Norges Bank

21 | 2024

Working Paper

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Norges Bank Research

Authors:
Hilde C. Bjørnland
Leif Brubakk
Nicolò Maffei-Faccioli

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ISSN 1502-8143 (online)

ISBN 978-82-8379-350-5 (online)

PIECING THE PUZZLE: REAL EXCHANGE RATES AND LONG-RUN FUNDAMENTALS [*]

HILDE C. BJØRNLAND[†], LEIF BRUBAKK[‡] and NICOLÒ MAFFEI-FACCIOLI[§]

December 19, 2024

Abstract: This paper examines the structural determinants of real exchange rates, emphasizing the persistent low-frequency movements that traditional models, such as Purchasing Power Parity (PPP) and Uncovered Interest Parity (UIP), often fail to capture. To address this, we propose a structural VAR model with common trends, enabling a clear distinction between transitory and long-term effects of structural shocks. Estimated using Bayesian techniques and applied to Canada and Norway — two resource-rich economies — the model reveals that productivity shifts and commodity market trends significantly influence domestic activity and the real exchange rate in both countries. Importantly, the model also avoids the delayed overshooting puzzle commonly associated with recursive VARs in response to monetary policy shocks. Instead, it generates exchange rate dynamics consistent with the UIP hypothesis, characterized by immediate overshooting followed by a gradual depreciation to equilibrium.

JEL classification codes: *C32, F41, O47, Q3.*

Keywords: *Oil shocks, Resource movement, productivity differentials, Long run, SVAR.*

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[*] This paper should not be reported as representing the views of Norges Bank. The views expressed are those of the authors and do not necessarily reflect those of the Norges Bank. We are thankful to Fabio Canova, Efrem Castelnuovo, Domenico Giannone, Giorgio Primiceri, Ørjan Robstad, Leif Anders Thorsrud, Ragnar Torvik and conference and seminar participants at the Bank of Italy, Norges Bank, the University of Padova, the European University Institute, the University of Sydney, the SNDE 2024 Annual Symposium in Padova, the ISF 2024 Annual Conference in Dijon, and the IAAE 2024 Annual Conferene in Thessaloniki for insightful discussions and helpful comments regarding this paper.

[†] BI Norwegian Business School and Norges Bank. Email: hilde.c.bjornland@bi.no

[‡] Norges Bank. Email: leif.brubakk@norges-bank.no.

[§] Norges Bank. Email: nicolo.maffei-faccioli@norges-bank.no.

1 Introduction

The determination of real exchange rates remains one of the most enduring and debated topics in international economics. Despite decades of research, fundamental questions about what drives exchange rates remain unsettled. A central concept in open economy models and monetary policy discussions is the long-run equilibrium real exchange rate, i.e. the level to which the real exchange rate will return when temporary shocks eventually die out. In many of the theoretical models, the long-run level of the real exchange rate is pinned down by the Purchasing Power Parity (PPP) and Uncovered Interest Parity (UIP) assumptions. However, both parities consistently fall short in accounting for the persistent deviations observed in empirical data. This has lead to a pursuit for alternative theories and economic fundamentals that can better capture the long-term divergence of real exchange rates from their expected parities. Yet, despite numerous efforts, the empirical evidence on the links between economic fundamentals and exchange rate movements remains inconclusive, a phenomenom famously described as the "disconnect puzzle" by Rogoff and Obstfeld (2000).

The aim of this paper is to provide a piece to this puzzle by shedding new insights into the empirical relevance of well-established theoretical exchange rate models and fundamentals. Specifically, we focus on explaining low-frequency movements in real exchange rates, which account for the majority of overall fluctuations in exchange rate data (Rabanal and Rubio-Ramirez (2015), Gehrke and Yao (2017)). To achieve this, we introduce a novel approach to identifying the structural long-run determinants of exchange rate variation by employing an estimated vector autoregressive (VAR) model with common trends. This econometric framework, originally developed by Del Negro, Giannone, Giannoni, and Tambalotti (2017), has recently been successfully applied in some other contexts, c.f. Maffei-Faccioli (2021) and Ascari and Fosso (2023).

We apply our model framework to two resource-rich economies, Canada and Norway. By focusing on these countries, we explore the broader implications of long-run structural drivers, such as natural resources and productivity changes, in shaping real exchange rates.

Movements in the real exchange rate arise from a complex interaction of interrelated economic forces, each exerting influence over varying time horizons. A significant econometric challenge lies in disentangling short-term fluctuations — primarily driven by nominal exchange rate changes — from the more persistent, low-frequency variations in the real exchange rate. Addressing this requires a framework that incorporates a comprehensive set of macroeconomic variables spanning the relevant frequency spectrum, alongside an econometric approach capable of distinguishing between transitory and secular factors. In our analysis, we implement several methodological choices that facilitate robust identification.

First, we rely on annual data, which allows us to abstract from high-frequency movements. In the short run, the exchange rate can be expected to be driven by news about the future (Shiller, 1981), which may be partly decoupled from current realizations of economic fundamentals. Relatedly, imperfect information and expectations revisions can lead to noisy exchange rate behavior in the short run, seemingly unrelated to fundamentals (Evans, 2010).

Second, the econometric model makes a clear distinction between trends and cycles, enabling us to distinguish short-term fluctuations, due to say, hypotheses such as the UIP[1], from the underlying low-frequent drivers. This distinction ensures that existence of cyclical variations in the real exchange rate do not obscure the identification of long-term structural trends.

Third, the choice of variables and identification of common trends are guided by both economic theory and previous empirical findings. In particular, in choosing the secular model specification we build on the Balassa–Samuelson hypothesis, a theoretical framework linking productivity differences across countries to long-term movements in real exchange rates, (Balassa, 1964; Samuelson, 1964). The theory implies that high productivity growth in the tradable sector induces an increase in the relative price of non-tradables, thereby appreciating the real exchange rate. A corollary to this is that countries experiencing stronger productivity growth will see higher relative price increases in non-tradables, resulting in real

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[1] The UIP predicts that exchange rate movements should offset interest rate differentials between countries to maintain arbitrage-free conditions in international financial markets

exchange rate appreciation.[2] This narrative also extends to resource-rich economies, where theories like Dutch disease have been invoked to explain how windfall gains due to say, higher terms of traede lead to real exchange rate appreciation and subsequently de-industrialization, see Corden and Neary (1982); Eastwood and Venables (1982); Corden (1984) for seminal papers.[3] However, as shown in Bjørnland, Thorsrud, and Torvik (2019), focusing solely on windfall gains from terms-of-trade improvements can lead to incorrect conclusions. While terms-of-trade-driven booms can result in de-industrialization through increased spending and currency appreciation, volume-driven booms (i.e, new discoveries or more productive fields) can enhance productivity across sectors via learning by doing and spillovers, see also Torvik (2001), Allcott and Keniston (2018) and Arezki, Ramey, and Sheng (2017). This highlights the importance of understanding the source of windfall gains for interpreting exchange rate dynamics and broader macroeconomic developments.

The state space representation of the econometric model is particularly useful when it comes to addressing our research question in light of these relevant theories. In particular, based on the above, we postulate that there are four macroeconomic trends characterizing the non-stationary variables in the system: an oil price trend, a petroleum activity trend, a productivity differential trend and a global productivity trend. Together, these trends aim to capture the key mechanisms underlying the Balassa-Samuelson hypothesis and Dutch Disease theory, including the effects of productivity differentials and resource windfalls on real exchange rate dynamics. In addition we also allow for a global productivity trend, to account for the effect of broader global economic developments for the domestic variables. The latent cyclical variation in the observables is represented by a reduced-form VAR, which also includes cyclical variables such as the unemployment rate and the interest rate differential, alongside the non-stationary variables. This structure allows us to simultaneously account for both business cycle and longer-run fluctuations in the real exchange rate.

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[2] This implicitly assumes that the law on one price holds for tradables.

[3] The Dutch disease term originates from the Netherlands' experience in the 1960s, when natural gas discoveries led to a stronger currency and weakened non-resource industries.

Applying the model to Canada and Norway, we find that, consistent with theory predictions, shocks to the productivity differential and the petroleum activity trend account for a sizeable share of the trend in non-oil productivity and the real exchange in both countries, consistent with the Balassa-Samuelson hypothesis and the Dutch Disease theory. Moreover, we demonstrate that, following a prolonged period of windfall gains and currency appreciation, the decline of the Norwegian petroleum sector has already markedly dampened the trend growth rate of productivity and led to a substantial weakening of the krone exchange rate. We do not yet observe a similar pattern in the Canadian data. Interestingly, while the oil price trend explains a considerable share of the real exchange rate appreciation observed over the sample period, it has a limited impact on domestic productivity. Finally, we find no trace of the delayed overshooting puzzle often reported in the literature following a monetary policy shock. Rather, the results indicate that the exchange rate appreciates immediately on impact, before the effect gradually dies out, consistent with the overshooting hypothesis proposed by Dornbusch (1976). This suggests that explicitly modeling structural trends alongside cyclical components provides a more comprehensive understanding of how exchange rates adjust to both short-term shocks and long-term structural drivers.

Related Literature. Our paper relates to and combines several approaches already developed in the literature. First, we fit into a large literature trying to explain or forecast exchange rate dynamics using relevant fundamentals, see the seminal papers by Meese and Rogoff (1983) and Rogoff and Obstfeld (2000), respectively. We contribute by using a structural common trends framework to analyse real exchange rates, simultaneously accounting for both temporary and secular drivers.

Second, we relate to a specific literature examining the macroeconomic effects of windfall gains, see e.g. Weber (2012), Gilje, Ready, and Roussanov (2016), Bjørnland and Thorsrud (2016), Feyrer, Mansur, and Sacerdote (2017), Allcott and Keniston (2018), Arezki et al. (2017), Bjørnland et al. (2019), Harding, Stefanski, and Toews (2020), and Bjørnland and Skretting (2024) for some recent paper analysing different resource rich economies. In this context, a related paper is also Bems, Boehnert, Pescatori, and Stuermer (2023), that analyze the effects of declining resource extraction on economic outcomes in resource rich economies using local projections.[4] In contrast to these papers, we take a broader perspective, by jointly accounting for short-term and long-term effects of structural shocks.

Third, we relate to a literature on commodity currencies, including the widely cited paper by Chen and Rogoff (2003), and more recent papers like Cashin, Céspedes, and Sahay (2004) and Ferraro, Rogoff, and Rossi (2015), linking commodity prices to fluctuations in exchange rates in resource rich economies. Our work extends this literature by incorporating additional structural drivers, such as productivity differentials and petroleum activity. By focusing on secular trends through a structural common trends framework, we provide a more comprehensive understanding of real exchange rate dynamics in resource-rich economies.

The paper is organized as follows. We summarize the main theories used to explain relevant long term drivers in resource rich economies in Section 2. In Section 3 we explain the econometric methodology used to extract the low-frequency components and to identify the structural shocks. Section 4 presents the main findings, whereas in Section 5 we analyze robustness. Section 6 provides concluding comments.

2 Long-term drivers in resource-rich economies

Economic theory suggests several reasons why there should be interaction effects between productivity gains-both within the resource sector and in other parts of the economy—and the exchange rate in countries reliant on natural wealth. Importantly, the Balassa-Samuelson hypothesis, as outlined by Balassa (1964) and Samuelson (1964), provides a framework for understanding how sectoral productivity differences influence relative prices and the real exchange rate in the long run. Productivity growth in the tradable sector raises wages across both tradable and non-tradable sectors due to labor mobility. Since non-tradables

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[4] Using local projections, Bems et al. (2023) estimate the impact of declining extraction on economic variables, covering 13 minerals and 122 countries, showing that reductions in extraction have persistent negative effects on real GDP and the trade balance, alongside a depreciation of the real exchange rate.

are not subject to international price competition, this results in higher relative prices for non-tradables, increasing the domestic price level (all else equal) and appreciating the real exchange rate. Extending this logic to aggregate productivity differences, economies with higher overall productivity relative to foreign economies often experience persistent real exchange rate appreciation, as their domestic price levels rise relative to foreign prices, see for instance Kravis and Lipsey (1988), Bergstrand (1991), De Gregorio, Giovannini, and Wolf (1994), and Cravino and Haltenhof (2020), for some evidence.

The Balassa-Samuelsson hypothesis, in its original form, rests on the assumption that the law of one price holds for tradable goods, which implies that the terms of trade is constant. Accordingly, the terms of trade play no role in shaping movements in the real exchange rate. The assumption that the law of one price holds is not supported by empirical findings, which point to persistent movements in the terms of trade over long horizons (Canzoneri, Cumby, and Diba, 1999 and Engel, 1999). In more recent theoretical work, deviations from the law of one price arise, inter alia, due to home bias in demand, trade specialization or product differentiation (Benigno and Thoenissen, 2003; MacDonald, 2007; Corsetti, Dedola, and Leduc, 2008; Choudhri and Schembri, 2010; Bordo, Choudhri, Fazio, and MacDonald, 2017). In models where the law-of-one-price assumption is relaxed, there will typically be a negative co-movement between the terms of trade and the real exchange rate. Hence, a positive shock to the terms of trade, implying a terms-of-trade improvement, leads to a real appreciation. At the same time, having a terms-of-trade channel means that productivity shocks originating in the domestic tradable sector can affect the real exchange rate, not only through a Balassa-Samuelsson effect, but also through a terms-of-trade effect. In some models, a positive productivity shock in the domestic tradables sector will lead to lower price in that sector and, as a result, a deterioration of the terms-of-trade. This could to some extent dampen or even reverse the Balassa-Samuelsson effect. However, for small open economies where export prices predominantly are determined in world markets, the endogenous terms-of-trade channel is probably less significant.

In resource-rich economies, the Balassa-Samuelson narrative and the terms-of-trade channel can be extended by the Dutch Disease framework. Formalized by Corden and Neary (1982) and Corden (1984), it explains how resource booms affect resource rich economies through two mechanisms. The spending effect raises demand for non-tradables, driving up their prices and appreciating the real exchange rate. The resource movement effect shifts labor and capital to resource and non-tradable sectors, reducing productivity in tradables and further appreciating the exchange rate. However, more recent studies suggest the effects may be more nuanced, emphasizing the role of resource booms in shaping productivity through learning by doing and productivity spillovers, cf. Torvik (2001), Allcott and Keniston (2018), Arezki et al. (2017), and Bjørnland et al. (2019). In particular, Bjørnland et al. (2019) highlight that production-driven resource booms can yield positive productivity effects, overturning earlier results, that suggest evidence of de-industrialization.[5] In contrast, however, they find no such effects following a terms of trade shock. This distinction underscores the importance of separating shocks driven by production increases from those driven by terms-of-trade improvements when interpreting exchange rate dynamics and broader macroeconomic developments.

To sum up, we expect real exchange rates in resource-rich economies to be influenced by three key long-term drivers (trends): **Productivity differential trend** impacts the exchange rate through the Balassa-Samuelson effect, where higher domestic productivity growth, particularly in tradables, enhances competitiveness and raises non-tradable prices, leading to real exchange rate appreciation. **Oil price trend** affects the exchange rate by increasing national income and spending, thereby pushing up demand for non-tradables and appreciating the real exchange rate. **Resource extraction trend** shifts resources, boost spending and work to appreciate the real exchange rate, but it may also generate positive spillovers to the non-oil economy through learning by doing.

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[5] Notably, in the case of Norway, the expansion of oil production and investment has given rise to a substantial and profitable oil service industry. In turn, this technologically advanced industry has likely exerted its influence on various other sectors in Norway through productivity spillovers.

In addition to these three trends, the influence of broader global economic developments will be relevant for the other domestic variables. We therefore also include a **global productivity trend** into the model, capturing long-term global shocks that shape domestic economic variables. Together, these four drivers provide a comprehensive framework for understanding long-run dynamics in resource-rich economies.

3 The model framework

Consider the following reduced-form VAR with common trends as in Del Negro et al. (2017):

$$y_t = \Lambda \tau_t + \tilde{y}_t \tag{1}$$

$$\tau_t = c + \tau_{t-1} + v_t, \quad v_t \sim N(0, \Sigma) \tag{2}$$

$$\tilde{y}_t = A_1 \tilde{y}_{t-1} + \cdots + A_p \tilde{y}_{t-p} + u_t, \quad u_t \sim N(0, \Omega) \tag{3}$$

where y_t is a $n \times 1$ vector containing all the n endogenous variables,and τ_t is a $q \times 1$ vector of low-frequency components, with $q \leq n$. The matrices $A_1, ..., A_p$ are $n \times n$ coefficient matrices associated with the p lags of the stationary component $\tilde{y}_t$. The residuals v_t and u_t are the reduced-form residuals of the trend and stationary components, respectively, and assumed to be orthogonal. The matix $\Lambda(\lambda)$ is a $n \times q$ loading matrix that maps the trend component τ_t to the dependent variable y_t. It reflects the co-integrating relations between the variables in the system, and depends on the parameter vector λ. This matrix has rank q, yielding $n - q$ co-integrating relations. Hence, the trend components of the observables, $\bar{y}_t$, are linear combinations of the common trends, τ_t, given by

$$\bar{y}_t = \Lambda \tau_t \tag{4}$$

3.1 Identification

The latent variables included in the model (1)-(3) will not be uniquely identified without additional parameter restrictions. For example, by pre-multiplying equation (2) by an arbitrary $q \times q$ matrix of full rank, B, and setting $\tilde{\Lambda} = \Lambda B^{-1}$, we obtain a new model which is observationally equivalent to the model given by equations (1)-(3). In order to uniquely identify both the trend components and Λ, q^2 additional restrictions are needed.

In this paper, we employ a set of identifying assumptions discussed in Bai and Wang (2015), which imposes restrictions on both the elements in Λ and the covariance matrix of the trend innovations. More specifically, let

$$\Lambda = \begin{bmatrix} \Lambda_1 \\ \Lambda_2 \end{bmatrix} \tag{5}$$

where Λ_1 is of dimension $q \times q$. We restrict Λ_1 to be lower triangular and assume that covariance matrix of the trend residuals, Σ, is diagonal. This also implies that the trend residuals are uncorrelated and, hence, by construction, can be given a structural interpretation. The restrictions on the covariance matrix are implemented into the estimation procedure in the form of relatively tight priors and a Cholesky factorization of the variance-covariance matrix.

3.2 Empirical Specification

The observables that we employ are chosen with the aim to provide a minimal, but sufficient information set that will allow us to: i) disentangle cyclical and trend variation in the real exchange rate and the other relevant macroeconomic variables, and at the same time, ii) facilitate the identification of four structural trends that both theory and previous empirical evidence point to as plausible secular drivers in resource-rich economies, c.f. Section 2.

To this end, we include nine observables in our information set, of which two are assumed to be purely cyclical. For both Norway and Canada, the vector of observables, y_t, includes the following macroeconomic variables (from the first element to the last): the logarithm of real oil prices (P^o), the logarithm of petroleum production as a share of non-petroleum real GDP ($\frac{Q^p}{Y^{np}}$), the labor productivity differential ($z^F - z^H$), which is the logarithm of Foreign productivity relative to Home productivity, the logarithm of non-petroleum real GDP per hour (z^H), the logarithm of petroleum investment as a share of non-petroleum GDP ($\frac{I^p}{Y^{np}}$), the logarithm of real hourly wages (w), the real exchange rate (RER), the interest rate differential between Foreign and Home ($i^F - i^H$), and the unemployment rate (u).[6]

By imposing the restrictions on Λ outlined above, we can now more specifically write the first part of equation (1) as:

$$\begin{bmatrix} P^o \\ \frac{Q^p}{Y^{np}} \\ z^F - z^H \\ z^H \\ \frac{I^p}{Y^{np}} \\ W \\ RER \\ i - i^* \\ u \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \lambda_1 & 1 & 0 & 0 \\ \lambda_2 & \lambda_7 & 1 & 0 \\ \lambda_3 & \lambda_8 & \lambda_{12} & 1 \\ \lambda_4 & \lambda_9 & \lambda_{13} & \lambda_{16} \\ \lambda_5 & \lambda_{10} & \lambda_{14} & \lambda_{17} \\ \lambda_6 & \lambda_{11} & \lambda_{15} & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} + ... \tag{6}$$

where Λ_1 corresponds to the upper 4×4 component of Λ, and allows us to identify the four common trends. The current specification of Λ includes 19 restrictions, above the cutoff of q^2 restrictions needed for identification. Given the identifying assumptions, the common trends (the $\tau's$) can be interpreted as exogenous and uncorrelated trends in the oil price (τ_1), petroleum activity (τ_2), the productivity differential (τ_3), and global productivity (τ_4), respectively. Both the interest rate differential and the unemployment rate are considered cyclical variables, characterized solely by stationary components. Consequently, the trend

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[6] A detailed description of the data and sources is included in Appendix B.

loadings on these variables are set to zero. This implies that changes in the interest rate differential and the unemployment rate can potentially affect the real exchange rate and other macroeconomic variables in the short run, but not in the long run. However, for the three remaining non-stationary variables—the petroleum investment share, the real wage, and the real exchange rate—we allow for non-zero loadings of the structural trends. The corresponding prior specifications, which we will discuss in the next section, are informed by both economic theory and previous empirical findings.

3.3 Inference

The model outlined in equations (1)-(3) is a linear Gaussian state-space model. We adopt a Bayesian perspective for its estimation, as detailed in Section A of the Appendix. The Bayesian approach is particularly advantageous within this framework due to its flexibility in incorporating additional variables and trends. It also allows for the statistical disciplining of low-frequency components and the integration of priors on both cyclical and trend components.

We specify the following priors for the VAR coefficients, $A = (A_1, ..., A_p)'$, and the covariance matrices of the transitory and trend components, Ω and Σ respectively:

$$\begin{aligned} p(vec(A)|\Omega) &\sim N(vec(\underline{A}), \Omega \otimes \underline{\Omega}) I(vec(A)) \\ \Omega &\sim IW(\kappa_u, (\kappa_u + n + 1)\underline{\Omega}) \\ \Sigma &\sim IW(\kappa_v, (\kappa_v + n + 1)\underline{\Sigma}) \end{aligned} \tag{7}$$

where $I(vec(A))$ is an indicator function which takes value 1 if the system is stable, and 0 otherwise, and $IW(\kappa, (\kappa + n + 1)\underline{\Omega})$ denotes an inverse Wishart distribution with mode $\underline{\Omega}$ and κ degrees of freedom. We include one lag for the transitory component, in order to cover a year's worth of data. The priors on the VAR coefficients are standard Minnesota priors with the hyperparameter of the overall tightness set to 0.2, a common value in VAR studies, see Giannone, Lenza, and Primiceri (2015). The choice of the priors for the stationary components follows Del Negro et al. (2017).

We choose conservative priors on the diagonal diagonal elements of the covariance matrix of the trend components (Σ) to ensure they do not capture business cycle fluctuations. The tightness parameter, κ_v, is set to 100. The prior on the variance-covariance matrix, $\underline{\Sigma}$, is designed so that the standard deviation of the expected change in the four trends over a period of fifty years matches the variance of the difference in HP-filter (bandwidth equal to 100) trends of the actual data. While these trends may fluctuate more than the priors suggest, we do not impose the priors rigidly. If the data strongly indicates significant movements in the low-frequency components, the posterior estimates will deviate from the prior assumptions.

Finally, we specify a prior distribution for the initial conditions of the trend and cycle components:

$$\begin{aligned} \tau_0 &\sim N(\underline{\tau_0}, I) \\ \tilde{y}_{0:-p+1} &\sim N(0, \Omega_0) \end{aligned} \tag{8}$$

where the prior mean $\underline{\tau_0}$ is set at pre-sample averages and Ω_0 is the unconditional variance of $\tilde{y}_{0:-p+1}$ implied by the third equation in (1).

3.4 Prior assumptions for Λ

We now turn to the prior assumptions on the loadings of the trends, i.e. the λ's in (6). First, we center the prior of the loading of the *oil price trend* on key oil and non-oil variables around zero, reflecting uncertainty about its effects. In particular, for conventional oil and gas producers such as Norway and Canada, drilling and exploration lead times often delay production and investment responses to oil price changes (Anderson, Kellogg, and Salant, 2018). In addition, while higher oil prices improves the terms of trade, the long run effects on the other macroeconomic variables, including the real exchange rate are uncertain, depending among other on resource dependence and economic policy, c.f. Bjørnland et al. (2019). In sum, this implies $\bar{E}[\lambda_j] = 0$ for $j = 1, \ldots, 6$.[7]

Turning to the *petroleum activity trend*, which is normalized to increase the petroleum activity share by 1, we expect it to load positively on the petroleum investment share ($\bar{E}[\lambda_9] > 0$), as both activity and investment are inherently linked through a shared underlying trend. Specifically, higher levels of petroleum activity typically necessitate increased investments in exploration, extraction, and related infrastructure. We further assume the trend is loading negatively (i.e., an appreciation) on the real exchange rate ($\bar{E}[\lambda_{11}] < 0$). In particular, as indicated in Section 2, higher oil-and gas activity as a share of GDP should be associated with a current account improvement and, consequently, a real appreciation, c.f. Corden and Neary (1982) and Corden (1984). The petroleum activity trend is expected to have positive spillovers to domestic productivity, ($\bar{E}[\lambda_8] > 0$), and to diminish the productivity differential ($\bar{E}[\lambda_7] < 0$), and it will also likely to be positively correlated with real wages ($\bar{E}[\lambda_{10}] > 0$), as wages in the petroleum sector are significantly higher than in other industries. Additionally, oil booms are expected to generate spillovers to other sectors, amplifying wage growth across the economy, c.f. Allcott and Keniston (2018) and Bjørnland and Thorsrud (2016).

Consistent with the Balassa-Samuelson hypothesis, we expect the real exchange rate to depreciate following a shock to the *productivity differential trend*, defined as Foreign productivity relative to Home, hence ($\bar{E}[\lambda_{15}] > 0$). Domestically driven shocks to the productivity differential trend could also potentially affect observed productivity, petroleum investment and real wages, although we center the prior means at zero (i.e. $\bar{E}[\lambda_{12}] = \bar{E}[\lambda_{13}] = \bar{E}[\lambda_{14}] = 0$ respectively) to reflect uncertainty of coefficients.

Finally, we anticipate the *global productivity trend* to load positively on the real wage trend ($\bar{E}[\lambda_{17}] > 0$. For the petroleum investment share, we center the prior on zero, $\bar{E}[\lambda_{16}] = 0$. In addition, we impose an overidentifying restriction, which will yield more efficient estimates. In particular we set the loading of the global productivity trend (level) on the

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[7] The operator $\bar{E}$ denotes the mean of the prior distribution of the respective $\lambda' s$.

real exchange rate (relative price) to zero.

All loadings with non-zero mean are centered around -1 or 1. Both loadings with zero and non-zero prior means are assumed to be normally distributed with a standard deviation equal to 0.5. Since all variables are standardized, this implies relatively non-informative priors.

4 Main findings

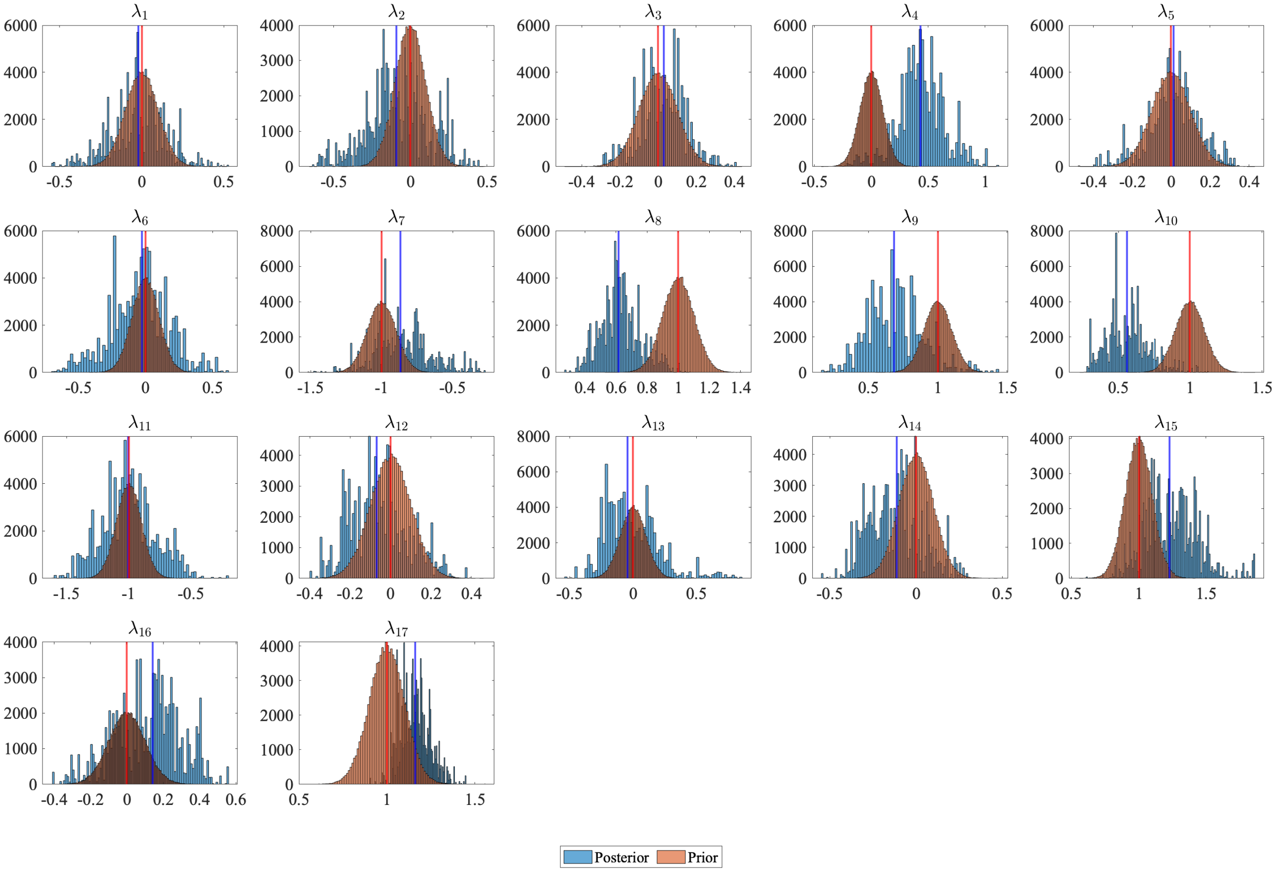
This section reports the main findings of the paper. We display the distributions of the posterior estimates of the loadings (λ), the estimated trends of the key variables, their historical decomposition and finally, the impulse responses to the cyclical shocks.

4.1 Posteriors

We describe the estimation of the coefficients of the matrix Λ in Figures 1 and 2 for Norway and Canada respectively. The red bars correspond to the prior distributions of each loading, while the blue bars represent the distributions of posterior estimates. The vertical blue lines represent the median of the posterior distributions, while the vertical red lines the median of the prior distributions, for each element of Λ.

Starting with Norway, Figure 1 shows that the posterior distribution for the oil price trend loadings remains close to the prior (centered at zero) for most variables, with the exception of petroleum investment (λ_4), where the posterior indicates a positive relationship with the oil price trend. The petroleum share trend also loads positively on petroleum investment (λ_9), and has also a positive effect on domestic productivity (λ_8) and wages (λ_{10}). The real exchange rate shows a clear appreciation effect, as indicated by the posterior for λ_{11} being close to -1. These results align with Bjørnland et al. (2019), showing that increased petroleum activity raises domestic productivity and wages, narrows the productivity differential, and appreciates the real exchange rate.

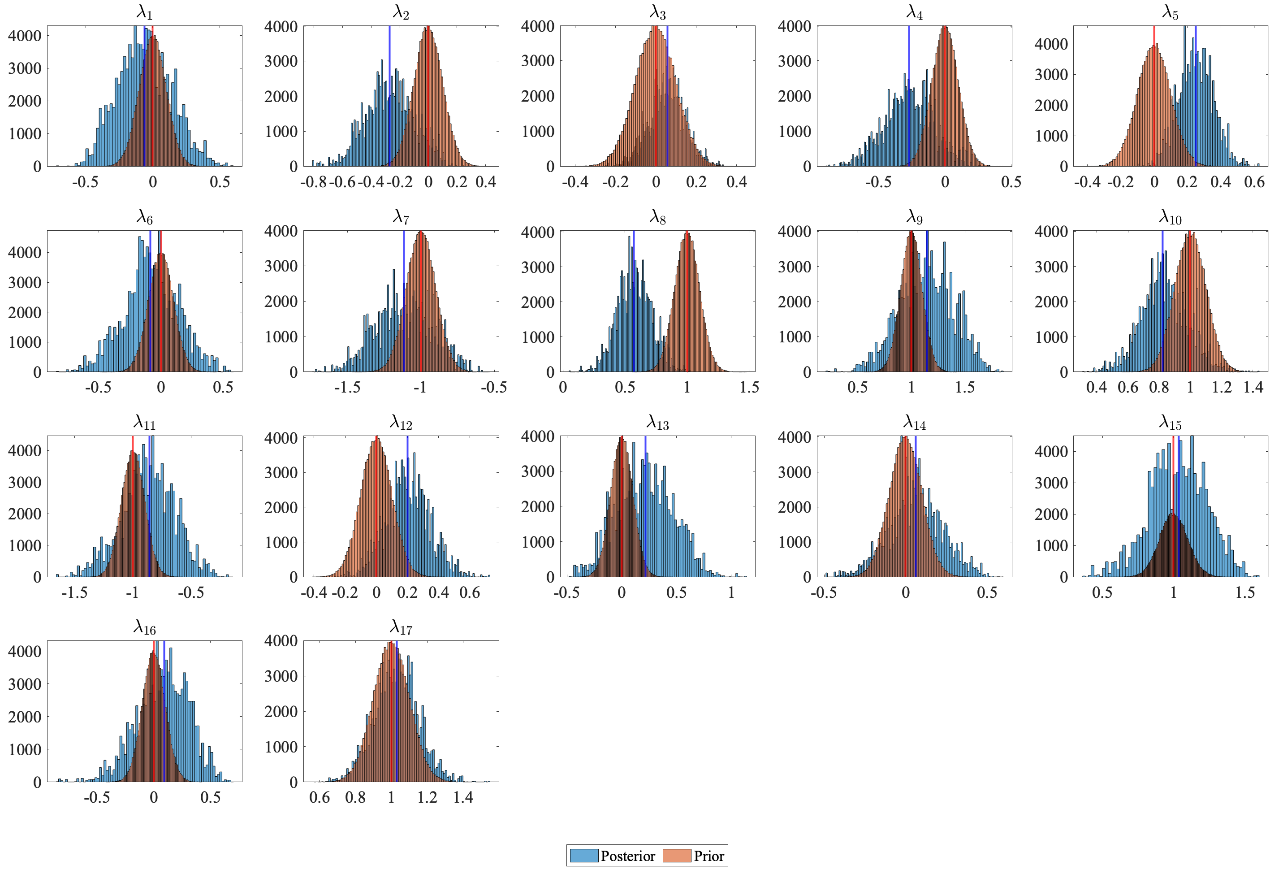
Figure 1: Norway: Priors and posterior distributions of Λ



Note: The red bars correspond to the prior distributions of each coefficient, while the blue bars represent the distributions of posterior estimates based on 100000 draws. The vertical blue line represents the median of the posterior distribution, while the vertical red line the median of the prior distribution, for each element of Λ.

For the productivity differential trend, the posterior for the loadings on productivity (λ_{12}), petroleum investment share (λ_{13}) and real wages (λ_{14}) remain near zero. However, the productivity differential trend significantly impacts the real exchange rate, with the posterior for λ_{15} showing a clear effect consistent with the Balassa-Samuelson hypothesis: higher foreign productivity relative to domestic productivity leads to a depreciation of the domestic currency. Finally, the global productivity trend, normalized to increase domestic productivity, pushes the posterior for petroleum investment (λ_{16}) slightly up from zero, and

Figure 2: Canada: Priors and posterior distributions of Λ



Note: The red bars correspond to the prior distributions of each coefficient, while the blue bars represent the distributions of posterior estimates based on 100000 draws. The vertical blue line represents the median of the posterior distribution, while the vertical red line the median of the prior distribution, for each element of Λ.

has a strong positive effect on real hourly wages, as seen by the posterior for λ_{17}.[8]

The results for Canada, displayed in Figure 2, suggest that the posterior distribution for the loadings of the trends matches those found for Norway, with some exceptions. Importantly, while the loading of the oil price trend on petroleum investment (λ_4) is more negative than in Norway, the loading on wages (λ_5) is pushed into positive territory, suggesting more dependence on commodity prices for the overall wage development. The figure also shows that the loading of the productivity differential trend is more positive for Home produc-

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[8] As a global trend, it does not influence the productivity differential or the real exchange rate.

tivity (λ_{12}) and petroleum investment (λ_{13}) in Canada than in Norway, suggesting a more important role for domestic productivity for the overall economic development.

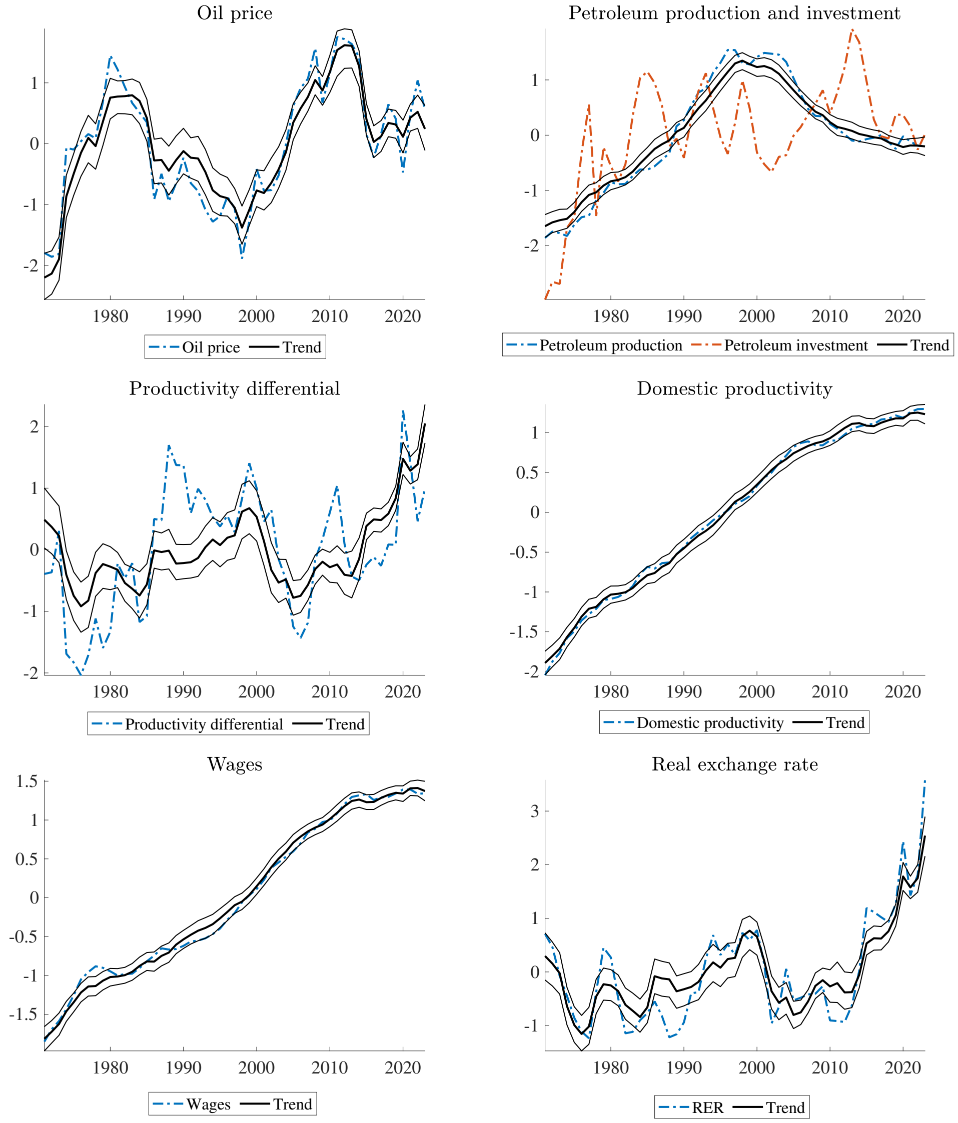
4.2 Estimated trends

We plot the estimated trends alongside the actual data for Norway in Figure 3, with Canada's results shown in Figure 4. All macroeconomic variables are standardized to enable meaningful comparisons. The black lines represent the point-wise median estimates of the trends, with associated 68% credible intervals, while the dash-dotted lines depict the actual data.

Overall, the trends successfully capture the low-frequency movements in the data over the observed sample period. Starting with Norway, Figure 3 shows that the oil price contains two prominent secular commodity cycles: the first peaking in the early 1980s, and the second peaking just before the financial crisis. Trends in oil production and investment shares exhibit a sharp increase from 1970 until the early 2000s, driven by the expansion of Norway's petroleum sector, followed by a more gradual decline as production reached maturity and investment stabilized. Domestic productivity and wages show steady growth from 1970 until around 2000, reflecting a period of economic expansion supported by the booming oil and gas industry. After 2000, a flattening of the trend growth in both productivity and wages becomes apparent. The productivity differential and real exchange rate trends for Norway have shifted notably over time. In the 1970s, petroleum sector discoveries and expansion coincided with a gradual real exchange rate appreciation as oil revenues flowed, alongside steady productivity growth. In the early 2000s, the real exchange rate appreciated further, driven by high oil prices and substantial petroleum inflows. Around the financial crisis, both the productivity differential and the real exchange rate weakened, reflecting primarily declining productivity relative to trading partners. The real depreciation intensified after 2014, as oil prices fell and petroleum investment declined.

For Canada, Figure 4 shows two major oil price cycles, peaking in the early 1980s and

Figure 3: Actual data and estimated reduced-form trends - Norway



Note: The black lines represent the point-wise median of the distribution of estimated trend components and the associated 68% confidence sets. The dash-dotted lines correspond to the actual data in standardized terms.

just before the financial crisis.[9] Oil production rose sharply from the mid-1960s to early 1970s, followed by steady fluctuations, while petroleum investment increased until 2014 before sharply declining. The shared trend highlights a significant increase during the 1970s

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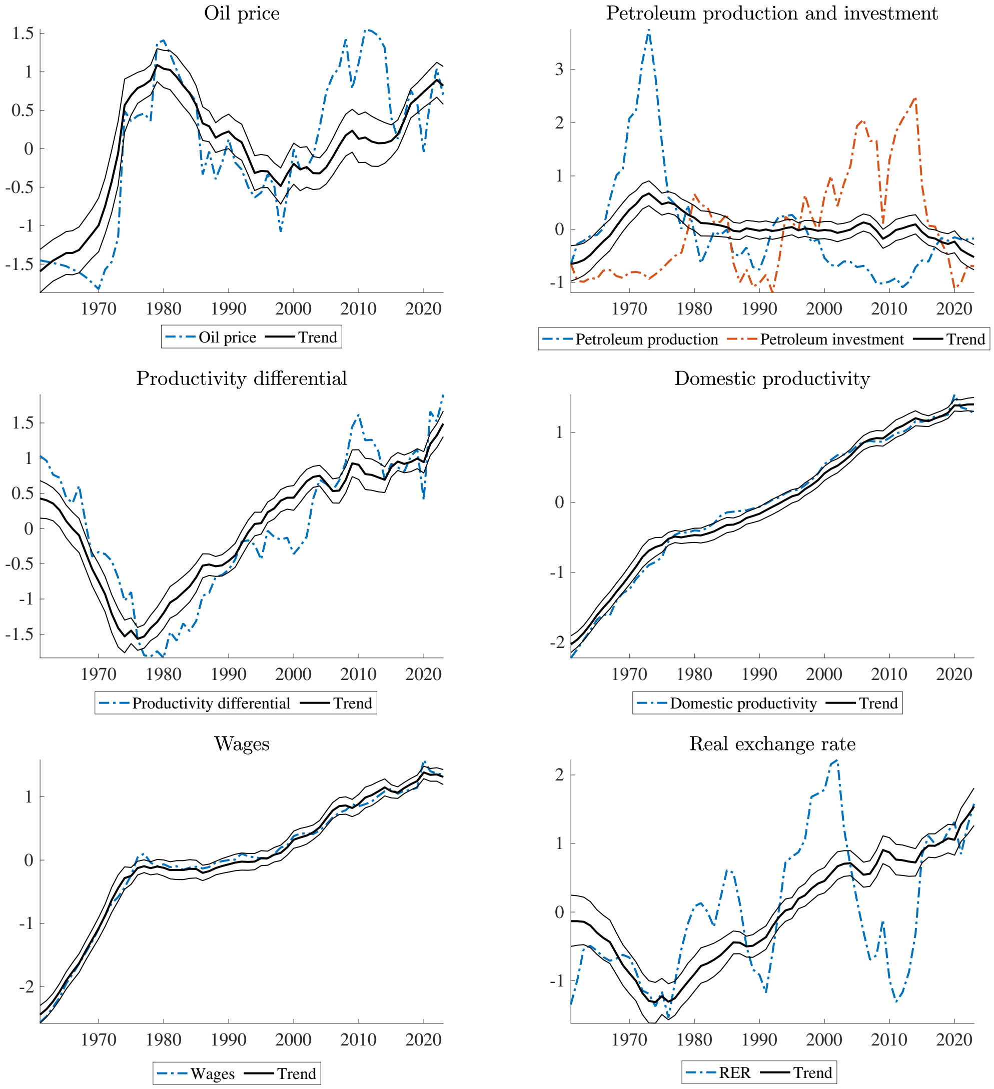
[9] Note that as the data for Canada starts already in 1960s.

Figure 4: Actual data and estimated reduced-form trends - Canada



Note: The black lines represent the point-wise median of the distribution of estimated trend components and the associated 68% confidence sets. The dash-dotted lines correspond to the actual data in standardized terms.

and a more modest rise beginning in the late 1990s. Productivity grew steadily until the 1980s, after which it plateaued, reflecting slower growth. Wages followed a similar pattern, with consistent increases until the 1980s, aligning with structural shifts in the Canadian economy. As in Norway, Canada's productivity differential and real exchange rate trends evolved notably over time. Before the 1980s, steady productivity growth relative to trading partners drove gradual real exchange rate appreciation, supported by rising resource exports. From the 1980s onward, both trends reversed, with the productivity differential weakening and the real exchange rate depreciating, albeit with some variability later.

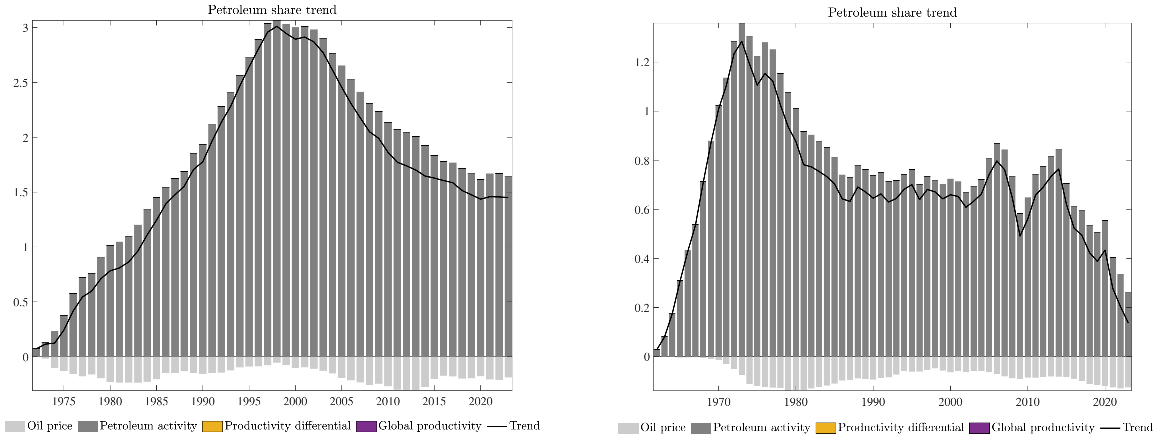
4.3 Historical decomposition

Having identified the trends, a natural question arises: How important are the structural drivers in explaining the estimated trends? In this section, we present historical decompositions for the trend in key variables such as the petroleum share trend and the (non-oil) productivity trend, before turning to the real exchange rate trend.

Figure 5 shows the historical decomposition of the petroleum share trend for Norway (left) and Canada (right). The black line represents deviations from initial conditions, with colored bars showing contributions from structural factors. For both countries, petroleum activity shocks (dark grey bars) drive most of the trend, while oil price shocks (light grey bars) play a minor role, particularly in Canada. The limited impact of oil prices reflects the sector's reliance on long-term planning and investment cycles rather than short-term price changes. In Canada, however, higher oil prices may occasionally influence production in cost-sensitive projects like oil sands.

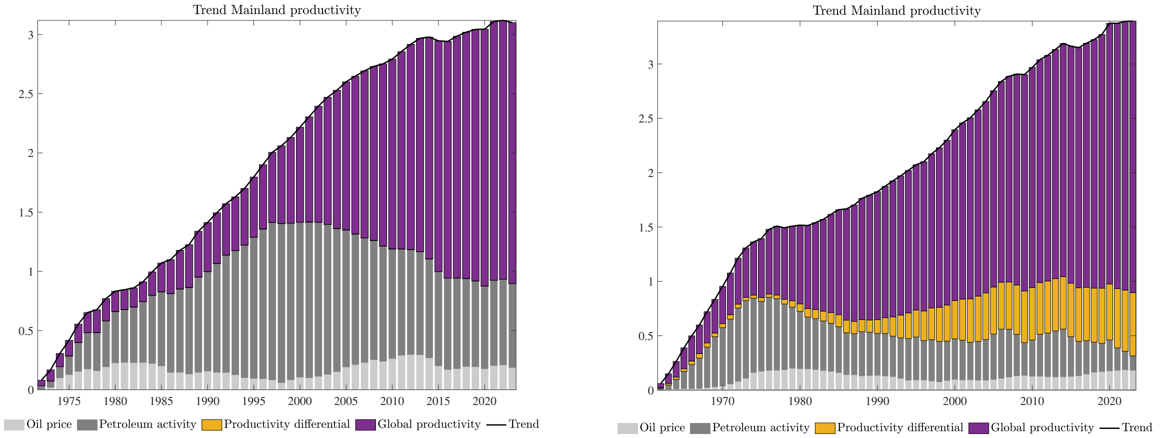
Figure 6 shows the historical decomposition of non-oil productivity trends in Norway (left) and Canada (right). Since the 1970s, global productivity (purple) has been the dominant driver in both countries, reflecting broader economic integration. In Norway, however, petroleum activity (dark grey) significantly influences non-oil productivity. This likely reflects the substantial role that the petroleum sector plays in Norway's economy, where its influence extends into other sectors through productivity spillovers, increased demand for local goods and services, and investment in infrastructure, c.f. Bjørnland et al. (2019). By contrast, in Canada, the productivity differential (yellow) plays a larger role, which may reflect the country's more diversified economy and the influence of relative productivity

Figure 5: Historical decomposition. Petroleum share trend Norway (left) and Canada (right)



Note: The black line is the point-wise median estimate in deviations from initial conditions. The colored bars represent the point-wise median contribution of the different structural factors which sum up to the black line.

Figure 6: Historical decomposition. Non-oil productivity in Norway (left) and Canada (right)

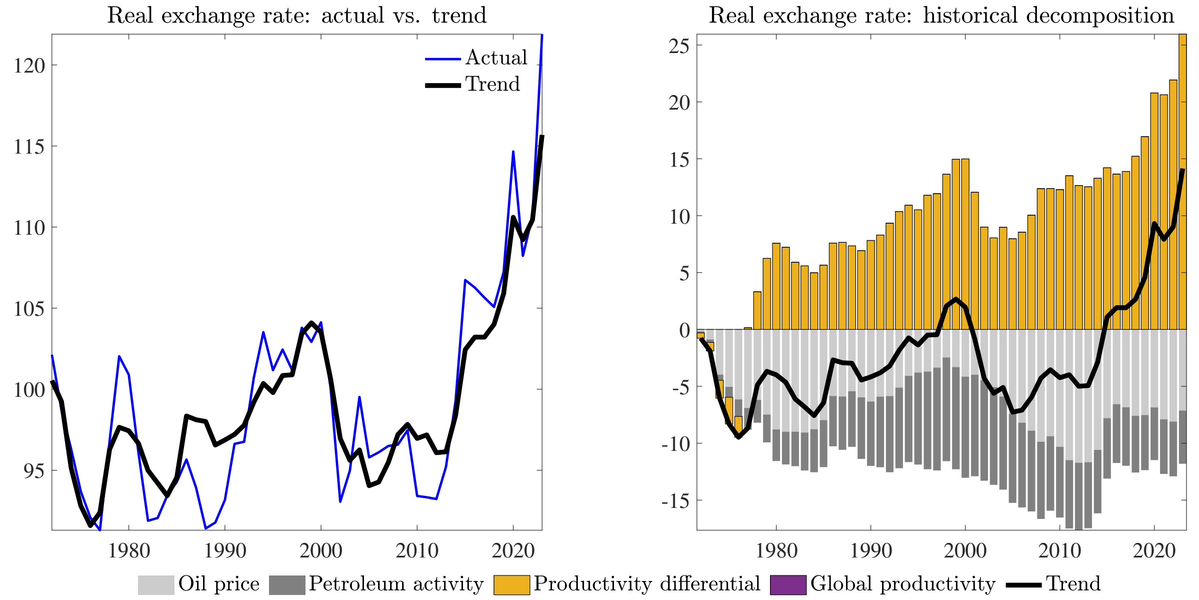


Note: The black line is the point-wise median estimate in deviations from initial conditions. The colored bars represent the point-wise median contribution of the different structural factors which sum up to the black line.

changes with trading partners. This distinction highlights Norway's reliance on its resource sector versus Canada's broader industrial base.

Figure 7 presents the historical decomposition of Norway's real exchange rate, with the

Figure 7: Historical decomposition. Real exchange rate in Norway



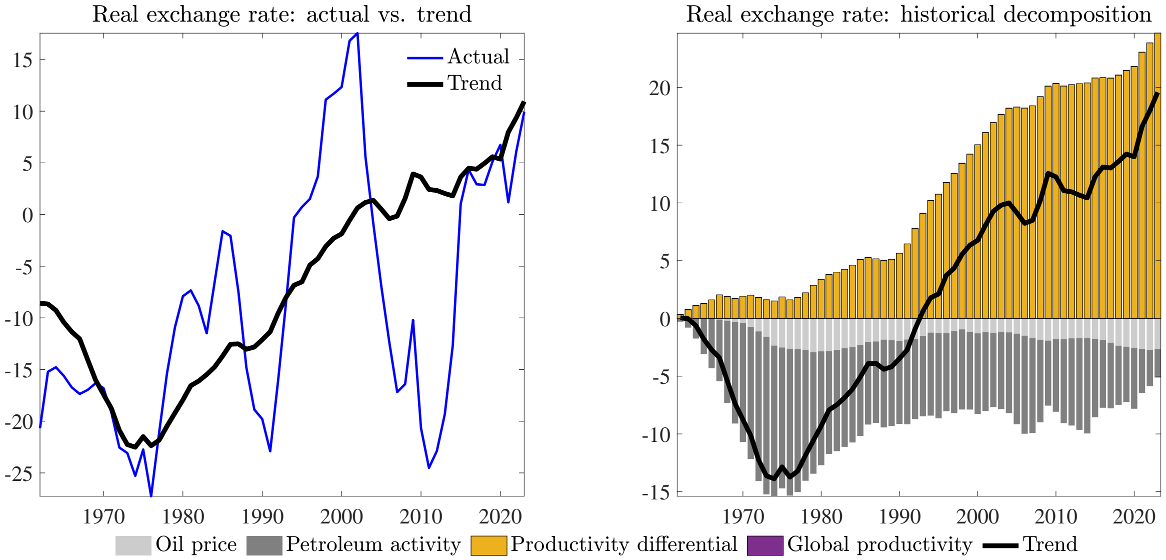
Note: The black lines represent the point-wise median of the distribution of trend components together with the actual data for the real exchange rate (left panel) and the contribution to the trend (right panel).

actual rate (blue line) and trend (black line) in the left panel, and structural contributions in the right panel. Upward movements indicate depreciation, while downward movements reflect appreciation.

From the 1980s to the early 2000s, petroleum activity (dark grey) drives periods of appreciation as the oil sector expands. From the early 2000s onward, productivity differential shocks (yellow) become the dominant factor, contributing to a marked depreciation trend, especially after the financial crisis, as Norway's productivity weakens relative to trading partners. Post-2014, declining contributions from petroleum activity, due to lower oil prices and reduced investment, further support the depreciation trend. We note that, toward the end of the sample, the trend does not fully account for the recent depreciation, suggesting additional short term factors, which are discussed in the next section.

Figure 8 shows Canada's real exchange rate decomposition, with again the actual rate (blue line) and trend (black line) in the left panel, and structural contributions in the right

Figure 8: Historical decomposition. Real exchange rate in Canada


Real exchange rate: actual vs. trend

Real exchange rate: historical decomposition

Note: The black lines represent the point-wise median of the distribution of trend components together with the actual data for the real exchange rate (left panel) and the contribution to the trend (right panel).

panel. Upward movements indicate depreciation, while downward movements indicate appreciation. From the 1970s to the 1980s, the real exchange rate appreciates, driven by oil production trends (dark grey) as Canada's resource sector expanded. This reverses in the late 1980s, with sustained depreciation into the 2000s, dominated by the productivity differential (yellow), reflecting shifts in Canada's relative productivity compared to trading partners. Recently, the productivity differential remains a key driver of depreciation, alongside wekening contributions from the petroleum trend (dark grey). Unlike Norway, Canada's more diversified economy provides resilience to oil price volatility. However, as with Norway, the identified trends do not fully explain the real exchange rate dynamics, suggesting additional factors discussed in the next section.

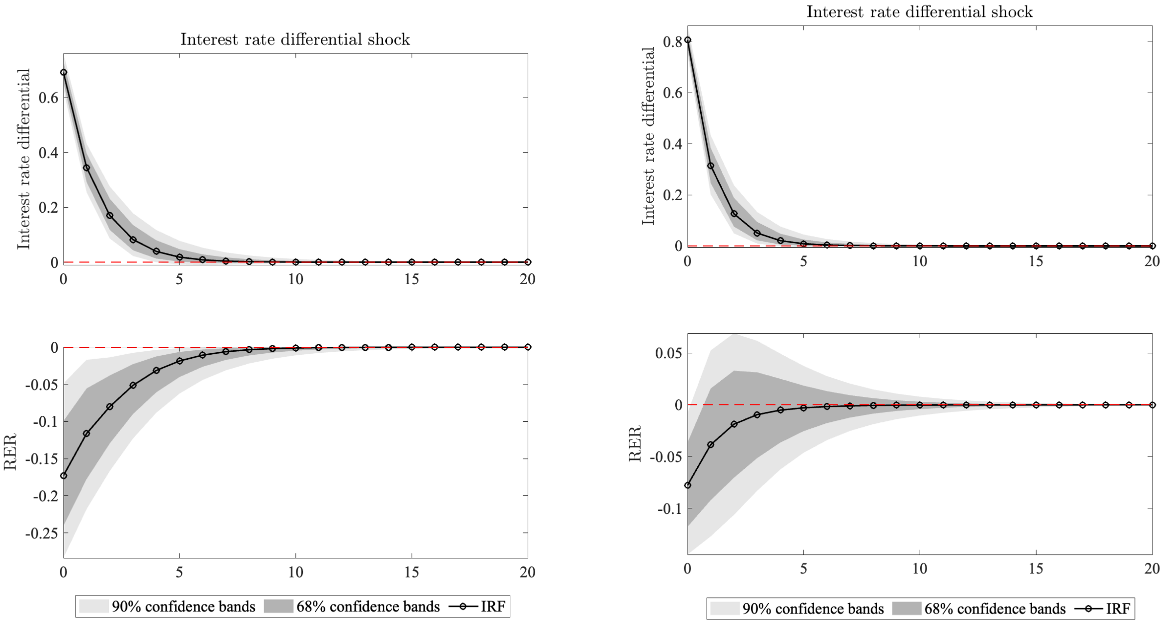
To sum up, the depreciation of the real exchange rate in Norway and Canada reflects weaker domestic productivity relative to foreign productivity and the declining influence of the petroleum sector. Both the Dutch disease effect and the Balassa-Samuelson hypothesis drive these trends, underscoring the interplay between resource dependence and productivity shifts in shaping long-term exchange rate dynamics.

4.4 Shocks to the cyclical component

So far, we have calculated the trends and examined the historical decomposition of structural shocks to these only. We now turn to the analysis of impulse responses to cyclical shocks, focusing on temporary shocks to the interest rate differential and oil prices. To construct impulse responses to cyclical shocks, we focus on the cyclical component (3) and impose a recursive scheme for identification. Let the mapping between reduced-form and structural disturbances be $u_t = S\epsilon_t$, where $\epsilon_t \sim N(0_n, I_n)$ is the n x 1 vector of unit variance structural disturbances. In the baseline specification, we define S as the Cholesky decomposition of Ω, thus as the unique lower triangular matrix such that $SS' = \Omega$. Oil price shocks are identified by assuming that these are the only shocks that move all variables contemporaneously in the cycle. Interest rate differential shocks, on the other hand, are identified by assuming that these have no contemporaneous effects on oil prices, productivity and unemployment. In what follows, we show the impulse responses of oil prices, interest rate differentials and real exchange rates only, for exposition purposes.

Figure 9 displays the impulse responses to a shock in the interest rate differentials for Norway (left) and Canada (right), which is interpreted as a monetary policy shock. In this context, monetary authorities adjust interest rates in response to macroeconomic variables, including the common trends. The monetary policy shock represents deviations from these systematic responses, capturing unanticipated policy actions or changes in the stance of monetary policy. The shock temporarily increases domestic interest rates relative to foreign rates, with the effect dissipating after 3–5 years. For Norway, the real exchange rate shows a pronounced appreciation in response to the monetary policy shock, consistent with the Uncovered Interest Parity (UIP) condition. In Canada, the real exchange rate also appreciates following the monetary policy shock, but the response is more muted. Importantly, the findings for both countries do not show evidence of delayed overshooting. In many studies

Figure 9: Impulse responses to shock to interest rate differentials (i.e., a monetary policy shock) Norway (left) and Canada (right)

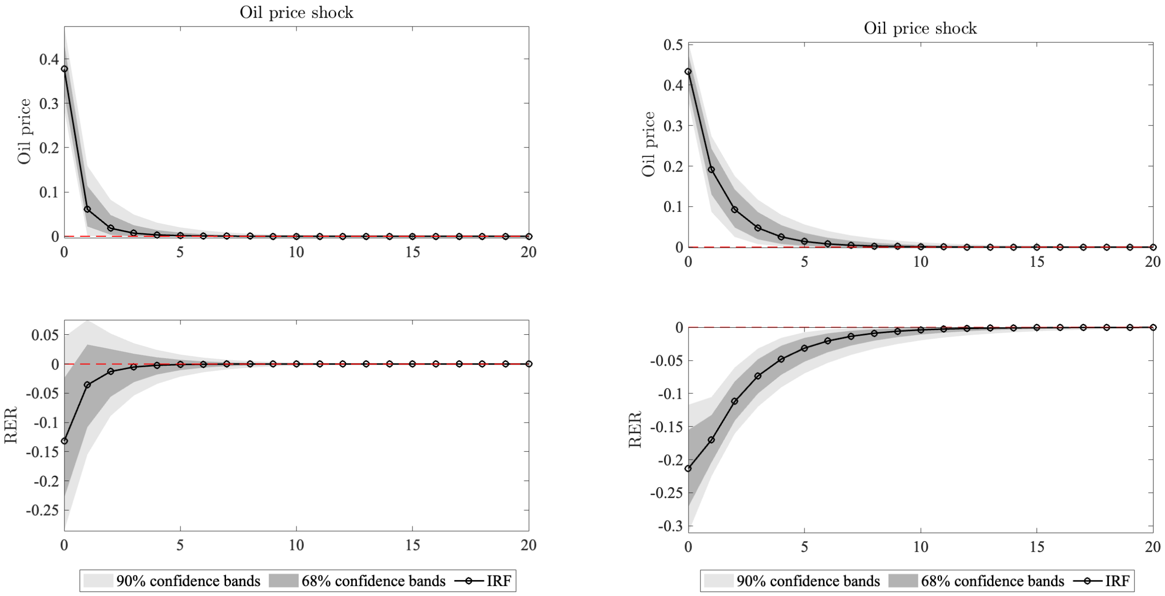


Note: The black lines represent the point-wise median of the distribution of the impulse responses and the associated 68% confidence sets.

employing recursive VARs, a contractionary monetary policy shock often causes the real exchange rate to either depreciate initially or appreciate gradually, producing a hump-shaped response over several years that violates UIP. This delayed overshooting puzzle has been documented in seminal studies such as Sims (1992), Eichenbaum and Evans (1995), and Kim and Roubini (2000). In contrast, our results align with the overshooting hypothesis first proposed by Dornbusch (1976) and supported by non-recursive approaches, including Faust and Rogers (2003), Scholl and Uhlig (2008), and Bjørnland (2009). The key innovation in our framework is the explicit modeling of structural trends alongside cyclical components. This allows for a clearer separation of short-term and long-term forces affecting the exchange rate.

Figure 10 displays the impulse responses to a cyclical oil price shock for Norway (left) and Canada (right). Following the shock, oil prices increase sharply before gradually returning to equilibrium after 2–3 years. In response, the real exchange rate appreciates in both countries,

Figure 10: Impulse responses to a cyclical shock to oil prices - Norway (left) and Canada (right)



Note: The black lines represent the point-wise median of the impulse responses and the associated 68% confidence sets.

reflecting the spending effect induced by higher resource income. As oil prices stabilize, the appreciation effect on the real exchange rate dies out, aligning with the cyclical nature of the shock. This analysis underscores how temporary oil price fluctuations generate short-term appreciations in the RER, complementing the findings on persistent oil price changes affecting long-term economic trends. These results are consistent with the broader literature, including Chen and Rogoff (2003), which highlights the strong link between commodity prices and real exchange rate dynamics in resource-rich economies. By examining both cyclical and permanent effects, we gain a more nuanced understanding of the relationship between oil prices and exchange rate dynamics in resource-dependent countries like Norway and Canada.

5 Robustness

We assess the sensitivity of our results to alternative specifications of the priors on two key elements of our empirical model: the matrix of loadings Λ and the variance-covariance matrix Σ. The rationale of the following exercise is to verify that our main results are not entirely driven by the prior assumptions we define in the benchmark VAR with common trends. The results of these exercises are reported in Appendix C for the real exchange rate only for exposition purposes.

Regarding the priors on the matrix of loadings Λ, we perform an exercise which targets the variance our prior. We assume that the variance of the normal prior on the coefficients in Λ is twice as small with respect to the baseline, since the baseline prior is quite disperse. This means that we consider normal priors with standard deviations of 0.25 for the elements of the Λ matrix. Figure 11 reports the findings for Norway and Canada. All in all, our results appear not to be driven by the assumption on the variance of the prior on the matrix of loadings Λ.

Regarding the priors on the matrix Σ, we consider two exercises that imply a prior on the variance-covariance matrix of the trend components that is twice as loose and twice as tight with respect to the baseline. This sensitivity check is aimed at ensuring that increasing or decreasing the prior variance of the trends doesn't modify substantially the estimated trends. Figure 12 reports the findings for Norway and Canada for the looser prior, while Figure 13 for the tigher prior. Our results appear robust to the alternative prior specification on the variance-covariance matrix of the trend components.

All in all, our main results are robust to different priorspecifications of the empirical model.

6 Concluding remarks

This paper explores key structural hypothesis, like the Balassa-Samuleson and the Dutch Disease, to identify long-term macroeconomic trends and structural drivers in resource rich countries. To this end, we estimate a structural VAR model with common trends to extract low-frequency movements in macroeconomic variables, including the real exchange rate. The model is estimated using Bayesian techniques and applied to Canada and Norway, two oil- and gas-producing economies. In alignment with theory, results indicate that productivity shifts and commodity market trends significantly influence domestic productivity and the real exchange rate in both countries. Additionally, the expected decline in Norwegian oil production has already importantly impacted productivity and the krone exchange rate.

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Appendix

A Bayesian estimation

The VAR with common trends specified in (1) and (2) is estimated using a Gibbs sampler, which involves the following steps:

1. The first block involves draws from the joint distribution $\bar{y}_{0:T}, \tilde{y}_{-p+1:T}, \lambda | vec(A), \Omega, \Sigma, y_{1:T}$, which is given by the product of the marginal posterior of $\lambda | vec(A), \Omega, \Sigma, y_{1:T}$ times the distribution of the initial observations $\bar{y}_{0:T}, \tilde{y}_{-p+1:T} | \lambda, vec(A), \Omega, \Sigma, y_{1:T}$. The marginal posterior of $\lambda | vec(A), \Omega, \Sigma, y_{1:T}$ is given by:

$$p(\lambda | vec(A), \Omega, \Sigma, y_{1:T}) \propto \mathcal{L}(y_{1:T} | \lambda, vec(A), \Omega, \Sigma) p(\lambda)$$

   where $\mathcal{L}(y_{1:T} | \lambda, vec(A), \Omega, \Sigma)$ is the likelihood obtained by using the Kalman Filter in the state-space model specified in (1). Since $p(\lambda | vec(A), \Omega, \Sigma, y_{1:T})$ does not feature a known form, this step involves a Metropolis-Hastings algorithm. Then, I use **?**'s simulation smoother to obtain draws for the trend and cycle components $\bar{y}_{0:T}, \tilde{y}_{-p+1:T}$, for given λ and $vec(A), \Omega, \Sigma, y_{1:T}$.

2. The second block involves the estimation of two VARs, given $\bar{y}_{0:T}, \tilde{y}_{-p+1:T}$ and λ. In the trend component equation, the coefficients are known and the posterior distribution of Σ is given by:

$$p(\Sigma | \bar{y}_{0:T}) = IW(\underline{\Sigma} + \hat{S}_v, \kappa_v + T)$$

   where $\hat{S}_v = \sum_{t=1}^{T} (\bar{y}_t - \bar{y}_{t-1})(\bar{y}_t - \bar{y}_{t-1})'$ is the sum of squared errors of the trend components. In the transitory component equation, the posterior distribution of $vec(A)$

and Ω is given by:

$$p(\Omega|\tilde{y}_{0:T}) = IW(\underline{\Omega} + \hat{S}_u, \kappa_u + T)$$
$$p(vec(A)|\Omega, \tilde{y}_{0:T}) = N(vec(\hat{A}), \Omega \otimes (\tilde{X}\tilde{X}' + \underline{\Omega}^{-1})^{-1})$$

where $\tilde{X} = (\tilde{y}_1', ..., \tilde{y}_T')'$, $\hat{S}_u = uu' + (\hat{A} - \underline{A})'\underline{\Omega}^{-1}(\hat{A} - \underline{A})$ and $\hat{A} = (\tilde{X}\tilde{X}' + \underline{\Omega}^{-1})^{-1}(\tilde{X}'\tilde{y} + \underline{\Omega}^{-1}vec(\underline{A}))$.

B Data

The estimation results for Norway are based on data for the period 1970-2023, whereas the Canadian data span the period from 1961 to 2023. In order to capture petroleum activity, i.e., related to both oil and gas extraction, we employ data on investments in the petroleum sector and petroleum production in value added terms, both measured as a share of non-petroleum GDP, i.e.:

$$\begin{aligned} \alpha_t^I &\equiv \frac{I_t}{X_t} \\ \alpha_t^O &\equiv \frac{X_t^O}{X_t} \end{aligned} \tag{9}$$

where I_t denotes investment in the petroleum sector and X_t^O, and X_t denotes value added in the petroleum and non-petroleum sector, respectively.

The productivity variable refers to value added per hours worked in the non-petroleum economy, i.e.:

$$Z_t^j \equiv \frac{X_t^j}{L_t^j}, \quad j = H, F \tag{10}$$

where L_t^j is hours worked in the non-petroleum sector. As a proxy for Foreign productivity, we use a weighted measure for the G7 countries where the weights reflect each country's share of total value added.

We define the real exchange rate as:

$$Q_t \equiv S_t \frac{P_t^F}{P_t^H} \tag{11}$$

where S_t denotes the nominal exchange rate measured as Home currency per unit of Foreign currency, and P_t^H and P_t^F denotes the Home and Foreign consumer price index, respectively. For Canada, we rely on the CAD/USD exchange rate. In the case of Norway, the real exchange rate measure is taken from the OECD database. It is defined as a trade weighted average of bilateral real exchange rates of the largest trading partners

As a measure of the real wage, we use hourly wage costs divided by the overall consumer price index. For Canada, we rely on two different data tables to construct time series' for value added, hours and wage costs. The two tables cover the years 1961-2011 and 1997-2022, respectively. We merge the series together by scaling variables from the first data table such that the value in 1997 is identical. We define the non-petroleum sector as total industries minus the oil and natural gas extraction industries. The various series involved are laid out in tables 1 and 2.

Table 1: Data Norway

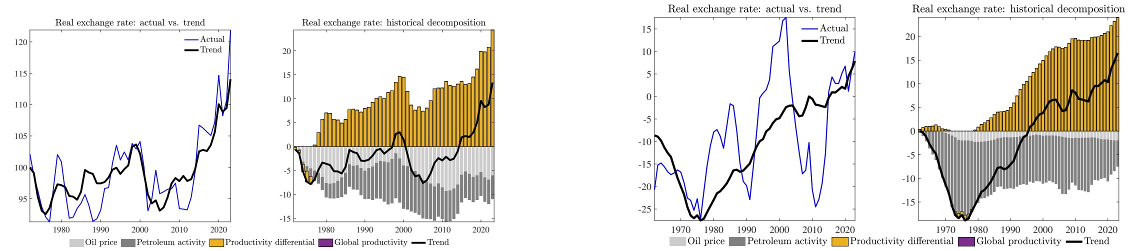
Variable	**Description**	**Source**
Value added petroleum sector	GDP value added, basic values, rebased volume, constant 2015 prices	Quarterly national accounts data, Statistics Norway
Value added non-petroleum sector	GDP value added, basic values, rebased volume, constant 2015 prices	Quarterly national accounts data, Statistics Norway
Gross Investments petroleum sector	Gross fixed capital formation. Extraction of crude oil and natural gas. Rebased volume. Constant 2015 prices	Quarterly national accounts data, Statistics Norway
Hours worked non-petroleum sector	Total hours worked, non-petroleum sector (mainland Norway)	Quarterly national accounts data, Statistics Norway
Productivity G7 countries	GDP per hour, constant prices, 2015 PPPs.	OECD
Real effective effective exchange rate	Weighted geometric average of bilateral main trading partner real exchange rates based on trade weights	OECD
Consumer price index, Norway	Headline CPI index	Statistics Norway
Wage costs	Total wage costs in non-petroleum sector, National Accounts	Statistics Norway
Unemployment rate	Registered number of persons unemployed relative to labour force, the latter taken from the labour force survey	NAV and Statistics Norway
Interest rates, Norway	3-month Norwegian interbank rate (1979-2022) and Norwegian euronok swap rates	Norges Bank
Interest rates, Trading partners	3-month interbank rates, 4 main trading partners using trade weights	Fred database, St Louis Fed
Oil price	Brent Blend spot price, US dollars	Thomson Reuters

Table 2: Data Canada

Variable	Description	Source
Real value-added petroleum sector	Oil and gas industries, 1992 constant dollars (1961-1996) and chained 2012 dollars (1997-2022)	Tables 36-10-0480-01 and 36-10-0303-01 Statistics Canada
Real value-added total economy	All industries, 1992 constant dollars (1961-1996) and chained 2012 dollars (1997-2022)	Tables 36-10-0480-01 and 36-10-0303-01, Statistics Canada
Gross Investments petroleum sector	Conventional and non-conventional oil and gas extraction, 2017 constant prices.	Table 36-10-0096-01, Statistics Canada
Hours worked petroleum sector	Hours worked for all jobs, oil and gas industries	Tables 36-10-0480-01 and 36-10-0303-01 Statistics Canada
Hours worked total economy	Hours worked for all jobs, all industries	Tables 36-10-0480-01 and 36-10-0303-01 Statistics Canada
Productivity G7 countries	GDP per hour, constant prices, 2015 PPPs.	OECD
Real effective exchange rate	Index 2015=100	OECD, Main Economic Indicators (MEI) - complete database
Nominal exchange rate	CAD/USD spot price	OECD, Main Economic Indicators (MEI) - complete database
Consumer price index, Canada	Headline CPI index, 2002=100	Statistics Canada
Consumer price index, US	Headline CPI index, 2015=100	Bureau of Economic Analysis (BEA)
Wage costs petroleum sector	Total compensation for all jobs, oil and gas industries	Tables 36-10-0480-01 and 36-10-0303-01, Statistics Canada
Wage costs total economy	Total compensation for all jobs, all industries	Tables 36-10-0480-01 and 36-10-0303-01, Statistics Canada
Unemployment rate	Labour force survey, unemployed relative to labour force	OECD, Main Economic Indicators (MEI) - complete database
Interest rates, Canada	3-month interbank rates	OECD, Main Economic Indicators (MEI) - complete database
Interest rates, US	3-month interbank rates	OECD, Main Economic Indicators (MEI) - complete database
Oil price	Brent Blend spot price, US dollars	Thomson Reuters

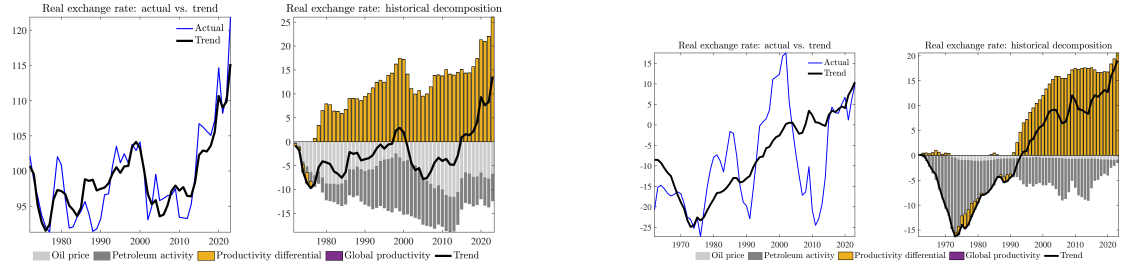
C Additional figures

Figure 11: Historical decomposition of the real exchange rate for $\sigma_\lambda = 0.25$. Norway (left) and Canada (right)



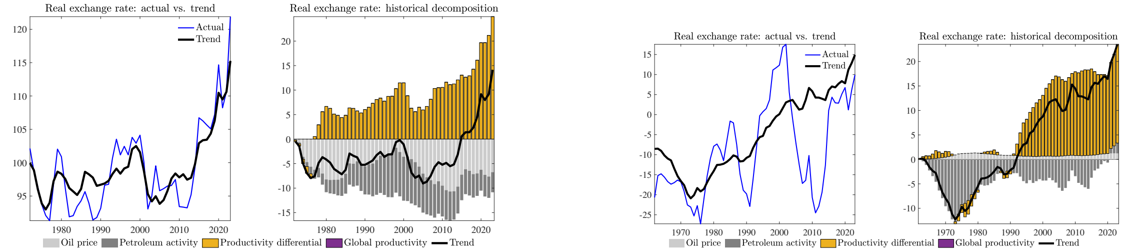
Note: The black lines represent the point-wise median of the distribution of trend components together with the actual data for the real exchange rate (left panel) and the contribution to the trend (right panel).

Figure 12: Historical decomposition of the real exchange rate for twice as loose prior on Σ. Norway (left) and Canada (right)



Note: The black lines represent the point-wise median of the distribution of trend components together with the actual data for the real exchange rate (left panel) and the contribution to the trend (right panel).

Figure 13: Historical decomposition of the real exchange rate for twice as tight prior on Σ. Norway (left) and Canada (right)



Note: The black lines represent the point-wise median of the distribution of trend components together with the actual data for the real exchange rate (left panel) and the contribution to the trend (right panel).