

Piecing the Puzzle: Real Exchange Rate and Long-run Fundamentals

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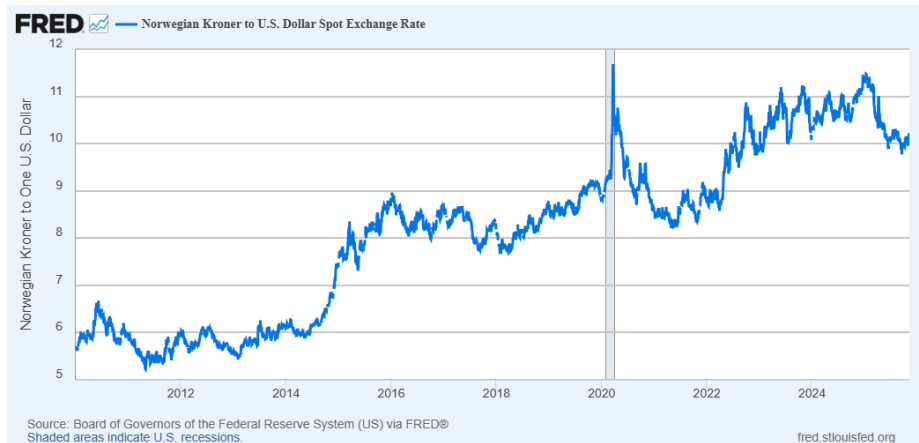
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NOK to USD, 2010-2025



The last 15 years, NOK had depreciated 75% against USD (68%YTD), 40% against EUR and 10% against SEK, among others. (1) Why? Commodity currency? Green transition? Other fundamentals? (2) Permanent or transitory? (3) Is it real?

It is real: The Real Effective Exchange Rate Norway, 2010-2025



Source: Fred

Introduction

- Real exchange rate determination - one of the most debated topics in international economics.
- Central concept is **long-run** equilibrium real exchange rate, often pinned down by PPP and UIP
- ... both parities consistently fall short in accounting for the persistent deviations observed in empirical data.
- This is the well-known **disconnect puzzle** (Rogoff and Obstfeld, 2000).

Introduction

- Economic theory: Complex interaction of interrelated economic forces influencing RER at **varying time horizons** (monetary policy, productivity, commodities ...)
- Econometric challenge: Disentangle short-term fluctuations in NER from more persistent variations in RER.
- Requires a framework that
 - incorporates a comprehensive set of macroeconomic variables
 - spans a relevant frequency spectrum
 - econometric approach capable of distinguishing between transitory and secular factors.

What we do

- Provide a piece to the puzzle by shedding new insights into the empirical relevance of theoretical exchange-rate models.
- Focus on explaining **low-frequency** movements that account for the majority of overall fluctuations in exchange rates (Rabanal and Rubio-Ramírez 2015; Gehrke and Yao 2017; Gornemann, Guerron-Quintana, and Saffie, 2023).
- But the model *also* explains short-run movements well, e.g. those driven by UIP.
- Applied to resource-rich economies, **Canada** and **Norway**, where exchange-rate dynamics have also been influenced by natural resources.

How we do it

1. **Unified structural framework:** Develop a *SOE model* for resource-rich countries that unifies productivity and resource-based channels into a tractable open-economy framework. The model features evolving steady states that anchor the time-varying long-run equilibrium.
2. **Mapping:** Solve the model analytically for the long-run loadings (“trend exponents”). Model provides closed-form expressions linking structural parameters to the direction of long-run RER movements. Clear mapping from theory to empirics.
3. **Novel empirical strategy:** Introduce a *Bayesian structural VAR with common trends* to disentangle persistent (trend) and transitory (cyclical) movements.

Core Mechanisms

Balassa–Samuelson effect

Higher relative tradable productivity $\Rightarrow$ wages $\uparrow \Rightarrow$ non-tradable prices $\uparrow \Rightarrow$ RER appreciation.

Dutch Disease channels

- *Spending effect*: resource income raises demand for non-tradables $\Rightarrow$ RER appreciation.
- *Resource-movement effect*: labor leaves T-sector $\Rightarrow$ possible de-industrialization. Effect on RER ambiguous.

Spillovers

Oil services create learning-by-doing and productivity diffusion across sectors. $\Rightarrow$ RER appreciation.

What we find

- Combining structural trends with cyclical factors gives a comprehensive view of long-term drivers and short-term shocks to exchange rates.
- Relative productivity and resource trends are key determinants of Canada's and Norway's real exchange rates.
- Tides have turned: weaker resource and productivity trends have recently depressed exchange rates, especially in Norway.
- Cyclically, interest-rate-differential shocks give immediate appreciation then gradual reversal, suggestive of Dornbusch overshooting (annual data, so not a sharp test).

Contribution to literature

1. **Exchange-rate models:** Meese and Rogoff (1983); Rogoff and Obstfeld (2000) ... Itskhoki and Mukhin (2021); Bodenstein, Cuba-Borda, Gornemann and Presno (2024);
2. **Trend-cycle VARs:** Del Negro, Giannone, Giannoni and Tambalotti (2017); Ascari and Fosso (2023); Maffei-Faccioli (2025).
3. **Macroeconomic effects of windfall gains:** Corden and Neary (1982); Corden (1984); Torvik (2001); Allcott and Keniston (2018); Arezki, Ramey and Sheng (2017); Bjørnland, Thorsrud and Torvik (2019); Bems *et al.* (2023); Bjørnland and Skretting (2024).
4. **Commodity currencies:** Chen and Rogoff (2003); Cashin, Céspedes and Sahay (2004); Ferraro, Rogoff and Rossi (2015); Harding, Stefanski and Toews (2020)...

Theoretical Model

Model environment

- **Two-country SOE.** Home: small, resource-rich economy producing non-tradables (N), non-oil tradables (T), oil-investment services (I), and petroleum (O). Foreign (ROW): large, exogenous block.
- Labor-only production with sectoral productivity A_T, A_N ; Armington home/imported tradables; sticky (Rotemberg) prices and local distribution costs.
- Government owns petroleum revenues, saves in a SWF, and spends via a fiscal rule; monetary policy follows a Taylor rule.
- The **real exchange rate** is the relative cost of consumption, $q_t = S_t P_C^* / P_C$.

Petroleum sector and fiscal rule

- Exhaustible reserves: exploration replenishes, production depletes.
- A competitive oil-services sector turns labour into new reserves with productivity Z_t , capturing technology and *learning-by-doing*:

$$i_t^o = Z_t L_{I,t}, \quad Y_{o,t} = \delta_o r_{t-1}.$$

- **Fiscal rule:** a share $(1 - \psi_G)$ of net oil income is saved abroad in the SWF; the remainder funds non-tradable government spending.

Solving for the trends: GBGP

- **Generalized balanced-growth path (GBGP)** solution (spirit of Canova and Paulsen, 2023): work with *exponents* (log-derivatives) of the unit-root drivers instead of scaling variables by hand.
- Each variable factorizes into a constant, the permanent drivers, and a stationary part:

$$X_t = \bar{X} \prod_{u \in U} u_t^{\eta_X^{(u)}} \tilde{X}_t, \quad U = \{A_T, A_N, A_T^*, A_N^*, S^{\text{exo}}, Z\}. \quad (1)$$

- Equilibrium conditions are then *linear* in the loadings $\eta_X^{(u)}$, with the same matrix reused driver by driver $\rightarrow$ a transparent **bridge from theory to the empirical trends** in the SVAR.

Analytical Results: RER Trend and Loadings

Solving symbolically (SymPy) gives us all loadings and compact expressions for trend components such as the real exchange rate:

RER trend (CPI-based):

$$\mathcal{T}_{q,t} = A_{T,t}^{\kappa_T} A_{N,t}^{\kappa_N} (A_{T,t}^*)^{\kappa_T^*} (A_{N,t}^*)^{\kappa_N^*} Z_t^{\kappa_Z} (\mathcal{S}_t^{\text{exo}})^{\kappa_S},$$

$$\kappa_T = \omega_C(1 - \omega_A), \quad \kappa_N = 1 - \omega_C + \delta\omega_A\omega_C,$$

$$\kappa_T^* = \omega_A\omega_C(1 - \delta) - \omega_C^*, \quad \kappa_N^* = \omega_C^* - 1,$$

$$\kappa_Z = \omega_A\omega_C(1 - \delta) - 1, \quad \kappa_S = 1 - \alpha_O^*\omega_C^* + (\alpha_O^* - 1)(1 - \delta)\omega_A\omega_C.$$

Sharp cases (imposed exactly in the priors): common productivity is neutral for the RER, $\kappa_T + \kappa_N + \kappa_T^* + \kappa_N^* = 0$, but loads one-for-one on real wages.

What drives the long-run currency value?

We calculate the non-stationary component of the real exchange rate and find the structural **trend loadings** derived from the GBGP:

- The real exchange rate (RER) moves mainly with slow “fundamentals”:
 - **Productivity at home vs. abroad**
Home productivity $\uparrow \Rightarrow$ stronger krone; foreign productivity $\uparrow \Rightarrow$ weaker krone.
 - **Oil-sector activity and expected wealth**
More viable activity/efficiency $\uparrow \Rightarrow$ stronger krone.
 - **World oil prices (terms of trade)**
Oil price $\downarrow \Rightarrow$ weaker krone.
- Framework **weights** each fundamental by how much it pushes the RER in the long run, and **separates** slow trends (fundamentals) from short-run disturbances.

Econometric Model

The econometric model

Observation equation (co-integration via loadings Λ):

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

Trends (random walks):

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

Cycles (stationary VAR):

$$\tilde{y}_t = A(L) \tilde{y}_{t-1} + u_t, \quad u_t \sim \mathcal{N}(0, \Omega)$$

where v_t and u_t are assumed to be orthogonal.

Why this helps. Clear separation of *secular* forces (Balassa–Samuelson, Dutch disease, global trend) from *cyclical* shocks (UIP/monetary, temporary oil price moves). Annual data abstract from high-frequency noise unrelated to fundamentals (Evans 2002, 2010).

Identification

- Latent variables not uniquely identified without further restrictions.
- Following Bai and Wang (2015): Λ_1 ($q \times q$) lower-triangular, with a tight prior centering Σ on a diagonal (exact diagonality only in the Cholesky robustness check).
- Implies that the trend residuals are (approximately) uncorrelated and 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.
- Four **reduced form** trends (i.e., $q = 4$).

Four structural trends (τ)

1. **Common productivity** (anchor z^F): secular world productivity; shifts activity and wages, but *neutral* for the long-run RER.
2. **Oil-price / terms-of-trade** (anchor P^o): long-run oil-market conditions $\Rightarrow$ real appreciation.
3. **Petroleum activity / oil wealth** (anchor Q^p/Y^{np}): scale of the petroleum sector, wealth/spending and export-capacity channels $\Rightarrow$ real appreciation.
4. **Relative productivity** (anchor $z^F - z^H$): external Balassa–Samuelson $\Rightarrow$ higher foreign productivity relative to home depreciates the currency.

Inference

- Gaussian state-space model, estimated with **Bayesian** techniques.
- Minnesota priors on VAR coefficients (A).
- Conservative priors on trend variances (Σ) so trends do not capture business-cycle fluctuations.
- Trend-variance priors calibrated to **Hamilton**-filter trend variances (HP filter as robustness).

The loading matrix Λ (measurement equation)

With $q = 4$ and the lower-triangular normalization on Λ_1 (Bai–Wang):

$$\begin{bmatrix} z^F \\ P^o \\ \frac{Q^P}{Y^{np}} \\ z^F - z^H \\ \frac{I^P}{Y^{np}} \\ w \\ RER \\ i^H - i^F \\ u \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \lambda_{21} & 1 & 0 & 0 \\ \lambda_{31} & \lambda_{32} & 1 & 0 \\ \lambda_{41} & \lambda_{42} & \lambda_{43} & 1 \\ \lambda_{51} & \lambda_{52} & \lambda_{53} & \lambda_{54} \\ \lambda_{61} & \lambda_{62} & \lambda_{63} & \lambda_{64} \\ \lambda_{71} & \lambda_{72} & \lambda_{73} & \lambda_{74} \\ \lambda_{81} & \lambda_{82} & \lambda_{83} & \lambda_{84} \\ \lambda_{91} & \lambda_{92} & \lambda_{93} & \lambda_{94} \end{bmatrix} \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} + \tilde{y}_t$$

The first four observables anchor the scales of the trends (τ_1 common productivity, τ_2 oil, τ_3 petroleum activity, τ_4 relative productivity); theory-based priors on the free loadings follow.

Theory-based priors for Λ (baseline map)

	τ_1	τ_2	τ_3	τ_4
Obs.	com.	oil	petr.	rel.
z^F	1	0	0	0
P^o	0	1	0	0
Q^p/Y^{np}	0	0	1	0
$z^F - z^H$	0	0	0	1
I^p/Y^{np}	0	0	+1	0
w	+1	0	+1	0
RER	0	-1	-1	+1
$i^H - i^F$	0	0	0	0
u	0	0	0	0

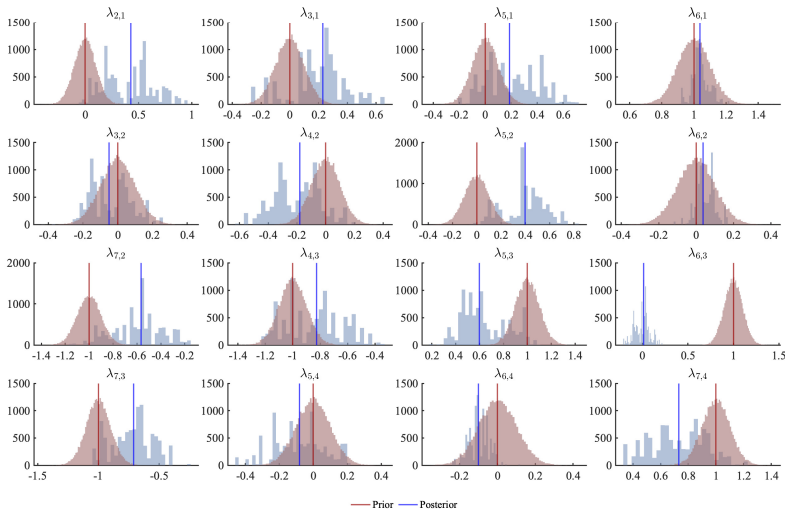
- 9 observables, 4 trends.
- Top 4 rows — the diagonal **1**s anchor and scale the trends (Bai–Wang).
- **Bold** = imposed exactly; other cells = soft priors centered at the GBGP value ($-1/0/+1$), sd 0.5.
- Two *exact* theory cases: *RER* on common productivity = 0; wages on common productivity = +1.
- Data can override

Summary: prior view for the real exchange rate

- **Common productivity**: neutral in the long run; $\Lambda_{RER,1} = 0$ imposed exactly ($\kappa_T + \kappa_N + \kappa_T^* + \kappa_N^* = 0$).
- **Oil-price / terms-of-trade**: appreciation, prior center -1 .
- **Petroleum activity**: appreciation, prior center -1 .
- **Relative productivity** (foreign vs. home): depreciation, prior center $+1$ (external Balassa–Samuelson).

Results

Estimated Λ : priors vs. posteriors (Norway)

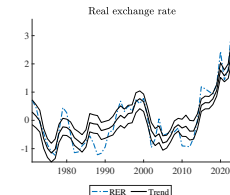
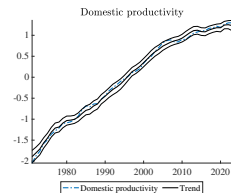
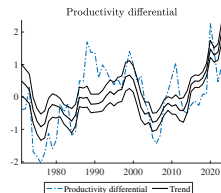
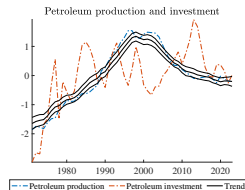
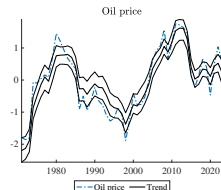


Estimated Λ : what the posteriors say (Norway)

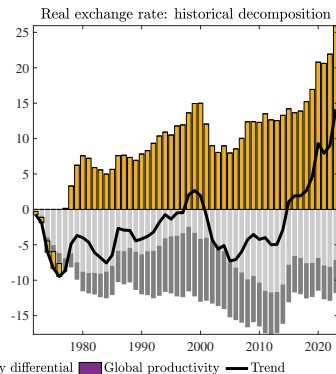
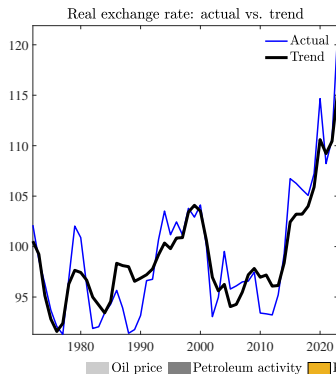
Posteriors (blue) move away from the priors (red) where the data are informative:

- **Common productivity (τ_1):** oil prices, petroleum activity and wages load *positively* $\rightarrow$ global demand spills over to Norway.
- **Oil price (τ_2):** higher long-run prices $\Rightarrow$ more petroleum *investment* but a *lower* production share (depletion/capacity); RER loading negative but modest.
- **Petroleum activity (τ_3):** clear RER *appreciation* ($\lambda_{7,3} < 0$), with higher investment and somewhat stronger wages.
- **Relative productivity (τ_4):** Balassa–Samuelson: higher foreign vs. home productivity *depreciates* the krone; wages load negatively.

Data and estimated trends: Norway

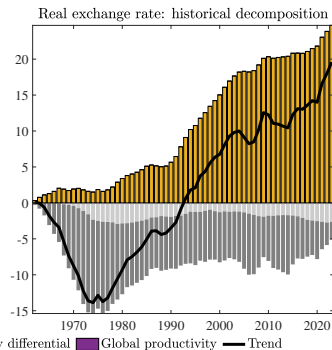
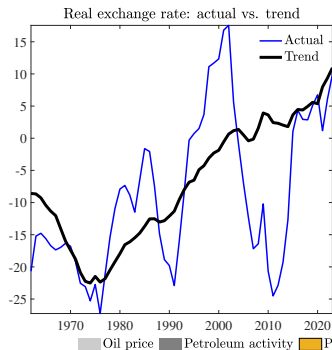


RER decomposition — Norway



- Appreciation from the 1980s to the early 2000s: mainly rising oil prices and an expanding petroleum sector (Dutch disease).
- After 2014, the weaker krone reflects lower oil prices, a shrinking petroleum sector, and a worsening productivity differential.

RER decomposition — Canada

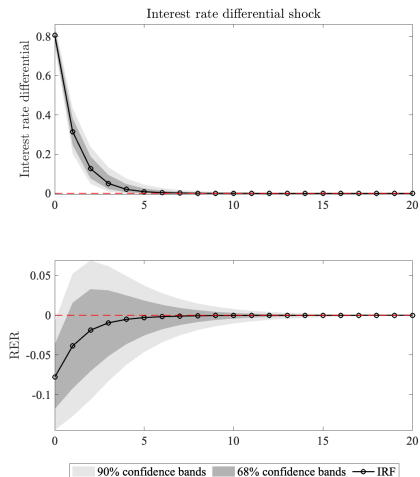
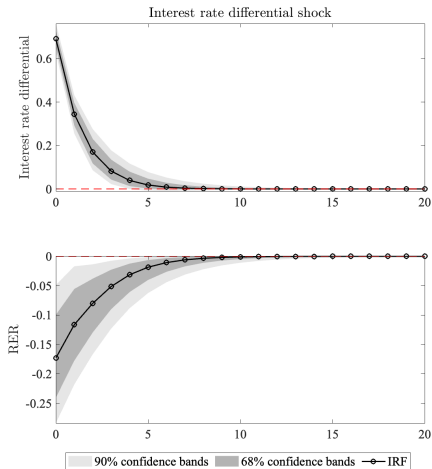


- Oil-price and relative-productivity trends jointly drive the prolonged depreciation.

Impulse responses

- So far we have calculated the trends and examined the historical decomposition of the structural shocks to the trends.
- We now analyse impulse responses to the shocks to the cyclical components.
- Focus on two shocks: a shock to the interest rate differential and a temporary shock to oil prices.
- Assume a Cholesky order for a subset of the model.

Shocks to the interest rate differential: Norway (left) and Canada (right)



Conclusions

- New theoretical SOE model with RER trends.
- Productivity trends in oil and gas explain a sizable share of domestic trend productivity.
- Evidence of Balassa-Samuelson and Dutch disease effects on the exchange rate: long period of appreciation.
- Slowdown in oil trend together with an unfavorable relative productivity trend has weakened the exchange rate the last decade.

Thank you!