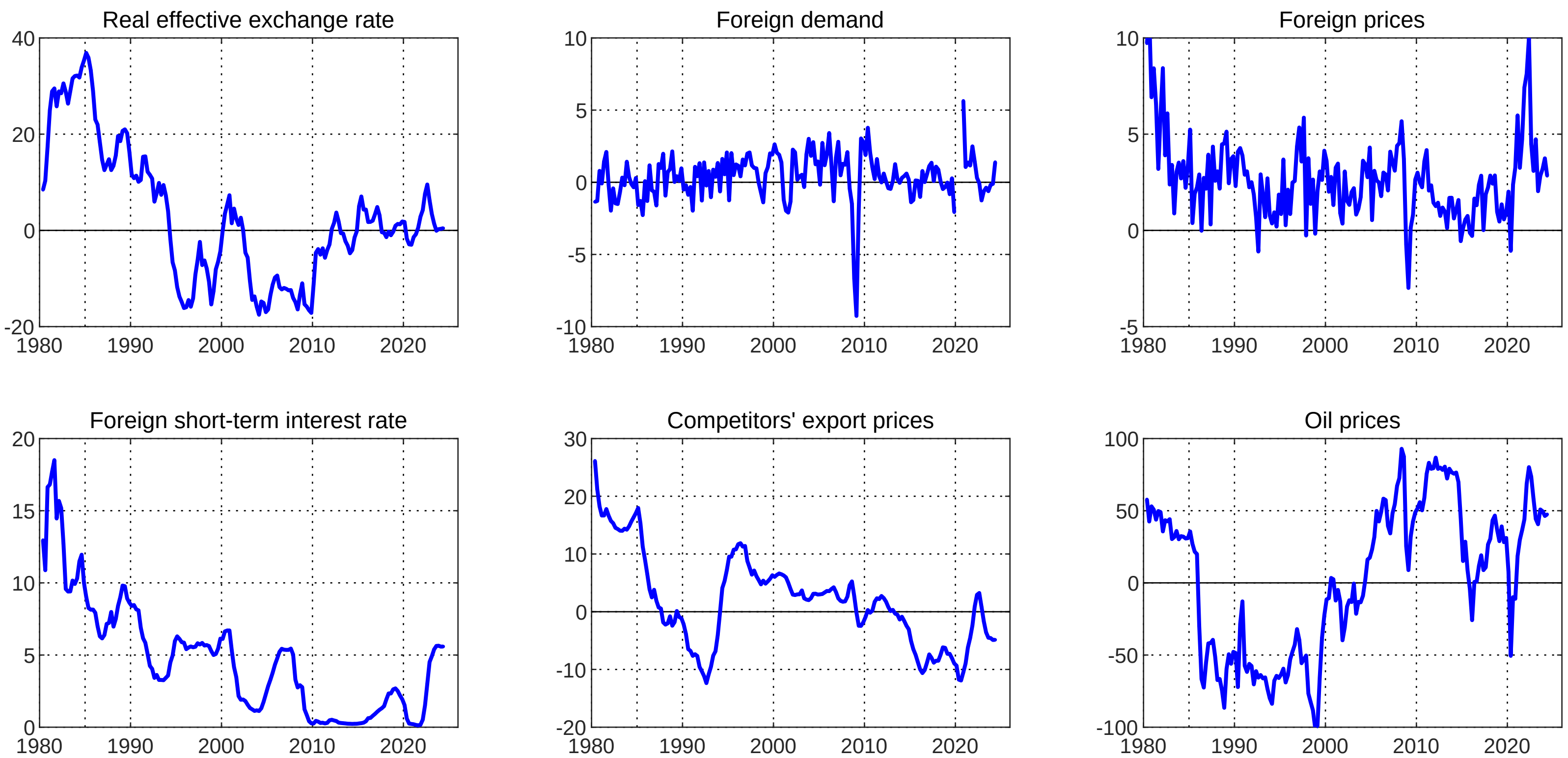
Note: See above.

Figure 1: The transformed data (continued)



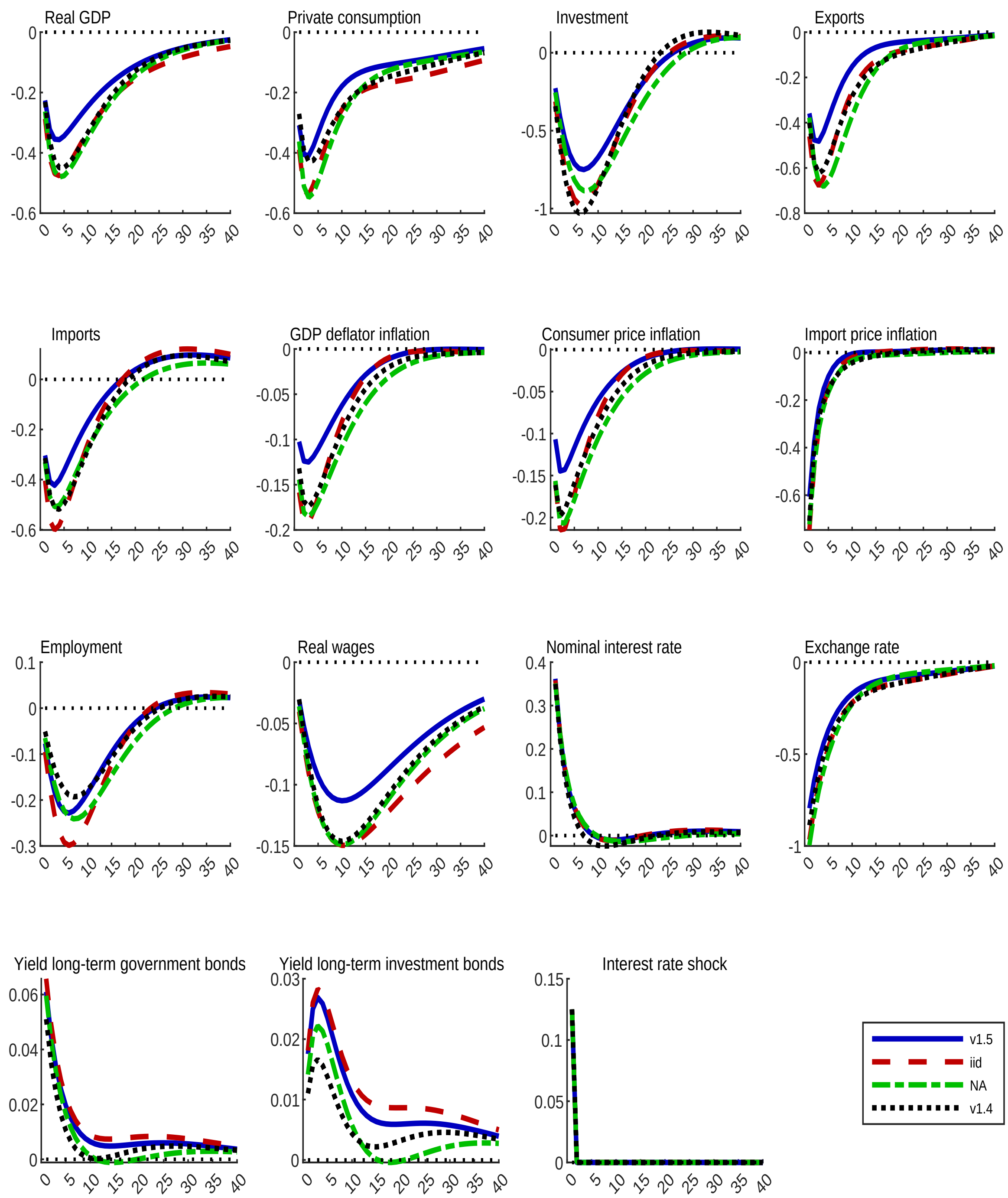
Note: See above.

Figure 1: The transformed data (continued)



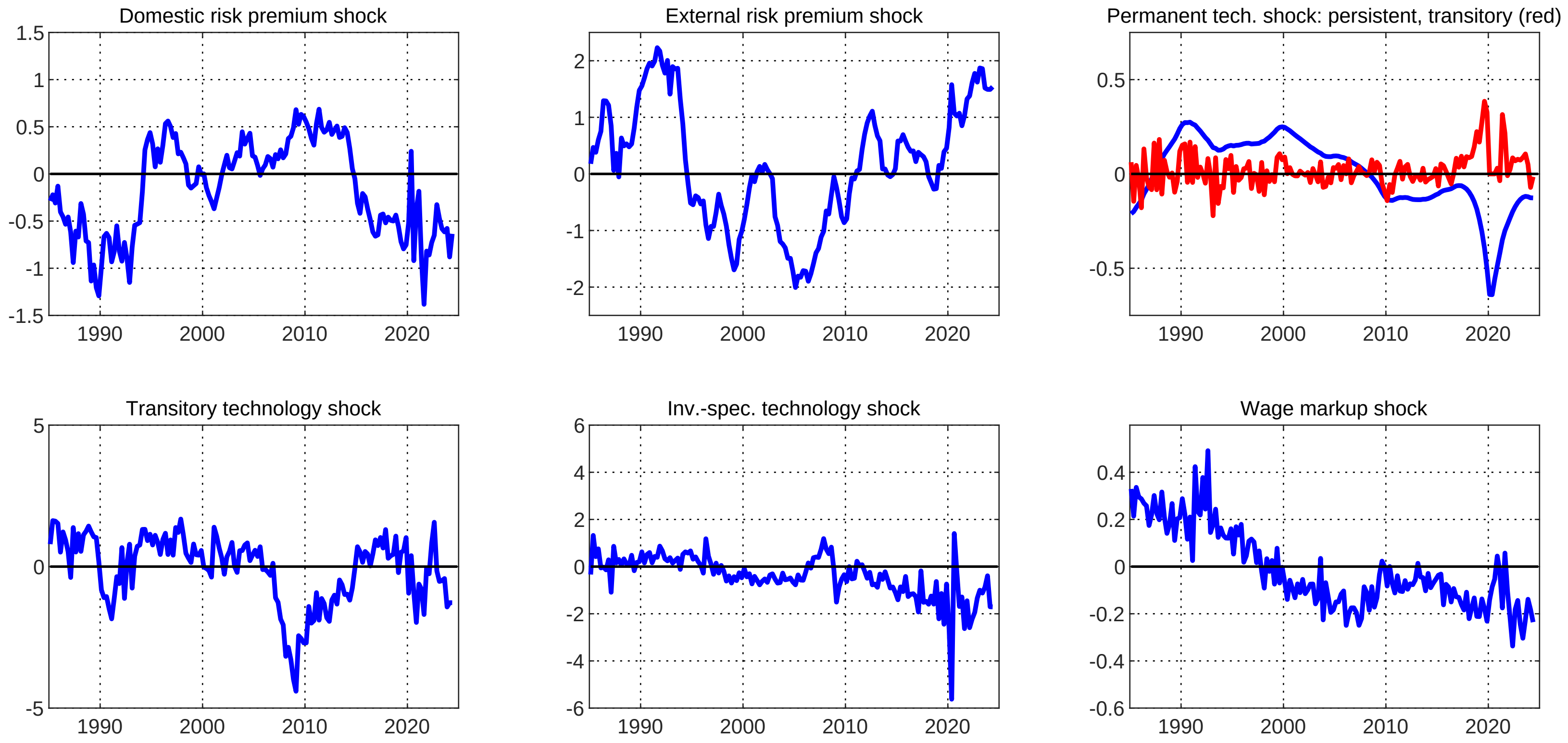
Note: See above.

Figure 2: Impulse responses to an interest rate shock



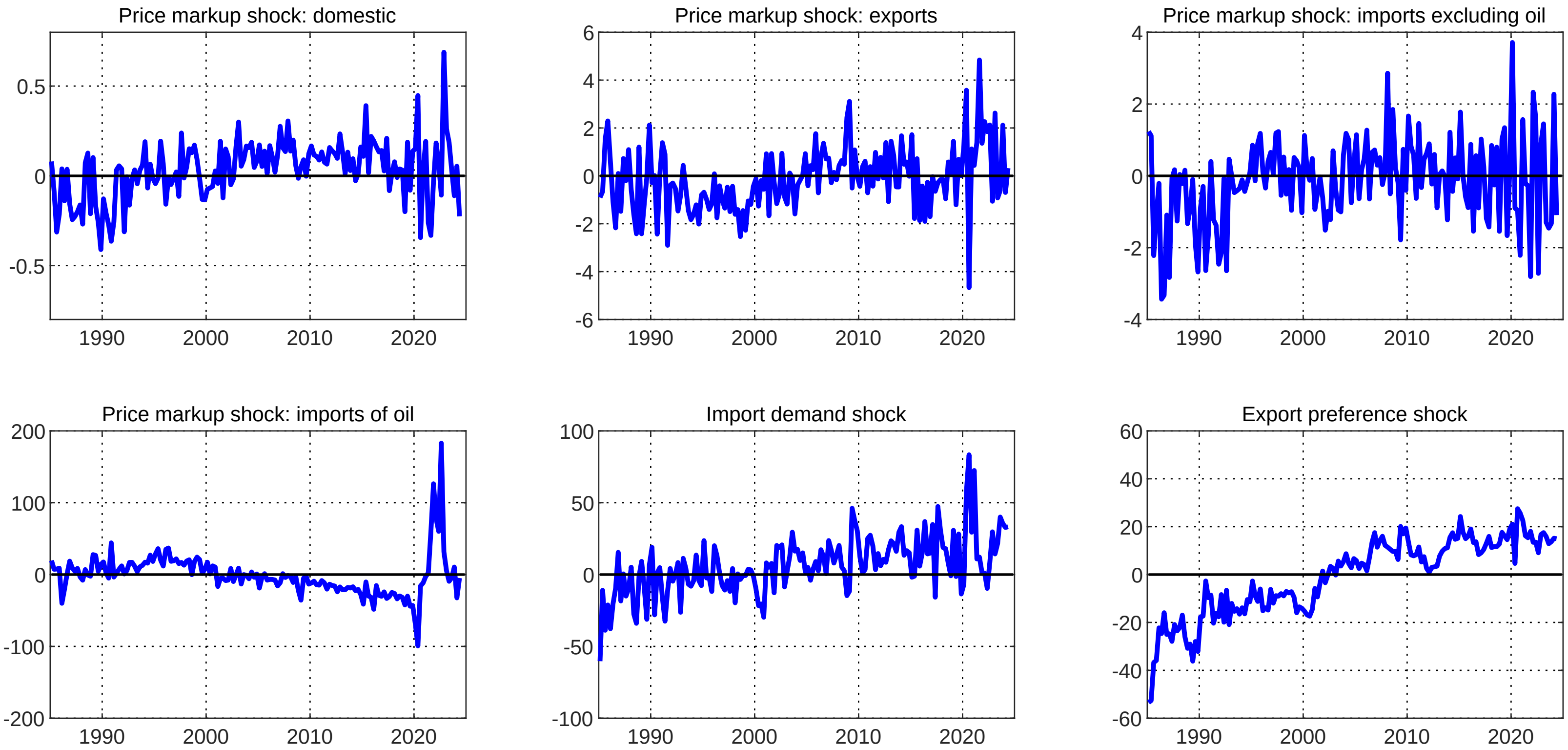
Note: For alternative versions of NAWM II, this figure depicts the impulse responses of selected domestic variables to an interest rate shock equal to 50 basis points in annualised terms. All impulse responses are reported as percentage deviations from the non-stochastic balanced growth path, except for the impulse responses of the inflation and interest rates which are reported as annualised percentage-point deviations.

Figure 3: Smoothed estimates of the shocks



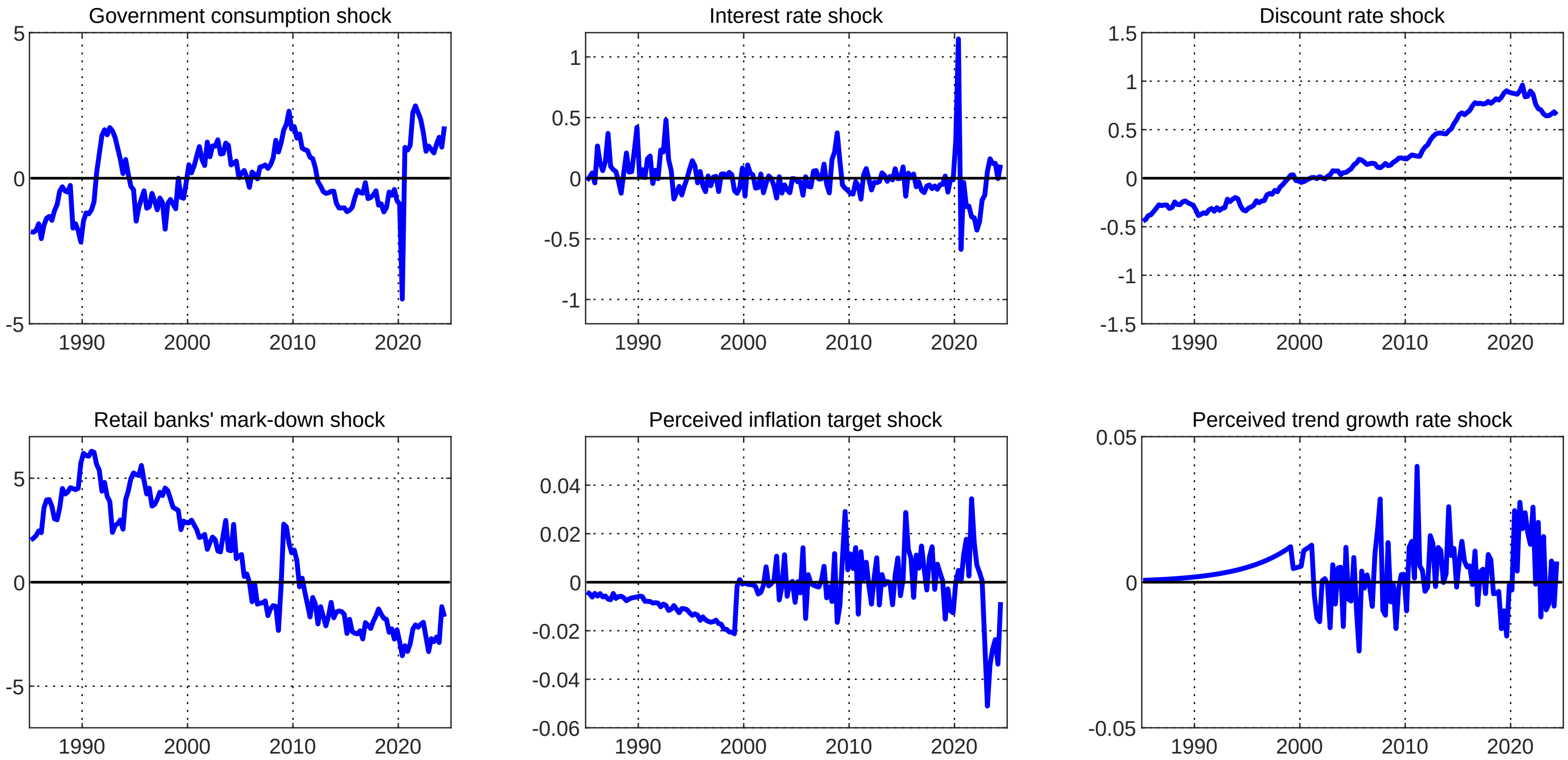
Note: This figure shows the smoothed estimates of the structural shocks of NAWM II, version 1.5, conditional on the posterior mode estimates of its parameters.

Figure 3: Smoothed estimates of the shocks (continued)



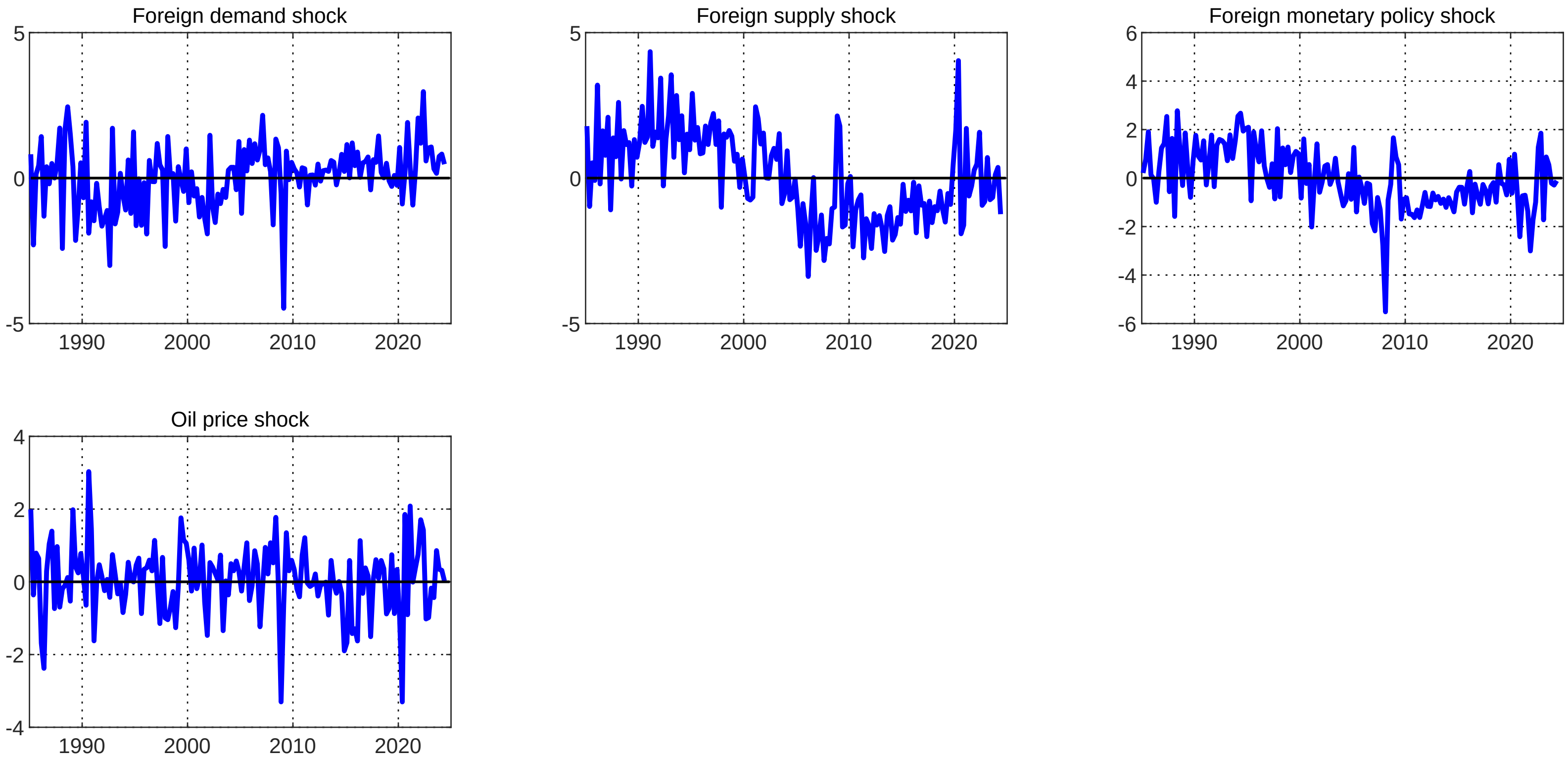
Note: See above.

Figure 3: Smoothed estimates of the shocks (continued)



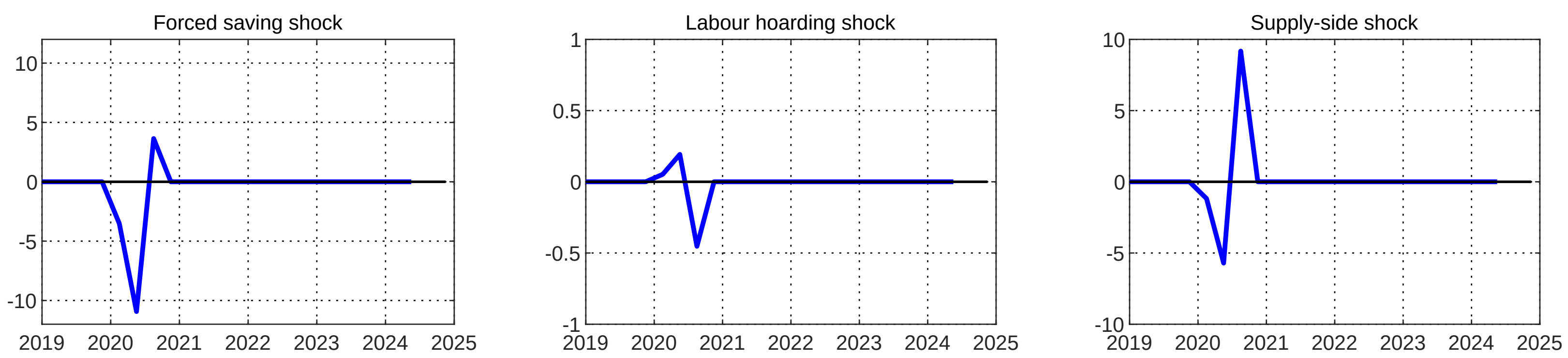
Note: See above.

Figure 3: Smoothed estimates of the shocks (continued)



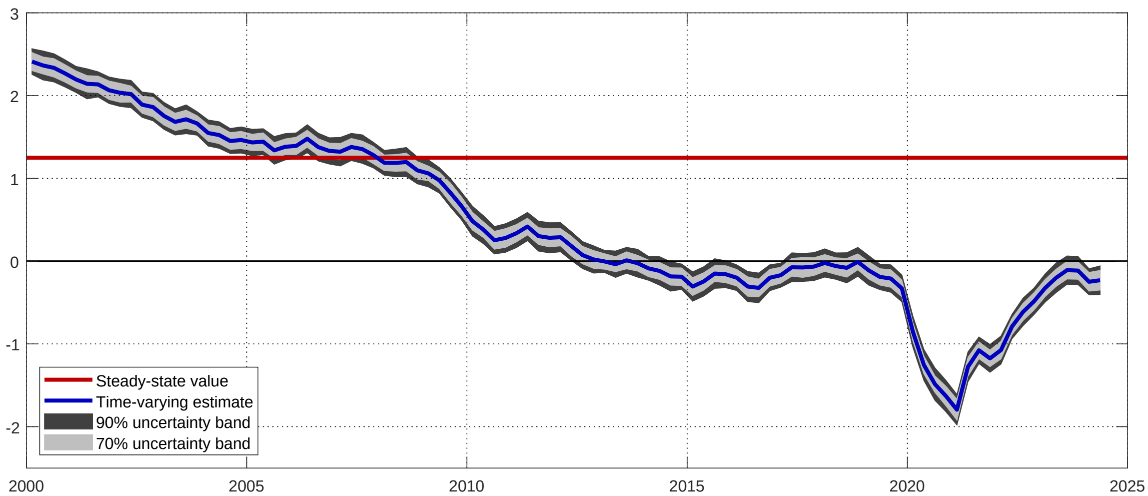
Note: See above.

Figure 3: Smoothed estimates of the shocks (continued)



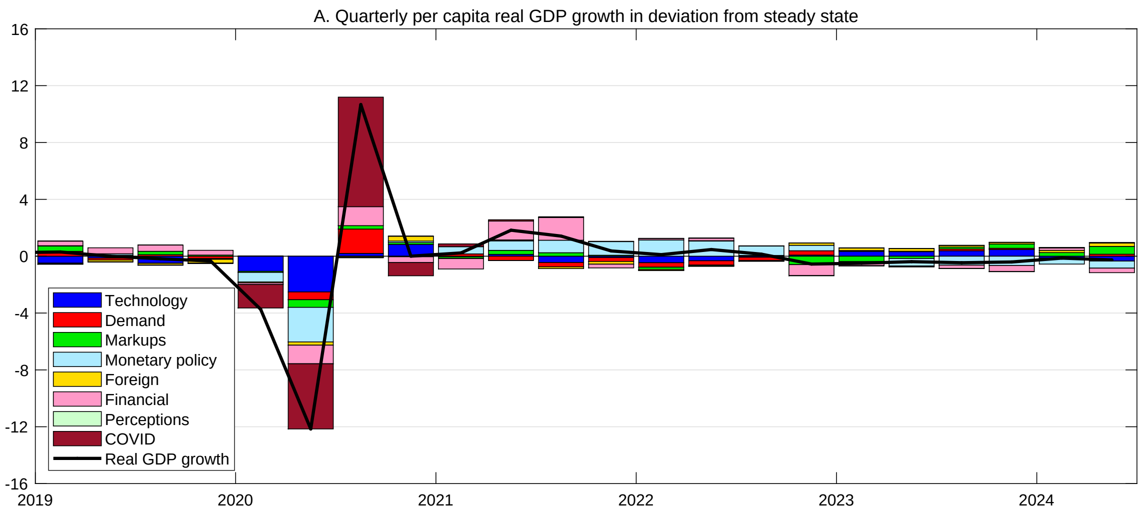
Note: See above.

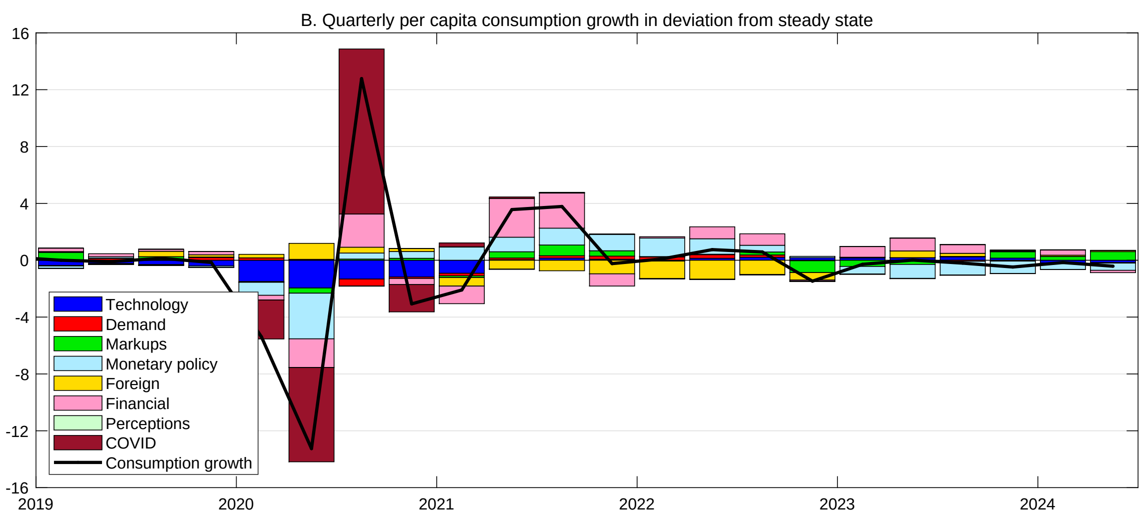
Figure 4: Model-based measures of the long-run real interest rate



Note: This figure shows the smooth estimates of the long-run real interest rate using the Kalman smoother along with equal-tails uncertainty bands. These bands have been estimated at the posterior mode parameter estimates with the simulation smoother using antithetic variables for balancing the location of the distribution; see, e.g., Durbin, J. and S. J. Koopman (2012), *Time Series Analysis by State Space Methods*, Oxford University Press, Oxford, 2nd Edition. The simulation smoother simulates draws from the distribution of the model's state variables over the full sample conditional on the observed data and the parameters. The uncertainty bands are based on 2,500 simulated values from this distribution based on three additional antithetic values per draw, resulting in a total of 10,000 draws. Further draws have little impact on the uncertainty bands.

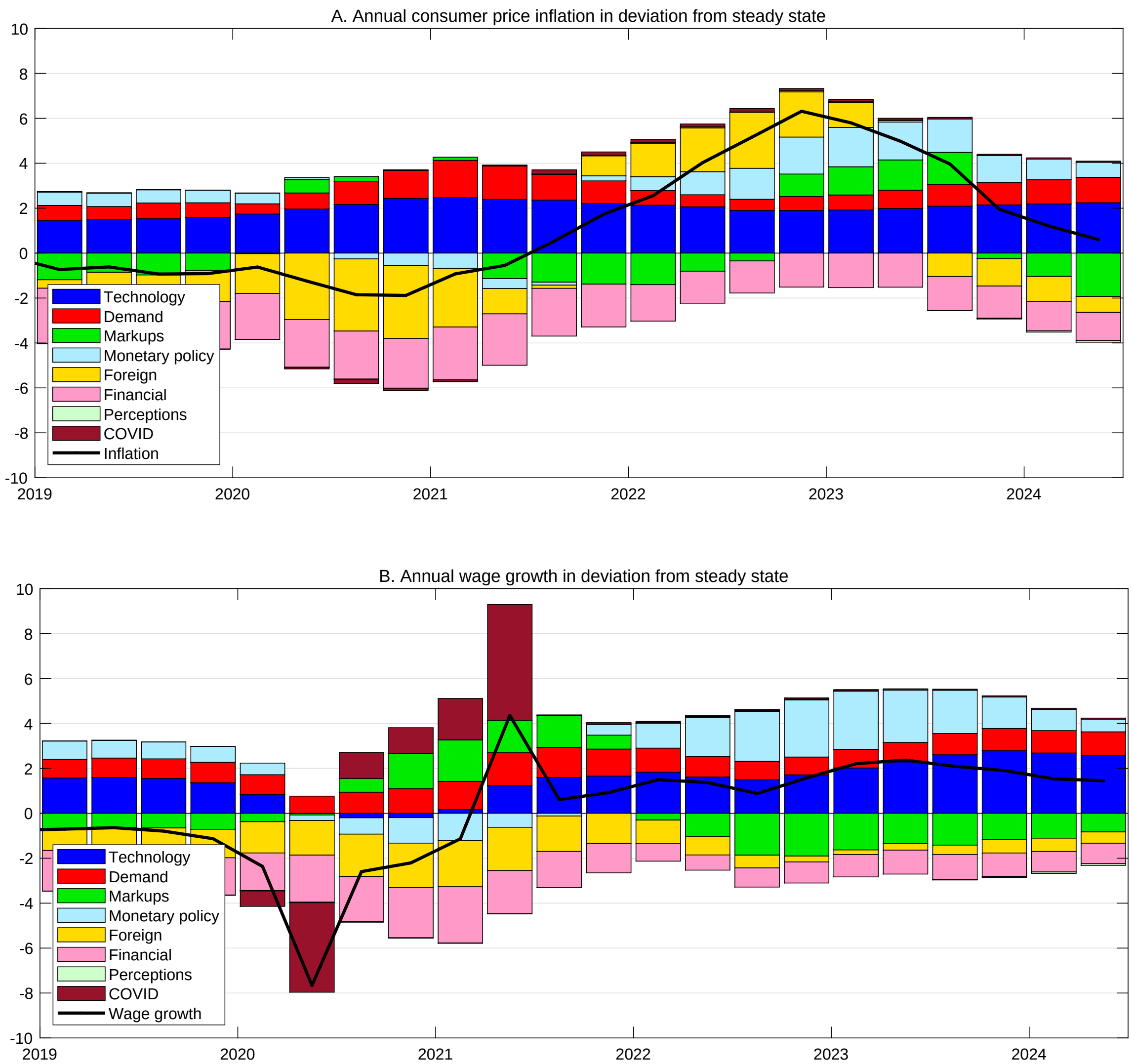
Figure 5: Historical decompositions of real GDP and private consumption growth





Note: The upper panel in this figure shows the decomposition of quarterly per-capita real GDP growth into the contributions of the structural shocks of NAWM II, version 1.5, over the period from 2019Q1 to 2024Q2. The shocks are bundled into seven groups: technology, demand, mark-up, foreign, financial and perception shocks, a monetary policy shock and the COVID shocks. The decomposition is computed in deviation from the model-implied steady-state growth rate of 0.375% per quarter using the posterior mode estimates of the model's estimated parameters. The lower panel shows the decomposition of quarterly per capita private consumption growth in deviation from the steady-state growth rate of 0.375%.

Figure 6: Historical decompositions of consumer price inflation and wage growth



Note: The upper panel in this figure shows the decomposition of annual consumer price inflation (measured in terms of the private consumption deflator) into the contributions of the structural shocks of the NAWM II, version 1.5, over the period 2019Q1 to 2024Q2 in deviation from the model's steady-state inflation rate of 2.0% per annum. The lower panel shows the decomposition of annual wage growth (measured in terms of compensation per head) in deviation from the steady-state growth rate of 3.2%. For details on the shock groups see Figure 5.