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Climate risks, balance-of-payments constraints and central banking in emerging economies – insights from Nigeria

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Abstract

This paper explores the question in how far physical and transition effects of climate change impact central banking transmitted through the balance-of-payments in emerging economies. We conduct a country case study of Nigeria by triangulating primary qualitative data generated from ten semi-structured interviews with secondary quantitative data used to construct two structural vector autoregressive models. We find that climate risks impact Nigeria's balance-of-payments both through the financial and current account channel to the detriment of the central bank's objectives. Long-term physical effects of climate change and the strong connection between crude oil and Nigeria's domestic economy, its financial system and its trade balance are key explanatory variables. They effectuate an aggravated pressure on the exchange rate, in particular when global instability rises, reduce foreign exchange income and increase the need thereof – further putting pressure on the exchange rate and undermining the acceptance of Nigerian financial assets. As a result, the central bank is forced to keep interest rates high. These effects have recessionary implications for the domestic economy and impede economic diversification as well as green transition in Nigeria. We empirically show how climate risks are exponents of challenges to central banking in emerging economies which perpetuates global inequality.

Keywords: central banking; global instability; emerging economies; climate change; balance-of-payments

Subject classification codes: E5; F32; Q54

1 Introduction

Climate risks – here defined as physical risks related to climate change and transition risks stemming from climate policies, sudden divestment strategies and changes in demand patterns – have important implications for central banking. They increase inflation rates by harming productivity and when carbon taxes are added to consumer prices (Batten, Sowerbutts, and Tanaka 2020; Parker 2018; Heinen, Khadan, and Strobl 2018; Dennig et al. 2015). They also impact prospective growth and heighten financial instability by increasing inequality and the volatility of prices for primary commodities, and by adversely impacting investors' financial portfolio when assets are destroyed by extreme weather events or fossil based assets strand due to climate policies (Leiter, Oberhofer, and Raschky 2009; Cavallo and Noy 2011; Dafermos, Nikolaidi, and Galanis 2017; Dennig et al. 2015). Increased instability impedes the potential of central banks to make informed decisions, translates into higher exchange rate volatility and poses the challenge of reconciling central banks' mandates with climate protection (Chenet, Ryan-Collins, and van Lerven 2021; Dafermos, Nikolaidi, and Galanis 2018; Dikau and Volz 2021; Baer, Campiglio, and Deyris 2021; Bush and López Noria 2021).

Despite growing attention paid to the impacts climate change has for monetary policy making, there are two important gaps in the present literature. Firstly, the specific conditions of central banking in emerging economies vis-à-vis climate risks remain under-researched. In these economies, the ability of central banks to achieve their primary objectives is limited by structural external constraints posed by their balance-of-payments (Andrade and Prates 2013; Paula, Fritz, and Prates 2017; Maxfield 1997). Seeming exceptions are the models by Moreno et al. (2024) and Yilmaz et al. (2023), where the former assesses Colombia's vulnerability to transition risks, and the latter the implications of reduced agricultural productivity for Tunisia's balance-of-payments, as well as Oberholzer's (2023) and Svartzman and Althouse's (2020) pieces on the impossibility to overcome the climate catastrophe as long as balance-of-payments restrictions remain. Though these studies focus on the nexus between a country's balance-of-payments constraints and climate change, they do not address the question of what implications this has for central banking in the affected countries.

Secondly, most empirical studies on the interplay between the international financial architecture and the climate crisis focus on either the transition (e.g. Kapfhammer, Larsen, and Thorsrud 2020; Svartzman and Althouse 2020) *or* the physical effects of climate change (e.g. Cavallo and Noy 2011; Coulibaly, Islam, and Managi 2020). To our knowledge, only few studies using stock flow consistent models incorporate both types of risks to analyze how climate hazards impact global growth prospects and financial stability (Dafermos, Nikolaidi, and Galanis 2018; 2017). This is a particularly important lacuna in the context of low- and middle-income countries, because they are disproportionately burdened by both types of risks.

This paper fills these gaps. It uses the example of Nigeria to assess the implications of climate risks for central banking in emerging economies. Nigeria is an interesting case because of its susceptibility to transition risks based on its oil dependence, and to physical risks due to its geographical position near the equator where physical risks are particularly concentrated (IPCC 2018). Although there is research on the nexus between oil prices, macroeconomic variables and central banking in Nigeria (e.g. Adi, Adda, and Wobilor 2022; Dafe 2019), little has been said about how climate risks impact central banking in Nigeria.

We apply an innovative mixed-method design which triangulates insights from primary qualitative data generated from ten semi-structured expert interviews with two structural vector autoregressive (SVAR) models. We find that climate risks reduce foreign exchange income, while making the holding of foreign exchange reserves more important because of grown susceptibility to external instabilities. Moreover, they render the exchange rate more volatile and undermine the confidence in Nigerian financial assets. This is particularly pronounced when global instability rises. As a consequence, the Central Bank of Nigeria (CBN) is forced to keep interest rates high to maintain demand for domestic financial assets. These effects taken together have recessionary implications for the domestic economy and impede economic diversification as well as green transition efforts. Moreover, the need to hold "costly" foreign exchange reserves absorbs crucial foreign exchange, which could be used for developmental purposes. These findings show the additional risks and complications posed by climate change for central banks in low- and middle-income countries faced with structural balance-of-payments constraints. We conclude that the design and implementation of climate policies have to consider foreign exchange dependence in the Global South to enable an equitable climate transition.

Following this introduction, section 2 provides some background to the nexus of central banking and the balance-of-payments constraint in Nigeria. Section 3 introduces our data and methodology. Section 4 analyses the qualitative data to provide in-depth information on how climate risks impact Nigeria's balance-of-payments and the implications thereof for the Nigerian central bank's main instruments. Section 5 presents the two SVAR models, whilst Section 6 concludes.

2 Central banking and the balance-of-payments constraint in Nigeria

Nigeria's balance-of-payments is characterized by instable foreign exchange income. Figure 1 represents Nigeria's external trade and current account balance in relation to GDP for the years 2003-22. Nigeria's current account balance seems to have deteriorated on average since 2005, went into deficits in 2015 and 2019-21, whilst 2022 marked significant surpluses. These fluctuations can be explained by volatile exports due to volatile international oil prices, whilst imports remained relatively stable. This shows the vulnerability of Nigeria's balance-of-payments, whose ability to autonomously generate foreign exchange is constrained and depends on internationally determined commodity prices. Slumps of the current account might have been more pronounced if the Nigerian government had not imposed import and foreign exchange restrictions (International Trade Administration 2023).

INSERT FIGURE 1 HERE

Figure 2 suggests that Nigeria's financial account becomes less sustainable. The external liability stock in relation to GDP has increased since 2012, though the curve flattens out after 2020, which gives hint to the dependence of Nigeria's financial account on international market conditions. The ratio of external debt securities to international foreign exchange reserves is also increasing steeply since 2012, but without a decrease in growth rates after the Covid-19 pandemics broke out (see Figure 2).

INSERT FIGURE 2 HERE

Nigeria's growing exposure to external liabilities takes place against the backdrop of its vulnerability vis-à-vis its exposure to portfolio flows, which are more mobile and represent an important channel through which international volatility spills into the domestic economy (Grabel 1996; Bortz and Kaltenbrunner 2018). Figure 3 provides insights into the volatile nature of these flows in the case of Nigeria.

INSERT FIGURE 3 HERE

As indicated above, Nigeria's balance-of-payments constraint is strongly intertwined with its oil-dependence. 90% of Nigeria's net exports come from crude oil and petroleum gases (see Figure 4). But the demand for oil is projected to fall as result of decarbonization efforts: One estimation predicts that by 2050 the demand for oil will be a quarter of what it is today (Mercure et al. 2021). Graaf and Bradshaw (2018, 25) purport that the "key uncertainty is not whether global oil demand will peak, but how soon it will peak and how quickly demand will fall thereafter".

Nigeria's susceptibility to transition risks is complemented with its vulnerability to physical risks. According to the Notre Dame Global Adaptation Index's (ND-GAIN) ranking of 192 countries, Nigeria deteriorated from rank 104 in 2006 to 158 in 2020 because of the projected change in agricultural yield and a lower level of readiness to tackle climate risks (ND-GAIN 2023). This points to another aspect of how climate risks are likely to impact Nigeria's balance-of-payments: Nigeria is a net importer of food stuff which makes it susceptible to higher food prices as result of climatically induced reduction of agricultural productivity.

Figure 4 shows that food and fuel imports make up about 40 per cent of merchandise imports. Oil rents contribute a relatively small share to GDP, but a massive one in the determination of exports. Because oil is the primary source of foreign exchange, there is a strong correlation between Nigeria's GDP and the price for crude oil (The Economist 2019).

INSERT FIGURE 4 HERE

The exposure of Nigeria's balance-of-payments to developments on international oil markets and its vulnerability to physical risks of climate change has important implications for the CBN's main mandates, namely price stability, stable domestic financial markets and ensuring sufficient foreign exchange funds to defend the naira (CBN 2023f). All mandates are limited by the balance-of-payments and feed back into it – establishing a strong nexus between central banking and the balance-of-payments.

The CBN targets to retain inflation within a range of 6-9% (Olurounbi and Osae-Brown 2023) – a goal consistently missed. The CBN herein hopes that predictable price levels ensure financial stability by reducing uncertainty and by helping economic agents to make rational decisions (CBN 2021). The CBN itself identifies the exchange rate, energy and food prices, foreign capital flows, government spending, reduced output ensuing poor energy supply and social conflict as main factors determining the price level (CBN 2023g). The CBN officially declares interest rates and exchange rates (because of the high pass-through of prices for imports to overall consumer prices) as its most important policy tools to influence the price level (CBN 2023g).

Stable domestic financial markets help to ensure sufficient credit supply to the domestic economy and the effective transmission of monetary policies (Mishkin 1995). According to the CBN, the main threats to financial stability in Nigeria are oil price shocks and global contractions, which imply reduced international trade and foreign portfolio investments outflows (CBN 2019; 2022). The CBN's main instruments to ensure stability of domestic financial markets is inflation and exchange rate control, the deepening of financial markets and regulations of the banking sector especially in regard to FX-denominated exposure (CBN 2023g).

Beyond domestic factors such as sudden asset re-evaluations and interest rate fluctuations, sufficient liquidity denominated in foreign exchange and exchange rate stability are central for financial market stability in low- and middle-income countries. Foreign exchange scarcity causes liquidity crunches vis-à-vis domestic financial actors' exposure to foreign exchange denominated liabilities. Financial stability also depends on stable exchange rates for two reasons: Firstly, as exchange rate depreciation and volatility destabilizes the entire economy, they come with spill-over risks for the financial sector. Secondly, sudden currency devaluations lead to divestments of domestic assets coming with solvency problems and adversely affecting the asset side of domestic financial actors' balance sheets (Taylor 1998; Bush and López Noria 2021).

The third main mandate of the CBN is to hold sufficient foreign exchange reserves (CBN 2023f). Foreign exchange reserves ensure the ability to service Nigeria's liabilities, to inject foreign exchange liquidity into domestic financial markets when needed and to conduct currency stabilization measures. Before the management of the exchange rate was abandoned in 2023, its driving motive was to tame the spill-over effects of volatile international oil prices to the exchange rate – as among others highlighted by the previous governor of the CBN (Sanusi 2004, 5; see also the fear-of-floating literature, e.g. Hausmann, Panizza, and Stein 2002).[1]

[1] A drastic regime shift in central banking took place in 2023, when Nigeria officially abandoned its three-tiered exchange rate regime consisting of the official rate managed by the CBN, the market-determined exchange rate benchmark called *Nigerian Autonomous Foreign Exchange Rate Fixing* (NAFEX) used by investors and exporters, and the so-called *parallel* exchange rate used by authorized dealers such as bureaux de change.

3 Mixed methods approach and data basis

In our analysis we applied a mixed approach by triangulating primary data derived from ten semi-structured interviews with two SVAR models based on eight time series. The interviews were carried out with experts in the fields of central banking, financial regulation, green finance and post-carbon transition in the Nigerian context and took place between April and July 2022. Appendix A provides an overview of the background of the interviewees and the length of the interviews. Choosing the interviewees, we did non-randomized, maximum variation sampling following the snowball principle (Byrne 2001). The interviews were transcribed and independently coded.

We used the interview results to inform the construction of our two SVAR-models. A (S)VAR-approach is suitable for our investigation because it uses a minimum of ex-ante assumptions and enables the model to take all possible cross-dependencies into account rendering it suitable for the analysis of monetary policy making (Sims 1980; Kilian and Lütkepohl 2017; Koluk and Mehrotra 2009). The models investigate the impact of climate risks on the CBN's key three monetary policy instruments: the nominal bilateral naira-dollar exchange rate, the level of foreign exchange reserves and the differential between the Nigerian monetary policy interest rate and the US Fed Fund rate. The latter spread is used as proxy for the profitability of Nigerian assets vis-à-vis safer investments (Kaltenbrunner 2015). Model 1 tries to approximate possible interactions between the CBN's policy variables and external shocks, which are likely to occur in climate transition scenarios. We here include (a) higher international financial instability, approximated by the VIX, because climate transition is said to lead to stranded assets with repercussions on international financial markets (Semieniuk et al. 2022); and (b) Nigeria's revenues generated from the export of oil, because decarbonization is said to diminish the role of fossil fuels (van de Graaf and Bradshaw 2018). Model 2 captures the potential physical effects of climate change: To consider how physical risks lower agricultural productivity both globally and in Nigeria, and might therefore increase Nigeria's import bill for food stuff and its inflation rates, we include the FAO's FoodPrice Index and the Nigerian food price inflation. To estimate the effects of physical climate risks stemming from natural disasters, we include a dummy variable where 1 denotes months during which a natural disaster in Nigeria was recorded in the Emergency Database (EM-DAT) and 0 indicates the absence of any recorded disaster.

All monthly time series were cleaned, missing values were linearly imputed and included in their natural logarithm for the time span January 2006 to December 2022. Appendix B gives an overview over the variables included in the models, their data sources and provides general descriptive statistics of the included time series. We follow Sims (1980) by incorporating all variables in their levels and by using Impulse-Response-Functions (IRFs) as means of interpretation, which do not depend on normality of the residuals. This is important as test-statistics in (S)VAR-models are sensitive to non-normality, and t- and F-statistics are not robust, especially when dummy variables are included (Sims 1980, 17).

For the recursive ordering of the time series according to a decreasing degree of exogeneity to identify the structure the models, we chose the following order based on theory: VIX, revenues from the export of oil, the interest rate spread, the exchange rate and foreign exchange reserves. For Model 2, we assume international food prices and Nigeria's exposure to natural disasters to be least endogenous to policy making in Nigeria, followed by the food price inflation whilst the ordering of the CBN's instruments is the same as in Model 1.

We built a Qual SVAR – a SVAR model with a qualitative variable – to incorporate the dummy variable which indicates the existence or absence of a natural disaster variable in a given month. A Qual VAR was first developed by Dueker (2005), who elaborates the interpretability of IRFs of binary variables given they are included as stationary time series. El-Shagi and von Schweinitz (2016) emphasise that Qual VAR come with serious identification problems and should therefore only be used in simple models and when the chains of causality are clear-cut. According to the authors, general dynamics represented in the Qual VARs' IRFs can still be derived, however not the magnitude of the shock represented by the IRF as the estimation of the variance is distorted (El-Shagi and von Schweinitz 2016). Because it is implausible that monetary variables cause natural disasters, the question of causality is clear in our model.

4 Climate risks' impacts on Nigeria's balance-of-payments and implications for the CBN's means of central banking

This section summarizes the interview results' insights on how climate risks impact Nigeria's balance-of-payments, followed by an elaboration of how they impact the CBN's means of central banking and identifies feed-back loops.

Impacts on the balance-of-payments

The analysis of the interviews identified how climate risks negatively impact Nigeria's trade balance.[2] Climate risks are likely to increase Nigeria's imports. Its physical effects deteriorate the productivity of Nigeria's agricultural sector: The spread of the Saharan dessert and recurrent floods in coastal and riverine areas reduce arable land and pasture (I2, I3, I4, I5, I6, I8, I9, I10). The resulting displacement of communities spurs social conflict, which causes farmers to abandon their plots (I2, I3). Overall reduced domestic production necessitates more imports of food-stuff (I6). What is more, when infrastructure and machinery are destroyed by floods, rebuilding material has to be imported (I5). Same holds when capital necessary for climate mitigation (e.g. the planned creation of 5-10 million solar homes) and for adaption measures (e.g. a land reclamation project on the shore of Lagos) cannot be produced domestically (I4, I5, I9). Because Nigeria imports most of its refined oil from Europe, its import bill is likely to

[2] We here focus on the trade balance part of the current account, as the interviews revealed little about climate risks' impact on the export of services.

inflate when climate policies such as carbon taxes, the EU's primary climate policy strategy (Eicke et al. 2021), increase the prices for refined oil.[3]

Climate risks are also likely to negatively impact exports. Climate transition measures like carbon tariffs and taxes are likely to harm Nigeria's competitiveness and export potentials in the future (I3, I9). Lower prices for crude oil ensuing a reduced demand in carbon-intensive goods will decrease export income by putting downward pressure on the price of crude oil (I2, I3, I7, I8, I10). Interviewee 4 stated: the "oil price is the mainstay of the Nigerian economy. [...] All sort[s] of crises that you can see in the country over the past years […; have] an element in dynamics of oil prices" (I4). By spurring social conflict and impoverishment, physical climate risks contribute to the sabotage of pipeline infrastructure and oil theft reducing domestic oil production (I2, I4, I7, I9, I10). Additionally, recurrent floods damage Nigeria's aging oil infrastructure and electrical grid, reducing the oil sector's productivity, and causing outages (I2, I3, I5). Uncertain energy supply is the greatest problem exporters face according to Interviewee 8 and 10. As the majority of manufacturing industries is situated in flood-prone coastal areas such as Lagos, manufacturers face high rebuilding and adaption costs, deterring investments in productivity enhancing facilities (I5, I7, I8, I9). Additionally, manufacturing exporters' production costs increase, when they have to rely on diesel generators during outages (I2, I3, I5). The deteriorated security situation, lowered productivity and export income negatively feeds back into investment rates (I2, I3, I4, I7, I8, I9, I10).

However, there are also chances for Nigeria's export sector. Climate policies might incentivize the exploitation and export of Nigeria's abundant natural gas, the expansion of renewables and production of green hydrogen. This might improve foreign exchange revenues, diversify Nigeria's export base, and improve its power supply (I2, I3, I8, I9). But as long as these opportunities have not materialized, climate risks are likely to negatively impact Nigeria's trade balance and therefore Nigeria's foreign exchange reserves.

Climate risks also impact Nigeria's financial account. They increase the servicing costs of external liabilities: Susceptibility to physical climate risks is already included as risk premia on external debt (Buhr et al. 2018) – e.g. in Fitch's rating of Nigeria according to Interviewee 3. But the consideration of transition risks by investors might weigh heavier in Nigeria, where most financial assets are connected to the oil sector and will potentially strand (I2, I6, I8).

Transition risks might hence devalue Nigerian financial assets and potentially lead to divestments. The disclosure of carbon-intensity in financial portfolios becomes more wide-spread and mandatory. According to Interviewee 8 "invariably more financial

[3] A possible solution might be the Dangote refinery (I4). However, its start of operation has been repeatedly delayed in part because it is located on a peninsula nearby Lagos and therefore affected by storms, floods and sea level encroachment (I5, I7, I8, I9).

institutions will require their clients to declare the climate risk position[s]. And that will filter its way through into the loan portfolio and how that is managed." This is also the case in Nigeria, where regulations steer towards mandatory carbon reporting, with adverse effects for investors whose portfolio is still largely fossil-based (I5, I8). Another reason why international investments might be drying up in the future is Nigeria's failure to meet international climate goals (I6). The latter might signal to international investors, that the capacity to restructure the economy towards less carbon-intensity is low, maintaining Nigeria's susceptibility to transition risks which contributes to a negative perception of Nigeria as investment destination.

The susceptibility to climate risks is also likely to change the nature of liabilities. Negative impacts on the trade balance are likely to increase Nigeria's need to attract foreign capital. The additional liabilities are most likely to come in the form of portfolio flows (Bortz and Kaltenbrunner 2018). This renders Nigeria more fragile because this form of finance is associated with an increased exposure of domestic macroeconomic variables to global financial instability transmitted through the balance-of-payments (Grabel 1996; Bortz and Kaltenbrunner 2018).

Furthermore, in Nigeria all green financial instruments are naira-denominated (I5). But Local Currency Bonds Markets (LCBM) in emerging economies come with higher interest rates, are more short-term and presuppose a number of ex-ante measures to ensure the convertibility, expatriation and profitability of investments (Elsner et al. 2022). Answering the question of what determines the demand for green bonds, Interviewee 8, who works in the Nigerian ESG-finance sector, replied:

> "Returns, obviously, […] how easy it is for them to leave their repertoire, the perceived and actual risks […] *and of course the convertibility of the local currency, because* […] *they invest in assets with local currency returns, which obviously needs to be converted at some point.* So we go back to the FX [foreign exchange] risk again. I mean, if there's a perception that [...; the exchange rate] will go against you in the short term, then that influences your need or wants to invest in such an economy" (I8; emphasis added).

Moreover, green taxonomies such as the EU's Green Taxonomy are too data-intensive and technologically demanding to be applicable in the Nigerian context:

> "We don't make the rules. It's not fit for purpose. *It's designed more for the Global North and for structured markets*. It's extremely scientific and data driven and right now *we don't have the tools necessary to defend the amount of data required for the disclosure*. […] They require a level of data which doesn't exist […] in the Global South" (I8; emphasis added).

The nexus between climate risks and international financial markets is hence likely to negatively impact Nigeria's financial account. Here, climate risks imply "a knock-on confidence in terms of future investments." (I2) Interviewee 9 summarizes: "So if we carry on this way […] the liquidity will dry up, less money will be lent" (I8).

Implications for the CBN's main instruments

Climate risks' impacts on balance-of-payments complicate central banking in Nigeria by influencing the CBN's main instruments, namely foreign exchange reserves, exchange and interest rates.

Climate risks make the management of foreign exchange reserves harder. They reduce foreign exchange income, whilst increasing external financing costs and necessitating more foreign exchange safeguarding funds caused by a greater exposure to external spill-overs. The potential increase of Nigeria's external fragility weighs particularly heavy because of the higher degree of turmoil in international financial markets climate risks are projected to cause (Dafermos, Nikolaidi, and Galanis 2017; 2018): Low- and middle-income countries will be the first victims of deteriorated confidence levels of internationally operating investors which scrabble to secure their portfolios' value by seeking refuge in safe havens causing outflows from these countries (Bonizzi and Kaltenbrunner 2019).

Climate risks are hence likely to aggravate the foreign exchange scarcity the CBN faces. This is self-perpetuating: The hoarding of foreign exchange – either in cash or in illegal foreign exchange deposits – vis-à-vis uncertain foreign exchange supply was described by some interviewees (I2, I3, I8). This sort of capital flight further deprives the central bank of already scarce foreign exchange reserves.

The CBN's second main instrument, the exchange rate, was mentioned as the centerpiece challenge in Nigeria (I4, I8, I10) – or as Interviewee 10 put it: „everything we work with or everything […] going wrong in the country, it has to do with the exchange rate." (I10) The interviews revealed two main rationales to maintain the management of the naira. Firstly, the special exchange rate window and the management of the naira aimed to support exports, economic diversification and industrialization. Especially non-oil investments are negatively impacted by a devalued or instable exchange rate (I2, I4). Secondly, the naira was supported to fight inflation as a depreciated naira translated into higher consumer prices against the backdrop of Nigeria's import dependence (I4, I6, I8, I9, I10).

Climate risks are likely to depreciate the naira: By aggravating foreign exchange scarcity, climate risks strip the CBN of means to prop up its currency and contribute to the perception of the naira being riskier to hold as convertibility into hard currencies cannot be granted. Shortage of foreign exchange was also behind the import- and foreign exchange restrictions imposed by the Nigerian government (International Trade Administration 2023). Foreign exchange restrictions contributed to the importance of the parallel market, which put devaluating pressure on the naira (I2, I6, I8, I10), which in turn led to the eventual liberalization of the exchange rate. Climate risks also depreciate the real exchange rate by fuelling inflation.

Leaving the exchange rate to market forces reduces the CBN's ability to buffer exchange rate volatility. Risen global uncertainty translates into higher volatility of exchange rates in emerging economies (Bush and López Noria 2021; Aysun 2024). When climate risks shorten financial cycles and raise global uncertainty levels, they also contribute to higher volatility of these currencies undermining their acceptance and leading to divestments (Löscher and Kaltenbrunner 2023). This weighs particularly heavy as peripheral currencies are increasingly integrated investors' portfolio as means to generate profits in carry trade transaction (Bortz and Kaltenbrunner 2018).

Under a floating exchange rate regime, structural conditions of the balance-of-payments are likely to have a more direct impact on the exchange rate, which weighs heavy because of Nigeria's susceptibility to climate transition. Interviewee 8 stated: "So if there's a shock to the oil industry, then it's going to impact our exchange rates". Climate transition might pose such a shock. Interviewee 4 summarized the interaction between climate policies and the Nigerian exchange rate as follows:

> "[I]magine that just all of a sudden nobody is demanding fossil fuel. Now we have a huge, huge effect on exchange rate in Nigeria. [...] Policies like reducing fossil fuels for cars and the rest, is [...] something that will affect demand for our oil and anything that affects demand at the present instance would affect our exchange rates. So definitely, global climate change and global climate policy will have [an] impact on exchange rates."

In addition, interviewee 6 identified the higher import dependency of food as result of physical risks of climate change as factor negatively impacting the exchange rate.

Both risen volatility and devaluation of the naira endanger the sustainability of Nigeria's balance-of-payments and financial stability. A depreciation of the naira increases the burden represented by foreign exchange denominated liabilities in real terms, implying potential liquidity problems for Nigerian financial actors. Higher volatility and depreciation undermine the acceptance of Nigerian financial assets with capital flight as likely consequence: It is the face value after conversion into the US-Dollar, determined by the nominal exchange rate – alongside their liquidity level and the interest paid on them – which matters for investors decision to hold them in their portfolios (Andrade and Prates 2013; Kaltenbrunner 2015; Paula, Fritz, and Prates 2017). Whilst depreciation equals a loss in face value of the financial asset, volatility introduces uncertainty concerning the expected face value at the moment of conversion. In a situation of an depreciated domestic currency, the signaling function of FX-communication in an attempt to counter the depreciation is likely to be ineffective – further diminishing the CBN's available policy tools, as was observed in other emerging markets (Parra-Polanía, Sánchez-Jabba, and Sarmiento 2024).

Having – at least officially – lost the ability to manage the naira, the CBN has to rely on interest rates to uphold the naira's acceptance and to manage the balance-of-payments through the financial account. The need to maintain high policy rates might additionally grow as policy rationale *vis-à-vis* climate risks for at least three reasons. Firstly, global instability caused by climate risks increases investors' taste for safe and liquid investments. In countries with illiquid currencies, higher interest rates need to be offered to prevent capital flight – also independent of their balance-of-payments dynamics. Secondly, climate risks are added as risk premia in sovereign ratings (Buhr et al. 2018). Thirdly, to maintain high enough spreads, which decide over the profitability in comparison to safer investments (Kaltenbrunner 2015; Paula, Fritz, and Prates 2017; Andrade and Prates 2013), policy makers in emerging markets have to raise their interest rate level, when climate change pushes up inflation, which policy makers in high-income countries try to address by deploying inflation targeting via the interest rate (Batten, Sowerbutts, and Tanaka 2020).

High interest rates suppress domestic growth and aggravate foreign exchange scarcity. They exercise recessionary pressure on the domestic economy by suppressing investments because of the high credit costs and the decreased value of firms' long-term assets (Mishkin 1995). Moreover, a deteriorated rating of sovereign debt based on climate vulnerability could destabilize affected countries' private sector through the mechanics of the sovereign ceiling, i.e. the increase in risk premia on private financial assets following deteriorated sovereign ratings (Eichengreen 2004).[4] This directly imperils the CBN's mandate of ensuring stability of domestic financial markets. Higher interest based in deteriorated ratings also increase refinancing costs and debt burden, which makes it necessary to deploy more foreign exchange to go into debt service which further exacerbating foreign exchange scarcity. Domestic recessions, e.g. as results of higher interest rates, is also likely to heighten domestic uncertainty, which feeds into higher exchange rate volatility (Bush and López Noria 2021).

Macroeconomic consequences

Climate risks' impact on the CBN's means of central banking through the balance-of-payments hamper diversification in Nigeria, a domestic green transition and increase global inequality levels. These effects negatively feed back into the balance-of-payments, which demonstrates the self-perpetuating nature of how climate risks curb effective central banking in emerging markets.

Diversifying the export base away from crude oil towards manufactured goods could increase the CBN's policy space by ensuring stable foreign exchange income and lessen the strong connection between volatile oil prices and the naira. To fulfill "developmental functions" is also one of the CBN's non-core mandates (CBN 2023f). The interviewees named the lack of funds, an instable exchange rate, a weak naira and competition with other developmental goals as main impediments to economic diversification (I3, I4, I9).

[4] The workings of the sovereign ceiling in Nigeria were exemplified in 2016: After foreign exchange reserves fell sharply, Nigerian public securities and subsequently Nigerian banks were downgraded by Moody's because of "the government's reduced capacity to provide support to Nigerian banks in times of stress" (Moody's Investors Service 2017).

Additionally, high rebuilding costs, higher interest rates as consequence of climate risks and the perception of Nigeria as risky investment destination hinder new investments. What is more, physical risks diminish agricultural productivity. But the agricultural sector is the most important mainstay of Nigerian policy makers' plans to economically diversify and was identified as the most feasible transformation trajectory by Interviewee 2.

Equivalently, a successful green transition in Nigeria could solve Nigeria's dependence on energy imports and improve its energy security levels. But domestic climate policies require policy space and cannot be prioritized because of other challenges such as high unemployment and inflation rates, a collapsed exchange rate and squeezed fiscal budget (I3, I4). Because of lacking expertise and the conditionality in terms of monitoring and a third party institution, Nigeria has not tapped any climate adaptation funds such as the Green Climate Fund, yet (I9). High interest rates also get in the way of a domestic green transition by deterring investments. Currency devaluations lead to the need to regularly update prices in the infant solar industry making it unprofitable (I6, I9).

Because climate risks impede the potential to undertake effective central banking, economic diversification and a green transition in countries like Nigeria, they perpetuate or even increase global inequality – which is also directly increased by climate risks (Diffenbaugh and Burke 2019; Dennig et al. 2015). The interviewees highlighted how climate transition risks, climate policies which do not consider foreign exchange dependence in particular, bear the risk of increasing global inequality. Interviewee 4 for instance projected that "we will see more […] imbalances between Nigeria or Africa and the other part of the world." Interviewee 6 added that it is the climate policies' reliance on markets which poses a particular challenge:

> "Climate action globally is very much market driven and without considering the structural impediments and even the social impediments that […] countries like Nigeria face. […] The carbon budget adjustment […] only high income countries are able to meet that while developing countries are unable to do that. So that continues to reinforce the kind of inequality and uneven development that we see globally. But also the idea of carbon intensity […] tends to reinforce carbon proliferation by certain sectors, certain countries relative to others. And that can […] be problematic for countries like Nigeria."

Interviewee 6 also said that mitigation measures in their current form reduce fiscal policy space for countries like Nigeria when they require the reduction of exploration of fossil fuels at the expense of energy security (I6). Speaking explicitly about carbon border adjustment mechanisms, Interviewee 9 explained that they "limit the choices in Nigeria or similar countries can make in terms of the type of energy, for example, they use to produce certain goods and commodities that they'd like to be traded. So it's definitely a threat" (I9).

By contributing to global inequality, climate risks also reduce macroeconomic policy space in low- and middle-income countries by widening the gap between the real or perceived liquidity of financial assets originating in the Global North and South. This might aggravate flight-to-quality phenomena and increases the pressure of countries in the Global South to keep their interest rate level up.

5 Empirical impacts of global instability, oil revenues, international food prices and natural disasters on the CBN's instruments of central banking

This section assesses the results of the SVAR models analysis by interpreting the IRF. The results of the VARs, including the stability test, are reported in Appendix C and D. Both models are stable as indicated by all eigenvalues being smaller than 1 (see Appendix C and D). The two models are based on a sample encompassing data from January 2006 until December 2022.[5]

Model 1: Transition risks

We shock the variables representing the CBN's instruments with the VIX, approximating global uncertainty, and revenues generated from the exports of oil, which is our proxy variable for the effects of climate policies. Figure 5 shows the IRF for the three monetary policy instruments and the oil export revenues resulting from a shock represented by the VIX.

INSERT FIGURE 5 HERE

A one-percent shock in global uncertainty approximated by the VIX results in a fall in Nigeria's revenues from the export of crude oil by between 0.2-0.4 per cent for about seven months. When shocked with a one per cent increase of the VIX, the spread between the Nigerian and US-American monetary policy rate increases by 0.05-0.07 per cent, with effects persisting for quarter of a year. The naira depreciates by between 0.05 and 0.1 per cent when shocked with a one per cent change of the VIX. This impact persists to be significant for about nine months. Nigeria's foreign exchange reserves are negatively affected by higher levels of the VIX in about the same magnitude as the exchange rate, though the effects are only significant for about six months. All results are significant within the 95%-confidence-interval.

[5] We refrained from incorporating structural shifts in, for instance, a Markov-Switching VAR framework because of the difficulties to identify the breaks (e.g. when official policy stances were not in line with realized policies to avoid rendering the latter ineffective) and because of the mere number of shifts (there were four changes in presidency of the CBN, in the sample period alone, alongside the recurrent shocks to international oil prices, among others) and last but not least to not complicate the interpretability of the results.

These results are in line with the theory: As global uncertainty grows, policy makers in emerging markets tend to increase the policy rate in an attempt to uphold the acceptance of their currencies and to avoid capital flight. As investor confidence crumbles so does the acceptance of currencies like the naira, which exercises depreciating pressure on them. Foreign exchange reserves fall as a consequence of diminished export income and capital flight, and because of central banks' attempt to defend their currencies.

Figure 6 depicts the IRF where the CBN's instruments of central banking are shocked with a one per cent increase in oil export revenues.

INSERT FIGURE 6 HERE

After three months, a shock coming in the form of a one per cent increase in the oil export revenues seems to have a positive effect on the policy rate spread between 0.1 and 0.25 per cent persisting to be significant at the 95 per cent confidence interval for about 20 months. The same shock results in an appreciation of the naira by about 0.1 per cent for about nine months at the 95 per cent confidence interval. The impact of the revenues from the export of oil seems to increase Nigeria's foreign exchange reserves by 0.04 to 0.08 per cent after three months. The impact is significant in the first and between the third and seventh month – however only within the 90% confidence interval.

The results are plausible, though several possible explanations exist. Higher revenues from oil exports contribute to an appreciation of the naira both directly, as more foreign exchange is converted into the naira and because the confidence in the currency and hence the readiness to hold it increases; and indirectly, by increasing foreign exchange reserves which the CBN could use to uphold the naira's value. That higher oil export revenues do not or only weakly positively impact the foreign exchange reserves can be explained by the exchange rate interventions by the CBN.

The lagged increase of the policy rate spread when shocked with higher oil revenues is less straight forward. A possible scenario is that the CBN unilaterally increases the policy rate in reaction to domestic inflation. Higher inflation might be caused by higher demand, in e.g. real estate, without improving production capacities, when oil revenues are monetized in domestic currency.[6] Higher domestic inflation might also be the result of higher oil prices, underlying the increases in oil revenues, as there is a high-pass

[6] We would like to thank an anonymous reviewer for pointing this out.

through of energy prices to the Nigerian price level. The Nigerian central bank might increase the interest rate level in an attempt to curb inflation, which is in line with its mandate.

Another possible explanation for the lagged increase of the policy rate spread when shocked with higher oil revenues is that the FED lowers the US-American policy interest rates in response to recessionary pressure –ante-dated by high commodity prices as was the case prior to the financial crisis 2007/08 – on the global and the US-American economy. Policy authorities in Nigeria, in turn, have to react to the higher uncertainty coming with the recession by increasing Nigeria's policy rate to avoid capital flight. That the shock coming in the form of a unit increase in the oil export revenues only significantly positively impacts the policy rate spread after a lag of three months can be explained by policy adjustments taking time. A negative relation between the policy rate spread and the oil export revenues in the non-structural VAR version of Model 1 (see covariance matrix in Appendix C) indicates that the reverse, i.e. a shock coming in the form of a one per cent decrease in oil export revenues leading to a decrease in the policy rate spread does not hold. It is possible that the policy rate spread increases both in reaction to higher and lower oil export revenues: If the decrease in oil export revenues is rooted in decreased oil prices or domestic supply problems, Nigerian monetary authorities are likely to increase the Nigerian policy rate to avoid capital flight as both factors will be considered by investors undermining the confidence in Nigeria as investment destination.

But drawing conclusions to the effects of transition risks on central banking in Nigeria through oil prices can only be done tentatively. Decarbonization is likely to have implications for global demand of fossil fuels, but effects take place in the long-term and on average independent from the business cycle. However, stranded fossil assets might impact the business cycle and the impacts of decarbonization processes on energy prices and demand are non-linear and prone to shocks. These short- to medium-term shocks are likely to impact central banking in oil-exporting countries of the Global South.

The results of Model 1 seem to suggest that transition risks are likely to negatively impact the ability to engage in effective central banking in Nigeria: higher global uncertainty and reduced oil revenues as likely results of climate transition exercise depreciating pressure on the naira and force the CBN to uphold the domestic interest rate level. Though the identified impacts are small, in their combined effects they can nevertheless represent important impediments to the ability to conduct effective central banking.

Model 2: Physical risks

The second model focuses on the physical risks of climate change and uses international food prices and the occurrence of a natural disaster in a given month as shock variables. Figure 7 represents the IRF of the SVAR model 2 where the logarithmized FAO FoodPrice Index acts as impulse.

Nigerian food inflation responds to a one percentage increase in the FAO FoodPrice Index by increasing by 1-1.3 per cent after a lag of about one year. This is plausible against the backdrop of Nigeria's food import dependency. In response to the same shock, the policy rate spread first decreases after two months by about 0.5 per cent, but increases by 0.5-1 per cent after a lag of ten months, whilst there is no significant impact of international food prices on the policy rate spread during the intermittent phase. A widening policy rate spread as response to higher international food prices can be explained by the CBN reacting to higher food inflation by increasing its policy rate. The FED might not be forced to such a step as food price inflation plays a much smaller role in the overall consumer price level in countries of the Global North. A shock by one unit increase of the FAO FoodPrice Index does not seem to have a significant impact on foreign exchange reserves and the exchange rate at the five per cent significance level.

INSERT FIGURE 7 HERE

Figure 8 depicts the IRF where the natural disaster dummy variable represents the impulse variable. Here, only the direction and significance indicated by the IRF is interpretable, but not the amplitude of the reaction of the response variable (El-Shagi and von Schweinitz 2016).

Whether a natural disaster occurred in one month or not neither seems to have a discernable effect on food price inflation, nor on foreign exchange reserves within the 90% confidence interval. However, it does seem to have a depreciating effect on the naira at a ten per cent significance level after a lag of two months lasting for about 17 months. Possible explanations might be that natural disasters impair the productivity of domestic firms with negative effects on the trade balance or that poor disaster management translates into weakened confidence in government capacities to conduct effective policies including exchange rate management. The policy rate differential reacts positively to a natural disaster shock with a lag of two months lasting for about 13 months at the 10 per cent significance level. The CBN reacting to deteriorated investor confidence as result of the natural disaster by increasing the policy rate might explain this.

INSERT FIGURE 8 HERE

In sum, the results of Model 2 seem to suggest that the capacity to conduct effective central banking has the potential to be impaired by physical climate risks by increasing the inflation rate, and by putting depreciating pressure on the naira.

6 Conclusions: Challenges and chances of climate risks for central banking in Nigeria

This contribution provided insights in the extent of, and channels through which transition and physical risks of the climate catastrophe impact the ability to conduct effective central banking through the balance-of-payments in Nigeria. The interviews revealed that climate risks are likely to deepen trade deficits, make the financial account more susceptible to capital outflows, and increase the burden represented by Nigeria's external liabilities, among others. This has negative implications for the central bank's main instruments making macro-financial management harder. Foreign exchange scarcity is aggravated and the naira is subjected to depreciating pressure. The currency depreciation together with reduced agricultural productivity contributes to the escalating inflation rates observable in Nigeria. Investment rates are hampered when climate change contributes to instable exchange rate, the reduction of available funds and social conflict. As climate risks render the acceptance of the naira more precarious, the CBN will have to resort to holding the interest rate level high to avoid capital outflows, which exercises recessionary pressures in the domestic economy.

These results are confirmed in the SVAR-models. The model on transition risks revealed that shocks coming in the form of higher global uncertainty and diminished oil export revenues lead to a depreciated naira, lower foreign exchange reserves and higher policy rate spreads. Modeling impacts of the physical effects of the climate catastrophe on Nigerian central banking, we found that when a climatically induced reduction of agricultural productivity translates into higher international food prices, this is likely to inflate Nigerian food prices, which is a major component of total inflation. Moreover, the occurrence of natural disasters can depreciate the domestic currency. Both higher international food prices and natural disasters increase the spread between Nigeria's and the US-American monetary policy rate.

A depreciation of the naira associated with climate risks has particularly far-reaching potential macroeconomic consequences. These include inflationary pressures and increased debt burden in real terms. Repeated devaluations also get in the way of a catching-up industrialization and a transition towards renewable energy generation in Nigeria by hampering profitability and investment certainty. This complements the impediments to late industrialization associated with the physical effects of the climate catastrophe when investments are diverted into mitigation and adaption measures, when social conflict is spurred and when competitiveness is lowered due to lowered productivity and higher productions costs. The pressure on the naira will become more severe as climatically induced global instability increases and with it the frequency and severity of shocks. Those shocks have to be addressed by Nigerian central bank and limit the policy space within which it can operate. A floating exchange rate regime is more risky as external shocks transmit to the naira more unhamperedly with adverse effects for the CBN's objectives.

Climate change aggravates the macroeconomic challenges coming with the precarious acceptance of currencies in low- and middle-income countries such as Nigeria. Climate risks are often transmitted through the balance-of-payments and crystallize in the exchange rate. As global uncertainty caused by climate risks are projected to grow, so does the divergence of demand for center and peripheral currencies. To safeguard against uncertainty, economic agents increase their demand of the more stable and liquid currencies issued by high-income countries. Low- and middle-income countries have to uphold their currencies' acceptance by increasing the interest rate level to the detriment of the domestic economy.

However, we also identified chances in climate transition. Nigeria's reserves of natural gas might help to diversify its export structure and the expansion of renewables might overcome energy poverty, a major impediment to the export sector. But as capital required for this transition is imported, the exploitation of these potentials requires foreign exchange and might exercise pressure on the balance-of-payments until benefits materialize.

Given the challenges at hand, domestic climate policies and economic diversification efforts cannot gain traction to the extent they could have otherwise. Against this backdrop, the validity of calls for reforms of the international financial architecture becomes apparent. Debt restructuring and climate reparation funds using Special Drawing Rights as unit of account could be means to free up policy space for climate mitigation and adaptation measures.

Future research should seek to extend the exercise to other countries in a panel data analysis to be able to draw broader conclusions on the interaction between physical and transition climate risks, central banking and a country's balance-of-payments in the current financial architecture.

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Appendix A

Table A.1: Professional background of interviewees, duration and mode of interviews.

	Professional Background	Duration of Interview	Mode of interview
Interview 1	Nigerian Incentive-Based Risk Sharing System for Agricultural Lending	18:30	Online via Jitsi
Interview 2	Heinrich-Böll Foundation Office Nigeria	46:44	Online via Jitsi
Interview 3	Consultant involved in the formulation of Nigeria's Nationally Determined Contributions (NDC)	40:20	Online via Jitsi
Interview 4	Economist at the Centre for the Study of the Economies of Africa	56:31	Online via Jitsi
Interview 5	FMDQ Exchange and Financial Centre for Sustainability (FC4S) Lagos	49:17	Online via Jitsi
Interview 6	Economist working on Nigeria in Cambridge, UK	39:22	Online via Jitsi
Interview 7	Senior fellow at the Centre for the Study of the Economies of Africa		Written response to the interview questions
Interview 8	Investor and expert specialized on green bonds working at the Climate Bonds Institute	35:00	Online via Jitsi
Interview 9	Senior Associate with the Africa Energy Program	35:44	Online via Jitsi
Interview 10	CBN	70:00	Online via Jitsi

Appendix B

Table B.1: Overview over used time series and their variable names.

Variable name	Variable description	Data source
EXR_log	logarithmised monthly average of naira-dollar exchange rate (central rate between buying and selling rate)	CBN (2023b)
FAOFoodP_log	logarithmised index measuring the monthly change in international prices of a basket of food commodities	FAO (2022)
FXRes_log	logarithmised monthly average of foreign exchange reserves (in US-dollars)	CBN (2023d)
Infl_food_log	logarithmised food price increases compared to 12 months average	CBN (CBN 2023c)
NbAffwDDum1	dummy variable indicating 1 when a disaster was recorded in the Emergency Database for a given month, 0 if there was no disaster recorded	CRED (2022)
PolicyRateSpread_log	logarithmised spread between the CBN's Monetary Policy Rate and the US-American Federal Funds Effective Rate	CBN (2023c) and FRED (2022)
RevEXOil_log	logarithmised monthly revenues generated from the export of Bonny Light crude oil (in million US-dollar)	CBN (2023e)
VIX_log	logarithmised monthly average of daily highs of VIX	Cboe Exchange (2023)

Table B.2: Statistical descriptives of used times series.

```
   EXR             FAOFoodP          FXRes              Infl_food
 Min.   :116.1   Min.   : 69.40   Min.   :2.342e+10   Min.   : 1.50
 1st Qu.:148.3   1st Qu.: 93.80   1st Qu.:3.323e+10   1st Qu.:10.08
 Median :155.5   Median : 99.35   Median :3.763e+10   Median :13.63
 Mean   :224.9   Mean   :107.40   Mean   :3.828e+10   Mean   :13.20
 3rd Qu.:306.0   3rd Qu.:122.53   3rd Qu.:4.222e+10   3rd Qu.:16.70
 Max.   :446.1   Max.   :159.70   Max.   :6.048e+10   Max.   :22.90

    NbAffwD          PolicyRateSpread    RevEXOil            VIX
 Min.   :       0   Min.   : 2.74    Min.   : 22.71    Min.   :10.59
 1st Qu.:       0   1st Qu.: 8.37    1st Qu.: 76.33    1st Qu.:14.60
 Median :      86   Median :11.61    Median :110.67    Median :18.31
 Mean   :  164133   Mean   :10.31    Mean   :124.60    Mean   :21.02
 3rd Qu.:    4436   3rd Qu.:11.97    3rd Qu.:172.18    3rd Qu.:25.26
 Max.   :19110398   Max.   :13.61    Max.   :245.25    Max.   :68.00
```

Note: For the number of people affected by natural disaster, the statistics were calculated using the absolute numbers.

Table B.3: Test results of unit root tests calculated with the tseries-package in R. All test statistics were interpreted at 5%-significance level. Where tests did not produced unequivocal results, we based our decision on the majority of test results.

	ADF-test (Augmented Dickey–Fuller test)	PP-test (Phillips-Perron test)	KPSS-test (Kwiatkowski-Phillips-Schmidt-Shin test)	Concluded order of Integration of time series in log-levels
EXR_log	H0	H0	H1	
EXR_log_diff	H1	H1	H0	I(1)
FAOFoodP_log	H0	H0	H1	
FAOFoodP_log_diff	H1	H1	H0	I(1)
FXRes_log	H0	H0	H1	
FXRes_log_diff	H1	H1	H0	I(1)
Infl_food_log	H1	H0	H1	
Infl_food_log_diff	H1	H1	H0	I(1)
NbAffwDDum1	H1	H1	H1	I(0)
PolicyRateSpread_log	H0	H0	H1	
PolicyRateSpread_log_diff	H1	H1	H0	I(1)
RevEXOil_log	H0	H0	H1	
RevEXOil_log_diff	H1	H1	H0	I(1)
VIX_log	H0	H1	H0	
VIX_log_diff	H1	H1	H0	I(1)

Appendix C

Table C.1: Regression results of VAR-model 1.

```
VAR Estimation Results:
=========================
Endogenous variables: VIX_log, RevEXOil_log, PolicyRateSpread_log, EXR_log, FXRes_log
Deterministic variables: const
Sample size: 202
Log Likelihood: 1374.481
Roots of the characteristic polynomial:
0.9976 0.9253 0.9188 0.9188 0.8109 0.6829 0.4054 0.2011 0.1932 0.03509
Call:
VAR(y = model1, lag.max = 2)


Estimation results for equation VIX_log:
========================================
VIX_log = VIX_log.l1 + RevEXOil_log.l1 + PolicyRateSpread_log.l1 + EXR_log.l1 + FXRes_log.l1 +
VIX_log.l2 + RevEXOil_log.l2 + PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                         Estimate Std. Error t value Pr(>|t|)
VIX_log.l1               0.812510   0.074519  10.903   <2e-16 ***
RevEXOil_log.l1         -0.102223   0.103225  -0.990    0.323
PolicyRateSpread_log.l1  0.019141   0.188175   0.102    0.919
EXR_log.l1              -0.525981   0.605127  -0.869    0.386
FXRes_log.l1            -0.208338   0.470727  -0.443    0.659
VIX_log.l2              -0.008782   0.073523  -0.119    0.905
RevEXOil_log.l2          0.123955   0.104394   1.187    0.237
PolicyRateSpread_log.l2 -0.114253   0.187252  -0.610    0.542
EXR_log.l2               0.602642   0.593727   1.015    0.311
FXRes_log.l2             0.346393   0.473448   0.732    0.465
const                   -3.065579   1.989023  -1.541    0.125
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Residual standard error: 0.1967 on 191 degrees of freedom
Multiple R-Squared: 0.7339,  Adjusted R-squared:  0.72
F-statistic: 52.68 on 10 and 191 DF,  p-value: < 2.2e-16


Estimation results for equation RevEXOil_log:
=============================================
RevEXOil_log = VIX_log.l1 + RevEXOil_log.l1 + PolicyRateSpread_log.l1 + EXR_log.l1 + FXRes_log.l1 +
VIX_log.l2 + RevEXOil_log.l2 + PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                         Estimate Std. Error t value Pr(>|t|)
VIX_log.l1              -0.215134   0.053618  -4.012 8.62e-05 ***
RevEXOil_log.l1          0.900514   0.074272  12.125  < 2e-16 ***
PolicyRateSpread_log.l1  0.041290   0.135395   0.305  0.76073
EXR_log.l1              -0.973491   0.435399  -2.236  0.02652 *
FXRes_log.l1            -0.035730   0.338696  -0.105  0.91610
VIX_log.l2               0.201363   0.052901   3.806  0.00019 ***
RevEXOil_log.l2          0.007077   0.075113   0.094  0.92503
PolicyRateSpread_log.l2 -0.098451   0.134731  -0.731  0.46584
EXR_log.l2               0.936867   0.427196   2.193  0.02951 *
FXRes_log.l2             0.016147   0.340653   0.047  0.96224
const                    1.281738   1.431134   0.896  0.37159
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 0.1415 on 191 degrees of freedom
Multiple R-Squared: 0.9212,  Adjusted R-squared: 0.917
F-statistic: 223.2 on 10 and 191 DF,  p-value: < 2.2e-16


Estimation results for equation PolicyRateSpread_log:
=====================================================
PolicyRateSpread_log = VIX_log.l1 + RevEXOil_log.l1 + PolicyRateSpread_log.l1 + EXR_log.l1 +
FXRes_log.l1 + VIX_log.l2 + RevEXOil_log.l2 + PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 +
const

                         Estimate Std. Error t value Pr(>|t|)
VIX_log.l1               0.076569   0.028797   2.659  0.00851 **
RevEXOil_log.l1          0.072441   0.039891   1.816  0.07094 .
PolicyRateSpread_log.l1  0.972532   0.072719  13.374  < 2e-16 ***
EXR_log.l1               0.389169   0.233848   1.664  0.09771 .
FXRes_log.l1             0.128506   0.181910   0.706  0.48078
VIX_log.l2              -0.032978   0.028412  -1.161  0.24722
RevEXOil_log.l2         -0.009352   0.040342  -0.232  0.81693
PolicyRateSpread_log.l2 -0.016187   0.072362  -0.224  0.82324
EXR_log.l2              -0.331853   0.229442  -1.446  0.14972
FXRes_log.l2            -0.184197   0.182961  -1.007  0.31533
const                    0.723713   0.768646   0.942  0.34762
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Residual standard error: 0.07602 on 191 degrees of freedom
Multiple R-Squared: 0.9532,  Adjusted R-squared: 0.9508
F-statistic: 389.3 on 10 and 191 DF,  p-value: < 2.2e-16


Estimation results for equation EXR_log:
========================================
EXR_log = VIX_log.l1 + RevEXOil_log.l1 + PolicyRateSpread_log.l1 + EXR_log.l1 + FXRes_log.l1 +
VIX_log.l2 + RevEXOil_log.l2 + PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                         Estimate Std. Error t value Pr(>|t|)
VIX_log.l1               0.021141   0.008494   2.489   0.0137 *
RevEXOil_log.l1         -0.007069   0.011766  -0.601   0.5487
PolicyRateSpread_log.l1  0.004782   0.021449   0.223   0.8238
EXR_log.l1               1.426261   0.068975  20.678  < 2e-16 ***
FXRes_log.l1            -0.040597   0.053656  -0.757   0.4502
VIX_log.l2              -0.015109   0.008380  -1.803   0.0730 .
RevEXOil_log.l2         -0.002412   0.011899  -0.203   0.8396
PolicyRateSpread_log.l2  0.008330   0.021344   0.390   0.6968
EXR_log.l2              -0.440598   0.067676  -6.510 6.45e-10 ***
FXRes_log.l2             0.035172   0.053966   0.652   0.5154
const                    0.208664   0.226718   0.920   0.3585
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Residual standard error: 0.02242 on 191 degrees of freedom
Multiple R-Squared: 0.9975,  Adjusted R-squared: 0.9973
F-statistic:  7473 on 10 and 191 DF,  p-value: < 2.2e-16


Estimation results for equation FXRes_log:
==========================================
FXRes_log = VIX_log.l1 + RevEXOil_log.l1 + PolicyRateSpread_log.l1 + EXR_log.l1 + FXRes_log.l1 +
VIX_log.l2 + RevEXOil_log.l2 + PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                         Estimate Std. Error t value Pr(>|t|)
VIX_log.l1              -0.019884   0.009269  -2.145   0.0332 *
```

```
RevEXOil_log.l1         -0.006267   0.012839  -0.488   0.6260
PolicyRateSpread_log.l1  0.004098   0.023405   0.175   0.8612
EXR_log.l1              -0.059651   0.075265  -0.793   0.4290
FXRes_log.l1             1.586187   0.058549  27.092   <2e-16 ***
VIX_log.l2               0.016031   0.009145   1.753   0.0812 .
RevEXOil_log.l2          0.011403   0.012984   0.878   0.3810
PolicyRateSpread_log.l2 -0.015161   0.023290  -0.651   0.5159
EXR_log.l2               0.067851   0.073847   0.919   0.3594
FXRes_log.l2            -0.611719   0.058887 -10.388   <2e-16 ***
const                    0.591052   0.247393   2.389   0.0179 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Residual standard error: 0.02447 on 191 degrees of freedom
Multiple R-Squared: 0.9851,  Adjusted R-squared: 0.9843
F-statistic:  1259 on 10 and 191 DF,  p-value: < 2.2e-16



Covariance matrix of residuals:
                        VIX_log RevEXOil_log PolicyRateSpread_log    EXR_log
VIX_log               0.0386955   -0.0078137            5.677e-04  3.065e-04
RevEXOil_log         -0.0078137    0.0200328           -5.145e-04 -6.886e-04
PolicyRateSpread_log  0.0005677   -0.0005145            5.779e-03  1.926e-04
EXR_log               0.0003065   -0.0006886            1.926e-04  5.028e-04
FXRes_log            -0.0003881    0.0004870            3.665e-05 -8.734e-05
                      FXRes_log
VIX_log              -3.881e-04
RevEXOil_log          4.870e-04
PolicyRateSpread_log  3.665e-05
EXR_log              -8.734e-05
FXRes_log             5.986e-04

Correlation matrix of residuals:
                      VIX_log RevEXOil_log PolicyRateSpread_log  EXR_log
VIX_log               1.00000     -0.28064              0.03796  0.06949
RevEXOil_log         -0.28064      1.00000             -0.04782 -0.21699
PolicyRateSpread_log  0.03796     -0.04782              1.00000  0.11301
EXR_log               0.06949     -0.21699              0.11301  1.00000
FXRes_log            -0.08065      0.14062              0.01970 -0.15921
                     FXRes_log
VIX_log               -0.08065
RevEXOil_log           0.14062
PolicyRateSpread_log   0.01970
EXR_log               -0.15921
FXRes_log              1.00000
```

Appendix D

Table D.1: Regression results of VAR-model 2.

```
VAR Estimation Results:
=========================
Endogenous variables: FAOFoodP_log, NbAffwDDum1, Infl_food_log, PolicyRateSpread_log, EXR_log,
FXRes_log
Deterministic variables: const
Sample size: 202
Log Likelihood: 1908.185
Roots of the characteristic polynomial:
0.9981 0.9596 0.9596 0.944 0.944 0.7091 0.7091 0.4956 0.3884 0.3884 0.06399 0.06399
Call:
```

```
VAR(y = modelPhys2, lag.max = 2)


Estimation results for equation FAOFoodP_log:
=============================================
FAOFoodP_log = FAOFoodP_log.l1 + NbAffwDDum1.l1 + Infl_food_log.l1 + PolicyRateSpread_log.l1 +
EXR_log.l1 + FXRes_log.l1 + FAOFoodP_log.l2 + NbAffwDDum1.l2 + Infl_food_log.l2 +
PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                          Estimate Std. Error t value Pr(>|t|)
FAOFoodP_log.l1          1.4299263  0.0659011  21.698  < 2e-16 ***
NbAffwDDum1.l1           0.0006215  0.0038234   0.163   0.8710
Infl_food_log.l1        -0.0107645  0.0236441  -0.455   0.6494
PolicyRateSpread_log.l1  0.0049496  0.0223423   0.222   0.8249
EXR_log.l1              -0.0611592  0.0667563  -0.916   0.3608
FXRes_log.l1            -0.0439196  0.0546007  -0.804   0.4222
FAOFoodP_log.l2         -0.4476463  0.0664590  -6.736 1.91e-10 ***
NbAffwDDum1.l2           0.0005679  0.0038685   0.147   0.8835
Infl_food_log.l2         0.0064914  0.0232576   0.279   0.7805
PolicyRateSpread_log.l2 -0.0275874  0.0218701  -1.261   0.2087
EXR_log.l2               0.0780857  0.0668336   1.168   0.2441
FXRes_log.l2             0.0297177  0.0543038   0.547   0.5849
const                    0.4013707  0.2357264   1.703   0.0903 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Residual standard error: 0.02304 on 189 degrees of freedom
Multiple R-Squared: 0.9854,     Adjusted R-squared: 0.9844
F-statistic:  1061 on 12 and 189 DF,  p-value: < 2.2e-16


Estimation results for equation NbAffwDDum1:
============================================
NbAffwDDum1 = FAOFoodP_log.l1 + NbAffwDDum1.l1 + Infl_food_log.l1 + PolicyRateSpread_log.l1 +
EXR_log.l1 + FXRes_log.l1 + FAOFoodP_log.l2 + NbAffwDDum1.l2 + Infl_food_log.l2 +
PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                        Estimate Std. Error t value Pr(>|t|)
FAOFoodP_log.l1         -0.45310    1.25981  -0.360    0.720
NbAffwDDum1.l1           0.44258    0.07309   6.055 7.41e-09 ***
Infl_food_log.l1         0.24389    0.45200   0.540    0.590
PolicyRateSpread_log.l1  0.25474    0.42711   0.596    0.552
EXR_log.l1              -0.32189    1.27615  -0.252    0.801
FXRes_log.l1             1.62960    1.04378   1.561    0.120
FAOFoodP_log.l2          0.22551    1.27047   0.177    0.859
NbAffwDDum1.l2          -0.03869    0.07395  -0.523    0.601
Infl_food_log.l2        -0.22828    0.44461  -0.513    0.608
PolicyRateSpread_log.l2 -0.08892    0.41808  -0.213    0.832
EXR_log.l2               0.35870    1.27763   0.281    0.779
FXRes_log.l2            -1.66907    1.03810  -1.608    0.110
const                    2.34627    4.50629   0.521    0.603
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Residual standard error: 0.4405 on 189 degrees of freedom
Multiple R-Squared: 0.2596,     Adjusted R-squared: 0.2126
F-statistic: 5.522 on 12 and 189 DF,  p-value: 4.671e-08


Estimation results for equation Infl_food_log:
==============================================
```

```
Infl_food_log = FAOFoodP_log.l1 + NbAffwDDum1.l1 + Infl_food_log.l1 + PolicyRateSpread_log.l1 +
EXR_log.l1 + FXRes_log.l1 + FAOFoodP_log.l2 + NbAffwDDum1.l2 + Infl_food_log.l2 +
PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                         Estimate Std. Error t value Pr(>|t|)
FAOFoodP_log.l1         -0.002186   0.134062  -0.016    0.987
NbAffwDDum1.l1          -0.004365   0.007778  -0.561    0.575
Infl_food_log.l1         1.709235   0.048099  35.536   <2e-16 ***
PolicyRateSpread_log.l1 -0.023743   0.045451  -0.522    0.602
EXR_log.l1              -0.035125   0.135802  -0.259    0.796
FXRes_log.l1            -0.146201   0.111074  -1.316    0.190
FAOFoodP_log.l2          0.043482   0.135197   0.322    0.748
NbAffwDDum1.l2           0.005077   0.007870   0.645    0.520
Infl_food_log.l2        -0.743849   0.047313 -15.722   <2e-16 ***
PolicyRateSpread_log.l2  0.039892   0.044490   0.897    0.371
EXR_log.l2               0.052191   0.135959   0.384    0.702
FXRes_log.l2             0.155582   0.110470   1.408    0.161
const                   -0.463147   0.479537  -0.966    0.335
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Residual standard error: 0.04687 on 189 degrees of freedom
Multiple R-Squared: 0.9924,     Adjusted R-squared: 0.9919
F-statistic:  2045 on 12 and 189 DF,  p-value: < 2.2e-16


Estimation results for equation PolicyRateSpread_log:
=====================================================
PolicyRateSpread_log = FAOFoodP_log.l1 + NbAffwDDum1.l1 + Infl_food_log.l1 + PolicyRateSpread_log.l1 +
EXR_log.l1 + FXRes_log.l1 + FAOFoodP_log.l2 + NbAffwDDum1.l2 + Infl_food_log.l2 +
PolicyRateSpread_log.l2 + EXR_log.l2 + FXRes_log.l2 + const

                         Estimate Std. Error t value Pr(>|t|)
FAOFoodP_log.l1         -0.179654   0.214083  -0.839  0.40243
NbAffwDDum1.l1           0.020896   0.012421   1.682  0.09414 .
Infl_food_log.l1         0.209563   0.076809   2.728  0.00697 **
PolicyRateSpread_log.l1  0.923523   0.072580  12.724  < 2e-16 ***
EXR_log.l1               0.127864   0.216861   0.590  0.55615
FXRes_log.l1             0.059030   0.177373   0.333  0.73965
FAOFoodP_log.l2          0.278010   0.215895   1.288  0.19942
NbAffwDDum1.l2           0.007920   0.012567   0.630  0.52930
Infl_food_log.l2        -0.211328   0.075554  -2.797  0.00569 **
PolicyRateSpread_log.l2  0.003664   0.071046   0.052  0.95893
EXR_log.l2              -0.122537   0.217112  -0.564  0.57315
FXRes_log.l2            -0.113643   0.176408  -0.644  0.52022
const                    0.971087   0.765768   1.268  0.20631
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Residual standard error: 0.07485 on 189 degrees of freedom
Multiple R-Squared: 0.9551,     Adjusted R-squared: 0.9523
F-statistic: 335.2 on 12 and 189 DF,  p-value: < 2.2e-16


Estimation results for equation EXR_log:
========================================
EXR_log = FAOFoodP_log.l1 + NbAffwDDum1.l1 + Infl_food_log.l1 + PolicyRateSpread_log.l1 + EXR_log.l1 +
FXRes_log.l1 + FAOFoodP_log.l2 + NbAffwDDum1.l2 + Infl_food_log.l2 + PolicyRateSpread_log.l2 +
EXR_log.l2 + FXRes_log.l2 + const

                         Estimate Std. Error t value Pr(>|t|)
FAOFoodP_log.l1         -0.042600   0.065355  -0.652    0.515
NbAffwDDum1.l1           0.003884   0.003792   1.024    0.307
```

```
Infl_food_log.l1         0.033919   0.023448   1.447    0.150    
PolicyRateSpread_log.l1 -0.007893   0.022157  -0.356    0.722    
EXR_log.l1               1.451659   0.066203  21.927  < 2e-16 ***
FXRes_log.l1            -0.069767   0.054148  -1.288    0.199    
FAOFoodP_log.l2          0.038341   0.065908   0.582    0.561    
NbAffwDDum1.l2           0.002828   0.003836   0.737    0.462    
Infl_food_log.l2        -0.033040   0.023065  -1.432    0.154    
PolicyRateSpread_log.l2  0.010439   0.021689   0.481    0.631    
EXR_log.l2              -0.455886   0.066280  -6.878 8.62e-11 ***
FXRes_log.l2             0.061730   0.053854   1.146    0.253    
const                    0.223118   0.233773   0.954    0.341    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Residual standard error: 0.02285 on 189 degrees of freedom
Multiple R-Squared: 0.9974,     Adjusted R-squared: 0.9972 
F-statistic:  5995 on 12 and 189 DF,  p-value: < 2.2e-16 


Estimation results for equation FXRes_log: 
========================================== 
FXRes_log = FAOFoodP_log.l1 + NbAffwDDum1.l1 + Infl_food_log.l1 + PolicyRateSpread_log.l1 + EXR_log.l1
+ FXRes_log.l1 + FAOFoodP_log.l2 + NbAffwDDum1.l2 + Infl_food_log.l2 + PolicyRateSpread_log.l2 +
EXR_log.l2 + FXRes_log.l2 + const 

                          Estimate Std. Error t value Pr(>|t|)    
FAOFoodP_log.l1          0.0953798  0.0705045   1.353   0.1777    
NbAffwDDum1.l1           0.0003885  0.0040905   0.095   0.9244    
Infl_food_log.l1         0.0162701  0.0252958   0.643   0.5209    
PolicyRateSpread_log.l1  0.0117350  0.0239030   0.491   0.6240    
EXR_log.l1              -0.0698483  0.0714195  -0.978   0.3293    
FXRes_log.l1             1.5850126  0.0584147  27.134   <2e-16 ***
FAOFoodP_log.l2         -0.0964089  0.0711014  -1.356   0.1767    
NbAffwDDum1.l2          -0.0026658  0.0041387  -0.644   0.5203    
Infl_food_log.l2        -0.0210390  0.0248823  -0.846   0.3989    
PolicyRateSpread_log.l2 -0.0117528  0.0233978  -0.502   0.6160    
EXR_log.l2               0.0719709  0.0715021   1.007   0.3154    
FXRes_log.l2            -0.6102110  0.0580971 -10.503   <2e-16 ***
const                    0.6225651  0.2521927   2.469   0.0145 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Residual standard error: 0.02465 on 189 degrees of freedom
Multiple R-Squared: 0.985,      Adjusted R-squared: 0.984 
F-statistic:  1033 on 12 and 189 DF,  p-value: < 2.2e-16 



Covariance matrix of residuals:
                     FAOFoodP_log NbAffwDDum1 Infl_food_log PolicyRateSpread_log
FAOFoodP_log            5.309e-04  -0.0010183    -9.107e-06           -1.914e-04
NbAffwDDum1            -1.018e-03   0.1940306    -3.253e-04            1.136e-03
Infl_food_log          -9.107e-06  -0.0003253     2.197e-03           -1.635e-04
PolicyRateSpread_log   -1.914e-04   0.0011358    -1.635e-04            5.603e-03
EXR_log                -1.755e-06   0.0003473     2.266e-05            1.410e-04
FXRes_log              -6.253e-06  -0.0001321    -5.216e-05           -4.953e-06
                        EXR_log  FXRes_log
FAOFoodP_log         -1.755e-06 -6.253e-06
NbAffwDDum1           3.473e-04 -1.321e-04
Infl_food_log         2.266e-05 -5.216e-05
PolicyRateSpread_log  1.410e-04 -4.953e-06
EXR_log               5.222e-04 -1.057e-04
FXRes_log            -1.057e-04  6.077e-04
```

Correlation matrix of residuals:

	FAOFoodP_log	NbAffwDDum1	Infl_food_log	PolicyRateSpread_log
FAOFoodP_log	1.000000	-0.10032	-0.008432	-0.110946
NbAffwDDum1	-0.100323	1.00000	-0.015755	0.034446
Infl_food_log	-0.008432	-0.01576	1.000000	-0.046595
PolicyRateSpread_log	-0.110946	0.03445	-0.046595	1.000000
EXR_log	-0.003334	0.03450	0.021159	0.082432
FXRes_log	-0.011008	-0.01217	-0.045139	-0.002684

	EXR_log	FXRes_log
FAOFoodP_log	-0.003334	-0.011008
NbAffwDDum1	0.034504	-0.012166
Infl_food_log	0.021159	-0.045139
PolicyRateSpread_log	0.082432	-0.002684
EXR_log	1.000000	-0.187670
FXRes_log	-0.187670	1.000000