STAFF MEMO

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Abstract

In this paper, we estimate the neutral real rate for the Norwegian economy using two different empirical models, a vector autoregressive model with time-varying parameters (TVP-VAR) and a State-Space (SS) model similar to the Laubach-Williams model, respectively. In line with international evidence, all estimates indicate a falling trend. Furthermore, the estimates for Norway suggest that the Norwegian neutral short-term money market rate is now close to 0 percent in real terms.

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1 Introduction

The difference between the actual real interest rate and the neutral real rate indicates whether monetary policy is expansionary or contractionary (or neutral). Hence, the neutral real rate is a useful concept for central banks, providing a benchmark against which to evaluate the stance of monetary policy. The neutral real rate cannot be observed, and must be estimated.

The concept of a neutral rate was first introduced by the Swedish economist Knut Wicksell, who defined the neutral rate as the level of the real rate consistent with a stable path for commodity prices.[1] If the real interest rate deviated from its neutral level, Wicksell claimed that the general price level would rise or fall indefinitely. The concept of a neutral rate was later formalized and further developed by Woodford (2003).

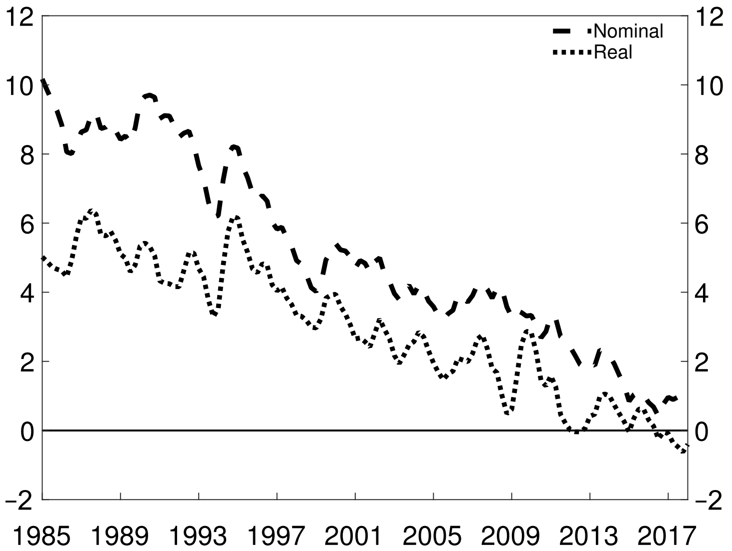
Here, we shall define the neutral real rate as the level of the real rate consistent with output at its potential and inflation on target, after all cyclical disturbances have dissipated, normally within 5-10 years. This will also be equivalent with the level of the real rate that clears the capital market in the medium to long run. The capital market is subject to various shocks, shifting both the investment and savings schedule. In a globalized world where savings move relatively freely between countries, international factors will play an important role in determining the domestic neutral rate.

As revealed in Figure 1, the level of real interest rates have been falling markedly over the last three decades in many countries, including Norway. Assuming that monetary policy cannot affect the real interest rate in the long run, the large and persistent decline in the real rates must be attributed to changes in fundamental real forces in the economy. This is confirmed by several studies, which, using different methods, conclude that the decline in real rates has been accompanied by a decline in the neutral level of the real rate, see e.g. Holston et al. (2017), Hamilton et al. (2015), Johannsen and Mertens (2016), Juselius et al. (2017), Kiley (2015) and Lubik and Matthes (2015).

In this paper, we estimate the neutral real rate for the Norwegian economy using two different empirical models, a VAR-model with time-varying parameters (TVP-VAR) and a State-Space (SS) model similar to Holston et al. (2017), respectively. In line with international evidence, all estimates indicate a falling trend. Furthermore, the estimates for Norway suggest that the neutral short term money market rate is now close to 0 percent in real terms. However, the uncertainty is significant.

[1] See Wicksell (1898). Wicksell named it the *neutral rate* of interest. In the literature, terms like *normal rate*, *equilibrium rate* and *natural rate* are also used alternately.

Figure 1. Ten-year government bond yields in 14 OECD countries including Norway. Percent. 1985 Q1 – 2018 Q1



Note: USA, Germany, France, Italy, UK, Japan, Netherlands, Austria, Belgium, Sweden, Denmark, Canada, Switzerland and Norway. Unweighted average. Source: OECD

2 Theory and background

What we in this paper term the neutral rate of interest is also known as the natural rate, the normal rate, the equilibrium rate and r-star (r*). All terms broadly refer to the same concept, and we will stick to the term neutral rate of interest in what follows. However, regardless of the name, slightly different definitions exist in both the economic literature and more popular writings. Even Wicksell, who first introduced the concept, would define it in different ways in his writings, both as the interest rate consistent with price stability and the real rate that would equate savings and investment. The fact that he viewed these definitions as mutually consistent is evident from the following quote:[2]

"There is a certain rate of interest on loans which is neutral in respect to commodity prices, and tend neither to raise nor to lower them. This is necessarily the same as the rate of interest which would be determined by supply and demand if no use were made of money and all lending were effected in the form of real capital goods."

Interestingly, he stresses that the neutral interest rate resides in an abstract world without money. In other words, the neutral rate of interest is independent of money - and monetary policy.

[2]See Wicksell (1898), p.102.

2.1 A short-run perspective

Woodford (2003) reintroduced the concept of the neutral rate within the context of New Keynesian models. He defines the neutral rate of interest as the equilibrium rate of interest that would prevail in the absence of nominal rigidities, i.e. when prices (and wages) are fully flexible. Again, this is an abstract setting where there is no rational for monetary policy and, hence, the neutral rate of interest is independent of monetary policy.

In its simplest form the standard New Keynesian model can be summarized by the following two equations:

$$y_t = E_t y_{t+1} - \sigma^{-1} \left(i_t - E_t \pi_{t+1} \right) + \mu_t \tag{1}$$

$$\pi_t = \beta \pi_{t+1} + \kappa \left(y_t - y_t^n \right) \tag{2}$$

where y_t and π_t denotes output and inflation, respectively, i_t is the nominal interest rate and μ_t summarizes all real disturbances. In the absence of nominal rigidities, inflation is zero and the equilibrium level of output is at its natural level, y_t^n. From the IS-curve, we then have:

$$y_t^n = E_t y_{t+1}^n - \sigma^{-1} i_t^n + \mu_t \tag{3}$$

which can be solved for the corresponding neutral (or natural) rate of interest, r^n, to yield:

$$r_t^n = \sigma \left[E_t \left(y_{t+1}^n - y_t^n \right) + \mu_t \right] \tag{4}$$

Hence, the neutral rate of interest depends on expected changes in the natural rate of output and real disturbances. Furthermore, the neutral rate of interest is defined in tandem with the natural rate of output. In Woodford's definition, any real disturbance, independent of its persistence, will move both the neutral rate of interest and the natural rate of output. This implies that the neutral rate, according to this definition, can move around substantially even in the short run.

A short term concept could be useful in some applications. However, as a point of reference and benchmark to gauge the degree of monetary stimulus, it might turn out to be too erratic to be of any practical use. For our purposes, a measure of lower frequency seems more appropriate. Using a medium to long-term definition, estimates of the neutral real rate also serve as an anchor for the real policy rate going forward.

The IS equation (1) is an equilibrium condition that implicitly defines the real interest rate that equates supply of savings from households with the demand for savings capital. In a model that includes real capital for production purposes (unlike the standard New Keynesian model), the latter will be equal to the demand for investment goods.

2.2 A medium to long run perspective

According to our definition, the real rate of interest that equates savings and investment in the medium to long run, when inflation can be expected to be on its target and output is equal to potential, is equivalent to the neutral real rate of interest. By definition it is independent of cyclical disturbances. However, it will vary in response to low-frequent movements in factors that shift the savings and investment schedules, such as e.g. demographics and trend productivity growth.

Several structural and persistent developments could potentially explain the downward trend in real neutral rates in the last two decades.[3] There has been a gradual decline in the underlying growth potential in most advanced economies since the early 2000s, both due to subdued growth in total factor productivity (TFP) and, more recently, a downward trend in the labor force following a gradual aging of the population.

There is also a more direct effect on savings from shifts in the age composition of the population. Consumption smoothing would imply that individuals have low savings rates when they are young and old, but high saving rates in between. Hence, as the baby-boomers have worked their way through the age bins, savings rates have been increasing. The fact that life expectancy has been steadily increasing has compounded this effect. People who live longer, need to save more. This has put downward pressure on real neutral rates around the world. However, some of these effects will most likely be reversed going forward.

Before the financial crisis demand in many countries was fueled by an increase in private debt, which in isolation led to a temporary increase in the neutral rate. Since the financial crisis the private sector has engaged in a prolonged period of deleveraging putting downward pressure on interest rates. In more recent years governments have also taken measures to reduce public debt.

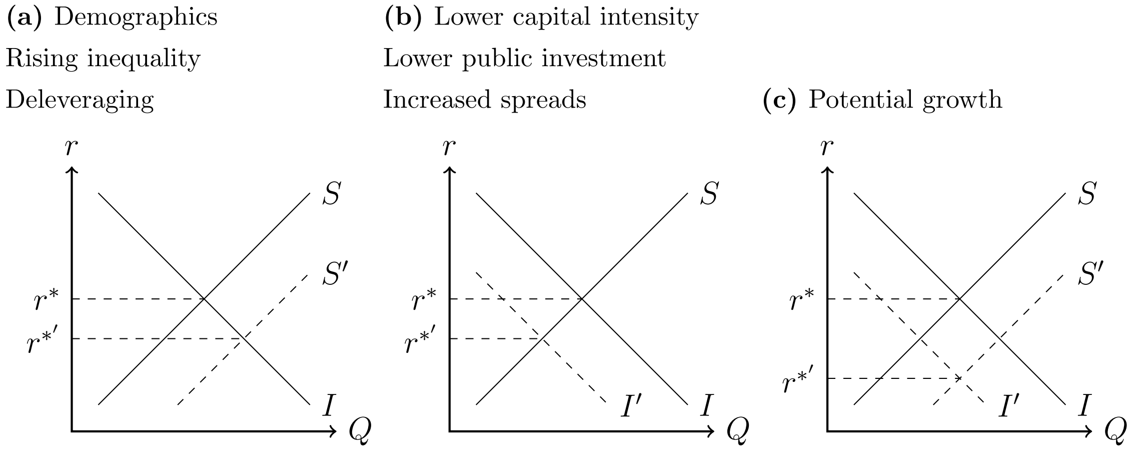
Some commentators have argued that increased inequality, in particular in the US, has contributed to increased savings. The reason is that rich people tend to spend less and save more than poorer people. Hence, when the income share of rich people increases, saving rates also tend to increase, pushing neutral rates down.

Turning to investment, some observers have pointed to the increased importance of large service-providing firms like e.g. Google and Amazon that are less capital intensive. This could to some extent explain the low investment rates seen in many countries, which has also contributed to push neutral rates down.

There is also some evidence suggesting that the spread between the risk-free rate and the return on capital has increased over time. The increased demand for safe assets,

[3] See Rachel and Smith (2015) for a thorough discussion.

Figure 2. Neutral real rate. Effects of changes in aggregate savings and investments.



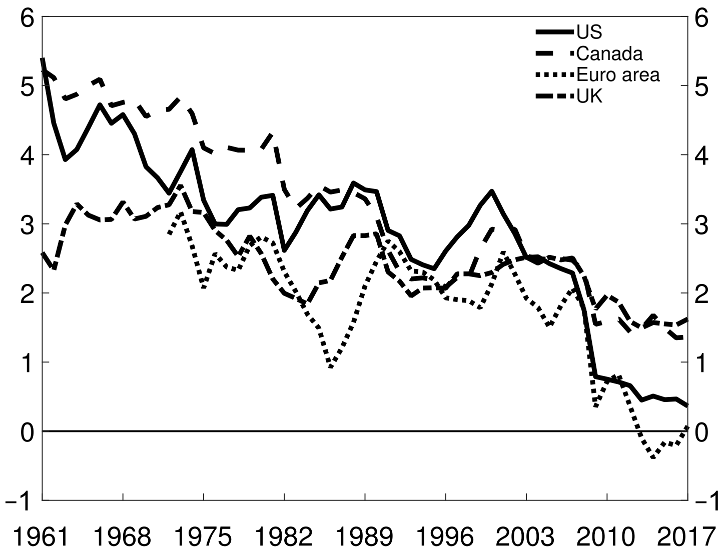
especially since the financial crisis, is one explanation. Because the relevant interest rate for firms' investment decisions is the risk-free rate plus a spread, an increase in the spread has contributed to push the neutral rates down.

In Figure 2, we illustrate how some of these factors affect the neutral real rate through low-frequency shifts in the saving and investment schedules. The two solid curves depict aggregate demand for investments and supply of savings, respectively. Some of the above-mentioned developments like e.g. an aging population, increased inequality and de-leveraging have predominately led to an increase in the supply of savings. This is illustrated in Figure 2a as a negative shift in the saving schedule, which results in a lower real rate. Figure 2b summarizes the effect of developments that mainly have led to a negative shift in the investment curve, like e.g. lower capital intensity and increased spreads, also resulting in a downward pressure on real rates. The reduction in productivity growth has probably lead to a shift in both the demand and supply schedule. This case is illustrated in Figure 2c. Taken together, these factors have likely contributed to a substantial reduction in the neutral level of real interest rates.

In a global economy, with relatively free movements of capital across borders, total savings in a country is not determined by domestic savings alone. Hence, the international return on capital also matters. In the long run it seems reasonable to assume that the domestic neutral rate will converge to a global neutral interest rate, which is the rate that equates global savings with global investment. Still, idiosyncratic disturbances can persist for quite some time.

The impression that estimates of neutral rates around the world share the same underlying drivers is supported by various studies. In Figure 3, we show estimates of neutral rates for the US, UK, Canada and the Euro area taken from Holston et al. (2017). Even though the estimates vary somewhat between the different countries, the correlations over time are quite strong.

Figure 3. Neutral real rate. Estimates from Holston et al. (2017). 2003 - 2017.



However, even if the domestic neutral rate to a large extent will be determined by global factors, this does not imply that we cannot use domestic data on e.g. output and inflation to obtain some information as to the magnitude of the neutral rate. For example in the absence of temporary disturbances, if the output gap and inflation rate changes over time, the prevailing interest rate cannot, by our definition, be equal to the neutral rate. Therefore it is still valid to make inference of the domestic neutral rate based on domestic data, even though the underlying drivers are determined internationally.

3 Empirical models

Although definitions of the neutral real rate might differ, they all share one common implication, namely that the neutral rate is unobservable and needs to be estimated. Various approaches have been proposed in the literature. They mainly differ in terms of the amount of structure - or theory - that is imposed. At the structural end of the spectrum, we find studies by Cúrdia et al. (2015) and Negro et al. (2017), who use a flex-price definition based on a medium scale DSGE model. Typically these studies include all real disturbances that hit the economy, both temporary and persistent. As alluded to above, this potentially yields more erratic estimates of the neutral rate. Another issue is that these estimates tend to be rather model dependent. In the following, we focus on two approaches that are both less structural, and thus, in some sense more general, and, more importantly, have a longer term perspective on the neutral rate.

3.1 VAR-model with time-varying parameters

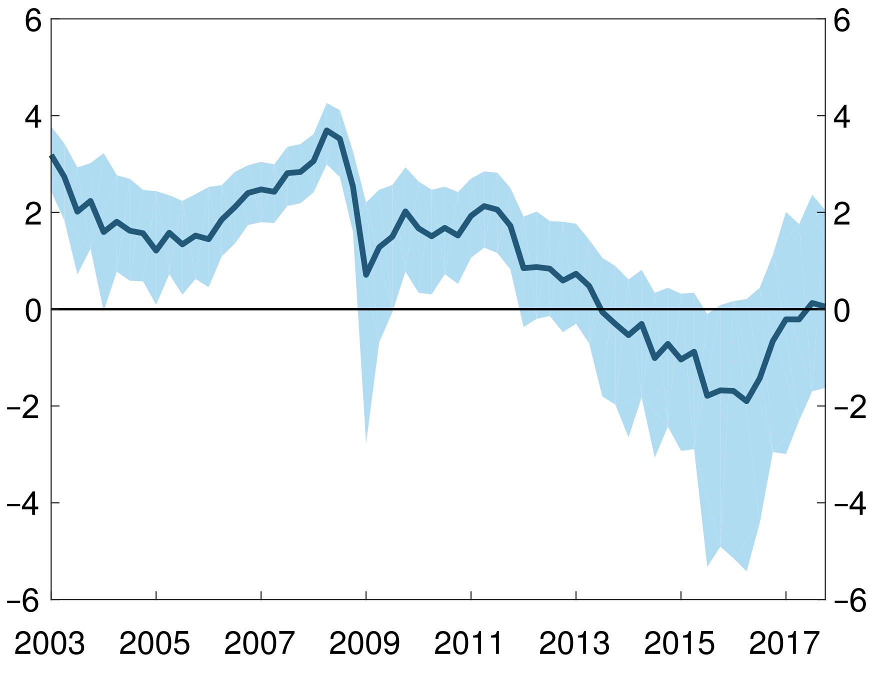
The first model is a vector autoregressive model with time-varying parameters (TVP-VAR), see Lubik and Matthes (2015). The model consists of three variables: real GDP, inflation and the real interest rate [4], each explained by lagged values of themselves and the other variables. In contrast to standard VAR models, we allow the parameter vector to vary over time. The model can be summarized compactly as:

$$X_t = \theta_t X_{t-1} + e_t \tag{5}$$

$$\theta_t = \theta_{t-1} + u_t \tag{6}$$

where X_t is a matrix of endogenous variables, θ_t, denotes a vector of time-varying parameters, and e_t and u_t are exogenous disturbances. We define the neutral real rate as the forecast from the model of the real interest rate 5 years from now, when all transitory shocks are assumed to have dissipated.[5] The model is estimated using a Bayesian

Figure 4. Neutral real rate. Estimate from TVP-VAR. 2003 - 2017.



perspective. We apply Gibbs sampling techniques, which allows us to recast the non-linear TVP-VAR into a conditionally linear state space model for each step of the Gibbs

[4] 3 month NIBOR minus CPI-ATE inflation.

[5] This seems to hold in our model, supported by the fact that model simulations show little difference in the 5 and 10 year ahead forecasts of the real interest rate.

sampling procedure (see e.g. Primicieri 2005), thus, making a rather complex non-linear inference problem tractable.

We start by obtaining smoothed estimates of the time-varying parameter vector, θ_t based on the whole sample period. For each t, we then produce a forecast of the real rate 5 years out. This is our time t estimate of the neutral rate. The estimates are shown in Figure 4.

The estimates indicate that the neutral rate has been on a downward trend since 2003. However, the results also point to significant variation over time. The estimates have increased somewhat since 2016 and suggest that the neutral rate currently is close to zero.

3.2 State-space models

The second model is a state-space (SS) model in the spirit of Holston et al. (2017). More specifically, the model is given by the following set of equations:

$$\hat{y}_t = \lambda_{\hat{y}} \hat{y}_{t-1} - \frac{1}{\sigma}(r_{t-1} - r^*_{t-1}) + \gamma_{\hat{y},\Delta op} \Delta op_t + e_{\hat{y},t} \tag{7}$$

$$\pi_t = \lambda_\pi \pi_{t-1} + \gamma_{\hat{y}} \hat{y}_{t-1} + e_{\pi,t} \tag{8}$$

$$\Delta y^*_t = g_t + e_{\Delta y^*,t} \tag{9}$$

$$\Delta y_t = \Delta \hat{y}_t + \Delta y^*_t \tag{10}$$

$$r^*_t = \sigma g_t + z_t \tag{11}$$

$$g_t = g_{t-1} + e_{g,t} \tag{12}$$

$$z_t = z_{t-1} + e_{z,t} \tag{13}$$

Equation (7) (IS-curve) specifies a relationship between the output gap and the real rate gap, where σ represents the intertemporal elasticity of substitution. Since Norway is a small open oil-exporting economy we include the change in the oil price as a control variable. Equation (8) represents a backward-looking version of the Phillips-curve, linking the inflation rate the output gap. Equation (9) specifies potential output (implicitly) as a random walk with a stochastic drift, g. Equation (10) decomposes output growth into changes in the output gap and changes in potential output. Equation (11) defines the neutral real rate as the sum of the trend growth rate of potential output, g, multiplied by the intertemporal elasticity of substitution, σ, and other unspecified determinants, z, potentially including low-frequent variation in factors like time preferences, demand for safe assets and demographics. The processes of g and z are specified in equation (12) and (13), respectively.[6]

Since the model is linear, we can use the standard Kalman-filter to obtain estimates of the unobservables and construct the likelihood function, see Hamilton (1994). As in Kiley (2015), we take a Bayesian perspective when estimating the parameters. The priors are relatively non-informative and are based on economic theory and prior evidence from empirical research on the Norwegian economy. For an overview of the prior and posterior distributions of the parameters, see Appendix C.

We rely on the following observables: real GDP, the 3-month money market rate deflated with core inflation, core inflation for domestically produced goods and services and the oil price. We also estimate a model where we use wage growth instead of domestic inflation, see Appendix B for a description of this model. All observables are demeaned prior to estimation. We use annual data from 1994 - 2017. For a more extensive description of the data, see Appendix A.

Figure 5. Neutral real rate. Smoothed estimates. State-Space models.
Mean and 68 percent highest density interval. 2003 - 2017.

(a) Model with domestic prices **(b)** Model with wages

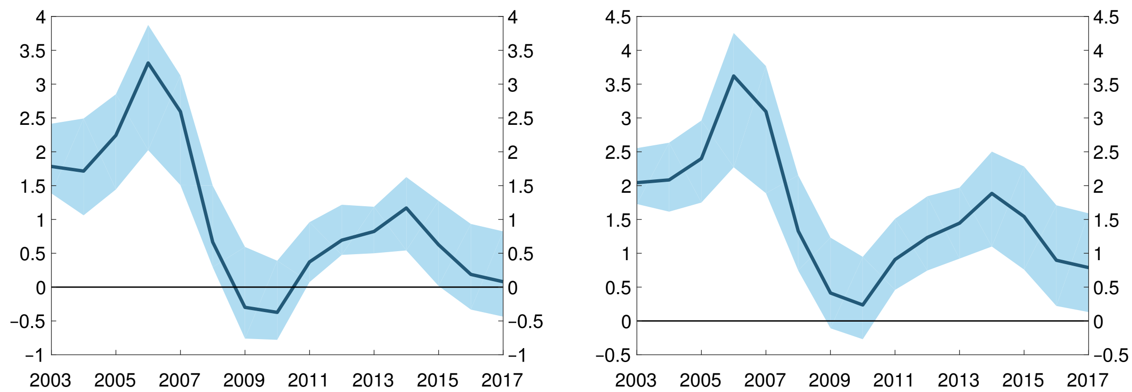


Figure 5a and 5b show the smoothed (two-sided) estimates from the Kalman-filter of the neutral real rate, employing the domestic part of CPI and wages, respectively, as measures of price pressure.[7] The estimates are obtained in the following manner, using Bayesian techniques. First, we simulate a sequence of 1,000,000 random samples from the posterior distribution of the parameters. Further, we obtain 50,000 draws from the simulated posterior distribution. For each of these 50,000 parameter draws we obtain an estimate using the Kalman-filter. The solid lines in figure 5a and 5b reflect the mean of

[6]In place of the random walk assumption, we have also experimented with alternative AR-specifications. However, this yielded rather similar results.

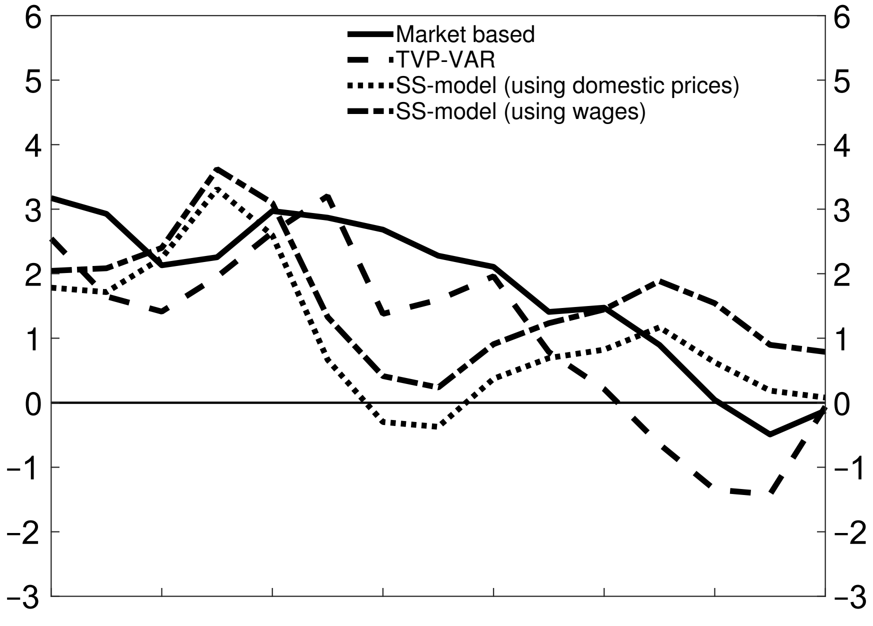
[7]Corresponding filter estimates for the output gap and potential growth can be found in Appendix D.

these estimates for each period. The probability bands represent the 68 percent highest density interval for each period based on the posterior distribution of the model parameters.

In line with the TVP-VAR estimates, the results indicate a falling trend in the neutral rate since 2003. Still, there is marked variation in the estimates over time. One thing to note is that the SS-estmates indicate a large drop in the neutral rate in the wake of the financial crisis, even below the estimates for 2017. Most of this fall is due to a corresponding drop in the estimated growth rate of natural output (g_t), shown in Appendix D. However, given the fact that the growth rate estimates are roughly similar in the two periods, some of the drop must also be attributed to other unspecified factors, captured by the z_t variable in equation (11).

Figure 6 summarizes the model estimates of the neutral real rate from the different models described above from 2003 - 2017. For comparison, we have also included estimates of long-term real rate expectations (labeled "Market based"), based on the 5-year nominal interest rates 5 years ahead, derived from swap contracts, and corresponding long-run inflation expectations. We note that all the estimates indicate a downward trend from 2003 - 2017. At the end of the sample, the estimates lie in the interval between −0.1 and 0.8 percent. Notably, in some periods, especially around the financial crisis, the various approaches yield rather different estimates for the neutral real rate.

Figure 6. Neutral real rate. Model estimates. 2003 - 2017.



4 Concluding remarks

In this paper we provide model estimates of the neutral real rate for Norway. The estimates are based on two empirical models previously used in the literature, a time-varying parameter VAR and a version of the Laubach-Williams model. Consistent with international studies, the estimates show a clear downward trend over the last two decades. Based on the mean values, we conclude that the neutral rate currently is close to zero. However, there is substantial uncertainty surrounding these point estimates.

The Laubach-Williams model could be extended along several dimensions. One interesting route to explore going forward would be to link financial stability more closely to the neutral rate concept. Juselius et al. (2017) find that explicitly taking financial factors into account somewhat modifies the drop in the neutral rate estimates for the US in recent years. Another extension that could yield some insights would be to account for international factors more directly in the model specification.

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Appendix A Data

Table 1. Extracted data. State-space models.

Variable	Source	Frequency
Gross domestic product Volume Mainland Norway	Statistics Norway	Annual 1994 - 2017
Consumer price index Adjusted for taxes and energy prices	Statistics Norway	Annual 1994 - 2017
Consumer price index Domestic sources	Statistics Norway	Annual 1994 - 2017
Wages	Technical Reporting Committee on Income Settlements	Annual 1994 - 2017
NIBOR 3-months	Norges Bank	Annual 1994 - 2017
Oil price Brent blend Dollar	Thomson Reuters	Annual 1994 - 2017
Total hours worked Mainland Norway	Statistics Norway	Annual 1994 - 2017

Table 2. Extracted data. VAR-model with time-varying parameters.

Variable	Source	Frequency
Gross domestic product Volume Mainland Norway	Statistics Norway	Quarterly 1994 - 2017
Consumer price index Adjusted for taxes and energy prices	Statistics Norway	Quarterly 1994 - 2017
NIBOR 3-months	Norges Bank	Quarterly 1994 - 2017

Appendix B State-Space model with wage growth

In the State-Space model where we use wage growth instead of domestic inflation we include the oil price and the productivity growth in the Phillips-curve, see equation (15).

$$\Delta y_t = \Delta \hat{y}_t + \Delta y_t^* \tag{14}$$

$$\Delta w_t = \lambda_{\Delta w} \Delta w_{t-1} + \gamma_{\hat{y}} \hat{y}_{t-1} + \gamma_{\Delta w, \Delta op} \Delta op_t + \gamma_{\Delta w, \Delta prod} \Delta prod_t + e_{\Delta w,t} \tag{15}$$

$$\hat{y}_t = \lambda_{\hat{y}} \hat{y}_{t-1} - \frac{1}{\sigma}(r_{t-1} - r_{t-1}^*) + \gamma_{\hat{y}, \Delta op} \Delta op_t + e_{\hat{y},t} \tag{16}$$

$$\Delta y_t^* = g_t + e_{\Delta y^*,t} \tag{17}$$

$$r_t^* = \sigma g_t + z_t \tag{18}$$

$$g_t = g_{t-1} + e_{g,t} \tag{19}$$

$$z_t = z_{t-1} + e_{z,t} \tag{20}$$

The $\Delta prod$ variable in equation (15) is a measure of the change in the trend productivity, computed as the change in the trend of real GDP per hour worked from a HP-filter with $\lambda = 100$.

Appendix C Parameters

Table 3. Estimated parameters. Domestic inflation.

Parameter	**Prior mean**	**Prior distribution**	**Posterior mean**
λ_{π}	0.5 (0.25)	Beta	0.47
$\gamma_{\hat{y}}$	0.5 (0.25)	Beta	0.29
$\lambda_{\hat{y}}$	0.5 (0.25)	Beta	0.74
σ	1 (2)	Normal	2.27
$\gamma_{\hat{y},\Delta op}$	0 (1)	Normal	0.06
Std of e_{π}	1 (2)	Inverse Gamma	0.53
Std of $e_{\hat{y}}$	1 (2)	Inverse Gamma	0.58
Std of $e_{\Delta y^*}$	0.5 (2)	Inverse Gamma	0.32
Std of e_g	0.5 (2)	Inverse Gamma	0.43
Std of e_z	0.5 (2)	Inverse Gamma	0.52

Standard deviation in parentheses.

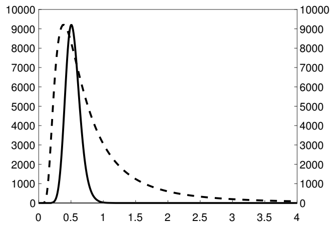
Table 4. Estimated parameters. Wage growth.

Parameter	**Prior mean**	**Prior distribution**	**Posterior mean**
$\lambda_{\Delta w}$	0.5 (0.25)	Beta	0.27
$\gamma_{\hat{y}}$	0.5 (0.25)	Beta	0.32
$\lambda_{\hat{y}}$	0.5 (0.25)	Beta	0.73
σ	1 (2)	Normal	2.24
$\gamma_{\hat{y},\Delta op}$	0 (1)	Normal	0.07
$\gamma_{\Delta w,\Delta op}$	0 (1)	Normal	0.02
$\gamma_{\Delta w,\Delta prod}$	1 (0.5)	Normal	1.07
Std of $e_{\Delta w}$	1 (2)	Inverse Gamma	0.68
Std of $e_{\hat{y}}$	1 (2)	Inverse Gamma	0.52
Std of $e_{\Delta y^*}$	0.5 (2)	Inverse Gamma	0.35
Std of e_g	0.5 (2)	Inverse Gamma	0.45
Std of e_z	0.5 (2)	Inverse Gamma	0.37

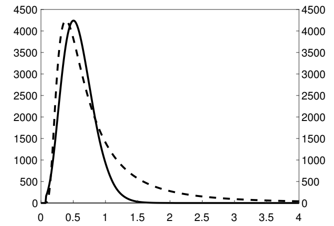
Standard deviation in parentheses.

Figure 7. Parameter distributions. Domestic inflation.
Prior (dotted) and posterior (solid).

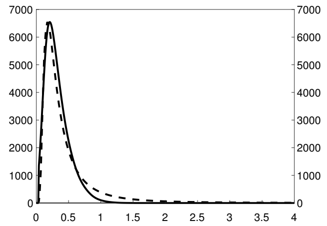
(a) Standard deviation of e_π



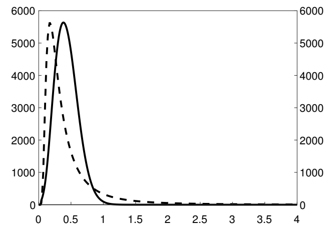
(b) Standard deviation of $e_{\hat{y}}$



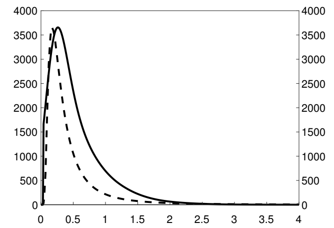
(c) Standard deviation of $e_{\Delta y^*}$



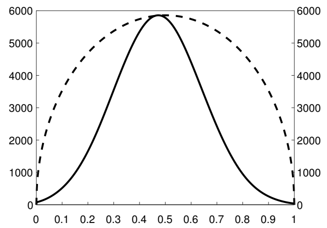
(d) Standard deviation of e_g



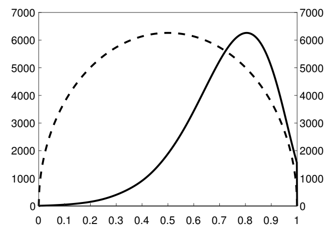
(e) Standard deviation of e_z



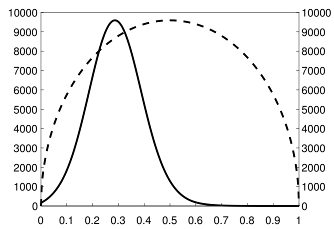
(f) λ_π



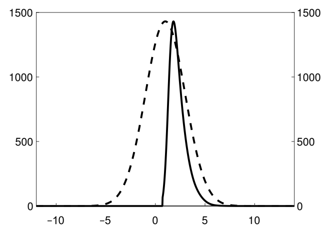
(g) $\lambda_{\hat{y}}$



(h) $\gamma_{\hat{y}}$



(i) σ



(j) $\gamma_{\hat{y},\Delta op}$

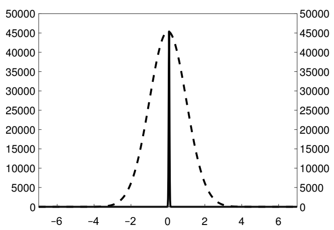
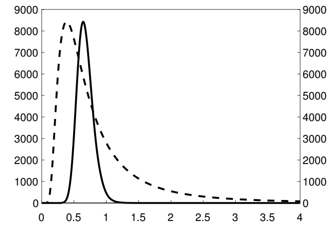
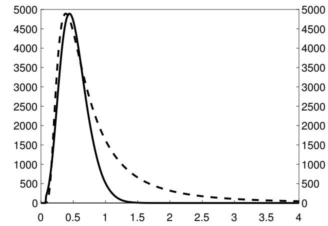


Figure 8. Parameter distributions. Wage growth.
Prior (dotted) and posterior (solid).

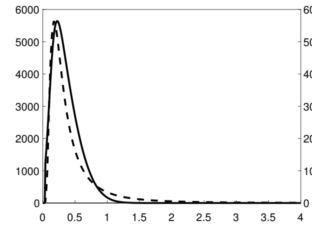
(a) Standard deviation of $e_{\Delta w}$



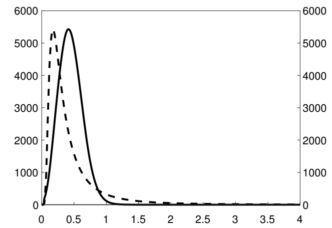
(b) Standard deviation of $e_{\hat{y}}$



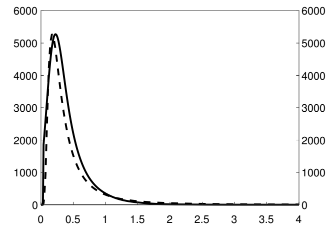
(c) Standard deviation of $e_{\Delta y^*}$



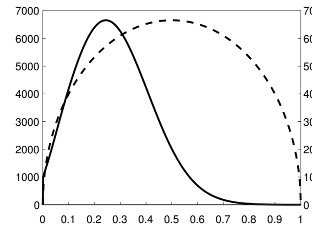
(d) Standard deviation of e_g



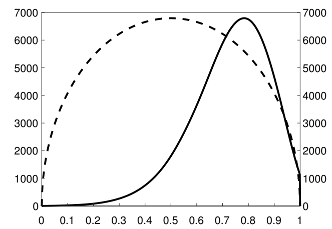
(e) Standard deviation of e_z



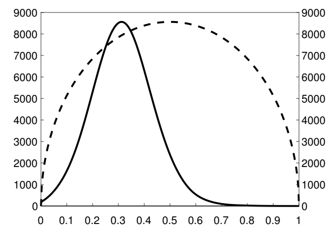
(f) $\lambda_{\Delta w}$



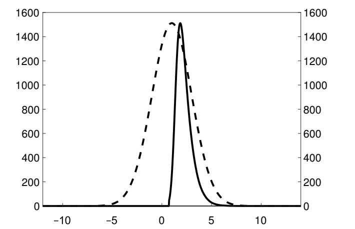
(g) $\lambda_{\hat{y}}$



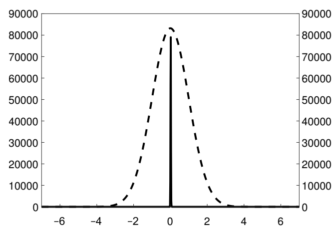
(h) $\gamma_{\hat{y}}$



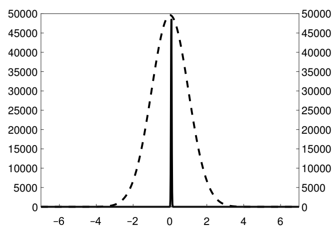
(i) σ



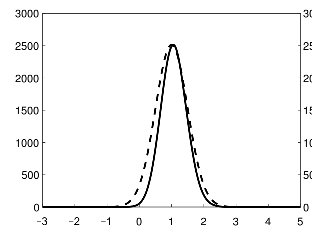
(j) $\gamma_{\Delta w,\Delta op}$



(k) $\gamma_{\hat{y},\Delta op}$



(l) $\gamma_{\Delta w,\Delta prod}$



Appendix D Output gap and potential growth

Figure 9. Smoothed estimates. State-Space model with domestic prices.
Mean and 68 percent highest density interval. 2003 - 2017.

(a) Output gap **(b)** Trend growth of potential output

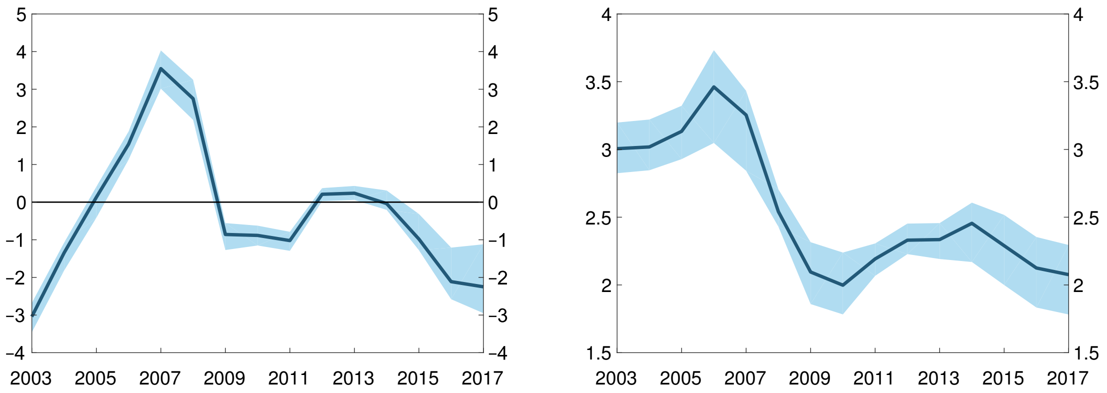


Figure 10. Smoothed estimates. State-Space model with wages.
Mean and 68 percent highest density interval. 2003 - 2017.

(a) Output gap **(b)** Trend growth of potential output