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Climate risk, petroleum resources and the Norwegian real exchange rate

Q. Farooq Akram*

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Abstract

We investigate possible effects on the Norwegian equilibrium real exchange rate of hypothetical restrictions on the extraction of petroleum resources motivated by climate goals. In our analytical framework, the equilibrium real exchange rate is affected by the permanent income from net foreign assets, including the Government Pension Fund Global (GPFG) and the present value of available petroleum resources. Our empirical analysis suggests that extraction restrictions may contribute only to a modest depreciation of the equilibrium real exchange rate. The depreciation increases with the scope of extraction restrictions but may be partly offset by a potential rise in petroleum prices resulting from these restrictions. If the real rate of return on the GPFG is higher than that on petroleum resources, a faster pace of extraction and transfer of petroleum revenues to the GPFG may also reduce exchange rate depreciation.

Keywords: Climate risk, stranded assets, exchange rates, FEER.

JEL codes: *Q54, Q56, Q58, F31, F37.*

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1 Introduction

There appears to be broad consensus that the production and consumption of all remaining carbon-intensive energy resources are not compatible with the achievement of global climate goals; see e.g., Muttitt (2016), Rogelj et al. (2018), Asheim et al. (2019), and Welsby et al. (2021). Moreover, the demand for and production of climate-friendly energy, goods, and services have increased over time, in line with growing environmental awareness, technological and economic opportunities, and government regulations.

Reduced production and consumption of carbon-intensive energy and products as a result of regulations and changes in technology and consumer preferences may affect foreign trade, government finances, and other economic activities in countries with large carbon-intensive resources; see Semieniuk et al. (2022) and Bems et al. (2024). A growing number of studies have also pointed to the significance of climate risk and potential stranded assets for the development of various asset prices, including exchange rates; see e.g., Cheema-Fox et al. (2021), Winkler (2022), and Peng et al. (2023).[1]

Norway is among countries that could suffer a relatively large loss in the value of its petroleum resources if their prices fall or if all resources cannot be extracted. Norway still has significant petroleum resources as a result of new oil and gas discoveries over time. Approximately half of the expected petroleum resources have been extracted since their initial discovery in the late 1960s.[2]

Some studies predict that the Norwegian krone, like several other commodity currencies, will depreciate as a result of limits on the extraction of, and/or lower demand for, fossil resources; see Kapfhammer et al. (2020), Aune et al. (2020), and Benedictow and Hammersland (2023). Several market commentators have also attributed the weakening of the krone and other commodity currencies in recent

[1] Climate risk can be broadly divided into physical risk and transition risk. Physical risk is associated with harm to nature, life, and property as a result of climate change. Transition risk is associated with asset depreciation and increased production, distribution, and consumption costs as a result of climate risk-related changes in preferences, technology, and public regulatory activity. Accordingly, this paper mainly focuses on the transition risk faced by Norway's petroleum resources.

[2] https://www.norskpetroleum.no/petroleumsressursene/ressursregnskap-norsk-sokkel/

years as a response to the increasing focus on climate risk and expectations of declining extraction and consumption of carbon-intensive energy sources.[3] However, Winkler (2022) considers the krone to be less exposed to climate risk than most other currencies. Akram (2024) finds no empirical evidence of a systematic relationship between the focus on climate risk and changes in the krone exchange rate.

This study examines the effects of hypothetical restrictions on the extraction of petroleum resources, in the face of climate risk, on the equilibrium (real) exchange rate for Norway.[4] The equilibrium exchange rate is defined as the real exchange rate that is consistent with a balanced external economy while the economies of Norway and its trading partners grow in line with their trend growth rates. Such an equilibrium exchange rate is commonly referred to as the fundamental equilibrium exchange rate (FEER); see MacDonald and Clark (1998) and Isard (2007).[5]

We derive the equilibrium exchange rate from a simple model for foreign trade for mainland Norway, as in Akram (2004). The trade deficit is assumed to depend on the permanent income from net foreign assets. The permanent income consists of the returns on Norway's net foreign assets in the form of the Government Pension Fund Global (GPFG) and the present value of available petroleum resources.[6, 7] The return on available petroleum resources depends, among other factors, on oil and gas prices. Restrictions on petroleum extraction may lead to an increase in petroleum prices and thus increase the return on petroleum resources; see Carlin et al. (2022).

To investigate the effects of possible extraction restrictions on the equilibrium exchange rate, we conduct scenario analyses with different assumptions about ex-

[3] "Krona er halvert i verdi...", Nettavisen 12.03.2023; https://www.nettavisen.no/okonomi/krona-er-halvert-i-verdi-en-ma-lure-pa-om-det-er-noe-grunnleggende-feil/s/5-95-944126

[4] Current Norwegian petroleum policy involves "development, not winding up of the petroleum sector". See e.g., the Hurdal platform: https://www.regjeringen.no/contentassets/cb0adb6c6fee428caa81bd5b339501b0/no/pdfs/hurdalsplattformen.pdf and the government's communication, e.g., after the climate summit in Dubai in 2023: https://e24.no/energi-og-klima/i/kEnAg6/aasland-om-klimaavtalen-endrer-ingenting-for-norge.

[5] See e.g., Driver and Westaway (2005) for an overview of different equilibrium exchange rate concepts.

[6] For information about the GPFG, see https://www.nbim.no/en/.

[7] Here and elsewhere in this paper, we use the term 'available petroleum resources' to differentiate them from 'remaining petroleum resources', where the former are remaining petroleum resources subject to extraction restrictions. Accordingly, available petroleum resources $\leq$ remaining petroleum resources; see Section 2.

traction restrictions, the return on petroleum resources, and the pace of extraction. The analyses show that whether and how much the equilibrium exchange rate depreciates depends on the scope of extraction restrictions and whether they coincide with a lower or higher return on available petroleum resources. Petroleum resources are continuously extracted and the resulting government revenues are transferred to the GPFG. The pace of extraction and revenue transfer affects the equilibrium exchange rate if the average real return on petroleum resources is assumed to deviate from that of the GPFG.[8]

We have structured the study as follows. Section 2 provides a brief overview of Norway's petroleum resources and discusses the effects on petroleum prices of potential restrictions on petroleum extraction. Section 3 focuses on the GPFG and the climate risks it may face. Section 4 presents our stylized model and assumptions made to derive the equilibrium exchange rate.[9] Section 5 conducts several scenario analyses to shed light on the relationship between revenue losses from petroleum resources and the equilibrium exchange rate. Section 6 concludes.

2 Climate risk and petroleum resources

Norway has significant remaining petroleum resources as a result of its extraction policy and several small and large discoveries over time. The present value of the remaining petroleum resources accruing to the government was estimated at NOK 3300 billion in 2021; see Finansdepartementet (2021). This was equivalent to about one year's GDP for mainland Norway. Potential climate-related decreases in the value of these resources may result from political restrictions, technological changes, and/or changes in consumer preferences.

Figure 1 provides an overview of estimated remaining petroleum resources at

[8]To simplify the analysis and text, we overlook time lags between the extraction of petroleum resources and the transfer of government revenues to the GPFG as well as other institutional features. A detailed description of the 'petroleum fund mechanism' is available at Norges Bank's website, including here: https://www.norges-bank.no/en/topics/liquidity-and-markets/Foreign-exchange-purchases-for-GPFG/.

[9]We refer to Akram (2024) for a more general analysis of the possible relationship between climate risk and the Norwegian real exchange rate.

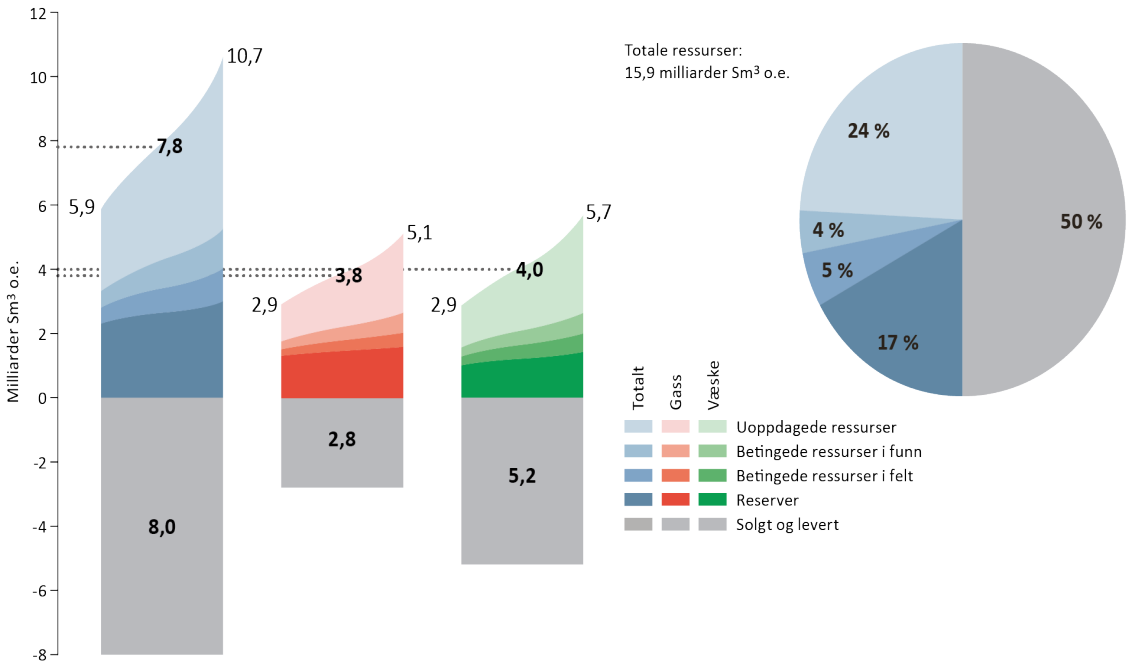

Figure 1: *Norwegian petroleum resources and associated uncertainty in estimates as of 2021. 'Betingede ressurser i felt' and 'Betingede ressurser i funn' are 'Contingent resources in fields' and 'Contingent resources in discoveries', respectively. Figure source:* https://www.norskpetroleum.no/petroleumsressursene/ressursregnskap-norsk-sokkel/ .

various stages of exploration and production. 'Reserves' shown in the darker parts of the figure represent the volume of remaining resources that are expected to be recoverable with a high degree of certainty. In contrast, the estimates labeled as 'Contingent resources in fields' and 'Contingent resources in discoveries' are less certain. These are expected resources in developed and undeveloped fields, respectively. 'Undiscovered resources', depicted in the lighter parts of the figure, are resources expected to be found in areas not yet opened for exploration. These resources are assumed to account for approximately half of the estimated total remaining resources, although their exact size is highly uncertain.

There is considerable uncertainty as to whether, and if so, to what extent, remaining petroleum resources may fall in value or have to be written down. Future market conditions for petroleum are highly uncertain, influenced by factors such as technological change, consumer preferences, and energy and climate policies. One may assume that any political restrictions on the extraction of petroleum resources will primarily affect areas not yet opened for exploration.

A simple assumption could be that political decisions leave most of the 'undiscovered resources' in the seabed, accounting for almost half of the remaining resources. Alternatively, one could assume as Aune et al. (2020) do, that only about 60 percent of 'undiscovered resources' remain unextracted, which implies that almost a quarter of the remaining resources are not extracted. A write-down ratio of between 1/4 and 1/2 of the remaining reserves would correspond to an assumed value loss of between NOK 792 billion and NOK 1650 billion to the government, based on the estimated present value of remaining reserves accruing to the government (i.e., NOK 3300 billion). The maximum estimate of this value loss is comparable to the loss of the GPFG in 2022.[10]

The potential loss of value may be significantly higher or lower than indicated by the point estimates. Figure 1 reveals considerable uncertainty about the total volume of remaining resources, particularly their subcomponent 'undiscovered resources'. Moreover, future petroleum prices, production costs, and interest rates that enter the calculation of the present value of remaining petroleum reserves are highly uncertain.

Petroleum prices may be affected by any extraction restrictions and/or taxes; see Carlin et al. (2022). A relatively large increase in petroleum prices, resulting from such policy actions, could potentially more than offset the loss due to the reduction in petroleum resources available for potential extraction, hereafter 'available petroleum resources'. However, a price effect is conditional on more or less internationally coordinated production restrictions or tax increases. Given the considerable size of remaining petroleum resources globally, measures that only affect Norwegian petroleum production may have little effect on petroleum prices.[11]

Technological changes, energy efficiency measures, and shifts in consumer preferences may, through lower demand for petroleum resources, lead to both a fall in prices and a decline in production. Such shifts may reduce the value of remaining reserves more than politically determined production reductions, which may have an uncertain effect on petroleum revenues due to conflicting price and production

[10] "Norway wealth fund posts record $164 billion loss" *Reuters* 31.01.2023

[11] See e.g., OPEC Annual Statistical Bulletin (2022), https://www.opec.org/opec_web/en/publications/202.htm and the overview on the website https://howmuch.net/articles/worlds-biggest-crude-oil-reserves-by-country.

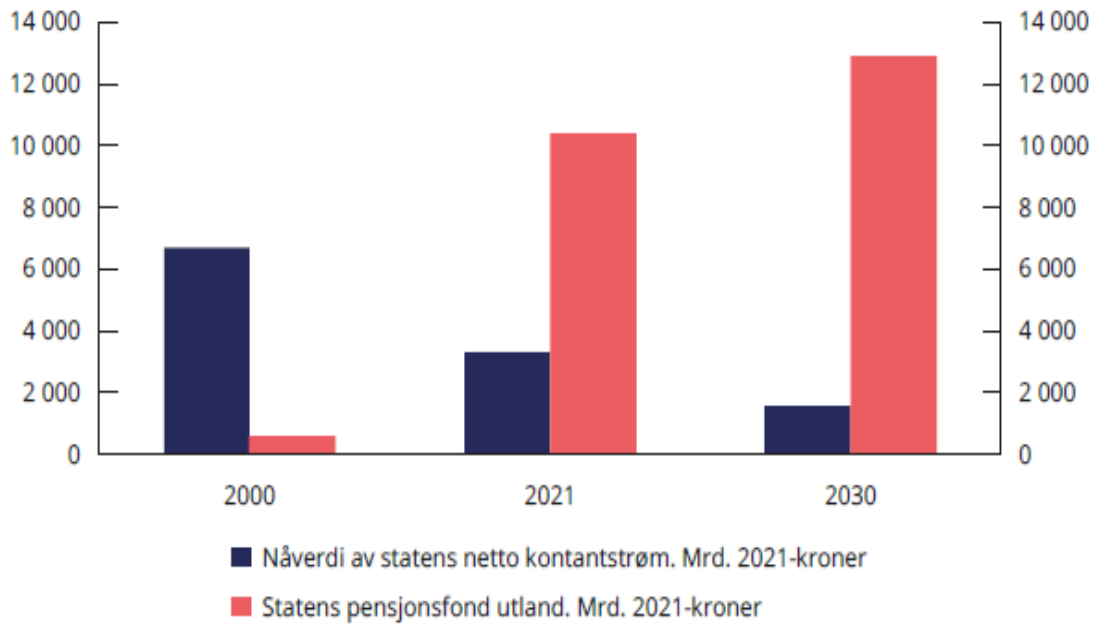

Figure 2: *Actual and projected transformation of petroleum wealth to financial wealth in the GPFG in the period 2000-2030. Figure source: Finansdepartementet (2021).*

effects. It is not obvious, however, that Norway will cut production even if global petroleum demand and production fall overall.

A possible fall in the value of remaining petroleum resources in the event of negative shifts in demand will also depend on how petroleum producers respond to such shifts. Producer countries might cooperate with the aim of moderating any fall in prices by regulating the decline in production, as proposed by Asheim et al. (2019). In this scenario, a fall in total production would support the achievement of climate goals, but the producer countries' loss of income would be smaller than in the event of a purely demand-driven production decline.

Time lags in the decline of demand for petroleum, due to inertia in consumer behaviour and sluggishness in technological and political processes, also contribute to reducing the risk of losses associated with remaining petroleum resources. Figure 2 indicates a decline in remaining petroleum resources over time, consistent with production projections under current climate and petroleum policies. In the absence of major new petroleum discoveries, the value of remaining petroleum resources may become relatively small over the coming decade relative to the GPFG.

3 Climate risk and the GPFG

Climate risk can contribute not only to a loss in the value of remaining petroleum resources but also to a reduction in the value of the GPFG. The value of the GPFG results from investments abroad of government petroleum revenues, and the returns on these investments. The GPFG accounts for the majority of the public sector's net foreign assets and Norway's total net foreign assets.

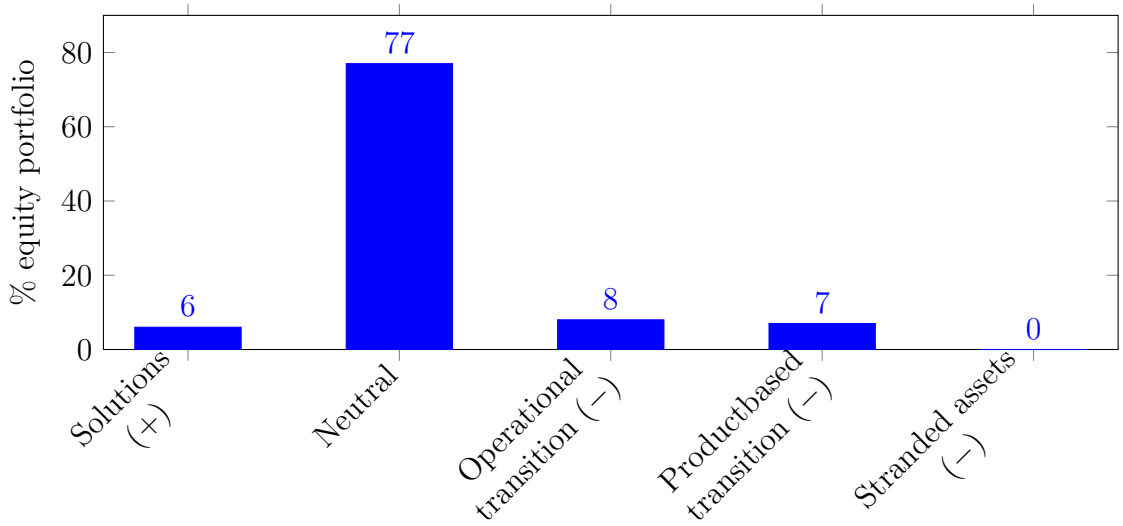

Figure 3: *Transition risk in the GPFG's equity portfolio. Shares of the GPFG's equity portfolio's market value exposed to various types of transition risk, according to the MSCI's five transition-risk categories, as of 25 March 2021. Plus and minus signs indicate whether the specified shares of the equity portfolio are expected to increase or decrease in value as a consequences of the various transition risks. Data source: NBIM (2021).*

Analysis by NBIM indicates that the GPFG's financial and real investments have only limited negative exposure to climate risk; see NBIM (2021).[12] While bond investments are assumed to have negligible exposure to transition risk, about 15% of equity investments are exposed to transition risk; see Figure 3. The GPFG's equity investments are not expected to lose significant value due to climate-motivated restrictions on the extraction or production of natural resources ('stranded assets'). On the contrary, 6% of the GPFG's equity investments may see an increase in value due to a shift towards climate-friendly processes and products.

Table 1 shows NBIM's estimate of the present value of the GPFG's total decline in value as a result of physical and transition risks under different scenarios for the

[12] https://www.nbim.no/no/publikasjoner/brev-til-finansdepartementet/2021/klimarisiko-i-statens-pensjonsfond-utland/

Table 1: *Estimates of the GPFG's transition and physical climate risk by 2080*

Scenario	Decrease in value, %	Decrease in value, bn. NOK
Transition risk if:		
$1,5^oC$	8%	650
2^oC	4%	300
2^oC (delayed)	9%	750
3^oC	1%	50
Physical risk: RCP 8,5	4%	300

Note: Estimated decrease in the value of the equity portfolio by 2080, under different scenarios, as of 31 December 2020, as a percentage and in NOK billion. The "2^oC (delayed)" scenario refers to a scenario of delayed transition and climate regulation which results in greater transition costs and loss of value in the longer term. The RCP (Representative Concentration Pathway) 8.5 scenario represents a scenario of high greenhouse gas emissions, which result in the highest level of global warming according to the Intergovernmental Panel on Climate Change (IPCC) classification. Data source: NBIM (2021).

increase in global temperature by 2080. More ambitious climate policies expressed in terms of a lower temperature rise entail a greater fall in value than less ambitious climate policies. Estimates of the transition risk-linked loss in value range from NOK 750 billion to NOK 50 billion. The physical risk-linked decrease in value is estimated at NOK 300 billion in a relatively extreme scenario where the temperature is assumed to increase by 3 degrees.

As a share of the GPFG's market value of almost NOK 11,000 billion at the end of 2020, the maximum estimated costs associated with both physical risk and transition risk equate to less than 10 percent (= (750 + 300)/11000). These point estimates of the GPFG's climate risk may be lower than the transition risk associated with the remaining petroleum resources in the event of a ban on the extraction of some or all 'undiscovered resources'. As mentioned above, the loss of value due to a ban on the extraction of some or all 'undiscovered resources' could amount to up to NOK 1650 billion for the government as of 2020/2021.

4 Equilibrium real exchange and climate risk

Below, we first present a simple model of foreign trade for mainland Norway. The model can be used to analyse the relationship between the equilibrium exchange rate and net foreign assets in the form of net financial assets and the present value

of petroleum resources.[13] An extensive literature shows a relationship between real exchange rates and countries' net foreign assets over time; see e.g. Obstfeld and Rogoff (1996), MacDonald and Clark (1998), Itskhoki (2021), and references therein. Net foreign assets generate foreign exchange earnings that can help balance the external economy.

We then use a calibrated version of the model to simulate the effects on the equilibrium exchange rate of a decline in income from total net foreign assets. We will focus on income losses resulting from assumed extraction restrictions on petroleum resources and/or changes in the returns on these resources as a result of climate risk.

4.1 Foreign trade and the real exchange rate

We assume that imports (M) measured in the home country's product units depend positively on the income level in the home country (Y) and negatively on the real exchange rate (R):

$$M = Y^{\beta_1} R^{-\alpha_1}. \tag{1}$$

The real exchange rate represents the ratio between the prices of foreign and domestic products in the same currency; an increase in the real exchange rate indicates a real depreciation. The Greek letters in the import function (1) are parameters with positive values, where β_1 represents the income elasticity of imports, while $-\alpha_1$ denotes the price elasticity, i.e. the sensitivity to changes in the real exchange rate.

Similarly, the home country's exports (X) can be assumed to depend positively on the level of income abroad (Y_f) and the real exchange rate, as expressed by the export function (2):

$$X = Y_f^{\beta_2} R^{\alpha_2}. \tag{2}$$

β_2 indicates the sensitivity of exports to changes in income abroad, while α_2 repre-

[13] This section is partly based on Akram (2004).

sents the price elasticity of exports.

The trade deficit (TD) can then be expressed as a function of domestic and foreign income and the real exchange rate:

$$TD \equiv M - X = Y^{\beta_1} R^{-\alpha_1} - Y_f^{\beta_2} R^{\alpha_2}. \tag{3}$$

From the import and export functions, it follows that the trade deficit falls when the real exchange rate depreciates (R rises). The trade deficit also falls when the level of income abroad increases, while it rises with the level of income in the home country. The real exchange rate that is consistent with a certain level of the trade deficit (for given values of domestic and foreign income) can be derived by inverting Equation (3) and simplifying:

$$R = \left[\frac{Y^{\beta_1}}{Y_f^{\beta_2}} \left(1 - \frac{TD}{M} \right) \right]^{1/(\alpha_1 + \alpha_2)}. \tag{4}$$

This relationship indicates that the real exchange rate must depreciate as domestic income rises to counteract the increase in the trade deficit due to higher imports; see Equations (3) and (1).[14] Similarly, the real exchange rate must appreciate when foreign income rises, so that the trade deficit does not fall because of higher exports; see Equations (3) and (2). The dynamics of the real exchange rate will therefore depend on the growth of income-determined import demand (Y^{β_1}) relative to income-determined export demand ($Y_f^{\beta_2}$), i.e. by $Y^{\beta_1}/Y_f^{\beta_2}$. This ratio can be interpreted as the income-driven trade deficit.

4.2 Fundamental equlibrium real exchange rate (FEER)

The fundamental equilibrium exchange rate (FEER) can be defined as the level of the real exchange rate when there is internal and external balance, i.e., when income levels in the home country and abroad and the trade deficit are at their equilibrium

[14] The focus on demand sides of the domestic and foreign economies in such models implies that effects of increases in domestic and foreign growth rates may be opposite to those in models which focus on the economies' supply sides; cf. Balassa (1964), Samuelson (1964), and Bjørnland et al. (2024).

levels, respectively $\overline{Y}$, $\overline{Y}_f$, and $\overline{TD}$.[15] That is:

$$FEER = \left[\frac{\overline{Y}^{\beta_1}}{\overline{Y}_f^{\beta_2}} \left(1 - \frac{PI}{M} \right) \right]^{1/(\alpha_1 + \alpha_2)} . \tag{5}$$

$\overline{Y}$ and $\overline{Y}_f$ can be assumed to be equal to potential GDPs at home and abroad, respectively, while the sustainable level of trade deficit, $\overline{TD}$, has been set equal to the permanent income from net foreign assets, PI. The use of permanent income would maintain the real value of net foreign assets.

In the absence of permanent income from net foreign assets ($PI = 0$), the external balance requires that the trade deficit is equal to zero in equilibrium ($\overline{TD} = 0$). In this scenario, all import expenditures would be covered by export revenues. The equilibrium exchange rate is then determined by the income-driven trade deficit $\overline{Y}^{\beta_1}/\overline{Y}_f^{\beta_2}$. It will be constant if $\overline{Y}^{\beta_1}/\overline{Y}_f^{\beta_2}$ is constant, which requires the same growth in income-determined imports and exports, i.e. $\beta_1 \Delta\overline{y}_t = \beta_2 \Delta\overline{y}_{f,\,t}$, where $\Delta\overline{y}$ and $\Delta\overline{y}_f$ denote the trend growth rates in home country and abroad, respectively. The equilibrium exchange rate will change over time if the trend growth in the home country differs from that abroad, and/or the income sensitivity of imports differs from the income sensitivity of exports.

Permanent income ($PI > 0$) generally causes the equilibrium exchange rate to be stronger than in the case of balanced trade ($\overline{TD} = 0$). The greater the share of imports that can be financed with permanent income (PI/M), the stronger the equilibrium exchange rate; cf. Equation (5). PI/M, which is equal to $(M - X)/M$ when the external economy is balanced, can be interpreted as the share of imports financed by permanent income, while $(1 - PI/M)$ can be interpreted as the share of imports financed by exports.

Changes in permanent income lead to changes in the equilibrium exchange rate. Permanent income, and hence the sustainable level of the trade deficit, would change as a result of changes in available petroleum resources or the return on these resources, for a given income from other net foreign assets, such as the GPFG. The

[15] See MacDonald and Clark (1998) for details on the FEER and numerous other equilibrium exchange rate concepts.

equilibrium exchange rate may vary in line with these changes, all else unchanged.

However, even for a given level of permanent income, the equilibrium exchange rate may vary over time if import demand changes over time. For example, if permanent income is constant or grows slower than import demand, the share of imports it can finance (PI/M) will become increasingly smaller. To keep the trade deficit equal to permanent income, the real exchange rate must become increasingly weaker to reduce imports and increase exports. In the long run, when PI/M becomes insignificant, the equilibrium exchange rate may be as in the case of zero permanent income ($PI = 0$). Then, imports will have to be financed mainly by exports. In other words, the FEER level for $PI > 0$ will converge to the FEER level for $PI = 0$ when $PI/M \longrightarrow 0$.

Whether the equilibrium exchange rate will be affected over time by factors other than permanent income depends on whether climate risk or other factors affect income-driven import demand ($\beta_1 \Delta \overline{y}_t$) more or less than income-driven export demand ($\beta_2 \Delta \overline{y}_{f,\,t}$). Arguably, a faster and larger transition to green technology in Norway can affect the income elasticities of imports and/or exports, β_1 and β_2, respectively, by increasing the preference for Norwegian goods and services both domestically and internationally. Lower β_1 and higher β_2 will, all else being unchanged, contribute to an appreciation of the real exchange rate.

We also note that Purchasing Power Parity (PPP), which implies a real exchange rate equal to 1, is a special case of the expressions (4) and (5) for the case of high price sensitivity of imports and/or exports. More precisely, R and $FEER \rightarrow 1$ when $(\alpha_1 + \alpha_2) \rightarrow \infty$. In this case, the real exchange rate is effectively independent of net foreign assets, permanent income, and income levels in the home country and abroad. This also implies that the real exchange rate will not be affected by factors that may influence these variables, including climate risk. However, empirical studies often find low estimates of the price sensitivity of imports and exports. This is consistent with commonly observed substantial and persistent deviations from PPP; see e.g. Taylor and Taylor (2004) and Akram (2006).

4.3 Assumptions underpinning different scenarios

Assumptions about trade elasticities, trend growth rates, and permanent income are important for the estimated impact of climate risk on changes in the equilibrium exchange rate over time. Below is an overview of our assumptions.

4.3.1 Trade elasticities

The price and income elasticities of imports and exports strongly influence the response of the equilibrium exchange rate to changes in permanent income and trend growth rates. However, the estimated values of these parameters, the alphas and betas mentioned above, vary across studies and depend on the data, modelling assumptions, and the estimation method; see e.g. Marquez (2002), Imbs and Méjean (2015), IMF (2015), and Bussière et al. (2020). For scenario analyses over long horizons, there is also considerable uncertainty associated with parameter estimates based on historical data.

We base our further analysis on estimates of price elasticities that are close to those often found in empirical studies for Norway and other advanced economies; see e.g. Akram (2004), Naug and Nordbø (2018), IMF (2015), and Bussière et al. (2020). In the main analysis, the price elasticities of imports and exports are assumed to be -0.5 and 0.5, respectively. Roughly symmetric price elasticities (in absolute terms) are not uncommon in the relevant empirical literature. In sensitivity analyses, we show the response of the equilibrium exchange rate to climate risk when alternative price elasticities are assumed. Price elasticities that are lower in absolute terms than those in the main analysis will lead to a larger exchange rate response in scenario analyses than those that are higher.

With regard to income elasticities, we assume that they are equal to 1 for both imports and exports. This implies that imports and exports as shares of Norwegian mainland GDP and trading partners' GDP, respectively, will be stable in the long run. While empirical studies often find larger income elasticities than 1, income elasticities equal to 1 are often imposed in macroeconomic equilibrium models to

avoid unrealistic import shares in the long run.[16] We also assume that price and income elasticities remain constant over the simulation horizon, which is obviously a bold assumption for the sake of simplicity.

4.3.2 Internal and external balance

We assume that there is internal balance when domestic and foreign growth rates are equal to their trend growth rates. These are assumed to be 2 percent per year for both Norway and its trading partners. For simplicity, we assume that the growth rates do not change over the simulation period, even when the permanent income from net foreign assets changes. Climate risk and demographic factors may over time lead to lower trend growth than we assume, while technological change may help to counteract this decline; see Goodhart and Pradhan (2020). Changes in petroleum-related industries over the simulation period may also affect trend growth in a positive or negative direction; see Bjørnland et al. (2019). The assumptions of identical trend growth rates for Norway and its trading partners, as well as symmetric income and price elasticities, make it easier to assess the effects of changes in permanent income as a result of e.g., climate risk; cf. Equations (1)–(5).

We assume that there is external balance when the trade deficit (TD) can be financed with the permanent income. This is assumed to be equal to the sustainable/permanent income from Norway's petroleum-based net foreign assets, which consist of the GPFG and the present value of petroleum resources (accruing to the government).[17]

We assume that permanent income is equal to the sum of the returns on the GPFG and the present value of the available petroleum resources. The return on the available petroleum resources is assumed to result from revaluations of the resources

[16] This is a well-known issue in the empirical trade literature, and we refer to e.g. Marquez (2002) for some explanations.

[17] For simplicity, we assume that the present value of available petroleum resources accruing to the (domestic) private sector and the negative net foreign assets of the private sector would largely cancel each other out. The sum of the GPFG and the present value of the petroleum resources accruing to the government would therefore not deviate too much from Norway's total net foreign assets. A precise allocation of the present value of available petroleum resources to the domestic private sector would require data and assumptions on the shares of domestic and foreign companies in future petroleum production in Norway, without adding much to the analysis. Note that both Norwegian and foreign petroleum companies are active in Norwegian petroleum production.

and/or downward adjustments of production costs due to technological change. If the rates of return on the GPFG and Norway's petroleum resources are the same, permanent income, and hence the real exchange rate, will not be affected by how fast the petroleum resources are extracted and petroleum revenues invested in the GPFG, i.e., by the composition of the net foreign assets. However, if there is a difference between the rates of return on the GPFG and the available petroleum resources, the pace of their extraction and the transfer of their value to the GPFG could affect the path of permanent income and thereby the real exchange rate over time.

The permanent income in the reference scenario is assumed to be equal to 3 percent of the market value of the GPFG in the first quarter of 2023 (NOK 14293 billion) and the latest available estimate of (the government's share of) the present value of the remaining petroleum resources, NOK 3300 billion, taken from the 2021 National Budget. The assumption of a 3 percent average real return on the GPFG is in line with estimates from the Ministry of Finance. The assumption of the same average real return (3 percent) on the remaining petroleum resources is in line with "Hotelling's rule", which postulates parity between the expected real return on financial wealth and wealth in the form of non-renewable natural resources; see Hotelling (1931). Permanent income thus amounts to NOK 528 billion per year ($= 0.03 \times 14293 + 0.03 \times 3300$) in the reference scenario.

Figure 4 shows that permanent income and the trade deficit for mainland Norway have followed each other over time, 1995q1–2023q1. The time series for permanent income shown in the figure is calculated as the average real return on the current market values of the GPFG and the present values of the remaining petroleum resources. The current market values of the GPFG are taken from NBIM's quarterly and half-yearly reports, while the annual present value figures for remaining petroleum resources are taken from the revised national budgets for the various years and divided by four to get quarterly values. For the years up to 2013, we have assumed a real rate of return of 4 percent per annum, and 3 percent per annum for the years thereafter.

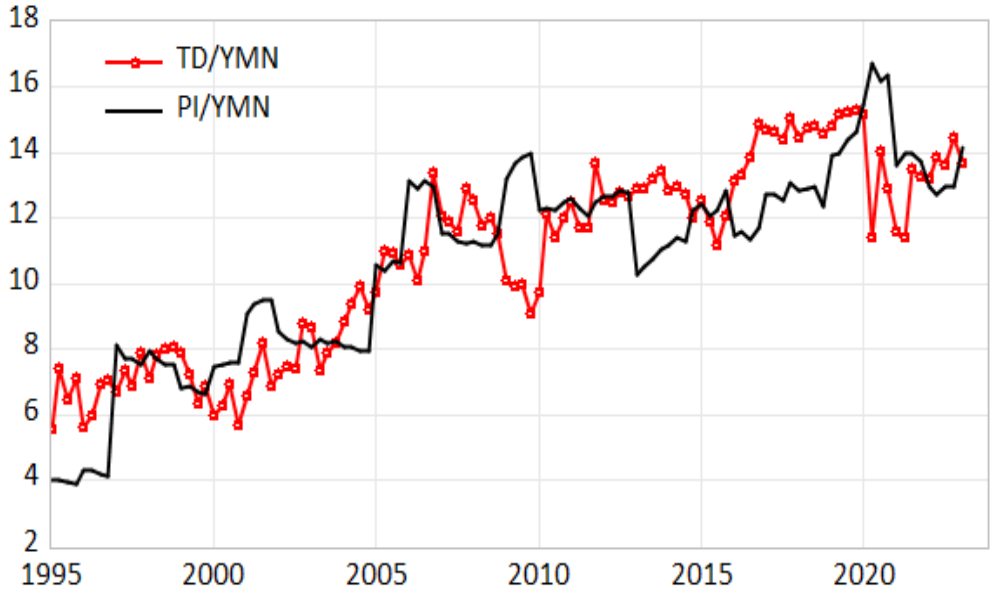

Figure 4: *Trade deficit for mainland Norway (TD) and permanent income (PI) from the GPFG and the government's share of the present value of remaining petroleum resources in the period 1995q1–2023q1. Both variables are presented as percentages of mainland GDP (YMN). Data sources: NBIM and the Norwegian Ministry of Finance.*

5 Equilibrium exchange rate in different scenarios

To derive the equilibrium exchange rate under different scenarios where permanent income is affected by climate risk, we use log-log versions of the equations for imports and exports, (1) and (2), and impose assumed values for price and income elasticities and trend growth rates.[18] The paths for the equilibrium exchange rate in the different scenarios follow from the imposed requirement that the trade deficit is equal to permanent income in the corresponding scenario over the entire simulation horizon: 2023–2080. The trajectory of permanent income over the simulation horizon is affected by the difference between the average real rate of return on the GPFG and on the petroleum resources, as well as by the pace at which petroleum resources are extracted and government petroleum revenues transferred to the GPFG.

Table 2 sets out four different scenarios in which permanent income is affected by climate risk, along with a reference scenario in which it is not. It is assumed that shifts in preferences, climate policy, and/or technological change contribute to

[18]The constant terms in both equations, as the only unknown parameters, are estimated using quarterly data for the period 2021q1-2022q4. A short estimation period helps to reduce deviations between actual and model-predicted values of imports and exports, thus providing reasonable starting values for them in the simulations over the period 2023–2080.

Table 2: *Permanent income under alternative climate risk scenarios*

Scenario		ΔW	r_{fund}	$r_{resources}$	PI
(ref.s.)	0	: 0	3%	3%	528 bn.
(a)	-1/10	: - 330 bn.	3%	3%	518 bn.
(b)	-1/3	: -1100 bn.	3%	3%	495 bn.
(c)	0	: 0	3%	2%	495–528 bn.
(d)	-1/3	: -1100 bn.	3%	4%	517–495 bn.

Note: Permanent income (PI) in the reference scenario (ref.s.) and in four other scenarios (a)–(d), where the permanent income changes as a result of write-downs of petroleum resources and changes in the return on petroleum resources, $r_{resources}$. The return on the GPFG is shown in the column headed r_{fund}, while the column headed 'PI' shows the permanent income in the different scenarios. In the reference scenario, the permanent income is assumed to be NOK 528 billion (= 0.03 × 14293 + 0.03 × 3300) per year. The permanent income in scenarios (a) and (b) is NOK 518 (= 0.03 × 14293 + 0.03 ×(1 − 1/10)× 3300) billion per year and NOK 495 (= 0.03 × 14293 + 0.03 ×(1 − 1/3)× 3300) billion per year, respectively. In scenario (c), the permanent income increases from NOK 495 billion per year to NOK 528 billion per year over the simulation horizon 2023–2080, because of a higher real return on assets in the GPFG than on petroleum resources in the seabed; $r_{fund} = 3\%$ $r_{resources} = 2\%$. In scenario (d), the permanent income declines from NOK 517 billion per year to NOK 495 billion per year because of an initial one-third write-down of resources and the transfer of the available petroleum resources with a higher real return as resources in the seabed to the GPFG, where the real return is assumed to be relatively lower; $r_{resources} = 4\%$ and $r_{fund} = 3\%$.

a write-down of petroleum resources and/or changes in their returns.

In scenarios (a) and (b), we assume write-downs of one tenth and one third of the present value of remaining petroleum resources, respectively, while the real rate of returns on the GPFG and petroleum resources remain the same as in the reference scenario, i.e., 3 percent. Scenario (b) can also be interpreted as a scenario in which the remaining petroleum resources are devalued by just over one-tenth, and the GPFG experiences a decline in value of NOK 650 billion due to the transition risk associated with the 1.5-degree target. This scenario is also consistent with a scenario where the present value of petroleum resources is marked down by almost one-tenth, and the GPFG experiences a total loss of NOK 770 billion (= NOK 1100 billion - NOK 330 billion) as a result of physical and/or transition risk in the case of a temperature target of less than 2 degrees; cf. Table 1.

Permanent income in scenarios (a) and (b) is not affected by the speed at which petroleum resources are extracted and their value transferred to the GPFG, as we have assumed equal real returns in both scenarios. It remains constant at NOK 518 billion (per year) and NOK 495 billion, respectively, throughout the simulation

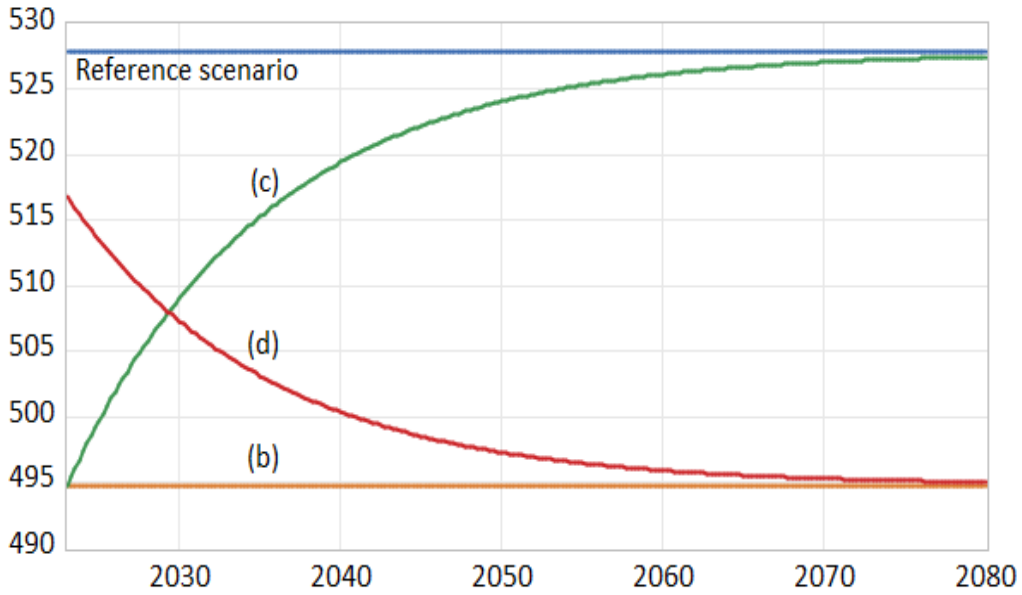

Figure 5: *The permanent income over the simulation horizon 2023-2080 in scenarios (b), (c), (d), and the reference scenario (ref.s.). The permanent income in scenario (a), which is not explicitly shown in the figure, is equal to NOK 518 billion per year and, like the permanent income in the reference scenario, constant over the entire simulation horizon. See Table 2 for details. The half-life of available petroleum resources which indicates how fast their value is transferred to the GPFG, is assumed to be close to 8 years. In scenarios (b) and (c), the present value of the petroleum reserves (NOK 3300 billion) and the return on them are adjusted downwards by 1/3. In scenario (d), the present value of the petroleum reserves is adjusted downwards by 1/3, while the return on available resources increases by 1/3 to 4 percent.*

horizon.

In scenario (c), we assume that the present value of the petroleum resources remains unchanged, although the return on the resources falls by a third to 2 percent per year. Additionally, we assume that petroleum resources are extracted and transferred to the GPFG at a pace corresponding to a half-life of almost 8 years for the available petroleum resources; cf. Figure 2. Scenario (c) may correspond to a scenario in which the resource base grows due to increased recovery rates, while real growth in petroleum prices declines, e.g., due to lower growth in petroleum demand.

In the event of a fall in the real rate of return on petroleum resources by one third, permanent income initially falls by the same amount as if the present value of the petroleum resources fell by one third; cf. scenario (b). As the petroleum resources are extracted and transferred to the GPFG, which has a relatively higher rate of return, permanent income increases. It converges to the level of permanent

income in the reference scenario, where the petroleum resources transferred in their entirety to the GPFG have the same high expected real rate of return.

Figure 5 shows the trajectory of permanent income in scenario (c) over the entire simulation horizon. Permanent income (per year) starts at NOK 495 billion as in scenario (b), but gradually rises to the level in the reference scenario, NOK 528 billion. The faster the petroleum resources are extracted, and their value transferred to the GPFG, the faster the permanent income converges to the level in the reference scenario.

In scenario (d), we assume that the present value of petroleum resources falls by one third, but the rate of return on petroleum resources rises to 4 percent per annum, e.g., due to lower growth in petroleum supply. Initially, the reduction in permanent income due to the fall in the present value of petroleum resources is largely offset by the increase in the return on the available petroleum resources. Permanent income in this scenario is initially close to the permanent income in scenario (a), where the present value falls by one-tenth; see trajectory (d) in Figure 5. As petroleum resources are extracted and transferred to the GPFG, which has a relatively lower rate of return, permanent income falls. It converges to the level of permanent income in scenario (b), where two thirds (2/3) of the petroleum resources are transferred to the GPFG and receive the same relatively lower real rate of return (3 percent).

Figure 6 shows the percentage weakening/depreciation of the equilibrium exchange rate over the period 2023-2080 in scenario (a) for alternative price elasticities. The equilibrium exchange rate can be up to one percent weaker than in the reference scenario if we assume price elasticities of -0.5 and 0.5 for imports and exports, respectively, but more than twice as much if the price elasticities are halved to -0.25 and 0.25. For price elasticities above 0.5 in absolute value, the depreciation was found to be smaller. For example, the depreciation associated with price elasticities of -2 and 2 was about a quarter of the depreciation associated with price elasticities of -0.5 and 0.5.

The weakening of the equilibrium exchange rate is greater in the short run than in the long run. This suggests that write-downs of petroleum resources has a di-

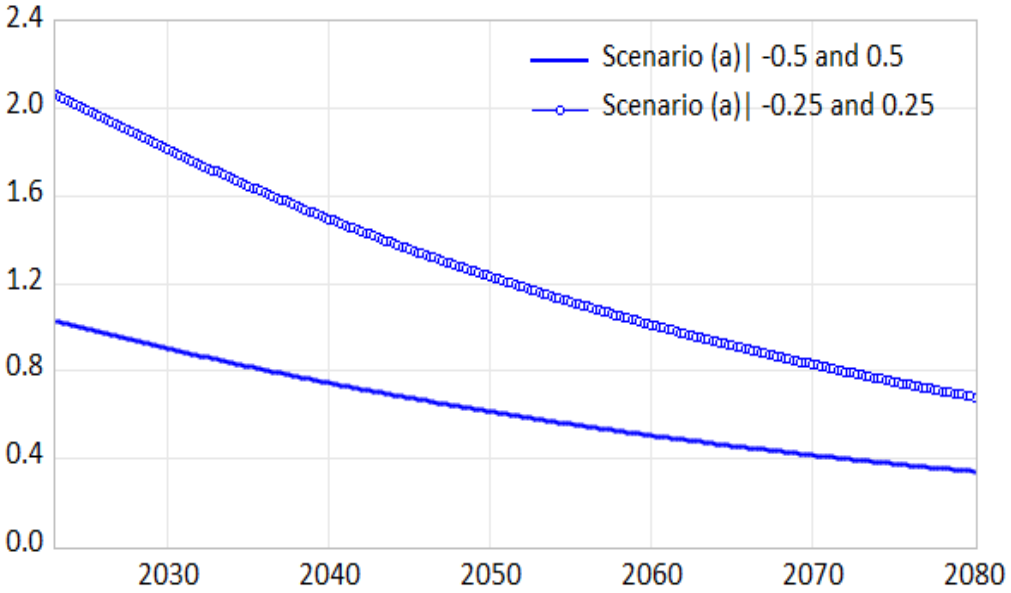

Figure 6: *Percentage depreciation of the equilibrium exchange rate in scenario (a) for two cases of price sensitivity for imports and exports. In one case the price elasticity is -0.5 for imports and 0.5 for exports. In the second case, the price elasticity is -0.25 for imports and 0.25 for exports. In both cases, internal balance is assumed, defined as trend growth of 2 percent per year in Norway and its trading partners. This assumption is also used in the other scenario analyses. The depreciation rates are calculated as percentage deviations of the equilibrium exchange rate in scenario (a) from the equilibrium exchange rate in the reference scenario, conditional on identical sets of price elasticities.*

minishing impact on the real exchange rate over time. This is consistent with the generally declining importance of permanent income relative to imports, which are assumed to grow over time with the trend growth of mainland GDP; cf. Equation (5).

In the analysis that follows, we assume price elasticities of -0.5 and 0.5 and focus on the significance of changes in the return on petroleum resources and the speed at which they are extracted and transferred to the GPFG. Figure 7 shows the equilibrium exchange rate in scenarios (b), (c), and (d); the corresponding permanent income paths have been displayed in Figure 5.

Given our linear model, the depreciation of the equilibrium exchange rate over the simulation horizon in scenario (b) is about three times larger than in scenario (a), measured as percentage deviations from the equilibrium exchange rate path in the reference scenario. The depreciation of the equilibrium exchange rate in scenario (c) is initially the same as in scenario (b), but decreases as permanent income increases

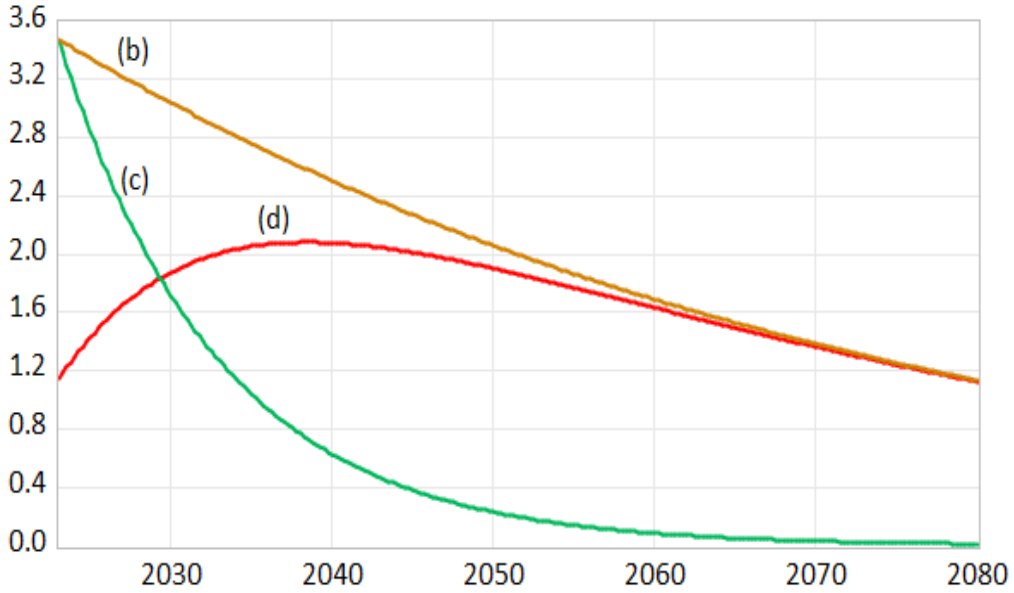

Figure 7: *Percentage depreciation of the equilibrium exchange rate in scenarios (b), (c), and (d) relative to the equilibrium exchange rate in the reference scenario (ref.s.) over the period 2023-2080. An extraction pace/half-life of 8 years is assumed for the available petroleum resources in all scenarios.*

with the transfer of petroleum resources' value to the GPFG, which is assumed to have a relatively higher rate of return in this scenario. Figure 8 suggests that the depreciation may be short-lived if the extraction pace is fast enough.

In scenario (d), the depreciation of the equilibrium exchange rate is initially about the same as in scenario (a). It then increases as petroleum resources, with a real rate of return of 4 percent, are extracted and their value transferred to the GPFG, which has a real rate of return of 3 percent. When the transfer is complete, the equilibrium exchange rate will be as in scenario (b), fully reflecting the effect of a one-third write-down of the present value of petroleum resources.

The above analysis illustrates the importance for (permanent income and) the equilibrium exchange rate of whether extraction restrictions on petroleum resources coincide with an increase or a decrease in the return on the available petroleum resources. How much the real rate of return changes will depend, among other factors, on whether and how political and/or technological changes affect the supply and demand sides of the petroleum market. When the average real rates of return on the GPFG and on petroleum resources differ, the speed at which the value of

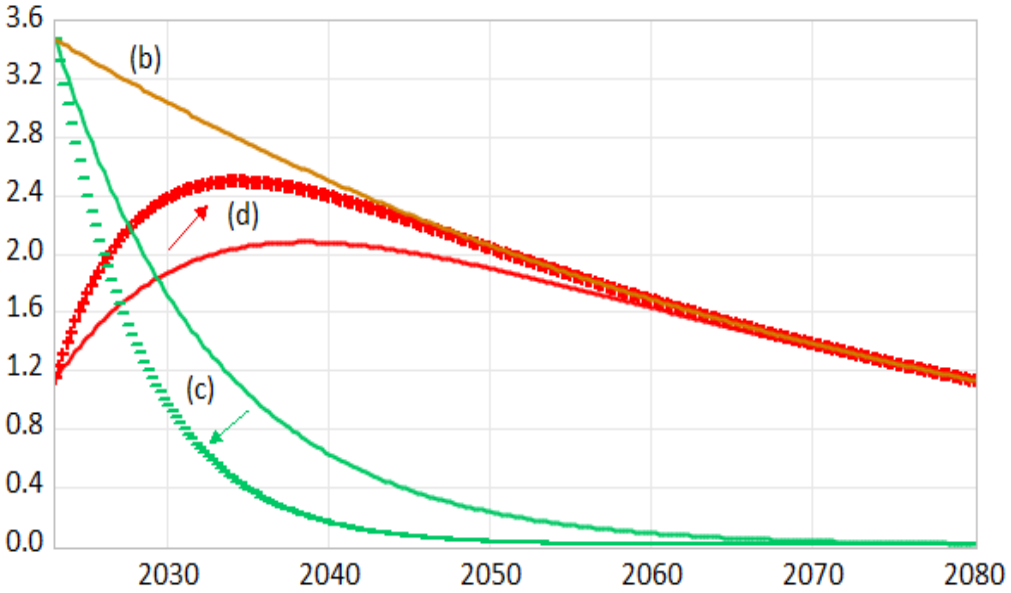

Figure 8: *The significance of alternative extraction paces/half-lives for the equilibrium exchange rate over the period 2023-2080 is illustrated. The vertical axis shows the percentage depreciation of the equilibrium exchange rate in scenarios (b), (c), and (d) relative to the equilibrium exchange rate in the reference scenario (ref.s.) conditional on half-lives of 8 years and 4 years (dashed/patterned lines). The half-life is not important in scenario (b) with equal rates of return on the GPFG and the available petroleum resources, as permanent income is not affected by transfers of the value of petroleum resources to the GPFG.*

petroleum resources is transferred to the GPFG has a substantial impact on the equilibrium exchange rate.

In the scenario analyses above, we have assumed that the write-downs of petroleum reserves and the changes in returns occur instantaneously, without taking into account time lags between the decision, announcement, and implementation phases, e.g., of policy changes. The shifts in the estimated equilibrium exchange rate were therefore instantaneous. However, empirical studies of the relationship between real exchange rates and petroleum discoveries show time lags of several years between petroleum discoveries and the real exchange rate changes that can be associated with them; see Harding et al. (2020) and Arezki et al. (2017). Petroleum discoveries can be seen as the opposite of depletion. These studies imply that the impact on real exchange rates may become sizable only when any restrictions on extraction actually result in reduced petroleum production.

6 Conclusion

Climate risk could lead to a loss in the value of petroleum resources, both through restrictions on extraction and through a reduction in their return. Climate risk may also reduce the value of the GPFG. We have investigated the effects of climate risk on the fundamental equilibrium (real) exchange rate (FEER) for Norway through scenario analyses. These scenarios are based on assumptions about extraction restrictions, the speed of petroleum extraction and transfer of (the government's share of) their value to the GPFG, and the real rates of return on both petroleum resources and the GPFG.

Our analysis suggests a limited depreciation of the equilibrium exchange rate under several scenarios. It shows that the depreciation increases with the scope of extraction restrictions, the decline in the real return on petroleum resources relative to the real return on the GPFG, and how slowly the extraction of petroleum resources and the transfer of their value to the GPFG take place.

In particular, an increase in the real rate of return on petroleum resources that coincides with restrictions on extraction may help to offset some or all of their effects on the equilibrium exchange rate. If the real rate of return on petroleum resources falls relative to the real rate of return on the GPFG, an increase in the pace of extraction may reduce both the magnitude and the duration of the depreciation.

In this study, we have focused on the potential effects of climate risk on petroleum resources and, to some extent, on the GPFG. However, a more comprehensive analysis should consider the overall effects of climate risk on the Norwegian economy and on the economies of its trading partners. It is not obvious that the Norwegian economy is more exposed to climate risk than the economies of its trading partners. Thus, contrary to what our partial analysis suggests, climate risk could lead to a stronger rather than a weaker equilibrium exchange rate.

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