
Essays in Macro-Finance



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This thesis is dedicated to

my family

for their love, encouragement,

and unwavering support throughout my journey.

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Abstract

This thesis consists of four papers exploring different topics in macro-finance. Papers 1 and 2 investigate sovereign external debt risk in the face of U.S. monetary policy shocks. In Paper 1, I develop a two-country, two-period monetary general equilibrium model to analyze the benefits of equilibrium sovereign default on external debt. I show that, in emerging market economies (EMEs), debt restructuring in response to U.S. monetary policy shocks smooths consumption across time and states, stabilizes exchange rates, reduces reliance on dollar-denominated debt, and, more importantly, increases domestic social welfare. Empirical evidence further supports these findings. Paper 2 extends the model from Paper 1 to an infinite-horizon, small open economy DSGE model to investigate how U.S. monetary policy shocks impact EMEs' sovereign default incentives under different capital compositions. I show that EMEs' incentives to default on external debt depend on their reliance on imported capital goods and on their overall capital share. Specifically, economies with a high dependence on imported capital goods and a high capital share experience greater exchange-rate externalities because of the inelastic demand for foreign capital. As a result, these externalities increase the potential costs of default, thereby reducing incentives to default on external debt. Paper 3 shifts focus to another important topic in macro-finance: how climate change affects the transmission of monetary policy, with a particular focus on price stability. I demonstrate that central banks face a trade-off between inflation stabilization and climate risks. I show that green monetary policy can address climate change issues and increase social welfare, particularly when carbon taxation is suboptimal, although it may come at the cost of inflation. Paper 4 develops knowledge-graph-based measures using a fine-tuned large language model. The factor testing results indicate that these thematic measures capture time-varying macroeconomic trends, exhibit unconditional forecasting power for economic activity, and serve as unconditional risk factors in asset pricing models.

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Chapter 1

Introduction and Literature Review

Introduction

In recent decades, financial globalization and technological development, particularly in artificial intelligence (AI), have profoundly changed economic dynamics, monetary policy frameworks, and financial market operations. All these have posed new emerging challenges regarding macroeconomic stability, financial risk management, and policy development. There are four chapters in this dissertation, and each addresses a new challenge posed by financial globalization and technological development. While each chapter contributes to a different strand of literature, they collectively seek to deepen the understanding of financial interdependencies in a global economy.

The first two chapters delve into the vulnerability of external debt in emerging market economies (EMEs) when facing external shocks. As documented by the seminal work of [Rey \(2015\)](#), a global factor that is closely related to U.S. monetary policy shapes capital flows and credit conditions globally. In particular, periods of U.S. monetary policy tightening serve as a catalyst, initiating a spillover effect that triggers significant capital outflows from EMEs. The capital outflows expose these EMEs to increasing default risk on US dollar-denominated debt. Motivated by these critical insights, the first chapter explores the impact of U.S. monetary policy tightening on EMEs and examines whether external debt restructuring can be implemented as an alternative stabilization policy tool.

EMEs with a history of sovereign debt crises often face the “original sin” problem ([Eichengreen and Hausmann, 1999](#); [Du et al., 2020](#); [Bertaut et al., 2021](#)), in that they cannot issue domestic-currency-denominated debt in international financial markets. This reliance on foreign-currency-denominated debt creates a constraint for EME governments and subjects them to U.S. Federal Reserve interest-rate policy fluctuations ([Rey, 2015](#); [Kalemli-Özcan, 2019](#)). U.S. monetary tightening will not only make external financing costly but also cause depreciation in domestic currencies, thereby deepening the burden of debt. Confronted with this challenging economic landscape, EMEs

face a painful policy dilemma: as documented by [Kalemli-Özcan \(2019\)](#), they are forced to raise domestic interest rates to twice the US interest rate tightening amount in an attempt to stabilize their currency exchange rate. Nevertheless, such an extreme reaction in monetary policy is economically costly, as it dramatically increases the domestic borrowing cost and reduces investment. The first chapter proposes an innovative alternative policy to tackle this systematic challenge: debt restructuring as a policy tool for absorbing external shocks.

To substantiate this argument, the first paper develops a two-country, two-period general equilibrium model and calibrates it using data on Argentina’s 2020 debt restructuring ([Delivorias, 2023](#)). This chapter shows that preemptive sovereign default, which occurs when a government strategically restructures its debt, can serve as a policy tool to mitigate the negative spillover effects of U.S. monetary tightening. As per the analysis, an increase in domestic interest rates instead of sovereign default can stabilize the exchange rate but at a significant cost, reducing domestic consumption and output and leading to overall welfare losses. However, when the default penalties imposed by lenders and international agencies are softened, allowing for an orderly sovereign default in equilibrium, such a default can make social welfare increase through a drop in the real burden of debt and a smoothing out of consumption and foreign exchange rates. This chapter also contributes to the “Mussa puzzle” literature ([Itskhoki and Mukhin, 2024](#)), with a demonstration that when EMEs have default risk, U.S. monetary policy spillover to them is amplified through default risk premia and depreciation of the exchange rate.

The second paper extends the two-period model from the first paper to an infinite-horizon small open economy model with imported capital goods and exchange rate externalities. The additional features allow for a more comprehensive analysis of the impact of exchange rate externality and foreign investment on sovereign external debt risk. I calibrate the model to match the EME data. The quantitative results are in line with empirical observations ([Bräuning and Ivashina, 2020](#); [Bhattarai et al., 2020](#);

Cristi et al., 2024) and show that a 0.5% U.S. monetary policy shock is accompanied by an increased sovereign default rate of 0.25% and a depreciation of 0.35% in the domestic currency. Most importantly, my calibration results reveal a new link between default incentives and capital share: economies with a high proportion of imported capital goods have a reduced default probability, as the exchange rate externality cost on default outweighs the benefits of debt reduction through default, thus lowering the likelihood of default. In addition, I show that the default incentive with a higher level of external debt to GDP depends on the capital share in the economy, underscoring the critical trade-off between the exchange rate externality cost on default and the benefits of relieving the debt burden in quantifying the default incentive.

The third chapter shifts its focus to climate change issues. As central banks increasingly recognize the economic dangers posed by climate change (Schnabel, 2022), new green monetary policy tools are under consideration in an attempt to address inflation and climate concerns at the same time. Despite current studies documenting the inflation risk stemming from the physical risk of climate change (Faccia et al., 2021; Kotz et al., 2023; Ciccarelli and Marotta, 2024), the consequences of green transition programs, particularly carbon taxes, remain uncertain.

Chapter 3 develops a theoretical framework to analyze the impact of climate-induced supply shocks and carbon taxation on inflation dynamics. I introduce a simplified green credit policy as a proxy for various green policies that lower borrowing costs for green projects. I calibrate the model using standard values from the past literature, and the results indicate that (1) climate change induces inflation pressure and undermines price instability, necessitating central bank attention, and (2) green credit policies can improve welfare and stabilize inflation when carbon taxation is suboptimal; nevertheless, it may introduce inflationary pressures when combined with stringent carbon regulation policies. This chapter contributes to the literature on climate-related macroeconomic risks (Nordhaus, 2007; Pindyck, 2013) by demonstrating that monetary policy responses to climate change must account for both supply-side shocks and financial frictions.

The final chapter transitions from theoretical and policy-driven macroeconomic analysis to an empirical and data-driven contribution. I introduce a novel LLM-driven approach to measuring the macro-financial network. As [Acemoglu et al. \(2016b\)](#) claim, the macro-financial system functions as a network. I propose a dynamic knowledge graph, constructed using a fine-tuned large language model (LLM) with newspaper data, to track the real-time evolution of macroeconomic themes and their impact on financial markets ([Li, 2023](#)).

I leverage the factor testing framework proposed in [Giglio and Xiu \(2021\)](#) and show that the thematic factors generated using my knowledge graph framework inherently capture the time-varying nature of macroeconomics and serve as unconditional risk factors in the asset pricing model. My findings show that these AI-generated indexes significantly improve the predictive accuracy of macroeconomic indicators, providing a novel methodology for measuring systemic risk in financial markets.

Literature Review

My theoretical model is based on the foundational work that models the monetary theory in general equilibrium with an incomplete market (GEI). Early contributions to this field, such as those by [Keynes \(1931\)](#), [Tobin \(1963\)](#), and [Minsky \(1977\)](#), have extensively discussed the creation of fiat money through bank credit and its implications for monetary theory. The incorporation of monetary theory in the general equilibrium model with an incomplete market has gained momentum with the work introducing cash-in-advance constraints ([Lucas, 1982](#); [Lucas and Stokey, 1987](#); [Svensson, 1985](#); [Cooley and Hansen, 1989](#)). This group of literature assumes that consumers must have cash on hand before making purchases. Money is a medium of transaction, subject to the cash-in-advance constraint, and doesn't enter into the utility function. Following this assumption, a strand of papers ([Dubey and Geanakoplos, 1992](#); [Tsomocos, 2003](#); [Goodhart et al., 2006](#); [Bloise and Polemarchakis, 2006](#); [Kumhof and Wang, 2021](#)) further

integrates the concept of inside money and outside money to GEI to capture the role of money in environments with bank credit. Inside money is created when agents borrow money from banks, entering the economy alongside a corresponding liability that ensures its eventual withdrawal. The outside money proposed in this strand of literature refers to the initial monetary endowment available to agents. The outside money is not tied to any debt obligations and is essential in both representing the real economy and determining the price level.

Building on the integration of monetary theory into the GEI model, the first two chapters of this thesis contribute to the literature on endogenous default in GEI models. The endogenous default framework in my model is closely related to the seminal works of [Shubik and Wilson \(1977\)](#), [Dubey et al. \(2005\)](#), and [Geanakoplos and Tsomocos \(2002\)](#). This strand of literature models debt default as an endogenous decision where agents face a non-pecuniary penalty proportional to the default amount, thereby influencing their borrowing and repayment behavior. This default penalty term, when applied to the sovereign default context, embeds the default costs documented in the literature, including reputational costs ([Eaton and Gersovitz, 1981](#); [Cole and Kehoe, 2000](#)), output fluctuations ([Arellano, 2008](#)), and financial sector instability ([Aguiar and Gopinath, 2006](#); [Gennaioli et al., 2014](#)).

The first two papers also contribute to the literature discussing the global financial cycle and the vulnerability of emerging market economies (EMEs) in sustaining external debt. [Rey \(2015\)](#) and [Miranda-Agrippino and Rey \(2020\)](#) show that global financial conditions are driven by a global factor closely related to U.S. monetary policy. [Kalemli-Özcan \(2019\)](#) provides empirical evidence that EMEs raise domestic interest rates in response to U.S. Federal Reserve rate hikes, challenging the dependence of EME monetary policy, which undermines the stability of prices and financial markets in EMEs. This highlights the spillover effects of U.S. monetary policy on economic growth and exchange rate instability in EMEs. This thesis also contributes to the analysis in [Peiris and Tsomocos \(2015\)](#) and [Wang \(2021\)](#), which provide models evaluating the trade-off

of equilibrium sovereign default. The role of debt restructuring as a policy tool to absorb U.S. monetary policy shocks is discussed in this thesis.

The third paper relates to the literature investigating government policies in addressing climate change issues. I focus on the effect of climate change on inflation, price stability, and green monetary policy. As discussed in [Pigou \(1947\)](#), taxation is the most efficient policy tool for addressing externalities, such as carbon emissions. [Nordhaus \(1977\)](#), [Goulder \(1995\)](#), [Nordhaus \(2007\)](#), [Parry et al. \(1999\)](#), and [Pindyck \(2013\)](#) discuss the optimal design of carbon taxes and how carbon taxation can increase social welfare by reducing emissions and lowering distortions caused by other taxes. However, the transmission of carbon taxes to inflation and the best strategy for central bankers to tackle climate change have been less investigated ([Känzig, 2023](#); [Schnabel, 2021, 2022](#)). [Faccia et al. \(2021\)](#), [Kotz et al. \(2023\)](#), and [Ciccarelli and Marotta \(2024\)](#), among many others, document the effects of climate damage on inflation and price stability, which is the main mandate of central banks, from both the supply and demand sides. To address this issue, the recent literature, [Del Negro et al. \(2023\)](#) and [Ferrari and Nispi Landi \(2024\)](#), explores how green monetary policy could incentivize the transition from brown capital to green capital to reduce climate damage, while its effect on inflation and the price level remains unclear. The third paper provides a stylized model to examine the effects of climate damage on inflation and, more importantly, how the interaction between green monetary policy and carbon taxation affects inflation and price stability.

Finally, the fourth chapter contributes to the growing literature on AI applications in asset pricing and macro-finance. The seminal Intertemporal Capital Asset Pricing Model (ICAPM) developed by [Merton \(1973\)](#) links macroeconomic factors to asset pricing models. The ICAPM extends the traditional CAPM by incorporating how asset prices vary with state variables that predict future economic activities. Under the framework of ICAPM, the past literature uses macroeconomic indicators as proxies for state variables ([Chen et al., 1986](#); [Ferson and Harvey, 1991](#); [Petkova, 2006](#)). However, [Chang and Li \(2018\)](#) show that traditional macroeconomic indicators are often noisy

and lagging, failing to capture the time-varying nature of the relationship between different economic indicators in different regimes (Lewellen and Nagel, 2006; Maio and Santa-Clara, 2012). To derive unconditional macro factors that capture the inherent time-varying relationship between macro indicators and economic growth, I propose a dynamic knowledge graph method and build thematic indexes based on it to capture the systematic importance of those variables to the economic landscape.

The application of knowledge graphs and large language models to macro-financial networks is a new field in the finance literature. I leverage the LLM model proposed in Li (2023) to generate a knowledge graph that reflects the complex relationships present in the economy. This contributes to the discussion in Kelly et al. (2023) and Ash and Hansen (2023), which explore AI-driven methods for generating asset pricing factors from unstructured data. This thesis extends the current literature by developing a dynamic knowledge graph capable of tracking real-time events in macroeconomic trends and by creating the original “polar centrality” index, which can be used as a pricing factor in asset pricing models.

Chapter 2

Dollar Denominated Sovereign Debt Risk and Restructuring in Emerging Markets

Dollar Denominated Sovereign Debt Risk and Restructuring in Emerging Markets*

Abstract

The leverage in emerging market economies (EMEs) has become highly dollarized in recent decades. This trend presents a significant challenge to EME sovereign debt sustainability, particularly in the face of U.S. monetary policy tightening. We construct a two-country monetary general equilibrium model to evaluate the effects of debt restructuring of EMEs. Our findings suggest the benefits of equilibrium sovereign default: we demonstrate that the role of the nominal exchange rate and state-contingent monetary policy in absorbing U.S. monetary policy shocks is limited in a dollarized environment because of the trade-off between relieving the external debt burden and maintaining domestic growth, whereas sovereign debt restructuring can effectively help EMEs smooth consumption both across states and time, stabilize nominal exchange rates, and reduce the level of dollar-denominated debt. Our empirical evidence further supports these theoretical findings.

Keywords: Sovereign debt restructuring; Dollar-denominated debt; exchange rate pricing; Mussa puzzle, original sin

JEL Codes: E1, E4, E5, H63, F31

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2.1 Introduction

In recent decades, the increasing reliance on dollar-denominated external debt (Hardy and von Peter, 2023) in emerging market economies (EMEs) has raised concerns about sovereign risks and economic vulnerability to foreign shocks. The high level of dollar-denominated debt limits the effectiveness of floating EME nominal exchange rates as a shock absorber and challenges the monetary autonomy of EMEs. These policy limitations raise questions about the impact of US Federal Reserve (Fed) fund rate hikes on EMEs' sovereign distress and economic recessions (Rey, 2015; Kalemli-Özcan, 2019).

As documented by Kalemli-Özcan (2019), EMEs increase their policy rates rather than defaulting on external debt to mitigate the negative spillover effects of the Fed funds rate fluctuations on the exchange rate in recent years¹. This policy tool stabilizes exchange rates in response to U.S. policy shocks. However, the fact that EME interest rates closely follow U.S. monetary policy highlights their limited independence. This lack of autonomy in domestic monetary policy reduces its effectiveness in attracting stable, long-term capital flows and protecting the economy from productivity shocks. Debt restructuring, on the other hand, could serve as an alternative tool for stabilizing the economy by directly addressing external debt vulnerabilities. Therefore, the question remains whether raising domestic interest rates is more advantageous than debt restructuring for stabilizing the domestic economy and ensuring smooth consumption across states and periods in an environment with a high level of US dollar debt.

To delve into this issue, we consider a two-country, two-good general equilibrium model with incomplete markets. One country represents an emerging market (e.g., Argentina) with a floating exchange rate, while the other represents the United States. Our model captures international linkages through goods trade and capital flows. Central banks in both countries set long-term interest rates and state-contingent short-term

¹This aligns with the stylized facts, as illustrated in Figure 1: Fed rate increases have disconnected with sovereign defaults cases in Emerging Market Economies (EMEs) since the global financial crisis.

rates to issue fiat money through the credit channel. In our model, the interest rate is exogenous. This feature provides sufficient degrees of freedom for domestic monetary instruments. A single representative household in the domestic country acts as a social planner that consolidates the decisions of households and the domestic government. The representative household in the emerging-market economy can access international markets only by issuing U.S. dollar-denominated sovereign debt, whereas domestic private agents borrow in local currency. The level of dollar-denominated debt in EMEs is defined as the ratio of U.S. dollar-denominated debt to total debt.

The model incorporates a debt default feature following the frameworks of [Dubey et al. \(2005\)](#), [Peiris and Tsomocos \(2015\)](#), and [Wang \(2021\)](#). Specifically, in our model, the creditor imposes an exogenous, non-pecuniary default penalty on the domestic external debt. This non-pecuniary default penalty embeds both the reputational costs of EMEs' external debt ([Eaton and Gersovitz, 1981](#); [Cole and Kehoe, 2000](#)) and the cost of potential exclusion from international financial markets ([Gelos et al., 2011](#); [Cruces and Trebesch, 2013](#)). Based on the state of nature, the domestic representative household determines the repayment amount. This framework enables the evaluation of the endogenous trade-off of external debt restructuring while accounting for the real penalties imposed by creditors and international organizations.

In our model, the external debt cost for the domestic country equals the sum of the U.S. interest rate and a default premium. A positive U.S. monetary policy shock has a larger spillover effect on external debt costs when the probability of domestic external debt restructuring is positive. The interaction between default risk and monetary tightening amplifies the domestic country's debt costs. To assess the impact of U.S. monetary policy on EMEs and evaluate the effectiveness of domestic monetary policy and debt restructuring in mitigating monetary tightening shocks, we decompose the equilibrium responses of optimal domestic social welfare to variations in key exogenous variables. Our analysis places particular emphasis on U.S. monetary policy. We break down the response of domestic social welfare into four components: "Direct Foreign

Import”, “Real Debt Default Adjustment”, “Real Import Expenditure”, and “Direct Default Penalty”, each capturing a distinct economic aspect. The fluctuations across these welfare components provide evidence of the effectiveness of debt restructuring for EMEs.

Our theoretical model is calibrated to the data from Argentina’s debt restructuring in 2020 and analyzes the trade-offs of the restructuring policy for the economy. Argentina has long grappled with the challenges of sovereign debt. Since 2001, the country has defaulted on its international sovereign debt three times: first in December 2001 following a severe financial crisis, again in 2014 during disputes with holdout creditors, and most recently in 2020 during the COVID-19 pandemic. The latest 2020 restructuring settled the clauses with creditors much more rapidly than in previous cases and successfully restructured the desired amount of debt. These restructurings didn’t face strict punishment. In 2022, President Alberto Fernández further reached a preliminary agreement with the International Monetary Fund (IMF) to restructure \$44.5 billion from a record 2018 bailout. These actions, along with other economic policies, helped the country avoid an immediate crisis akin to that of 2001 despite a challenging global economic environment (Delivorias, 2023). Argentina’s 2020 debt restructuring provides an example to support our model that a preemptive default, combined with a rapid restructuring process and mild penalties from international organizations, does not necessarily lead to an economic crisis.

First, the numerical solutions using Argentina data demonstrate that when the terms for debt restructuring are so stringent that an orderly sovereign default is excluded from the equilibrium, the stabilizing and hedging effects of monetary policy are constrained, even when the domestic central bank mirrors the US monetary policy tightening on a one-to-one basis. This limitation arises from the high level of dollar-denominated debt as an equilibrium outcome. Specifically, when the domestic economy is impacted by the spillover effect of a US monetary policy shock, the exchange rate of the EMEs depreciates excessively, exacerbating the real burden of dollar-denominated

sovereign debt, i.e., the “Real Debt Value” component of welfare. If EMEs’ central banks hike the domestic interest rate to stabilize the exchange rate and mitigate the debt burden, they will at the same time adversely reduce domestic production and gains from trade, directly increase real import expenditures, and negatively impact social welfare. According to our calibration results, EMEs need to raise their interest rates to twice the magnitude of the US interest rate change to hedge the negative spillover effect of US monetary policy shocks. However, the result that EME interest rates closely follow U.S. monetary policy highlights their limited independence. This lack of autonomy in domestic monetary policy reduces its effectiveness in attracting stable, long-term capital flows and protecting the economy from productivity shocks.

However, when the non-pecuniary penalty for debt restructuring is softened, allowing for orderly sovereign default in equilibrium, we demonstrate that the EME’s social utility increases compared with scenarios without debt restructuring. This holds true in the face of both productivity shocks and US interest rate hikes. In equilibrium, a higher expected level of default in the second period will raise the domestic external debt costs and may increase real import expenditures for consumption goods and production factors. However, the dominant effect is that orderly sovereign debt restructuring lowers the “Real Debt Value” in equilibrium, and mitigates depreciation pressure on the domestic currency by reducing the demand for US dollars. The stronger value of the domestic currency in bad states facilitates more effective consumption smoothing across states and hedges against economic downturns caused by negative productivity shocks. This result suggests that default can act as an insurance mechanism, hedging against spillover effects from external U.S. monetary policy shocks and internal productivity shocks. Nevertheless, there is no monotonic relationship between social welfare and default. There is an optimal value for softening the terms of debt restructuring, i.e., there is an optimal amount of haircut allowable by the creditors. If the sovereign default haircut exceeds this optimal level, the costs of default would lead to a collapse of trade, outweighing the benefits of smoothed consumption and a stable exchange rate.

In this scenario, sovereign default would become a disorderly choice.

Our work also sheds light on the “Mussa puzzle”². In both the case with orderly default and the case without, we prove that US monetary policy has non-neutral effects, affecting both nominal and real exchange rates, and also has a spillover effect on the domestic country. In the case allowing for debt restructuring, the default risk premium further aggregates the effect of monetary policy on real exchange rates, under the float exchange rate regime. This offers one explanation for the “Mussa puzzle”, where both the Mussa puzzle and monetary non-neutrality can be attributed to the impact of U.S. monetary policy on the domestic country’s default risk, complementing the current literature (Itskhoki and Mukhin, 2024).

Empirical evidence further supports the results of our theoretical model, which suggests that default can serve as a tool to hedge against US shocks. Specifically, our empirical study explores the potential of sovereign defaults in EMEs to act as a hedging mechanism against US monetary policy shocks after controlling other macroeconomic indicators. Using Local Projection methods on data from 1980–2020, we investigate the intricate dynamics between US monetary policy shocks and EMEs macroeconomic responses, with a particular focus on how the government bond default choice affects macroeconomic responses. Based on the dataset collected by Asonuma and Trebesch (2016), we differentiate between two types of defaults: hard default and preemptive default. Our findings suggest that preemptive defaults act as a strategic buffer, mitigating the adverse impacts of US monetary policy tightening on the economic stability

²The “Mussa puzzle” is the occurrence of a significant and abrupt increase in real exchange rate volatility after the implementation of a floating exchange rate system in 1973. This puzzle provides evidence of monetary non-neutrality and is explained by sticky prices in conventional literature. However, the sticky price explanation is not consistent with the fact that the pattern of other macro variables remains the same with the change of exchange rate regimes. Specifically, changes in monetary policy are necessary to reduce equilibrium exchange rate volatility, which under sticky prices must be followed by variations of output, consumption, and other real variables. Itskhoki and Mukhin (2024) explain this puzzle through a financial market channel. They propose a model with financial market segmentation with financial intermediaries hold the majority of the nominal exchange rate risk. They argue the “Mussa puzzle” and monetary non-neutrality arise due to the impact of monetary policy on risk premium and financial intermediation. In this way, they provide clear evidence regarding monetary non-neutrality from a financial market perspective and highlight the importance of risk premium as a monetary transmission channel.

of EMEs.

Moreover, the simulated results of our calibrated model also explain some empirical facts related to sovereign default and external debt of EMEs. As [Figure 2](#) and our calibration results show, EMEs tend to issue more debt denominated in the US dollar during normal times. The level of dollarization increases during these times and reaches a peak before markets start to acknowledge the possibility of sovereign default, after which it begins to decline. As proven in our model, a higher probability of default leads to a higher external debt cost, which diminishes the relative advantages of issuing US dollar-denominated debt and thus reduces the magnitude of external debt, mainly due to the low external financial cost³. Additionally, quarterly GDP in EMEs declines before the default, persists until two quarters after the sovereign default, and then commences a recovery period on average half a year after the default, as shown in [Figure 3](#). Past literature has documented that a sovereign default is followed by a decline in total output value ([Borensztein and Panizza, 2008](#); [Hébert and Schreger, 2017](#); [Trebesch and Zabel, 2017](#)). However, [Yeyati and Panizza \(2011\)](#) argue that the sovereign default marks the start of recovery. Our results are broadly aligned with these two strands of literature. In our model, the anticipation of default might shrink investment but could smooth consumption in the future and maintain the relevance of domestic monetary policy. The third stylized fact is that the exchange rate depreciates before and after the default, but with a lower depreciation rate after the default, as documented in [Figure 4](#). In our model, the exchange rate experiences a sharper depreciation before the default, but when the default occurs, the exchange rate starts to bounce back. This finding is consistent with [Na et al. \(2018\)](#), which suggests that sovereign default decisions are not associated with a sharper depreciation rate.

Our paper is built on papers discussing dollarized debt in EMEs. It is well-documented in past literature that both government and corporate debt in EMEs are heavily issued in US dollars ([McCauley et al., 2015](#); [Bruno and Shin, 2015b](#); [Maggiore](#)

³See also [Reinhart et al. \(2003a\)](#); [Uribe and Schmitt-Grohé \(2017\)](#).

et al., 2020; Kose et al., 2022). Several reasons have been suggested in the literature for why governments and corporations in emerging markets often choose to issue debt in dollars instead of their local currency, even at the risk of exposure to currency mismatches. For instance, undervalued insurance value against exchange rate risk in the domestic financial market (Caballero and Krishnamurthy, 2003); domestic investors and savers demand a higher saving rate to compensate for the domestic currency risk (Bocola and Lorenzoni, 2020); and the demand for safe dollar assets (Jiang et al., 2024). Our paper takes the high levels of dollarized debt in EMEs as given and focuses on analyzing the risks and potential policy responses of EMEs to various shocks, and evaluating the welfare implications of these policy choices.

The high demand for the US dollar in international markets has given rise to two concepts that have gained prominence in recent years: the global financial cycle and the spillover effect of US interest rates. Rey (2015) documents that there is a comovement between global financial indicators, named the global financial cycle(GFC). Miranda-Agrippino and Rey (2020) and Miranda-Agrippino and Rey (2022) further provide casual evidence between the FED rate and closely related to the global financial cycle. One of the key empirical facts is the positive FED monetary policy shock generates a lower capital inflow and higher capital outflow in EMEs(See also Bruno and Shin (2015a), and Obstfeld and Zhou (2022)). To avoid a sharp depreciation of domestic currency and heavy capital outflows, the EMEs increase the policy rate twice more than the FED magnitude on average as a response to the shock (Kalemli-Özcan, 2019). This strand of literature argues that without capital control, the monetary policy independence of EMEs like Argentina is undermined, regardless of the exchange rate regimes. However, increasing the domestic policy rate may lead to a recession and amplify the negative spillover effects of US monetary policy shocks, potentially making it a suboptimal policy choice. In our model, we demonstrate an orderly default is a policy tool for the EMEs to hedge the international monetary policy. In our calibration cases, there are both significant and heterogeneous effects of the US policy rate on the

domestic economy. We analyze this problem through three channels: the Capital Flow Channel (Bonds), the Exchange Rate Channel, and the Foreign Trade Channel. Our result confirms the stylized facts by showing the positive FED monetary policy shock leads to a lower net capital inflow to the EMEs.

Our paper contributes to the literature investigating the “Twin Ds”. “Twin Ds” refers to the phenomenon that sovereign default is often accompanied by a sharp depreciation of the domestic currency. This phenomenon is first documented by [Reinhart \(2002\)](#)⁴ and is also supported by [Du and Schreger \(2022b\)](#), and [Augustin et al. \(2020\)](#). [Na et al. \(2018\)](#) demonstrate the devaluation of the currency as an optimal policy choice in the equilibrium to reduce the real wage and, in turn, increase the unemployment rate. [Della Corte et al. \(2022\)](#) argue that sovereign risk, with CDS spread as a proxy variable, could partly explain the variation of the exchange rate and could be viewed as a risk factor in the standard asset pricing model to price the currency. Nevertheless, it remains a challenge to identify whether the sovereign default directly leads to a sharper rate of depreciation. Our research provides a theoretical mechanism to show that the function of an orderly sovereign default can help stabilize the exchange rate and does so in a less distortionary way than hiking domestic monetary policy rates. We show that sovereign distress is correlated with a higher depreciation of the domestic currency before the default but a slight appreciation immediately after the default. Furthermore, we argue that the anticipation of economic downturns rather than debt restructuring is the main reason for depreciation.

In addition, our paper links to the existing literature on the costs of sovereign default events by addressing the direct costs and benefits of foreign investment and total output. [Uribe and Schmitt-Grohé \(2017\)](#)(Chapter13) and [Bolton et al. \(2023\)](#) provide a comprehensive survey. Traditionally, the major incentive for the government to repay debt is a reputational cost in a broad sense as in ([Eaton and Gersovitz, 1981](#); [Cole and Kehoe, 2000](#); [Gelpern and Panizza, 2022](#)), possible exclusion from the financial

⁴See also [Krugman \(1979\)](#)

market (Gelos et al., 2011; Cruces and Trebesch, 2013)⁵, and direct sanction by the creditor (Rose, 2005). However, recent research suggests that the costs above are not sufficient to explain the low frequency of international sovereign defaults (Gennaioli et al., 2014)⁶. In Arellano (2008), an exogenous shock to output is assumed to align with the sovereign default, a common setup used in recent literature, as documented by Uribe and Schmitt-Grohé (2017) and Aguiar and Amador (2023). While the existing literature provides a robust link between banking crises, financial markets, and sovereign default (Reinhart and Rogoff, 2011; Bocola, 2016; Hébert and Schreger, 2017), the joint effects of sovereign default on output, inflation, and nominal exchange rates remain less clear. We contribute to the literature by modeling these joint effects of sovereign default risks on output, inflation, and nominal exchange rates.

The paper is structured as follows: Section II describes the model structure. Section III outlines the characteristics of the theoretical model and its implications. Section IV shows the calibration results of our model based on Argentina’s data. Section V presents our empirical stylized facts. The final section concludes and discusses potential future extensions.

2.2 Model

The main features of our model are described in Figure 2.1. Assume there are two periods, $t \in T = \{0, 1\}$, where $t = 1$ has two possible states of nature, indexed by $s \in S = \{g, b\}$, with g representing the good state and b the bad state. The two countries are indexed by I and J , where country I represents the home country (EMEs) and country J represents the foreign country, i.e. the United States. Each country has measure-one households and its own central bank. Households consume goods in both periods and produce tradable goods in $t = 1$. In the home country we aggregate the

⁵They argue the exclusion from the financial market depends on the fundamental conditions

⁶They argue sovereign default ruins the balance sheets of the banking sector, which is an implicit cost of sovereign default.

household and government sectors into a single representative household acting as a domestic planner. This representative planner makes optimal choices for consumption, production, borrowing, and default, internalising both private and public decisions. Production in country I is subject to state-contingent total factor productivity (TFP), $A_{I,s}$ for $s \in \{g, b\}$, with $A_{I,g} > A_{I,b}$. Central banks set an inter-period interest rate at $t = 0$ and a state-contingent intra-period interest rate at $t = 1$. This setup provides sufficient degrees of freedom for conducting monetary policy and enables us to evaluate how fluctuations in U.S. long-term and short-term interest rates affect the domestic economy.

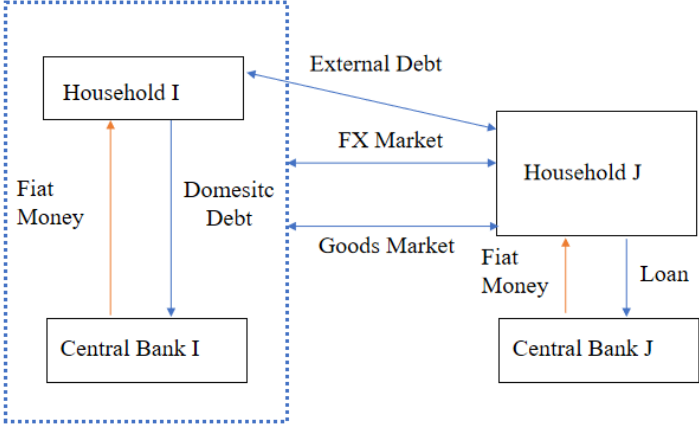


Figure 2.1: Nominal flows of the economy

Figure 2.2 illustrates the timeline of our two-period model. At $t = 0$ domestic households i are endowed with a domestic good e_I and outside money m_I . They may borrow domestic currency via loans extended by the domestic central bank and exchange it for U.S. dollars on the foreign-exchange market; they may also obtain U.S. dollars by issuing external debt denominated in U.S. dollars. Households use U.S. dollars to purchase U.S. goods for consumption and investment. They have an investment technology that converts imported goods $z_{J,0}^i$ from the United States into capital goods used for production at $t = 1$. Similarly, U.S. households J start with U.S. goods endowment e_J and U.S. dollars m_J . They either invest in the home country's sovereign external debt or exchange U.S. dollars for domestic currency on the foreign-exchange

market to purchase domestic goods for consumption.

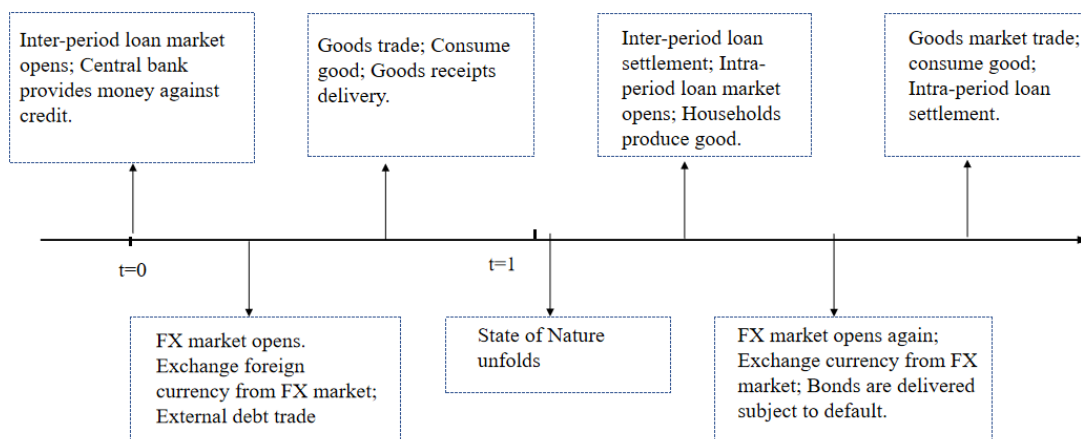


Figure 2.2: Timeline

At $t = 1$ domestic households use goods revenue and state-contingent intra-period loans to repay outstanding loan balances from the previous period and exchange currency for U.S. dollars to purchase U.S. goods and repay external debt, subject to default. U.S. households use export revenue and bond repayments to settle their own outstanding loan balances and exchange domestic currency to purchase goods from the home country.

The representative domestic household borrows U.S. dollars by issuing external bonds denominated in U.S. dollar with face value Q_J^i at $t = 0$, paying an endogenous interest rate ρ_I . At $t = 1$ the domestic planner repay the sovereign bonds subject to a default, depending on the cost of debt-restructuring terms and the state of nature.

2.2.1 Representative Domestic Household

In the home country, we aggregate the household and government sectors into a single representative household that acts as a social planner. This planner makes optimal choices for consumption, production, borrowing, and default, internalising both private and public decisions. External debt is interpreted as a sovereign liability: by con-

solidating the household and government sectors, we consider sovereign default as an explicit policy choice while abstracting from intra-country distributional frictions. In Appendix A1, we present the government problem explicitly and show its equivalence to this consolidated setup. The social planner maximises welfare, defined as the utility derived from household consumption net of a non-pecuniary penalty associated with sovereign default:

$$W_I = \text{Max} \quad \frac{C_0^{i1-\sigma^i} - 1}{1 - \sigma^i} + \beta_I \mathbb{E}_0 \left[\frac{C_s^{i1-\sigma^i} - 1}{1 - \sigma^i} - \beta_I \chi^g \frac{\max((1 - \gamma_{I,s})Q_J^i, 0)}{p_s} \right], \quad (2.1)$$

where $C_{s^*}^i$ is the aggregate consumption level of domestic households and is a bundle of the consumption of home goods c_{I,s^*}^i and foreign goods c_{J,s^*}^i with $s^* \in (0, b, g)$, where

$$C_{s^*}^i = \left((\iota^i)(c_{I,s^*}^i)^{1-\nu^i} + (1 - \iota^i)(c_{J,s^*}^i)^{1-\nu^i} \right)^{\frac{1}{1-\nu^i}}.$$

The utility function from consumption is characterized by a constant elasticity of substitution (CES) between domestic and foreign goods ($\frac{1}{\nu^i}$), and a constant intertemporal elasticity of substitution (CIES) ($\frac{1}{\sigma^i}$).

The non-pecuniary default-penalty term, captures the utility loss of default on the external debt, equal to the real value of external debt multiplied by a penalty parameter χ^g . This parameter represents the strictness of the sovereign-debt-restructuring terms. The real value of debt is calculated based on a price index p_s , which is defined as a welfare-based consumer price index (Redding and Weinstein, 2020; Guerrieri et al., 2022). This price index represents the exact cost in U.S. dollars required for a one-unit increase in aggregate consumption C_s^i , where

$$p_s = \left(\iota^i \left(\frac{p_{I,s}}{x_s} \right)^{\frac{\nu^i-1}{\nu^i}} + (1 - \iota^i) (p_{J,s}(1 + r_{I,s}))^{\frac{\nu^i-1}{\nu^i}} \right)^{\frac{\nu^i}{\nu^i-1}}.$$

At $t = 0$, the representative household issues external sovereign debt denominated in U.S. dollars to foreign investors, raising B_J^i U.S. dollars. At $t = 1$, the domestic

country repays the sovereign debt at a state-contingent rate $\gamma_{I,s}$. Let Q_J^i denote the face value of the external debt and ρ_I the external debt interest rate, thus $Q_J^i = (1 + \rho_I)B_J^i$. The state-contingent repayment rate $\gamma_{I,s}$ on this debt depends on the state of nature and the harshness of the restructuring terms. The repayment rate $\gamma_{I,s}$ ranges between 1, representing full repayment of the bond's face value, and 0, indicating full default.

Households i face the following flow of funds constraints

$$f_{I,0}^i \leq \frac{\mu_{I,0}^i}{1 + r_I} + m_I. \quad (2.2)$$

At $t = 0$, households use their initial endowment of outside money m_I and money borrowed via an inter-period loan to exchange for U.S. dollars in the foreign exchange market. In equation (2.2), $f_{I,0}^i$ denotes the domestic currency traded in foreign exchange markets at time $t = 0$, and $\mu_{I,0}^i$ represents the face value of an inter-period loan with a domestic interest rate equal to r_I . As shown in equation (2.3), the U.S. dollars exchanged at an exchange rate x_0 , along with the external debt revenue G_J^i , are used to purchase foreign goods at a price $p_{J,0}$ denominated by the U.S. dollar. These goods are either used for investments, denoted as $z_{J,0}^i$, or for consumption, represented by $c_{J,0}^i$.

$$p_{J,0}(z_{J,0}^i + c_{J,0}^i) \leq B_J^i + \frac{f_{I,0}^i}{x_0}. \quad (2.3)$$

Equation (2.4) completes households' constraints at $t = 0$. Domestic households receive a home goods endowment e_I , export a portion of goods $q_{I,0}^i$, and allocate the remainder for their own consumption.

$$c_{I,0}^i \leq e_I - q_{I,0}^i. \quad (2.4)$$

At the start of $t = 1$, domestic households use their export revenue $p_{I,0}q_{I,0}^i$ and state-contingent intra-period loans to exchange for U.S. dollars and settle the inter-period loan $\mu_{I,0}^i$. In equation (2.5), $f_{I,s}^i$ represents the domestic currency used to exchange U.S. dollars at state s , and $\mu_{I,s}^i$ represents the intra-period loan with a loan rate $r_{I,s}$. The

U.S. dollars exchanged at the foreign exchange market at exchange rate x_s are used to purchase foreign goods $c_{J,s}^i$ for consumption, priced at $p_{J,s}$, and to repay external debt subject to a default $\gamma_{I,s}Q_J^i$, as described in equation (2.6).

$$\mu_{I,0}^i + f_{I,s}^i = p_{I,0}q_{I,0}^i + \frac{\mu_{I,s}^i}{1 + r_{I,s}}; \quad (2.5)$$

$$\gamma_{I,s}Q_J^i + p_{J,s}c_{J,s}^i = \frac{f_{I,s}^i}{x_s}. \quad (2.6)$$

At the end of $t = 1$, households settle the intra-period loan $\mu_{I,s}^i$ with export revenue $p_{I,s}q_{I,s}^i$, as shown in equation (2.7). Domestic output $y_{I,s}$ is produced using investment goods $z_{J,0}^i$ through the production function $y_{I,s} = A_{I,s}z_{J,0}^i$, where $A_{I,s}$ is the state contingent total factor productivity(TFP) level. Domestic households consume the rest of domestic goods $c_{I,s}^i$, as shown in equation (2.8).

$$\mu_{I,s}^i = p_{I,s}q_{I,s}^i; \quad (2.7)$$

$$c_{I,s}^i = y_{I,s} - q_{I,s}^i. \quad (2.8)$$

Remark on Elasticity of Substitution

The sign and magnitude of $\frac{1}{\nu^i} - \frac{1}{\sigma^i}$ play a pivotal role in determining how TFP of domestic country in the bad state affects the domestic consumption of U.S. goods, i.e., the direction of $(\frac{dc_{J,b}^i}{dA_{I,b}})$. Specifically, when $\frac{1}{\nu^i} < \frac{1}{\sigma^i}$, it implies a lower elasticity of substitution between domestic and U.S. goods, suggesting that intratemporal effects are predominant and the domestic and U.S. goods are complements. If $\frac{1}{\nu^i} < \frac{1}{\sigma^i}$ holds, an increase in $A_{I,b}$ increases domestic goods consumption, which in turn increases demand for U.S. goods ($\frac{dc_{J,s}^i}{dA_{I,b}} > 0$). Conversely, if $\frac{1}{\nu^i} \geq \frac{1}{\sigma^i}$, suggesting a higher elasticity of substitution and highlighting the significance of intertemporal consumption smoothing. In this case, domestic and U.S. goods are substitute goods. A higher $A_{I,b}$ leads to a lower demand for U.S. goods ($\frac{dc_{J,s}^i}{dA_{I,b}} < 0$).

2.2.2 Foreign Household

The preference of U.S. households j is symmetric to that of the domestic households

$$U^j = \frac{C_0^{j1-\sigma^j} - 1}{1 - \sigma^j} + \beta_J \mathbb{E}_0 \left[\frac{C_s^{j1-\sigma^j} - 1}{1 - \sigma^j} \right],$$

where $C_{s^*}^j$ with $s^* \in (0, b, g)$ is the aggregate consumption and equals to:

$$C_s^j = \left((\iota^j)(c_{I,s}^j)^{1-\nu^j} + (1 - \iota^j)(c_{J,s}^j)^{1-\nu^j} \right)^{\frac{1}{1-\nu^j}}.$$

At $t = 0$, U.S. households combine their initial endowment of U.S. dollar m_J and money borrowed via an inter-period loan to exchange for domestic currency in the foreign exchange market or invest B_J^i in the domestic external debt. In equation (2.9), $f_{J,0}^j$ represents the U.S dollar traded in foreign exchange markets at time $t = 0$, and $\mu_{J,0}^j$ represents the face value of an intertemporal loan with an interest rate equal to r_J .

$$B_J^i + f_{J,0}^j \leq \frac{\mu_{J,0}^j}{1 + r_J} + m_J. \quad (2.9)$$

As shown in equation (2.10), the domestic currency obtained from the foreign exchange market at the exchange rate x_0 is used to purchase domestic goods, which are priced in the domestic currency. These goods are then consumed, as denoted by $c_{J,0}^i$.

$$p_{I,0} c_{I,0}^j = f_{J,0}^j x_0. \quad (2.10)$$

U.S. households allocate some of their initial endowment e_J as exports $q_{J,0}^j$ to households i . The remaining goods are allocated to investment goods $z_{J,0}^j$ and consumption $c_{J,0}^i$, as shown in equation (2.11).

$$c_{J,0}^i = e_J - q_{J,0}^j - z_{J,0}^j. \quad (2.11)$$

At the start of $t = 1$, as shown in equation (2.12), U.S. households j use the first period's export revenue $p_{J,0}q_{J,0}^j$ and money from loan $\mu_{J,0}^j$ at the loan rate $r_{J,s}$ to exchange for EMEs' currency and repay outstanding loan balances $\mu_{J,0}^j$. This constraint is described in equation (2.12). Households spend $f_{J,s}^j$ to exchange for domestic currency at the exchange rate x_s , and use EME currency to buy imports from EME country I : $p_{I,s}c_{I,s}^j = f_{J,s}^j x_s$.

$$\mu_{J,0}^j + f_{J,s}^j = p_{J,0}q_{J,0}^j + \frac{\mu_{J,0}^j}{1 + r_{J,s}}. \quad (2.12)$$

At the end of $t = 1$, households j use their export revenue $p_{J,s}q_{J,s}^j$ and the sovereign external bond repayments from country I to settle the loan $\mu_{J,s}$, as detailed in equation (2.13), where ρ_I is the interest rate on the external bond. Due to the possibility of domestic household I defaulting, in equation (2.13), $D_{I,s} \in [0, 1]$ represents the state-contingent external debt repayment rate received by households j .

$$\mu_{J,s} = p_{J,s}q_{J,s}^j + B_J^i(1 + \rho_I)D_{I,s}. \quad (2.13)$$

For simplicity, country J 's production follows $y_J = A_J z_{J,0}^j$. The foreign goods produced y_J are either directly consumed by the foreign country or sold to domestic households as exports $q_{J,s}^j$.

$$c_{J,s}^j = y_J - q_{J,s}^j. \quad (2.14)$$

2.2.3 Domestic Central Bank

The domestic central bank, hereafter referred to as Central Bank I , issues reserves M_{I,s^*} for $s^* \in (0, b, g)$, and sets both the inter-period policy rate r_I and the intra-period policy rate $r_{I,s}$ for $s \in (b, g)$. Central Bank I provides domestic liquidity to households through inter- and intra-period loans. Similarly, Central Bank J , the U.S. central bank, is responsible for providing the U.S. dollar liquidity to U.S. households. The Central Bank J issues reserves M_{J,s^*} for $s^* \in (0, b, g)$, and sets both the inter-period policy rate r_J and the intra-period policy rate $r_{J,s}$ for $s \in (b, g)$, which guides

foreign currency lending activities.

2.2.4 Definition of Equilibrium

The two-country general equilibrium is defined as an allocation $(c_{I,s^*}^i, c_{J,s^*}^i, c_{I,s^*}^j, c_{J,s^*}^j, f_{I,s^*}^i, f_{J,s^*}^j, z_{J,0}^i, z_{J,0}^j, q_{I,s^*}^i, q_{J,s^*}^j, \mu_{I,s^*}^i, \mu_{J,s^*}^j, B_J^i, Q_J^i)$ with prices $(x_s^*, \rho_I, p_{I,s^*}, p_{J,s^*}, \gamma_{I,s}, D_{I,s})$, given the inter-period and intra-period policy rates and the penalty parameter χ^g , for $\forall s \in \{b, g\}$, and $s^* \in \{0, b, g\}$ such that households maximize their utility function subject to cash-in-advance constraints and budget constraint, the following markets clear and expectations are rational.

- Goods markets:

$$z_{J,0}^i + c_{J,0}^i = q_{J,0}^j;$$

$$c_{J,s}^i = q_{J,s}^j;$$

$$c_{I,0}^j = q_{I,0}^i;$$

$$c_{I,s}^j = q_{I,s}^i.$$

- Foreign exchange market:

$$f_{I,0}^i = x_0 f_{J,0}^j;$$

$$f_{I,s}^i = x_s f_{J,s}^j;$$

- Loan markets:

$$M_{I,0} = \frac{\mu_{I,0}^i}{1 + r_I};$$

$$M_{J,0} = \frac{\mu_{J,0}^j}{1 + r_J};$$

$$M_{I,s} = \frac{\mu_{I,s}^i}{1 + r_{I,s}};$$

$$M_{J,s} = \frac{\mu_{J,s}^j}{1 + r_{J,s}}.$$

- Bond markets:

$$Q_J^i = (1 + \rho_I)B_J^i.$$

- Rational expectation on default:

$$D_{I,s} = \gamma_{I,s}.$$

2.3 Equilibrium Characterisation

In this section, we present the key equilibrium conditions capturing the interactions between sovereign default decisions, social welfare, and macroeconomic variables in the model. By formalizing the trade-off faced by EMEs when defaulting on external debt, we aim to characterize how default penalties, productivity shocks, and external borrowing costs impact the economy's strategic choices.

2.3.1 Default On-the-Verge Condition

We start by defining the conditions under which a default is optimal, capturing the trade-off of default.

Lemma1: *In equilibrium, the Default On the Verge Conditions are characterized by*

the shadow price for the domestic country in the bad state, $\theta_I(b)$; the Kuhn-Tucker multipliers, μ_0 and μ_1 , which correspond to conditions $\theta_I(b) \geq 0$ and $\theta_I(b) \leq 0$, respectively; the exchange rate in the bad state, x_b ; the domestic price index in the bad state, p_b ; and the non-penalty parameter, χ^g , formally expressed as

$$\frac{\pi_b \chi^g}{p_s} + \mu_0 - \mu_1 = x_b \theta_I(b). \quad (2.15)$$

Proof: See [Appendix A2](#).

In equation (2.15), the left-hand side represents the marginal cost of default in real terms, and the right-hand side represents the marginal benefit from default. The non-pecuniary default penalty parameter, χ^g , captures sanctions or penalties imposed directly by creditors. In line with the stylized fact illustrated in [Figure 2.C](#), which shows that sovereign restructuring typically occurs during periods of domestic economic downturn, we assume that default is permitted only in the bad state. The default level $1 - \gamma_{I,b}$ is a monotonic function of the penalty parameter χ^g , where a higher level of χ^g leads to a non-increasing level of default. Given the fixed interest rate level, let $\bar{\chi}^g$ represent the lowest penalty level that prevents default, and let $\underline{\chi}^g$ denote the highest penalty level that leads to full default. We formalize this into three cases:

- For $\chi^g \in (\underline{\chi}^g, \bar{\chi}^g)$, it follows that $\gamma_{I,b} \in (0, 1)$, and $\mu_0 = \mu_1 = 0$;
- For $\chi^g \in [\bar{\chi}^g, \infty)$, it follows that $\gamma_{I,b} = 1$, $\mu_0 = 0$, and $\mu_1 \geq 0$;
- For $\chi^g \in (-\infty, \underline{\chi}^g]$, it follows that $\gamma_{I,b} = 0$, $\mu_0 \geq 0$, and $\mu_1 = 0$.

The first case quantifies a scenario with an interior solution, which is the primary focus of this paper. This scenario assumes that sanctions imposed by creditors and international organizations are moderate, allowing the domestic country to renegotiate its external debt with creditors following a negative economic shock. In the absence of a negative productivity shock—when total factor productivity (TFP) remains constant across states—the marginal benefits of default are smaller than the associated costs due

to favourable economic conditions and low marginal utility for consumption. In this situation, the first-order condition (FOC) constraints for default are not binding.

However, when a negative productivity shock hits the domestic economy, as assumed in our model ($A_{I,b} < A_{I,g}$), it shifts the domestic marginal utility curve upward, increasing the demand for consumption of U.S. goods and, in turn, raising the marginal benefits of default. When the marginal benefits exceed a certain threshold, the constraints become binding, leading the government to pursue restructuring with creditors as a policy tool to improve social welfare. Full default occurs when the increase in marginal utility from an additional dollar under a zero-repayment scenario exceeds the marginal cost of default. In this case, the domestic government completely defaults on external debt without pursuing debt restructuring. In this paper, we focus on the first case, where the default penalty or terms of debt restructuring are neither excessively strict nor overly lenient, to quantify the trade-offs associated with default.

Remark on Productivity Shock and Default Level

For the interior solution case, a negative productivity shock leads to a higher level of default if $\frac{1}{\nu^i} \geq \frac{1}{\sigma^i}$.

Understanding the impact of TFP changes on default rates requires analysing two distinct scenarios characterized by the relationship between intra-temporal ($\frac{1}{\nu^i}$) and inter-temporal ($\frac{1}{\sigma^i}$) consumption smoothing. If $\frac{1}{\nu^i} \geq \frac{1}{\sigma^i}$, indicating that inter-temporal consumption smoothing is predominant. In this case, foreign goods and domestic goods are substitute goods, as discussed in [Remark on Elasticity of Substitution](#). The decrease in total factor productivity (TFP) in the bad state leads to a higher default rate. This is because lower TFP amplifies the demand for foreign consumption, which requires higher foreign borrowing from external debt. The higher borrowing, in turn, raises the default rate to loosen the budget constraint and allow a larger quantity of imports. This assumption, which forms the basis of our calibration results, also finds support from the literature on international economics ([Na et al., 2018](#); [Kleinman et al., 2023](#)).

On the other hand, if $\frac{1}{\nu^i} < \frac{1}{\sigma^i}$, foreign goods and domestic goods are complements. In this case, a decline in TFP during a bad state implies lower foreign consumption demand. This decrease in demand causes domestic households to demand fewer U.S. dollars, thereby enhancing their capacity to repay external debts in the bad state.

2.3.2 Asset Prices

In the previous section, [Default On-the-Verge Condition](#) and the [Remark on Productivity Shock and Default Level](#) specify conditions under which restructuring occurs at the equilibrium and illustrate how restructuring affects allocations under different assumptions about the elasticity of substitution parameters. This section presents propositions that characterize the impact of restructuring on asset prices, including government bond prices and yields, as well as the exchange rate. These propositions provide an analysis of how external debt default probabilities affect financial market dynamics in EMEs.

Proposition 1: Domestic Country External Debt Price

Suppose $r_J > 0$, $r_{J,s} > 0$, the price of the domestic external debt p_d , equals the foreign interest rate discounted by the expected repayment rate, formally expressed as:

$$p_d = \frac{1}{(1 + \rho_I)} = \frac{1}{1 + r_J} E_{\mathbb{Q}_J} \left[\frac{D_{I,s}}{(1 + r_{J,s})} \right], \quad (2.16)$$

where $E_{\mathbb{Q}_J}$ denotes the expectation under the U.S. risk-neutral probability measure \mathbb{Q}_J , defined as:

$$\mathbb{Q}_J(s) = \frac{\theta_J(s)}{\theta_J(b) + \theta_J(g)},$$

where $\theta_J(s)$ is the shadow price of the foreign country in state s , and $\theta_J(b)$ and $\theta_J(g)$ are the shadow prices in the bad and good states, respectively.

Proof: See [Appendix A3](#).

In the absence of sovereign default, where $D_{I,b} = D_{I,g} = 1$, it follows that $E_{\mathbb{Q}_I}[D_{I,s}] = 1$. Under this condition, the external debt rate of the domestic external debt is equivalent to the U.S. policy rate.⁷ This equivalence highlights that, within our framework, default risk is the only source of the risk premium associated with U.S. dollar-denominated debt issued by emerging markets. An increase in either the probability or the magnitude of default decreases the values of $E_{\mathbb{Q}_I}[D_{I,s}] = 1$, resulting in higher external borrowing costs and a lower price of external debt. Furthermore, default risk also influences the equilibrium through the exchange rate channel, which shapes borrowing conditions and debt pricing.

Corollary 1.1: Covered Interest Rate Parity and Wedge:

Suppose $r_I > 0$, $r_{I,s} > 0$, $r_J > 0$, $r_{J,s} > 0$, the forward exchange rate, $E_{\mathbb{Q}_I}[x_s]$ equals the spot exchange rate x_0 adjusted by the difference between the domestic interest rate r_I and the external debt interest rate ρ_I , formally:

$$E_{\mathbb{Q}_I}[x_s] = \frac{1 + r_I}{1 + \rho_I} x_0, \quad (2.17)$$

where $E_{\mathbb{Q}_I}$ denotes the expectation under the domestic country's risk-neutral probability measure \mathbb{Q}_I , defined as:

$$\mathbb{Q}_I(s) = \frac{\theta_I(s)}{\theta_I(b) + \theta_I(g)},$$

where $\theta_I(s)$ is the shadow price of the domestic country in state s , and $\theta_I(b)$ and $\theta_I(g)$ are the shadow prices in the bad and good states, respectively.

Proof: See [Appendix A4](#).

In scenarios involving domestic sovereign default, the conventional covered interest rate parity does not hold in our model. This deviation arises due to default risk

⁷Note since we assume the settlement of external debt occurs at the end of the second period, both the intra-period and inter-period interest rates contribute to the external debt yield.

faced by US investors in investing in the domestic fixed-income market. Specifically, US investors can only participate in the domestic asset market through domestic government US dollar bonds, which inherently carry a default risk premium, as shown in proposition [Domestic Country External Debt Price](#). This risk premium, or wedge, is more significant with a higher rate of default or larger haircuts in the event of default.

Such characteristics align with the documented breakdown of covered interest rate parity by [Du and Schreger \(2022a\)](#), attributed to default risk, financial frictions, and intermediary constraints. Corollary 1.1 further indicates the exchange rate dynamic following an anticipated default. When investors anticipate the possibility of default, represented as $E_{\mathbb{Q}_I}[D_{I,s}] < 1$, the domestic currency depreciates in the first period, i.e., the period before the potential default. However, this depreciation is not a permanent effect. The left-hand side of the equation, which represents the expected exchange rate in the second period (the future), suggests an appreciation of the domestic currency. This equation shows that in terms of exchange rate pricing, there exists a fundamental trade-off involving sovereign default. The exchange rate pricing function also links the U.S. pricing kernel to that of the domestic country. The implications of sovereign default on the equilibrium allocation, particularly concerning the domestic pricing kernel, are described in [Government Bond Price and marginal rate of inter-temporal substitution](#).

Corollary 1.2: Government Bond Price and Marginal Rate of Intertemporal Substitution

Suppose $r_I > 0$, $\rho_I > 0$, the difference between the domestic interest rate r_I and the external debt interest rate ρ_I equals the expected value of the marginal rate of intertemporal substitution of U.S. goods

$$\frac{1 + r_I}{1 + \rho_I} = E \left[\beta_I \frac{\frac{U_{c^i_{J,s}}}{p_{J,s}}}{\frac{U_{c^i_{J,0}}}{p_{J,0}}} \right]. \quad (2.18)$$

Proof: See [Appendix A5](#).

Corollary 1.2 characterizes the marginal rate of inter-temporal substitution with U.S. goods as the numeraire. This equation establishes a link between the price of external debt and the real marginal rate of inter-temporal substitution for U.S. goods in the domestic country. It suggests that when the cost of external debt, denoted by ρ_I , increases, domestic households consume less in the first period, invest more, and shift towards future consumption. This provides a direct trade-off channel that the domestic government needs to evaluate when considering debt restructuring with US investors.

2.3.3 Monetary Policy

The asset pricing section describes the fundamental mechanics of how defaults impact financial markets while also emphasizing that pricing functions are inherently determined by the monetary policies of both countries. This naturally leads to a discussion on the role of U.S. monetary policy in shaping these dynamics. It is important for the EMEs government to understand the effects of the US monetary policy spillover effect to design optimal policies.

Proposition 2: Money Non-Neutrality

Suppose $r_J > 0$, and $r_{J,s} > 0$, any change in US monetary policy rate r_J or $r_{J,s}$ results in an equilibrium where both U.S and domestic household consumption change.

Proof: See [Appendix A6](#).

Proposition 2, as outlined above, shows that within our model, changes in the US interest rate have real impacts on domestic output and consumption allocations. This proposition highlights the spillover effect of US monetary policy in shaping EMEs consumption allocations within our two-country framework. These results highlight that our model can capture the global spillover effects of US interest rate shocks, which are in line with the global financial cycle literature that US monetary policy shock is one of the main determinants of the fluctuation in the global financial cycle.⁸

⁸e.g. [Rey \(2015\)](#), [Miranda-Agrippino and Rey \(2020\)](#), and [Miranda-Agrippino and Rey \(2022\)](#)

Corollary 2.1: Monetary Base Connection

Suppose $r_I > 0$, $r_{I,s} > 0$, $r_J > 0$, $r_{J,s} > 0$, the U.S. dollar monetary base and the domestic monetary base are connected through the domestic external debt and foreign exchange markets, formally expressed as

$$\frac{Q_J^i}{1 + \rho_I} + \frac{(M_{I,0} + m_I)}{x_0} = M_{J,0} + m_J. \quad (2.19)$$

Proof: See [Appendix A7](#).

Building on the proposition established in [Money Non-Neutrality](#) regarding the spillover effects of US monetary policy on EMEs, Corollary 2.1 further formalizes this connection by establishing a direct linkage between the monetary bases of the US and the domestic country. This linkage shows that US monetary policy transmits to EMEs through exchange rates and external debt markets. The left-hand side (LHS) represents the total US dollar reserves of the domestic country. It is composed of two parts: the domestic country's monetary base, $M_{I,0} + m_I$, adjusted for the exchange rate, and the US dollars obtained from external debt markets. The right-hand side (RHS), $M_{J,0} + m_J$, represents the monetary base of the US.⁹ This corollary shows that a tightening of US monetary policy induces tighter financial conditions in EMEs due to a reduced inflow Q_J^i of US dollars for investment. Such a contraction would be further amplified in the foreign exchange market because of a decreased supply of US dollars, resulting in a significant appreciation of the US dollar, as indicated by a higher value of x_0 . This dynamic aligns with the observations documented in the global financial cycle literature, which notes that tightening monetary policy shocks in the US tend to trigger capital outflows from EMEs. In addition, a higher risk-neutral probability of default, denoted by $\mathbb{Q}_J(b)$, or a lower repayment rate, denoted by $\gamma_{I,b}$, as outlined in [Domestic Country External Debt Price](#), leads to a lower expected value of external debt as priced by the

⁹When referring to the monetary base in this paper, it implicitly refers to the monetary base involved in the international market.

risk-neutral measure. This, in turn, leads to a further depletion of US dollar reserves in EMEs. This dynamic provides a mechanism through which the spillover effects of US monetary policy are amplified via the channel of sovereign credit risk.

Corollary 2.2: Term-Structure of Interest Rates

Suppose $r_J > 0$ and $r_{J,s} > 0$, the term structure of interest rates holds, which indicates the initial U.S. dollar endowments m_J , are equal to the U.S. central bank's interest rate revenue across periods in the U.S. economy, formally expressed as

$$m_J = M_{J,0}r_J + M_{J,s}r_{J,s}. \quad (2.20)$$

Proof: See [Appendix A8](#).

Extending from [Monetary Base Connection Corollary](#), Corollary 2.2 explores the term structure of interest rates, linking the cumulative Central bank's interest rate revenue across two periods in the US economy to the initial monetary endowment and its implications for EMEs. This corollary establishes a connection between the money supplies of two periods within our model. It demonstrates that a shock to either the inter-period or the intra-period interest rate will affect the money supply in both periods and in the same direction. For example, an increase in the US long-term (inter-period) interest rate, denoted by r_J , will result in a reduction in the money supplies $M_{J,0}$ and $M_{J,s}$. This finding complements the [Monetary Base Connection Corollary](#), which underscores both the forward guidance and the consistent impact of US monetary policy on EMEs. Specifically, the anticipation of a future interest rate hike or the implementation of concurrent tightening monetary policy can result in a shortage of US dollar supply and tighter financial conditions in the foreign exchange market. To understand how this spillover effect on the financial market translates into changes in social welfare, it is essential to examine the impact of these dynamics on consumption allocation.

Corollary 2.3: Demand and Supply of US Dollar

Suppose $r_J > 0$ and $r_{J,s} > 0$, any change in the U.S. monetary base would influence the domestic country's allocation through the demand and supply functions, where

$$p_{J,0}(z_{J,0}^i + c_{J,0}^i) = M_{J,0} + m_J, \quad (2.21)$$

$$p_{J,s}c_{J,s}^i + Q_J^i \gamma_{I,s} = M_{J,s}(1 + r_{J,s}). \quad (2.22)$$

Proof: See [Appendix A9](#).

Corollary 2.3 establishes the connections between US monetary policy and the domestic economy by quantifying its implications for domestic consumption and social welfare trade-offs under tightening US monetary policy. Specifically, it defines a relationship between the demand for and supply of US dollars across both periods. The left-hand side (LHS) quantifies the total demand for US dollars in both periods, while the right-hand side (RHS) represents the total supply of US dollars by US households. This corollary links the [Monetary Base Connection](#) and the [Term-structure of Interest Rates](#) to real-side effects on Emerging Market Economies (EMEs). It shows that a shortage of US dollars in international markets causes depreciation pressure in the foreign exchange market, reducing the volume of imports in real terms. This depreciation diminishes both current consumption and future investment. Furthermore, it underscores the consistent influence of US monetary policy on domestic markets through the supply and demand channel.

2.3.4 Welfare Analysis

In the previous sections, we develop theoretical propositions in our model to show the spillover effects of U.S. monetary policy on the domestic economy, as well as the trade-offs of debt restructuring in terms of consumption allocation and financial markets. In this section, we leverage the welfare techniques described in [Dávila \(2020\)](#) and [Dávila](#)

and Schaab (2022) to evaluate the effects of exogenous policy parameters and debt restructuring on domestic social welfare.

The indirect utility function for the domestic country, denoted as W_I^* , is expressed as $W_I^*(Y_I^*, \Omega)$. In this function, the term Y_I^* includes all endogenous variables at equilibrium, corresponding to the equilibrium state of the internal dynamics of the model. The parameter Ω denotes all the exogenous parameters of the model. In the first period, let $R_{J,0} \equiv 1 + r_J$ be the gross interest rate in the U.S. In the second period, let $R_{J,s} \equiv 1 + r_{J,s}$ be the gross interest rate in the U.S. at state s , where $s \in \{b, g\}$. The change in domestic optimal social welfare with respect to the U.S. interest rate can be characterized by the following proposition.

Proposition 3: Domestic Welfare Assessments: Change in the U.S. Interest Rate

In equilibrium, the normalized change of domestic optimal social welfare W_I^ with respect to the change of U.S. interest rate R_{J,s^*} , with $s^* \in \{0, b, g\}$ could be decomposed as the following two components: direct effect on consumption, and the default penalty adjustment. The decomposition is normalized and expressed as the real value in terms of U.S dollar at $t=0$, where*

$$\frac{\frac{dW_I^*}{dR_{J,s^*}}}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^{i*}}} = \underbrace{\frac{du_{ih|c}^*(s_0^*)}{dR_{J,s^*}} + E_{\mathbb{Q}_I} \left[\beta_I \phi_s^* \frac{du_{ih|c}^*(s_b^*)}{dR_{J,s^*}} \right]}_{\text{Direct Effect on Consumption}} - \underbrace{\frac{1}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^{i*}}} \beta_I \pi_b \chi^g \frac{d\Delta_b^*}{dR_{J,s^*}}}_{\text{Default Penalty}}, \quad (2.23)$$

where ϕ_s^* denotes the ratio of discounted price levels between two periods, defined as $\phi_s^* = (p_{I,s}^*/(1 + r_{I,s})) / p_{I,0}^*$ with $s \in \{b, g\}$. Let Δ_b^* represents the total non-pecuniary default penalty, given by $\Delta_b = (1 - \gamma_{I,b}^*)Q_J^{i*}/p_b^*$. The $du_{ih|c}^*(s_s^*)/dR_{J,s^*}$ denotes the derivative of the total consumption with respect to the interest rate R_{J,s^*} at state s^* ,

with $s^* \in \{0, b, g\}$, where

$$\frac{du_{ih|c}^*(s_s^*)}{dR_{J,s^*}} = \frac{dc_{I,s^*}^{i*}}{dR_{J,s^*}} + \frac{\frac{\partial u_s^{i*}}{\partial c_{J,s^*}^{i*}}}{\frac{\partial u_s^{i*}}{\partial c_{I,s^*}^{i*}}} \frac{dc_{J,s^*}^{i*}}{dR_{J,s^*}}.$$

In equation (2.23), the U.S. interest rate directly affects domestic consumption of goods. The direct effect on the consumption term consists of two components: the impact on first-period consumption, $dc_{I,s^*}^{i*}/dR_{J,s^*}$, and the expected change in consumption under the risk-neutral measure $E_{\mathbb{Q}_T}$, adjusted for the inter-temporal price change ϕ_s . As outlined in Corollary [Demand and Supply of US Dollar](#), an increase in the U.S. interest rate, $r_{J,b}$, during a bad state leads to a reduction in the monetary base in both periods. This reduction, in turn, lowers the level of domestic consumption under adverse conditions, denoted as $c_{J,b}^i$. Furthermore, [Term-structure of Interest Rates](#) indicates that the anticipation of a more volatile interest rate in the subsequent period reduces the supply of U.S. money invested in the foreign exchange market in the first period, which directly decreases first-period consumption.

The hike in U.S. interest rates further impacts domestic social welfare through the external debt market. According to [Domestic Country External Debt Price](#), the higher level of U.S. interest rates increases the external debt cost ρ_I . The higher external debt cost enhances the incentive for the domestic government to reduce the repayment level and engage in restructuring with U.S. investors. This induces a direct increase in the total non-pecuniary default penalty Δ_b , which reduces social welfare.

While [Proposition 3](#) analyses the direct effect of U.S. monetary policy on social welfare, it doesn't illustrate the indirect interactions between endogenous variables that affect domestic social welfare. To understand the indirect effect of a U.S. interest rate shock and the external debt default effect on the equilibrium and the trade-off, we could further decompose social welfare into four components with economic meanings. In [Proposition 4](#), we analyse the trade-off effects associated with sovereign default by examining the impact of a higher default penalty term and U.S. interest rates on the

optimal level of social utility.

Proposition 4: Default Penalty and Social Welfare:

In equilibrium, the normalized change of domestic optimal social welfare W_I^ with respect to the change of default penalty term χ^{g*} could be decomposed into four components: Direct Foreign Import Change, Real Debt Default Adjustment, Real Import Expenditure Adjustment, and Default Penalty Term Adjustment. The decomposition is normalized and expressed as the real value in terms of U.S dollar at $t=0$:*

$$\begin{aligned}
\frac{\frac{dW_I^*}{d\chi^{g*}}}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^{i*}}} &= \underbrace{\text{MRS}_0^* \frac{d(c_{J,0}^{i*} + Z_{J,0}^{i*})}{d\chi^{g*}} + E_{Q_I} \left[\phi_s^* \text{MRS}_s^* \frac{dc_{J,s}^{i*}}{d\chi^{g*}} \right]}_{\text{Direct Foreign Import Change}} \\
&+ \underbrace{E_{Q_I} \left[\frac{d \left(\frac{x_0^* Q_J^{i*}}{(1+\rho_I^*) p_{I,0}^*} - \frac{\phi_s^* Q_J^{i*} \gamma_{I,s}^* x_s^*}{p_{I,s}^*} \right)}{d\chi^{g*}} \right]}_{\text{Real Debt Default Adjustment}} \\
&- \underbrace{E_{Q_I} \left[\frac{d \left(\frac{x_0^* p_{J,0}^* (c_{J,0}^{i*} + Z_{J,0}^{i*})}{p_{I,0}^*} + \frac{\phi_s^* x_s^* p_{J,s}^* (c_{J,s}^{i*})}{p_{I,s}^*} \right)}{d\chi^{g*}} \right]}_{\text{Real Import Expenditure Adjustment}} \\
&- \underbrace{\frac{1}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^{i*}}} \beta_I \pi_b \frac{d\chi^g \Delta_b^*}{d\chi^{g*}}}_{\text{Direct Default Penalty Adjustment}},
\end{aligned}$$

where $\text{MRS}_{s^*}^*$ denotes the marginal rate of substitution at time s^* $\text{MRS}_{s^*}^* = \frac{\partial u_{s^*}^{i*}}{\partial c_{J,s^*}^{i*}} / \frac{\partial u_{s^*}^{i*}}{\partial c_{I,s^*}^{i*}}$ with $s^* \in \{0, b, g\}$.

Proof: See [Appendix A10](#).

Proposition 4 shows the decomposition of the response of optimal domestic social welfare W_I^* to the changes in the default penalty parameter χ^{g*} . Please note that this decomposition is generalized, allowing us to decompose the effects of other policy changes on social welfare, including U.S. interest rates, using the same four components.

The first component represents the Direct Foreign Import Change. The Direct Foreign Import Change captures the immediate change of goods consumption and investment in response to policy change in the domestic country, adjusted by the marginal rate of substitution (MRS) across different periods. It quantifies how policy changes directly influence consumption allocations and investment decisions within the economy.

The second component denotes the Real Debt Default Adjustment. The expression reflects the adjustments in the expected real value of debt due to policy shifts. It highlights how policy adjustments can affect the economy's real debt burden and its default risk.

The third is the Adjustment in Real Import Expenditure. The Adjustment in Real Import Expenditure component captures the impact of policy changes on the valuation and affordability of imports. This component shows how policy shifts may increase the valuation of imports, changing affordability for domestic producers. Specifically, it shows the aggregate cost in U.S. dollars necessary to fund the volume of aggregate imports.

The fourth component is the same as the second term in [Propositions 3](#), which denotes the effect of Default Penalty Term Adjustment on social welfare. The term delineates the adjustment in the default penalty mechanism in response to a policy change. This term represents the interaction between default penalty and strategic default decisions of the economy, underlining the resulting changes in social welfare.

In our model, the trade-off involved in the default choice could be understood by analysing the decomposition. A lower default penalty term χ^g broadens the space for default, leading to significant adjustments in debt default levels $1 - \gamma_{I,b}$, which, paradoxically, can benefit the overall economy through a debt burden relief mechanism. In particular, a lower repayment rate, represented by $\gamma_{I,s}^*$, would directly decrease the debt burden in the second period in real terms $Q_J^* \gamma_{I,s}^* x_s^* / p_{I,s}^*$. This would lead to a higher real debt default adjustment, indicating a debt burden relief. As demonstrated

in Corollary [Demand and Supply of U.S. Dollar](#), this relief subsequently enhances the capacity for foreign consumption. The effect on social welfare is particularly pronounced during economic recessions when the marginal utility of consumption is high.

However, a higher default rate generates costs through exchange rate volatility and increased external debt costs. As illustrated in [Domestic Country External Debt Price](#), a higher default rate raises external debt costs. The higher external debt costs lead to a decline in the real value of government bonds at $t = 0$, reducing the Real Debt Default Adjustment. Moreover, [Covered Interest Rate Parity and Wedge](#) suggests that the domestic currency will depreciate, particularly in the first period, implying an increase in the real import expenditure of domestic households. Finally, domestic social welfare is further adversely affected by a higher default penalty.

2.4 Calibration Results

In this section, we apply a numerical analysis to evaluate the implications of our theoretical model. We explore how productivity shocks and U.S. interest rates influence the economic dynamics of Emerging Market Economies (EMEs) under different default regimes.

We choose the 2020 Argentina sovereign default as our base case for calibration. Since the 1990s, among the LAC-7 (Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela) countries, Argentina defaults the most times and experiences different exchange rate regimes and fiscal regimes during this period and accordingly could provide us the most insights regarding the sovereign default. The period unit is a quarter. We calibrate our model in two regimes: moderate lambda default penalty and infinity lambda default penalty. According to the [Default On-the-Verge Condition](#), the infinite default penalty ensures that no default occurs in the bad state since the cost of default is always higher than the benefits. We calibrate parameters to match the macroeconomic indicators in Argentina for the second quarter, 2019(2019Q2). The second quarter of

2019 was the last quarter before the public realized there would be a sovereign default in Argentina.¹⁰

2.4.1 Calibration of Model Parameters

We calibrate the exogenous parameter space to match empirical data and past literature. We set the policy rates of the two countries in the model with the respective policy rates of Argentina and the U.S. The one-year CDS spread for Argentina at the end of Q2 2019 stood at 1100 bps, implying a risk-neutral probability of default of 0.2.¹¹ Furthermore, we set the outside money of the domestic country at 10 and calibrate the outside money endowment of the US that is in trade with Argentina, to match the nominal exchange rate at 43 pesos per dollar. Assuming Argentina's goods endowment is 1, we calibrate the endowment of U.S households to match the external debt as a percentage of GDP. Applying the Cobb-Douglas utility function, the preference parameter, approximately equal to imports as a percentage of GDP, is set at 0.18. The subjective discount factor follows the choice in [Mendoza and Yue \(2012\)](#). The default penalty parameter χ^g for the moderate case is calibrated to reflect the restructuring agreement between the Argentine government and its creditors at 55%. For the base case, we select a substitution parameter ν of 2, following [Uribe and Schmitt-Grohé \(2017\)](#). Moreover, the coefficient of relative risk aversion σ is set at 2, a value commonly used in standard Real Business Cycle and default analysis models (e.g., [Mendoza and Yue \(2012\)](#)).

¹⁰The CDS spread of Argentina's one-year sovereign bond reached more than 10,000 bps during the third quarter in 2019, which implies a default probability higher than 0.8.

¹¹We assume a recovery rate of 0.4, a standard value for calculating the probability of default, as documented by [Hull et al. \(2012\)](#).

Table 2.1: Calibration and Target Values of Model Parameters

Parameters	Calibration Value	Target Value
Substitution parameter	$\nu^i = \nu^j = 2$	Uribe and Schmitt-Grohé (2017)
Risk aversion degree	$\sigma^i = \sigma^j = 2$	Na et al. (2018)
Share parameter	$\iota^i = 0.8167$	Argentina Import as Percentage of GDP
	$\iota^j = 0.18$	Argentina Export as Percentage of GDP
Prob. of states	$\pi_b = 0.2, \pi_g = 0.8$	Default probability implied from CDS
Discount factor	$\beta_I = 0.85, \beta_J = 0.9950$	Na et al. (2018)
Endowment	$e_I = 1, e_J = 5.8963$	External debt as percentage of GDP
Bankruptcy code	Regime1 $\chi^g = 0.4881$	Recovery
	Regime2 $\chi^g = \infty$	
Outside Money	$m_I = 10, m_J = 0.0142$	Nominal Exchange Rate
Policy rate	$r_I = r_{I,g} = 0.13, r_{I,b} = 0.115$	Argentina Policy Rate(APR)
	$r_J = r_{J,g} = 0.006, r_{J,b} = 0.005$	Federal Funds Rate(FFR)
Total Factor Productivity	$A_J = 1, A_{I,b} = 0.4, A_{I,g} = 0.81$	Feenstra et al. (2015)

2.4.2 Productivity Shock

Figure 2.3, Figure 2.4, and Figure 2.5 plot the numerical solution for the equilibrium as a function of the productivity level at bad state. The numerical solution illustrates how a negative TFP shock affects the domestic economy and how default in a bad state could potentially hedge such shock by increasing social welfare.

The horizontal axis represents the value of the productivity level in the bad state, $A_{I,b}$, for the domestic country. The further to the right, the higher the productivity level. In our calibration case, the productivity level ranges from 0.4 to 0.81, with the largest value, 0.81, equating to the productivity level in a good state, indicating a scenario with no productivity shock. The lower level of productivity at bad state can be attributed to a higher productivity shock occurring in the second period. The vertical axis represents the values of the endogenous variables corresponding to the titles of the figures.

The black solid line shows the numerical solutions with a moderate default penalty,

indicating that sovereign default is allowed, while the black dashed line represents the numerical solutions with an infinite default penalty, indicating a regime where default is not permitted.

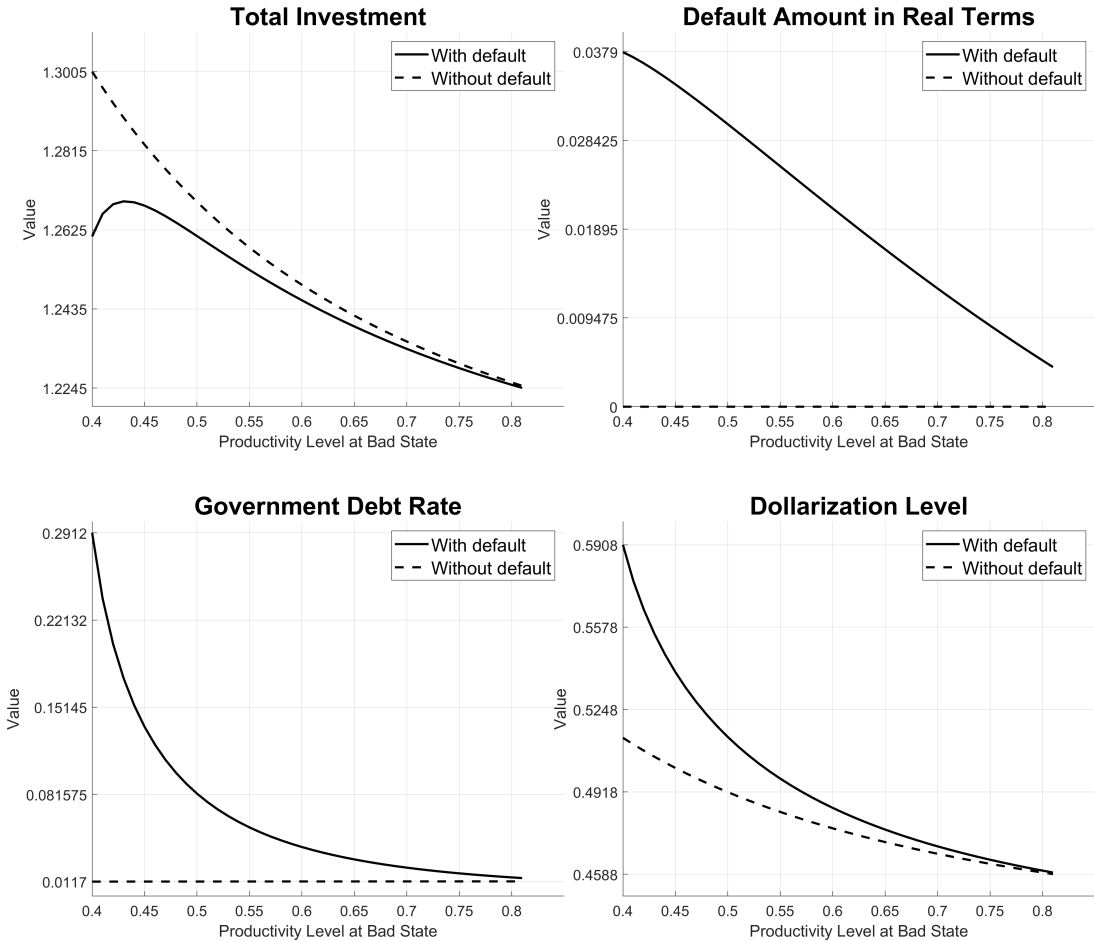


Figure 2.3: Investment and Government External Debt as a Function of Bad State Productivity Level

According to Figure 2.3, for both regimes, a low productivity level in a bad state decreases the expected value of productivity and increases the volatility of the economy in the second period. This decrease in TFP generates a higher marginal utility in consumption at the bad state, leading to a greater incentive for domestic households to invest in production factors denominated in US dollars in the first period. Furthermore, as discussed in Remark on Elasticity of Substitution, the substitution relationship be-

tween domestic and foreign goods leads to a higher demand for foreign goods in the bad state because of a shortage of domestic goods¹². These factors contribute to an increased level of dollarization in the domestic economy, defined as the proportion of US dollar debt to total debt.

If default is not allowed, the increased demand for dollars from the higher demand for imports and external debt would generate depreciation pressure on the domestic currency. These depreciation pressures are persistent across periods, as illustrated in Figure 2.4. This observation aligns with **Monetary Base Connection**, which claims that higher demand for the U.S. dollar and the external debt in the first period increases the exchange rate x_0, x_b , and x_g . The permanent exchange rate depreciation in the second period, as shown in the figure, is supported by the theoretical proposition presented in Corollary **Covered Interest Rate Parity and Wedge**. This permanent depreciation of the domestic currency, in turn, exacerbates the impact of productivity shocks on the domestic economy, as evidenced by a sharp decrease in domestic consumption in the bad state, illustrated in Figure 2.5. Figure 2.5 highlights the numerical evidence that currency depreciation and increased external debt pressure tighten the domestic country’s room to import foreign goods. As a result, this reduction limits the domestic country’s ability to hedge utility loss from domestic productivity shock.

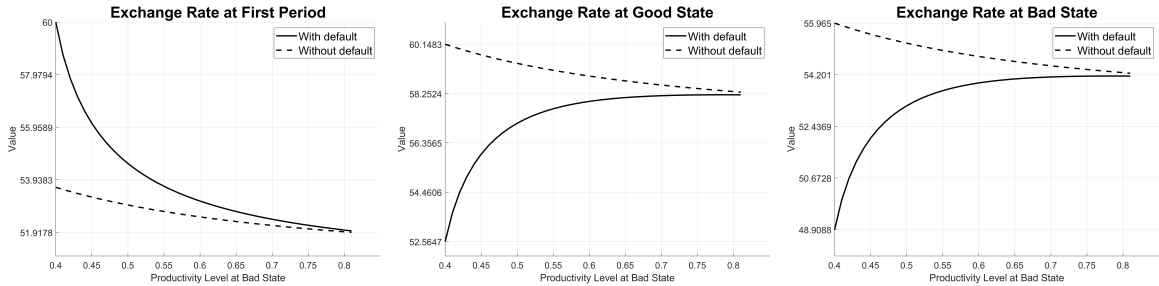


Figure 2.4: Exchange Rate Dynamics as a Function of Bad State Productivity Level

If the default penalty is not strict and default in a bad state is permitted, restructuring with creditors can help the domestic country hedge against a negative TFP

¹²In Appendix C we show how substitution between domestic and foreign goods affects the results and contributes to the discussion of the transfer paradox.

shock. First, as shown in [Demand and Supply of US Dollar](#), default can partially relieve the burden of high debt during unfavorable economic conditions. As the productivity level declines in adverse economic conditions, both the state price and exchange rate are expected to rise, thus increasing the government's incentive to impose haircuts on sovereign default, which is indicated in [Default on the Verge Condition](#). The moderate default penalty level allows the domestic government to default when experiencing a negative shock. This, in turn, increases the total capacity for external debt in the initial period, as documented in [Figure 2.3](#).

Second, a decrease in the demand for the US dollar results in an appreciation of the domestic currency in the second period, as depicted in [Figure 2.4](#). [Demand and Supply of US Dollar](#) explains that this appreciation occurs due to reduced demand for US dollars to repay external debt. Moreover, the appreciation of the exchange rate in the second period is accompanied by a relatively minor depreciation of the exchange rate in the first period, as supported by the [Covered Interest Rate Parity and Wedge](#) and numerical solutions. Therefore, we argue that domestic currency depreciation occurs before the default happens. This finding contradicts existing literature, which often finds that the default decision further decreases the value of the domestic currency. In our model, the depreciation comes about due to the rational expectation of a negative productivity shock and the associated increased hedging demand. Default choice can be understood as a fiscal policy implemented by the domestic government to smooth the exchange rate and, correspondingly, the social welfare of the domestic economy.

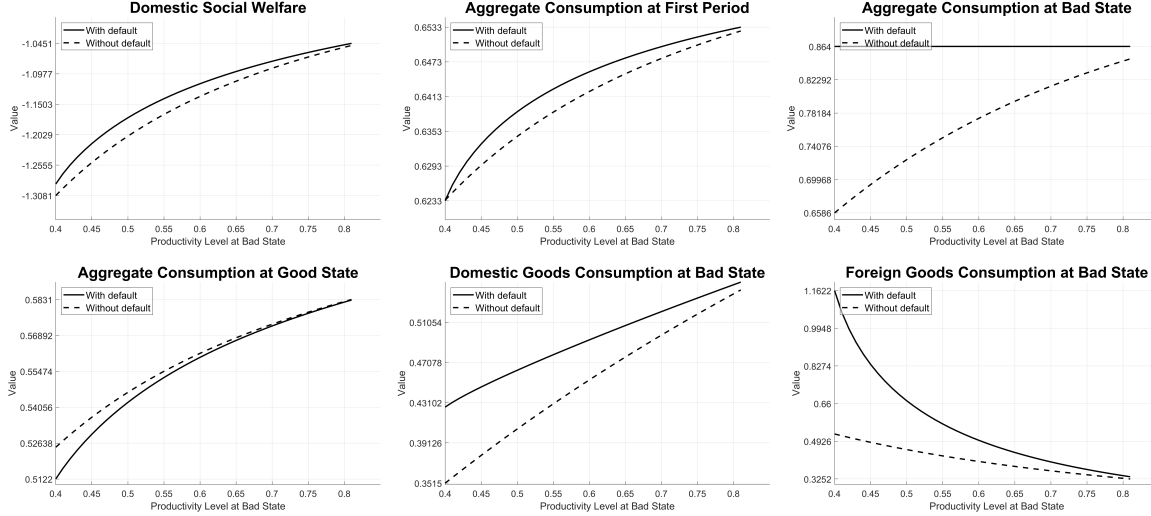


Figure 2.5: Welfare and Consumption Allocations as a Function of Bad State Productivity Level

The stabilization of the exchange rate and the reduction of the domestic debt burden highlight the insurance effect of the default option, which is also directly reflected in consumption allocations. If there is a substantial shock to productivity, domestic social welfare would experience a significant increase compared to the no-default scenario. As depicted in Figure 2.5, a haircut on sovereign bonds would enhance the ability of domestic households to purchase imports for consumption. This, in turn, softened the losses from domestic goods and therefore offered a smoother consumption level in aggregate across states in the second period. Furthermore, the first-period consumption is expected to be higher due to the “income effect” generated by sovereign default.

However, the default option is not costless. The choice to restructure raises the price of external debt borrowing, as supported by the **Domestic Country External Debt Price** Proposition. Consequently, both total first-period investment and debt decline due to the higher cost of borrowing. Under favorable economic conditions, the consumption of domestic goods declines marginally compared to the no-default case due to the higher demand for U.S. dollars to repay external debt.

This static comparative study analyses the effect of a TFP shock in a bad state on

the domestic economy and points out the importance of default decisions in hedging the TFP shock. Our results illustrate the complex nature of default decisions and show that they can be a powerful tool for the government to stabilize exchange rates and alleviate the burden of high debt when productivity is expected to be low. Moreover, we stress the interaction between currency depreciation, external debt obligations, and default decisions, as it dramatically affects consumption allocation and domestic social welfare. In the next section, we will analyse how the size of haircuts matters for social welfare.

2.4.3 Default Penalty

In this section, we discuss endogenous trade-offs involved in sovereign default decisions. The **Default On-the-Verge Condition** implies that the lower the penalty for default, represented by χ^g , which captures the sanctions by international organizations and U.S. creditors, the greater the flexibility in default decisions and the lower the optimal repayment rate. It further shows that the effect of penalty χ^g enters our optimal equilibrium only through the choice of external debt default and the repayment rate. Therefore, static comparative analyses on the default penalty variable provide a useful tool to evaluate the costs and benefits of default decisions for the domestic economy.

The figures below, Figure 2.6, Figure 2.7, and Figure 2.8, present comparative static analyses with respect to the default penalty for each increment of 0.01 unit. The default penalty term spans from 1.47 to 2.55, corresponding to a repayment rate ranging from around 0.5 to 1. In these figures, both the social welfare and its respective derivatives are normalized by dividing by the social welfare in the no-default scenario, which is utilized as the benchmark for this analysis. The value of the derivatives is interpreted as the percentage change in the corresponding component resulting from a one-increment change in the default penalty term χ^g . When interpreting the figures from right to left, the negative values of points on the line illustrate how the corresponding component changes with a smaller default penalty term, corresponding to a higher default amount

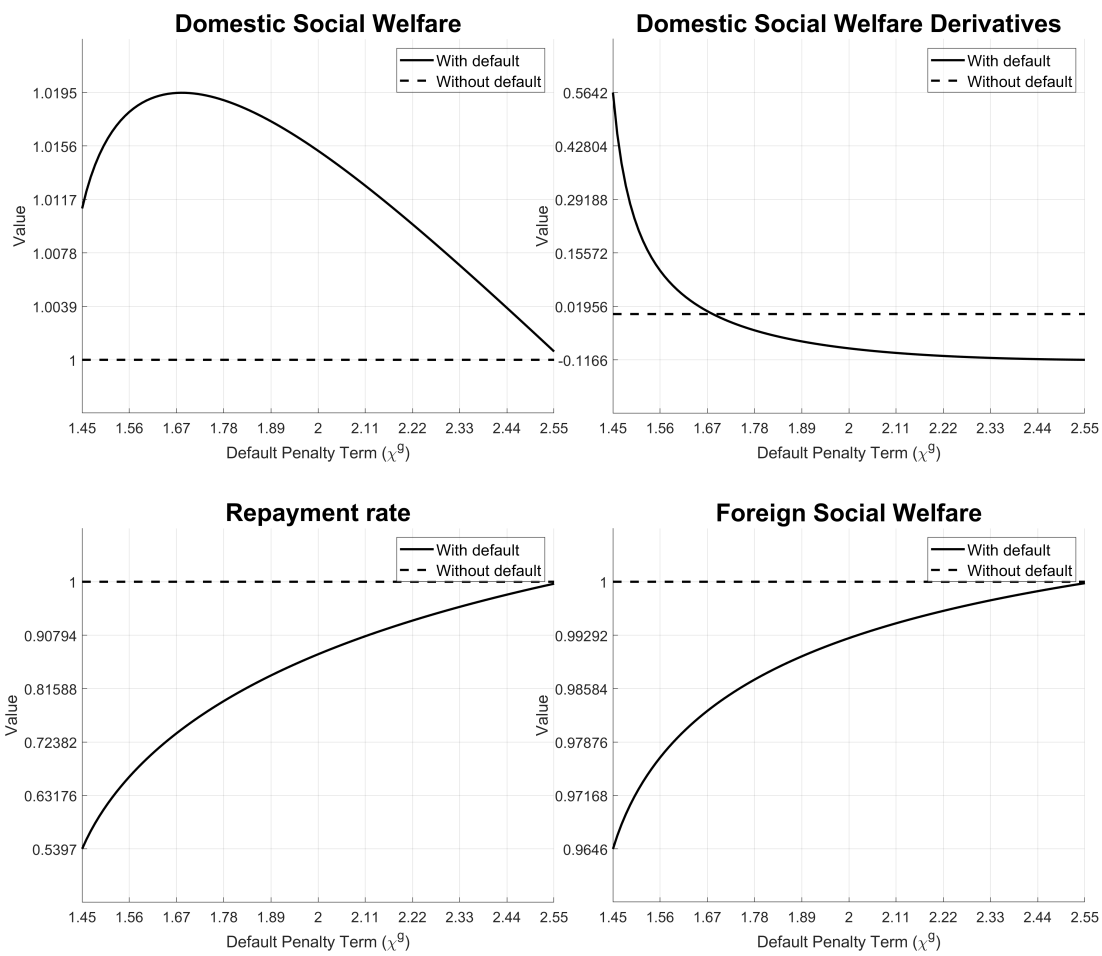


Figure 2.6: Welfare and Repayment Rate Change to Default Penalty Term

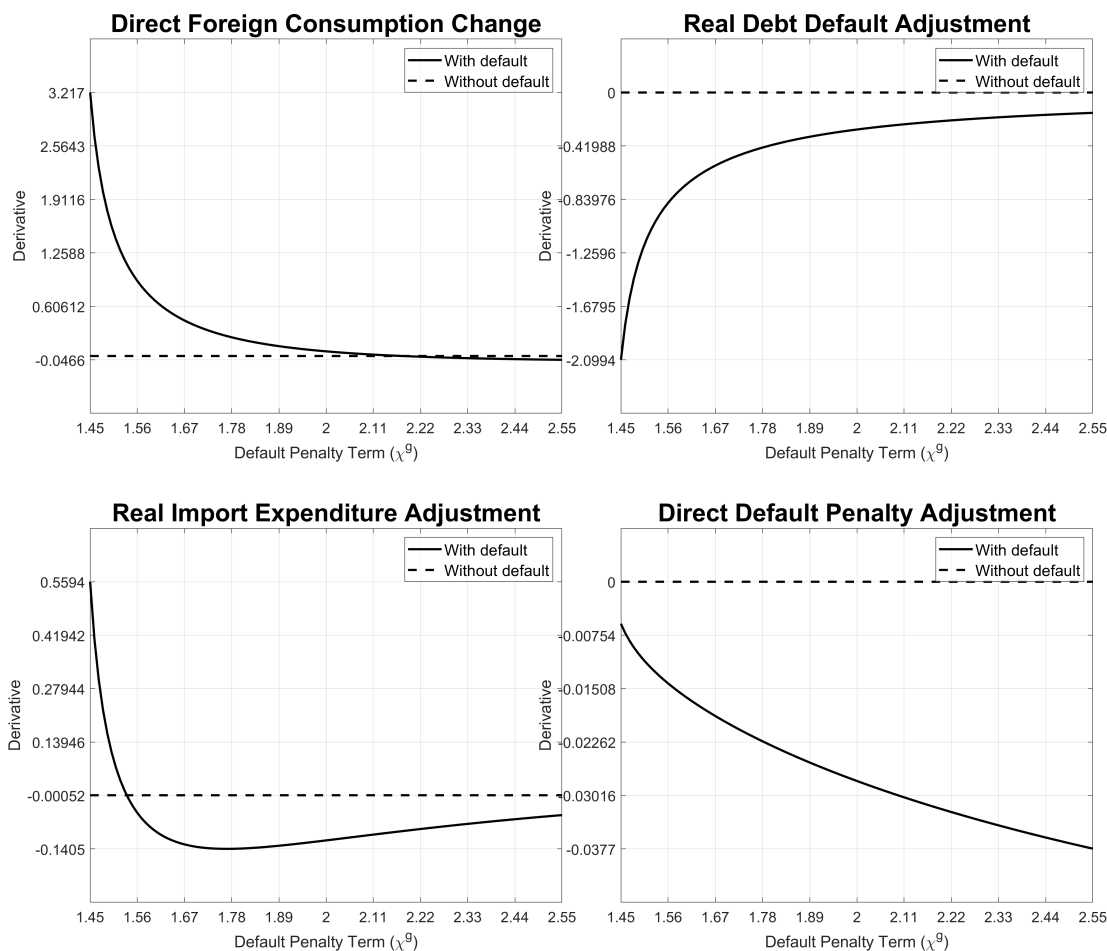


Figure 2.7: Welfare Change Decomposition to Default Penalty Term

As shown in Figure 2.6, consistent with the **Default On-the-Verge Condition**, the repayment rate monotonically increases and has a concave relationship with the default penalty term. However, domestic social welfare does not display a consistent trend with the repayment rate. It increases first with the default penalty term when this term is at a low threshold but then decreases as the extent of the default penalty term increases. This pattern demonstrates that an optimal moderate level of default penalty and repayment exists in the equilibrium, showing the trade-off effect and implying that default is not necessarily harmful to the domestic economy. This also suggests

that international organizations may help the EMEs by calibrating the default penalty term.

According to the decomposition equation in [Proposition 4](#), changes in social welfare driven by differences in default penalties can be decomposed into four terms, each with distinct economic implications, as shown in [Figure 2.7](#).

One key component is the Direct Foreign Import change, which measures the marginal change in the consumption and investment of U.S. goods adjusted by their relative price. As demonstrated in [Figure 2.7](#), a lower default penalty term and a higher default amount are initially associated with a marginal positive change in Direct Foreign Imports, which then slightly decreases to negative when the default penalty term falls below a certain threshold.

The direct channel affecting the consumption of foreign goods is illustrated by the [Default On-the-Verge Condition](#), which indicates that a lower default penalty term reduces the marginal cost of default and induces a higher marginal utility of foreign consumption in bad state in equilibrium. The higher marginal utility results in a higher consumption of foreign goods in the bad state. On the other hand, the reduced commitment to repayment caused by a lower default penalty increases the cost of external debt, as shown in [Domestic Country External Debt Price](#). This, in turn, raises the real cost of consuming foreign goods in the first period and during good states, thus reducing direct investment and consumption of foreign goods. When the effect of higher external debt costs dominates, a higher default rate results in decreased real-term consumption of foreign goods.

The second term, referred to as the Real Debt Default Adjustment, captures the relief in the debt burden provided by the choice to default. A negative value, as shown in [Figure 2.7](#), indicates a greater reduction in the real debt burden due to a higher default rate. When the default penalty is less severe and the optimal default rate for the domestic country increases, the extent of relief from the real debt burden becomes

more significant.

The third term, defined as the Real Import Expenditure Adjustment, reflects the marginal change in the total US dollars spent to purchase imports from the US. This expenditure is equivalent to the aggregate demand for the US dollar, spanning across different periods for consumption purposes. A higher level of default can lead to reduced demand in bad states, thus diminishing the overall demand in the second period. Nonetheless, an increase in external debt escalates the cost in US dollars for purchasing foreign goods in the first period. This relationship is elucidated in [Corollary 3.3](#), which delineates the shift in demand across periods. The final term is the direct default penalty adjustment, which is the direct default penalty captured by the default penalty term after normalized by the marginal utility of the first period. Clearly, a higher level of repayment rate would lead to a lower level of default penalty.

In summary, when the default penalty χ^g is reduced from an extremely strict level to a moderate one, and the default rate gradually increases from 0 to an intermediate level, relief from the real debt burden becomes the dominant factor driving changes in domestic social welfare. The insurance effect of default in the second period is of a similar magnitude to the reduction of consumption experienced in the first period. However, beyond a certain threshold, further relaxation of the default penalty and a higher default rate cause the direct change in consumption to outweigh the other three effects. In this scenario, the decrease in consumption during the first period becomes the primary driver of social welfare, highlighting that the anticipation of default and a disorderly default rate can lead to a significant reduction in current-period consumption. This mechanism clearly illustrates the trade-offs faced by the domestic country in its decision to default, relative to overall economic conditions.

Finally, we discuss how restructuring impacts exchange rate fluctuations. As demonstrated in [Covered Interest Rate Parity and Wedge](#), a government default disrupts the Covered Interest Rate Parity (CIP): there is a wedge in the CIP for the

exchange rate pricing to reflect credit and market risks. Given the potential for future defaults, the current period’s exchange rate is likely to decline, followed by an appreciation in the subsequent period, as illustrated in Figure 2.8. These exchange rate fluctuations complement the welfare change analysis, indicating that the depreciation of the domestic currency raises the cost of foreign goods consumption in the first period, whereas an appreciation trend induces an income effect in the second period and shifts the demand for consumption curve upward. This sequential adjustment leads to a reduction in social welfare in the first period and an enhancement in welfare in both states during the subsequent period. This discussion connects the direct effects of sovereign default and market dynamics on exchange rates with their broader implications for social welfare in EMEs.

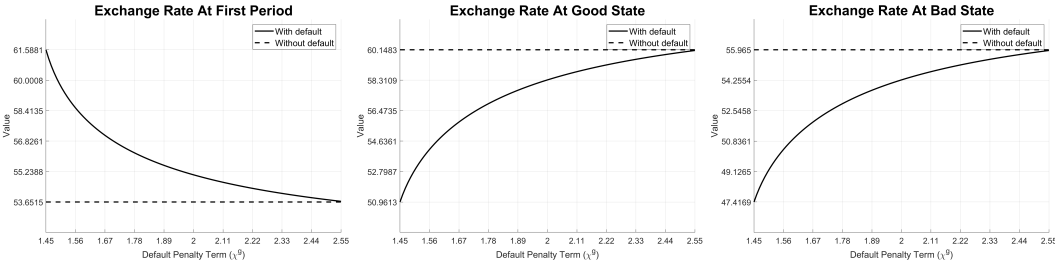


Figure 2.8: Exchange Rate Dynamics to Default Penalty Term

2.4.4 U.S. Interest Rate

Building on our analysis of the direct impacts of government external debt default on social utility and macroeconomic indicators, we further investigate the effectiveness of default policies in the context of tightening US monetary policy. To link our model with the existing literature (Kalemli-Özcan, 2019), which suggests that domestic economies usually follow U.S. monetary policy, we calibrate our model by assuming two additional cases: the domestic interest rate increases at the same rate as the U.S. rate and increases at twice the U.S. rate. The third scenario aligns with empirical results documented by Kalemli-Özcan (2019). Figure 2.9 shows how domestic social welfare changes when the domestic government implements different policy strategies to hedge against the

U.S. shock. The horizontal axis represents the U.S. interest rate level, and the Y-axis represents social welfare normalized by the benchmark case, i.e., the no-shock case. The red line with square dots represents the case where the domestic country increases the domestic interest rate twice more than the U.S. interest rate, while the blue line with triangle dots represents the one-to-one match scenario.

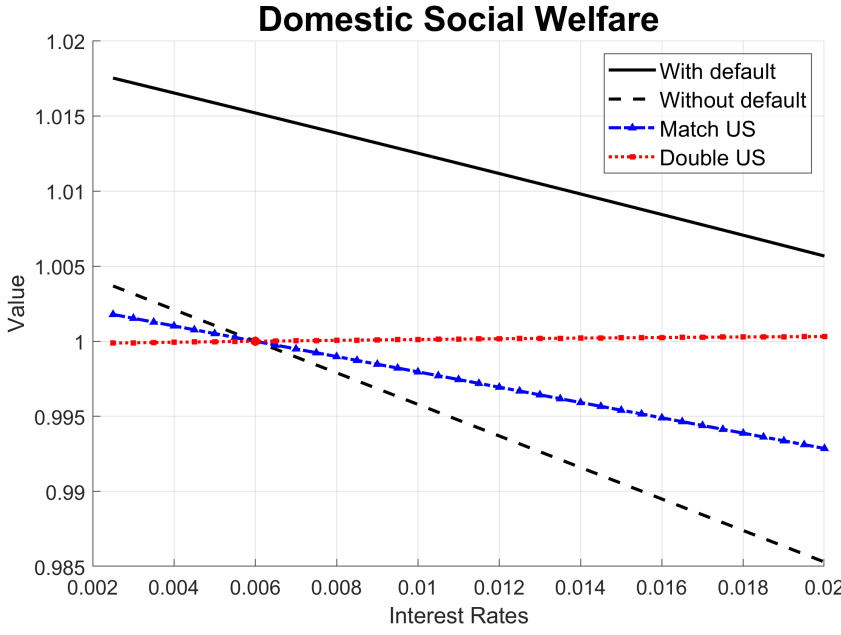


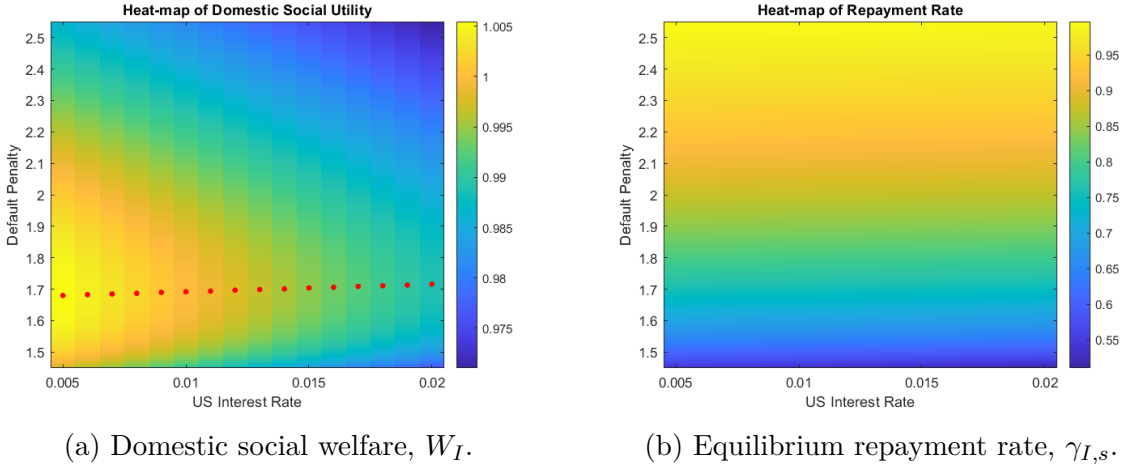
Figure 2.9: Domestic Social Welfare Response to US Monetary Policy Shocks under Different Government Policies

The results indicate that a one-to-one match is insufficient to hedge against the shock. Although doubling the increase almost perfectly hedges the shock, stabilizes the exchange rate, it suggests an excessive rise in the domestic interest rate, resulting in a lack of autonomy and an inability to shield the domestic economy from a large productivity shock. This result indicates raising domestic policy rate to hedge foreign shock remains a blunt, poorly targeted instrument when the sovereign’s liabilities are largely denominated in U.S. dollars. Our model captures two mechanisms that undermine its effectiveness. First, a higher domestic interest rate, r_I , raises the cost of inter- and intra-period loans that finance domestic investment; the tighter cash-in-advance (CIA) constraint shifts resources away from productive uses toward liquidity hoarding,

reducing total domestic output. Second, as shown in Proposition [Covered Interest Rate Parity and Wedge](#), covered interest rate parity breaks down in the presence of default risk. In this case, even large hikes in the local-currency policy rate do not fully compress the sovereign credit spread, leaving external debt costs—and thus exchange-rate pressure—largely intact. By contrast, debt restructuring can outperform interest-rate hedging under a moderate default-penalty regime. To understand why default might be an effective tool for hedging monetary-policy spillovers, we next explore default policies in the context of U.S. monetary tightening.

Linking U.S. Rate Hikes to Sovereign Default

In this section, we calibrate the long-term inter-period US interest rates to simulate scenarios where EMEs face a long-term international financial tightening shock. We test the spillover effects of US monetary policy shocks on EMEs and understand how EMEs react to external monetary disturbances, thereby enhancing the coherence of our analysis by connecting domestic default reactions to global financial conditions.



Both panels plot the equilibrium outcomes over two dimensions: the U.S. policy rate on the horizontal axis and the default-penalty parameter χ^g on the vertical axis (*higher* $\chi^g \rightarrow$ less default). The two subfigures report the optimal domestic social welfare(left) and optimal repayment rate(right) in equilibrium for each (i^*, χ^g) pair. The Red dots track the welfare-maximising default-penalty level for each US-interest-rate value.

Figure 2.10: Trade-off Between U.S. Monetary Tightening and Default Penalties

Figure 2.10 presents two heat-maps that plot equilibrium outcomes over the U.S.

policy rate i^* on the horizontal axis and the default-penalty parameter χ^g on the vertical axis. The figure illustrates how an appropriately calibrated sovereign haircut can hedge the domestic economy from U.S. monetary policy shocks.

First, along the ridge marked by the red dots, the welfare loss triggered by a higher i^* is largely offset by a partial default. A rise in i^* raises external borrowing costs and strengthens the dollar, which lowers domestic consumption. A moderate haircut, however, reduces the real burden of foreign-currency liabilities and curbs the resulting exchange-rate depreciation, increasing the domestic social welfare, as discussed in [default analysis section](#).

Second, for any fixed i^* , domestic welfare is non-monotonic in χ^g . When χ^g is very low the planner selects a low repayment rate, risk premia hike, default cost increase, and in turn reduces social welfare. When χ^g is very high, the default is ruled out from the equilibrium, the dollar-debt overhang remains, and welfare decreases. Between these extremes lies a well-defined interior region, highlighted by the red dots, where a repayment rate of roughly 40% to 60% maximises welfare by balancing the insurance benefit of restructuring against the penalty cost of default.

These findings support the policy implications that sovereign-debt frameworks should promote timely, rules-based restructurings. A moderate haircut is not simply a last-resort measure; it is a key instrument for shielding emerging markets from global financial-cycle shocks. To clarify the mechanism through which default hedges U.S. monetary-policy shocks, we complement the heat-map evidence with a welfare-decomposition exercise based on a static analysis.

US Interest Rate and Sovereign Default: Welfare Decomposition Analysis

The figures below—Figure 2.11, Figure 2.12, and Figure 2.13—document the effects of U.S. monetary policy on the domestic economy for each 25 bps increase in the U.S. interest rate. The quarterly U.S. interest rate ranges from 0.01 (annualized) to 0.08,

with intervals of 25 bps. As in the calculations presented in the default penalty sections, both the social welfare and its respective derivatives in these figures are normalized by dividing them by the social welfare in the no-default scenario for the 0.02 interest rate case, which serves as the benchmark for this analysis. The value of the derivatives represents the percentage change in the corresponding component resulting from a 25 bps change in the long-term U.S. interest rate.

Figure 2.11 below depicts the variation in total social welfare in response to changes in the US inter-period interest rate, comparing scenarios with and without default. These calibration results are consistent with the **Money Non-Neutrality** proposition, demonstrating that fluctuations in the US interest rate have significant spillover effects on EME, affecting their consumption allocations: an increase in the US interest rate leads to a monotonic reduction in domestic social welfare.

This trend is explained by the **Monetary Base Connection** and **US Demand and Supply Connection** propositions, which show that a tightening of U.S. monetary policy creates a shortage in the supply of U.S. dollars. The shortage thus created then devalues EME currencies and tightens budget constraints faced by households in EMEs, leading to less consumption in the first period. According to the **Term-Structure of Interest Rates**, the rise in the long-term interest rate further decreases the money supply in the second period. The decline in monetary supply means that EMEs will consume less of the foreign goods in the second period, resulting in a permanent decline in consumption. These dynamics have underlined the complicated interrelationship between U.S. monetary policy and its global effects on economic welfare and consumption patterns in EMEs.

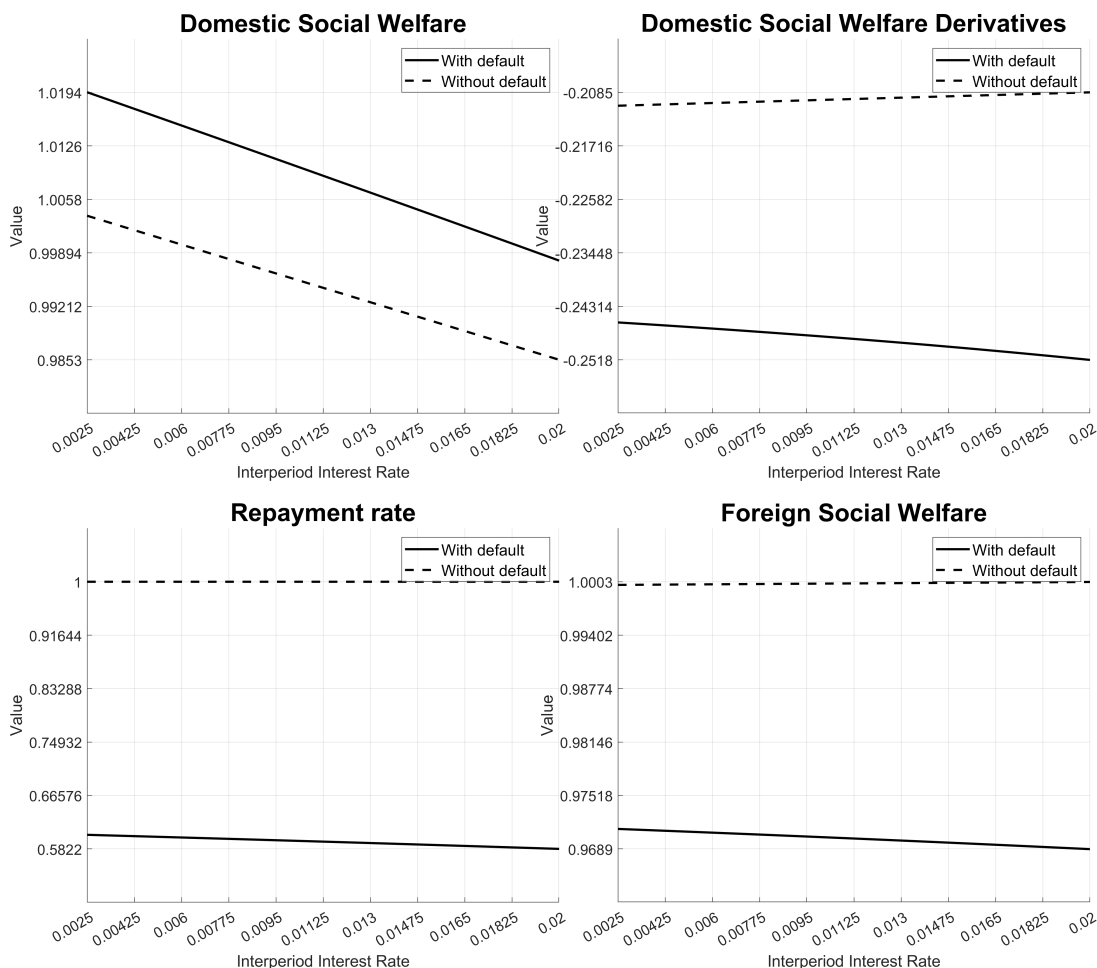


Figure 2.11: Welfare and repayment rate change with respect to Inter-period Interest Rate

The key observation is that allowing sovereign default, even though it results in social welfare being a monotonically decreasing function of the U.S. interest rate, can improve the position of domestic households relative to the case without default. For example, if the annual U.S. interest rate were to rise from 2% to 5.5%, as during the Federal Reserve rate hikes between 2022 and 2023, domestic social welfare would fall by about 1% without default. However, with a mild penalty for default and an orderly default, welfare could return to normal levels. This suggests that the prospect of future default may mitigate the negative effects of U.S. monetary policy shocks, potentially restoring or even increasing social welfare. The option to default could, therefore, act

as a form of insurance against the adverse impact of U.S. monetary policy changes.

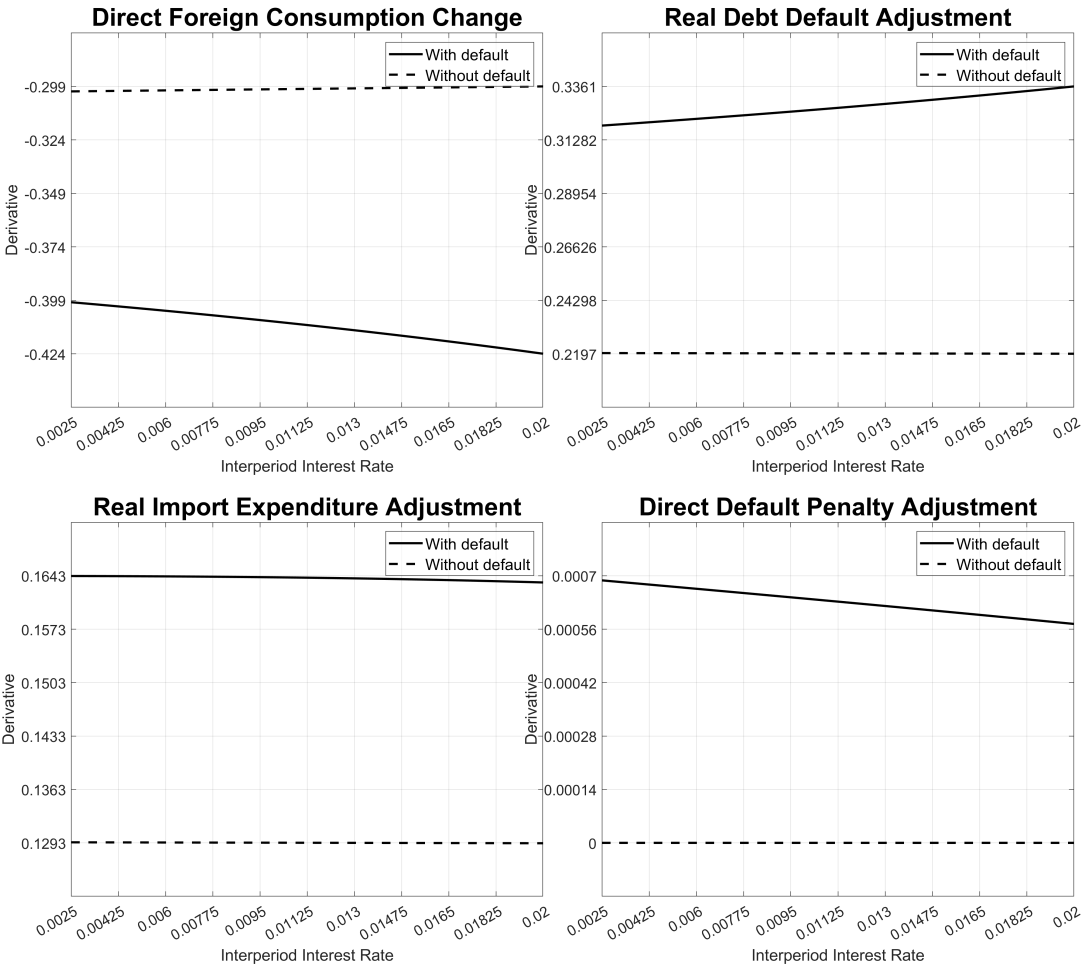


Figure 2.12: Welfare Change Decomposition with respect to Inter-period Interest Rate

Expanding on this observation, it becomes important to examine the specific mechanisms that underline the hedging effectiveness accompanying sovereign default. In this respect, Figure 2.12 and Figure 2.13 undertake an in-depth analysis of the changes in social welfare and nominal exchange rates, furthering an understanding of the reasons and ways through which default can be a feasible financial strategy.

From Figure 2.12, it is evident that the benefits of defaulting arise from Real Debt Default Adjustments, which alleviate the debt burden when monetary policy shocks and productivity shocks interact and amplify in bad states. This policy brings an

increase in social welfare when defaults are accommodated in some orderly way despite the cost of the first period on account of a lower level of foreign consumption. This cost is explained by the immediate effects on the levels of foreign consumption and also the rising cost tied to consumption, shown in the changes in Real Import Expenditure Adjustment.

The unfavorable change in the import of foreign goods and consumption expenditure is also reflected in the dynamics of the exchange rate. When the interest rates in the United States rise, according to the conventional wisdom and the **Covered Interest Rate Parity and Wedge** in our model, the domestic currency experiences pressure to devalue, as illustrated in the no-default scenario in Figure 2.13. The second period has a higher rate of depreciation, indicating a steeper downward slope for the future exchange rate in EMEs. This exerts upward pressure on the import price and, consequently, total import expenditure.

When the option of default is introduced, the dynamics of the exchange rate become smoother. The **US Demand and Supply Connection** proposition indicates a default choice would reduce demand for the US dollar in bad states, thus increasing the value of domestic currency in the bad state. However, increased loan rates due to default risk result in higher borrowing costs and a higher exchange rate in the initial period compared to non-default scenarios. On one hand, the further depreciation of the exchange rate, as a consequence of default risk, increases the cost of importing goods and reduces the consumption of foreign goods in the current period. On the other hand, the appreciation effect following a default can enhance utility in the bad state by reallocating US dollar reserves from bond repayment to importing goods. The latter effect tends to dominate when default coincides with a productivity shock period, due to the elevated marginal utility in adverse states. This suggests that default acts as a form of insurance, smoothing both the exchange rate and domestic consumption. Our model's results are consistent with the stylized facts that a decline in GDP and investment typically precedes a default. However, we introduce an innovative perspective

suggesting that the option to default actually serves as a mechanism for the economy to insulate itself against negative shocks from both productivity disturbances and US monetary policy shifts. The insurance effect helps the economy through the “exchange rate channel” and refreshing tight financial conditions.

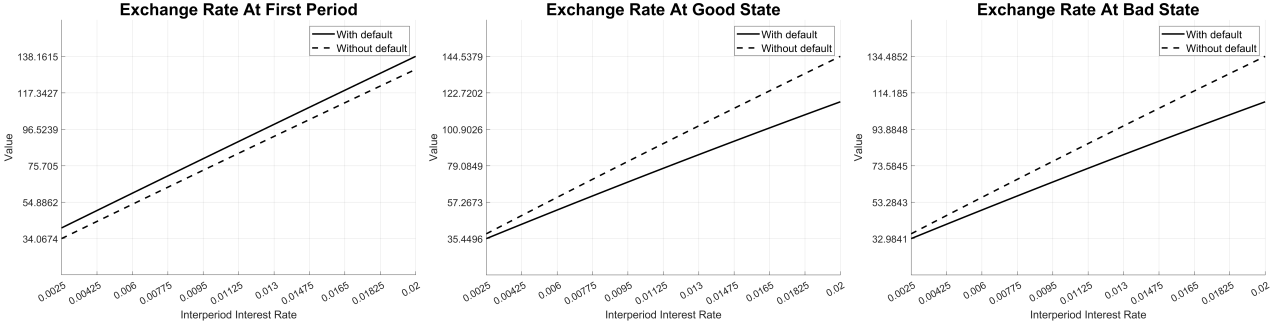


Figure 2.13: Exchange Rate Dynamics to Inter-period Interest Rate

It is worth noting that the change in the default punishment is small compared to other factors, which means that changes in the default amount are hardly affected by the interest rate. This indicates that the potential for default is almost orthogonal to the level of interest rate. Our model suggests that a strategy of orderly default, as opposed to a reactionary default dictated by the U.S. interest rate level, is optimal for EMEs. In this way, EMEs manage to balance the benefits from defaulting while keeping credit risk at a tolerable level in order to minimize the adverse impact on welfare in normal conditions.

In this section, our results show that an orderly default serves as an effective fiscal policy tool for EMEs to hedge against U.S. monetary policy shocks and domestic productivity shocks. Specifically, orderly default helps smooth exchange rate dynamics and increase domestic social welfare. It mitigates the negative social welfare impacts while enhancing economic resilience in the face of external shocks.

2.5 Empirical Stylized Facts

In this empirical section, we analyse the effects of sovereign defaults in Emerging Market Economies (EMEs) on GDP and exchange rates in response to positive U.S. monetary policy shocks, particularly during periods of tightening. This analysis follows the theoretical model and supports its numerical solution by examining how EME macroeconomic variables empirically react to U.S. policy shifts, with a specific focus on the interaction between monetary policy changes and default scenarios. Utilizing a comprehensive dataset, we apply local projection methods to investigate these dynamics. The findings aim to address a key question posed by the theoretical model: whether sovereign defaults in EMEs can serve as a hedging mechanism against U.S. monetary policy shocks.

2.5.1 Data

A detailed data collection process was conducted for this analysis, covering the period from 1980 to 2020. Global economic indicators, including GDP, inflation rates, exchange rates, and external debt levels, were sourced from the World Bank database over this 40-year period.

The key variable in our empirical analysis, the monetary policy shock, is identified following the methodology established by [Romer and Romer \(2004\)](#), often referred to as the RR shock. This measure is a benchmark in evaluating the impacts of monetary policy. It uniquely isolates changes in the Federal Reserve's target for the federal funds rate that result from discretionary policy decisions, distinguishing these from changes driven by evolving economic conditions. The Romer and Romer approach involves analyzing Federal Reserve documents, particularly the Federal Open Market Committee (FOMC) greenbooks and meeting minutes, to identify policy decisions. This method uses both quantitative data and narrative records of the meetings to provide clarity on the intentions of the Federal Reserve in the period where there is no explicit

rate targets change. This technique offers a clear and comprehensive view of monetary policy actions and their consequences. The sample period of the RR shock originally spanned from 1969 to 1996. We follow the same methodology and extend the analysis of the RR shock through 2020. We downloaded FOMC greenbooks and meeting minutes from the Fed’s website and extracted forecast information. These documents are very important since they offer great insight into the Federal Reserve’s decisions concerning monetary policy and the deeper rationale for these decisions, thereby helping to identify specific episodes of monetary policy shocks.

In addition, we included data including all sovereign default cases, especially in EMEs, based on the work of [Asonuma and Trebesch \(2016\)](#). Based on their dataset, we found 18 cases of default in EMEs and classified them into post-default renegotiation cases and preemptive debt restructuring cases. In the post-default cases, the government first defaults and then enters into debt renegotiation. Preemptive restructurings, by contrast, occur before any unilateral payment default.

2.5.2 Methodology

$$\Delta GDP_{i,t+h} = \alpha + \beta_h \text{Monetary shock}_t + \phi_h \text{Monetary shock}_t \times \text{default}_{i,t} + \iota X_{i,t} + \epsilon. \quad (2.24)$$

In this model, $\Delta GDP_{i,t+h}$ represents the growth rate of Gross Domestic Product for a country, indexed by i , at a future time point, $t + h$. The model incorporates several key components: α , a constant term. One of the key features of this model is that it contains US monetary shock, represented by Monetary shock_t . This term captures the level of US monetary shock at time t . In addition, the interaction term $\text{Monetary shock}_t \times \text{default}_{i,t}$ is included to capture the combined effect of a monetary shock at time t and the default state of country i at the same time. The coefficients β_h and ϕ_h are of particular importance in this analysis. In particular, β_h quantifies the effect of monetary policy on GDP in case of no default, while ϕ_h is important to explain how monetary policy shocks affect GDP in the event of a default, bringing forth

the differential effects under these two states. The model includes additional control variables to account for country-specific characteristics, denoted as $\iota X_{i,t}$. These entity- and time-period-specific factors comprise a set of variables, including a dummy variable capturing default, the first and second lags of GDP growth rate, the exchange rate with respect to the U.S. dollar, domestic inflation, and the change rate of external debt, in accordance with the existing literature (e.g., [Asonuma et al. \(2016\)](#)).

2.5.3 Results

Figure 2.14: Impulse Response of GDP Growth Rate (%) to a 1 bps RR US Monetary Policy Shock

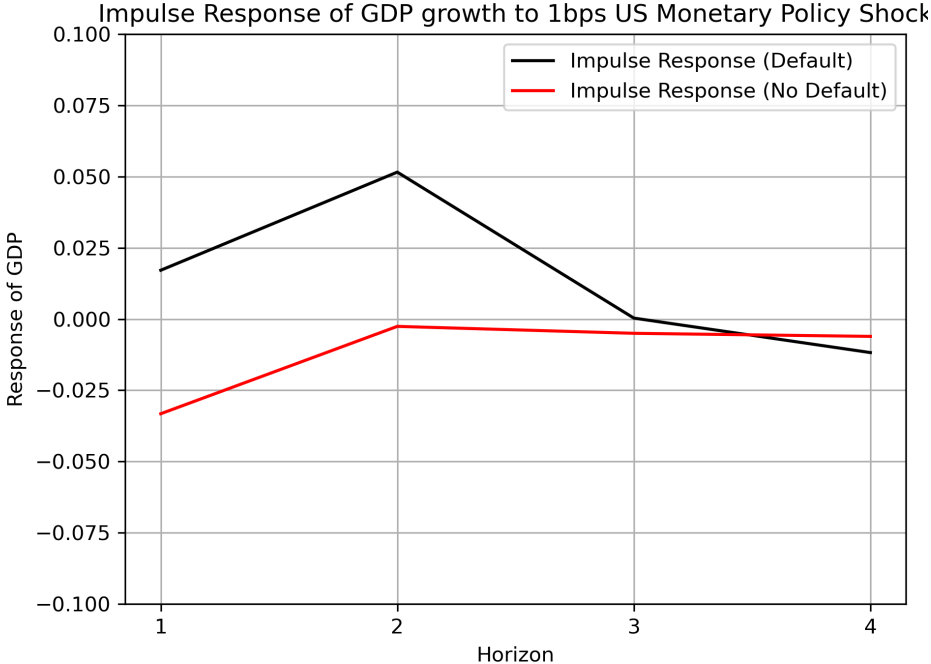


Figure 2.14 illustrates the impulse responses of a 1 basis points (bps) U.S. monetary policy shock on the GDP growth rate of EMEs using the data we collected. The red line depicts the response of EMEs GDP growth to a U.S. monetary policy shock in the absence of a default, corresponding to ϕ_h in our model settings. The black line shows the EME GDP’s reaction to a U.S. monetary policy shock following a default, represented by the sum of β_h and ϕ_h , while the dashed black line demonstrates the difference

between these two scenarios, indicated by β_h . The positive value of β_h suggests that a default could partially offset the negative impact of U.S. monetary policy on EMEs and stabilize their GDP growth.

Figure 2.15 further documents the interactions between monetary policy shocks and different types of defaults. Following the definition in Asonuma and Trebesch (2016), we categorize default cases into post-default negotiation and preemptive negotiation cases. In Figure 2.15, we plot the differences in GDP growth rate responses in two scenarios compared to cases with no default. While GDP growth tends to decline following a real default, preemptively addressing debt—effectively an orderly default—can lead to an increase in GDP levels. This suggests that such preemptive measures may mitigate the adverse effects of U.S. monetary policy shocks on GDP growth. These findings support our numerical and theoretical results.

Figure 2.15: Impulse Response of GDP Growth Rate (%) to a 1-bps RR US Monetary Policy Shock: Different Default Types

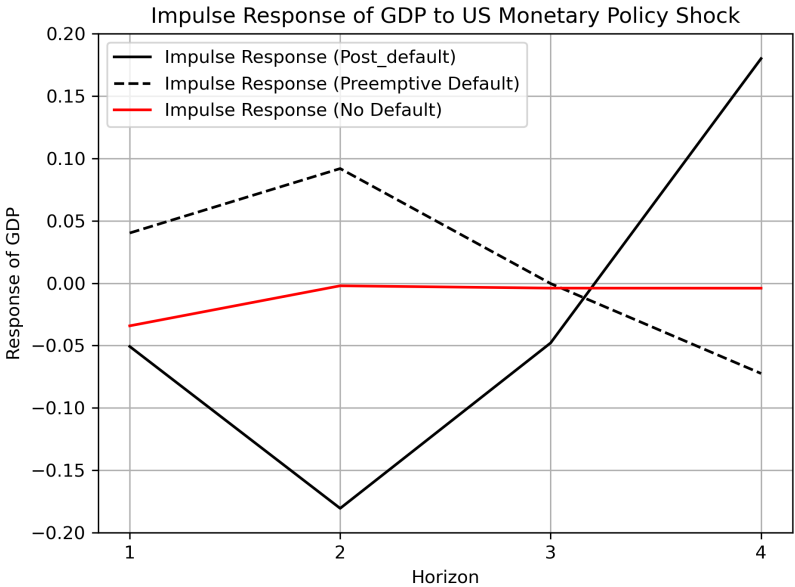
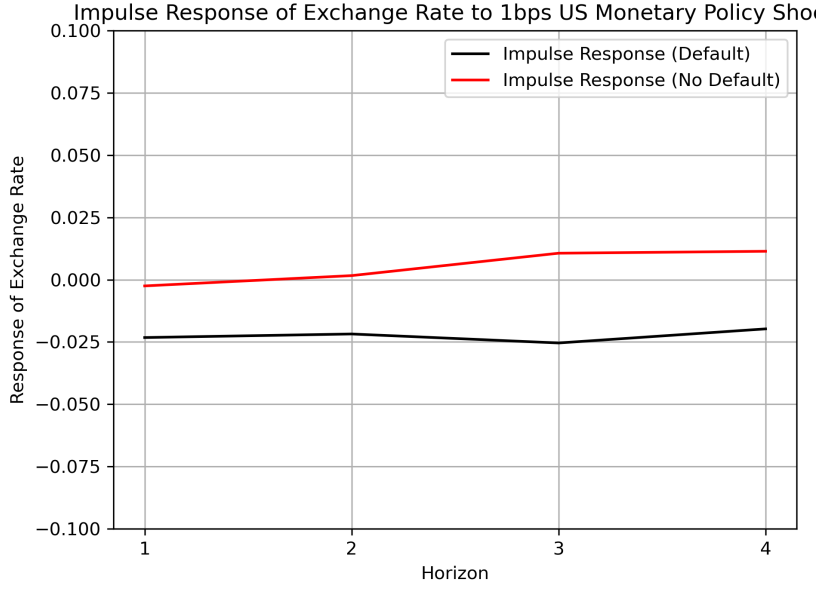


Figure 2.16 illustrates the impulse responses of a 1 basis points (bps) U.S. monetary policy shock on the exchange rates of Emerging Market Economies (EMEs). Similar to the GDP case, the red line depicts the response of the EME exchange rate to a U.S. monetary policy shock in the absence of a default, corresponding to ϕ_h in our model

settings. The black line shows the EME GDP’s reaction to a U.S. monetary policy shock following a default, represented by the sum of β_h and ϕ_h , while the dashed black line demonstrates the difference between these two scenarios, indicated by β_h . The negative of β_h suggests that a default could partially offset the negative impact of U.S. monetary policy on exchange rate depreciation pressure and stabilize the exchange rate.

Figure 2.16: Impulse Response of EME Exchange Rates to a 1-bps RR US Monetary Policy Shock



The analysis presented in Figure 2.14, Figure 2.15, and Figure 2.16 offers insightful evidence on the transmission mechanism of U.S. monetary policy shock to EMEs, especially for cases of sovereign default. Figure 2.14 illustrates that a sovereign default may attenuate the negative impact of the U.S. policy shock on the GDP growth of EMEs to some extent, which is represented by the positive value of β_h . exchange rate. This argument is further supported by Figure 2.15, which shows that proactive debt management strategies, like preemptive defaults, can potentially lead to an increase in GDP levels, suggesting a mitigating effect on the adverse impacts of U.S. policy shocks. Again, extending this analysis by bringing in the exchange rates, Figure 2.16 depicts a similar pattern wherein a default situation can ease the depreciation pressures of emerging market economies’ exchange rates because of U.S. policy shocks. This is consistent

with our numerical solution in [Section 4.4](#), which demonstrates that an optimal level of default, under a moderate default penalty, increases social welfare by reducing the debt burden and stabilizing the exchange rate.

These empirical stylized facts document the complex interactions between U.S. monetary policy, sovereign default, and their implications for economic variables in emerging markets. The results indicate that default may compensate for part of the undesirable spillover effects of U.S. monetary policy. The empirical findings corroborate the hypothesis and numerical predictions of the theoretical model. They suggest that the outcomes of our proposed model align with observed empirical patterns and provide a basis for drawing policy implications for EMEs facing similar economic conditions.

2.6 Conclusion

In recent decades, the heavy reliance of EMEs on U.S. dollar-denominated debt and the currency mismatch problem have presented a major challenge to EME policymakers in keeping up monetary policy independence while simultaneously hedging against U.S. shocks. Our paper addresses this challenge, offering new theoretical insights into the mechanisms of sovereign default in EMEs under the tightening of U.S. monetary policy shocks. Our analysis, by developing a two-country, two-good general equilibrium model with incomplete markets, brings out the complex interactions between debt dollarization, sovereign default, and monetary policy in the context of global financial cycles and U.S. monetary policy spillovers.

The propositions and numerical results of our model provide critical insights into the impact of sovereign default on the economy of EMEs: while sovereign defaults are correlated with output recessions, they facilitate the smoothing of consumption across states and contribute to economic recovery, especially when there are simultaneous shocks from US monetary policy and productivity downturns. This highlights their dual role in the economic landscapes of EMEs. More importantly, our findings suggest

that default could serve as a better insurance policy than a domestic interest rate hike against these two shocks. It also ensures the autonomy of monetary policy in EMEs.

Furthermore, our empirical findings, applying Local Projection methods and using a comprehensive sovereign default dataset, provide an empirical foundation for our model. Specifically, our empirical analysis indicates that an orderly default is not the reason for a GDP drop or exchange rate depreciation, especially when the US monetary policy shock impacts EMEs. In conclusion, our study sheds light on the complex roles of sovereign defaults in helping EMEs deal with difficulties during global financial instability. By exploring when defaults can act as a protective measure against outside disturbances, our work provides important details to the discussion on managing sovereign risk and strengthening the economy in emerging markets.

Appendix

Appendix A.1: Domestic Government Problem

The domestic government maximizes the utility of domestic households, denoted as U_i , while subtracting a non-pecuniary default penalty. The social utility function of the domestic country is represented as

$$W_I = \underset{\gamma_{I,s}, T_s, G_J^i, Q_J^i}{Max} \mathbb{E} \left[U_i - \beta_I \chi^g \frac{\max((1 - \gamma_{I,s})Q_J^i, 0)}{p_s} \right], \quad (2.25)$$

At $t = 0$, the domestic government issues sovereign bonds B_J^i to the foreign country in order to raise U.S. dollars. These funds G_J^i are transferred to domestic households at $t = 0$, and $G_J^i = B_J^i$, which could replace the B_J^i in equation 2.3. At $t = 1$, the government charges taxes T_s from households to repay the sovereign debt, which equals to $\gamma_{I,s}Q_J^i$, which replaces the corresponding term in Equation 2.6.

We restate the optimisation problem of the stand-alone government in equations (2.1)–(2.8). Solving this problem and combining the resulting tax/transfer rules with the household's budget constraint reproduces exactly the consolidated first-order conditions derived in the main text. Hence the decentralised formulation (separate household and government) is isomorphic to the social-planner problem once the two sectors are consolidated, confirming the equivalence of the two approaches.

A.1 First-Order Conditions (FOCs) for domestic country I

The constraints for the domestic country I can be consolidated into two equations, as shown below:

$$p_{J,0}(z_{J,0}^i + c_{J,0}^i)x_0 - \frac{Q_J^i}{1 + \rho_I}x_0 = \frac{\mu_I^i}{1 + r_I} + m_I, \quad (I_1)$$

$$\mu_I^i + x_s(p_{J,s}c_{J,s}^i + Q_J^i\gamma_{I,s}) = p_{I,0}(e_I - c_{I,0}^i) + \frac{p_{I,s}(A_{I,s}z_{J,0}^i - c_{I,s}^i)}{1 + r_{I,s}}. \quad (I_2)$$

let λ_I be the Lagrange multiplier of equation (I_1);

let $\theta_I(s)$ be the Lagrange multiplier of equation (I_2) at state s , where $s \in \{g, b\}$.

The FOCs with respect to each variable are outlined as follows.

$$\theta_I(g)p_{I,0} + \theta_I(b)p_{I,0} = U_{c_{I,0}^i}, \quad (c_{I,0}^i)$$

$$\lambda_I p_{J,0} x_0 = U_{c_{J,0}^i}, \quad (c_{J,0}^i)$$

$$\lambda_I p_{J,0} x_0 = \frac{\theta_I(g)p_{I,g}A_{I,g}}{1+r_{I,g}} + \frac{\theta_I(b)p_{I,b}A_{I,b}}{1+r_{I,b}}, \quad (z_{J,0}^i)$$

$$\lambda_I \frac{1}{1+r_I} = \theta_I(g) + \theta_I(b), \quad (\mu_I^i)$$

$$\pi_g \beta_I U_{c_{I,g}^i} = \theta_I(g)p_{I,g} \frac{1}{1+r_{I,b}}, \quad (c_{I,g}^i)$$

$$\pi_b \beta_I U_{c_{I,b}^i} = \theta_I(b)p_{I,b} \frac{1}{1+r_{I,b}}, \quad (c_{I,b}^i)$$

$$\pi_g \beta_I U_{c_{J,g}^i} = \theta_I(g)p_{J,g}x_g, \quad (c_{J,g}^i)$$

$$\pi_b \beta_I U_{c_{J,b}^i} = \theta_I(b)p_{J,b}x_b, \quad (c_{J,b}^i)$$

$$\frac{\pi_b \chi^g}{p_s} + \mu_0 + \mu_1 = x_b \theta_I(b), \quad (\gamma_{I,b})$$

$$\frac{1}{1+\rho_I} \lambda_I x_0 = x_b \gamma_{I,b} \theta_I(b) + x_g \theta_I(g) + \frac{\pi_b \chi^g}{p_s} (1 - \gamma_{I,b}), \quad (Q_J^i)$$

where μ_0, μ_1 be the Kuhn-Tucker coefficients corresponding to the constraints that repayment rate $\gamma_{I,b}$ must be greater than or equal to 0 and less than or equal to 1, respectively.

First-Order Conditions (FOCs) for Foreign country J

We simplified the budget constraints of Foreign country J into two equations as follows:

$$B_J^i + \frac{p_{I,0} c_{I,0}^j}{x_0} = \frac{\mu_J^j}{1+r_J} + m_J, \quad (J_1)$$

$$\mu_J^j + \frac{p_{I,s} c_{I,s}^j}{x_s} = p_{J,0}(e_J - c_{J,0}^j - z_{J,0}^j) + \frac{p_{J,s}(A_J z_{I,0}^j - c_{J,s}^j) + B_J^i(1+\rho_I)D_{I,s}}{1+r_{J,s}}. \quad (J_2)$$

let λ_J be the Lagrange multiplier of equation (J_1);

let $\theta_J(s)$ be the Lagrange multiplier of equation (J_2) at state s , where $s \in \{g, b\}$.

The FOCs with respect to each variable are outlined as follows.

$$\theta_J(g)p_{J,0} + \theta_J(b)p_{J,0} = U_{c_{J,0}^j}, \quad (c_{J,0}^j)$$

$$\lambda_1 \frac{p_{I,0}}{x_0} = U_{c_{I,0}^j}, \quad (c_{I,0}^j)$$

$$\theta_J(g)p_{J,0} + \theta_J(b)p_{J,0} = \theta_J(g)p_{J,g}A_J \frac{1}{1+r_{J,g}} + \theta_J(b)p_{J,b}A_J \frac{1}{1+r_{J,b}}, \quad (z_{J,0}^j)$$

$$\lambda_1 \frac{1}{1+r_J} = \theta_J(g) + \theta_J(b), \quad (\mu_J^j)$$

$$\lambda_1 = \theta_J(g)(1+\rho_I)D_{I,g} \frac{1}{1+r_{J,g}} + \theta_J(b)(1+\rho_I)D_{I,b} \frac{1}{1+r_{J,b}}, \quad (B_J^i)$$

$$\pi_g \beta_J U_{c_{I,g}^j} = \theta_J(g) \frac{p_{I,g}}{x_g}, \quad (c_{I,g}^j)$$

$$\pi_b \beta_J U_{c_{I,b}^j} = \theta_J(b) \frac{p_{I,b}}{x_b}, \quad (c_{I,b}^j)$$

$$\pi_g \beta_J U_{c_{J,g}^j} = \theta_J(g)p_{J,g} \frac{1}{1+r_{J,g}}, \quad (c_{J,g}^j)$$

$$\pi_b \beta_J U_{c_{J,b}^j} = \theta_J(b)p_{J,b} \frac{1}{1+r_{J,b}}. \quad (c_{J,b}^j)$$

A.2 Default On-the-Verge Condition

Proof: Refer to the first-order condition (FOC) for the domestic government's repayment rate in equation ($\gamma_{I,b}$).

A.3 Domestic Country External Debt Price

Combing the FOCs of foreign households for (μ_J^j) and (B_J^i) gives,

$$(1+r_J)(\theta_J(g) + \theta_J(b)) = \theta_J(g)(1+\rho_I)D_{I,g} \frac{1}{1+r_{J,g}} + \theta_J(b)(1+\rho_I)D_{I,b} \frac{1}{1+r_{J,b}}.$$

Define the martingale measure or the risk-neutral probability of a foreign country as $\frac{\theta_J(s)}{\theta_J(g)+\theta_J(b)}$ for state $s \in (b, g)$. We can further define the risk-neutral expectation as $E_{\mathbb{Q}_J}$,

We can rewrite the equation as: $\frac{1}{1+\rho_I} = \frac{1}{1+r_J} E_{\mathbb{Q}_J} \left[\frac{D_{I,s}}{(1+r_{J,s})} \right]$

A.4 Covered Interest Rate Parity and wedge:

Combing the FOCs of domestic government for $(\gamma_{I,b})$ and (Q_J^i) gives,

$$\frac{1}{1 + \rho_I} \lambda_I x_0 = x_b \theta_I(b) + x_g \theta_I(g).$$

Substitute λ_I with the FOC of of domestic government for (μ_I^i) gives,

$$\frac{1}{1 + \rho_I} (1 + r_I) (\theta_I(g) + \theta_I(b)) x_0 = x_b \theta_I(b) + x_g \theta_I(g).$$

Define the martingale measure or the risk-neutral probability of domestic country as $\frac{\theta_I(s)}{\theta_I(g) + \theta_I(b)}$ for state $s \in (b, g)$. We can further define the risk-neutral expectation as $E_{\mathbb{Q}_I}$, and rewrite the equation as:

$$E_{\mathbb{Q}_I} [x_b] = \frac{1 + r_I}{1 + \rho_I} x_0. \quad (2.26)$$

A.5 Government Bond Price and marginal rate of intertemporal substitution:

We can rewrite the equation and combine the FOCs of $(c_{J,0}^i)$, $(c_{J,g}^i)$, and $(c_{J,b}^i)$

$$\frac{1 + r_I}{1 + \rho_I} = \pi_b \beta_I \frac{\frac{U_{c_{J,b}^i}}{p_{J,b}}}{\frac{U_{c_{J,0}^i}}{p_{J,0}}} + \pi_g \beta_I \frac{\frac{U_{c_{J,g}^i}}{p_{J,g}}}{\frac{U_{c_{J,0}^i}}{p_{J,0}}} = E \left[\beta_I \frac{\frac{U_{c_{J,s}^i}}{p_{J,s}}}{\frac{U_{c_{J,0}^i}}{p_{J,0}}} \right].$$

A.6 Money Non-Neutrality

Proof: Prove by contradiction. Assume Money Neutrality holds, according to the FOCs of household i and j , we have:

$$\frac{p_{I,0}}{(1+r_I)p_{J,0}x_0} = \frac{U_{c_{I,0}^i}}{U_{c_{J,0}^i}}, \quad (2.27)$$

$$\frac{p_{I,0}(1+r_J)}{p_{J,0}x_0} = \frac{U_{c_{I,0}^j}}{U_{c_{J,0}^j}}. \quad (2.28)$$

if r_I increases, then according to the money neutrality condition, $\frac{p_{I,0}}{p_{J,0}x_0}$ would increase, where as (2.28) implies $\frac{p_{I,0}}{p_{J,0}x_0}$ would remain the same. This is a contradiction. if r_J increase, then according to the money neutrality condition, $\frac{p_{I,0}}{p_{J,0}x_0}$ would decrease, where as (2.27) implies $\frac{p_{I,0}}{p_{J,0}x_0}$ would remain the same. This is also a contradiction. We could derive the same proposition for $t=1$; Assume Money Neutrality holds, according to the FOCs of household i and j , we have:

$$\frac{U_{c_{J,s}^i}}{U_{c_{I,s}^i}(1+r_{I,s})} = \frac{U_{c_{J,s}^j}(1+r_{J,s})}{U_{c_{I,s}^j}} = \frac{p_{J,s}x_s}{p_{I,s}}. \quad (2.29)$$

if $r_{I,s}$ increases, then according to the money neutrality condition, $\frac{p_{I,s}}{p_{J,s}x_s}$ would increase, where as equation (2.28) implies $\frac{p_{I,s}}{p_{J,s}x_s}$ would remain the same. This is a contradiction. if r_J increase, then according to the money neutrality condition, $\frac{p_{I,s}}{p_{J,s}x_s}$ would decrease, where as equation (2.27) implies $\frac{p_{I,s}}{p_{J,s}x_s}$ would remain the same. This is also a contradiction.

A.7 Monetary base Connection:

Combining the budget constraint (2.2) for the domestic household in the first period, the budget constraint (2.9) for the foreign household in the first period, and the market

clearing conditions for the foreign exchange and money markets, we obtain:

$$\frac{Q_J^i}{1 + \rho_I} + \frac{(M_I + m_I)}{x_0} = M_{J,0} + m_J.$$

A.8 Term-structure of interest rates:

According to the (J_1) , and (J_2) , money market and the foreign market clearing condition, we have

$$B_J^i + \frac{p_{I,0}c_{I,0}^j}{x_0} = M_{J,0} + m_J,$$

$$M_{J,0}(1 + r_J) + \frac{p_{I,s}c_{I,s}^j}{x_s} = p_{J,0}(e_J - c_{J,0}^j - z_{J,0}^j) + \frac{p_{J,s}(A_J z_{I,0}^j - c_{J,s}^j) + B_J^i(1 + \rho_I)D_{I,s}}{1 + r_{J,s}},$$

$$B_J^i + \frac{p_{I,0}c_{I,0}^j}{x_0} = p_{J,0}(e_J - c_{J,0}^j - z_{J,0}^j),$$

$$\frac{p_{I,s}c_{I,s}^j}{x_s} = p_{J,s}(A_J z_{I,0}^j - c_{J,s}^j) + B_J^i(1 + \rho_I)D_{I,s}.$$

\implies

$$m_J = M_{J,0}r_J + M_{J,s}r_{J,s}.$$

A.9 Demand and Supply of US dollar:

Based on the A.7 and A.8, combined with domestic household's budget constraint (2.5), (2.6), we have

$$p_{J,0}(z_{J,0}^i + c_{J,0}^i) = M_{J,0} + m_J,$$

$$p_{J,s}c_{J,s}^i + Q_J^i \gamma_{I,s} = M_{J,s}(1 + r_{J,s}).$$

A.10 Demand and Supply of US dollar:

Define $MRS_s = \frac{\frac{\partial u_s^{i*}}{\partial c_{I,s}^i}}{\frac{\partial u_s^{i*}}{\partial c_{I,s}^i}}$, where $s \in (0, b, g)$. According to the social utility function, we can write the derivative of social welfare to policy normalized by the marginal utility of domestic goods as:

$$\begin{aligned} \frac{\frac{dW_I^*}{d\chi^{g*}}}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^i}} &= \frac{dc_{I,0}^{i*}}{d\chi^{g*}} + MRS_0^* \frac{dc_{J,0}^{i*}}{d\chi^{g*}} + \pi_b \beta_I \frac{\frac{\partial u_b^{i*}}{\partial c_{I,b}^i}}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^i}} \left(\frac{dc_{I,b}^{i*}}{d\chi^{g*}} + MRS_b^* \frac{dc_{J,b}^{i*}}{d\chi^{g*}} \right) \\ &+ \pi_g \beta_I \frac{\frac{\partial u_g^{i*}}{\partial c_{I,g}^i}}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^i}} \left(\frac{dc_{I,g}^{i*}}{d\chi^{g*}} + MRS_g^* \frac{dc_{J,g}^{i*}}{d\chi^{g*}} \right) - \frac{1}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^i}} \beta_I \pi_b \frac{d\chi^g \Delta_b^*}{d\chi^{g*}}. \end{aligned} \quad (A10-1)$$

Define ϕ_s as the ratio of the discounted price levels between two periods, $\phi_s = \frac{p_{I,s}/(1+r_{I,s})}{p_{I,0}}$.

The equation could be rewritten as

$$\pi_s \beta_I \frac{\frac{\partial u_s^{i*}}{\partial c_{I,s}^i}}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^i}} = \frac{\theta_I^*(s)}{\theta_I^*(b) + \theta_I^*(g)} \phi_s^*. \quad (A10-2)$$

where $\frac{\theta_I^*(s)}{\theta_I^*(b) + \theta_I^*(g)}$ is the risk-neutral probability.

First, for the first period, combine the budget constraint of equations (2.3), (2.4), and the market clearing condition of the foreign exchange market, we have:

$$p_{I,0}^*(e_I - c_{I,0}^{i*}) = p_{I,0}^* q_{I,0}^{i*} = f_{J,0}^{j*} = \frac{f_{I,0}^{i*}}{x_0^*} = (p_{J,0}^*(c_{J,0}^{i*} + Z_{J,0}^{i*}) - \frac{Q_J^{i*}}{1 + \rho_I^*}) x_0^*,$$

which can be simplified as:

$$c_{I,0}^{i*} = e_I - \frac{(p_{J,0}^*(c_{J,0}^{i*} + Z_{J,0}^{i*}) - \frac{Q_J^{i*}}{1 + \rho_I^*}) x_0^*}{p_{I,0}^*}.$$

Therefore, we have

$$\frac{dc_{I,0}^{i*}}{d\chi^{g*}} = - \frac{d \left(\frac{(p_{J,0}^* (c_{J,0}^{i*} + Z_{J,0}^{i*}) - \frac{Q_J^{i*}}{1+\rho_I^*}) x_0^*}{p_{I,0}^*} \right)}{d\chi^{g*}}. \quad (\text{A10-3})$$

Regarding the second period, we have

$$p_{I,s}^* (A_{I,s} Z_{J,0}^{i*} - c_{I,s}^{i*}) = p_{I,s}^* q_{I,s}^{i*} = f_{J,s}^{j*} = \frac{f_{I,s}^{i*}}{x_s^*} = (p_{J,s}^* (c_{J,s}^{i*}) - Q_J^{i*} \gamma_{I,s}) x_s^*,$$

and

$$c_{I,s}^{i*} = A_{I,s} Z_{J,0}^{i*} - \left(\frac{(p_{J,s}^* c_{J,s}^{i*} - Q_J^{i*} \gamma_{I,s}) x_s^*}{p_{I,s}^*} \right).$$

Therefore:

$$\frac{dc_{I,s}^{i*}}{d\chi^{g*}} = \frac{d(A_{I,s} Z_{J,0}^{i*})}{d\chi^{g*}} - \frac{d \left(\frac{(p_{J,s}^* c_{J,s}^{i*} - Q_J^{i*} \gamma_{I,s}) x_s^*}{p_{I,s}^*} \right)}{d\chi^{g*}}. \quad (\text{A10-4})$$

Combine the FOC of $(z_{J,0}^i)$, $(c_{I,0}^i)$, $(c_{I,g}^i)$, $(c_{I,g}^i)$, we have

$$\pi_b \beta_I \frac{\frac{\partial u_b^{i*}}{\partial c_{I,b}^i}}{\frac{\partial u_0}{\partial c_{I,0}^i}} \cdot \frac{dA_{I,b} Z_{J,0}^{i*}}{d\chi^{g*}} + \pi_g \beta_I \frac{\frac{\partial u_g^{i*}}{\partial c_{I,g}^i}}{\frac{\partial u_0}{\partial c_{I,0}^i}} \cdot \frac{dA_{I,g} Z_{J,0}^{i*}}{d\chi^{g*}} = \frac{\frac{\partial u_0}{\partial c_{J,0}^i}}{\frac{\partial u_0}{\partial c_{I,0}^i}} \frac{dZ_{J,0}^{i*}}{d\chi^{g*}} = \text{MRS}_0^* \frac{dZ_{J,0}^{i*}}{d\chi^{g*}}. \quad (\text{A10-5})$$

Then rewrite equation (A10-1) with equations (A10-2), (A10-3), (A10-4), (A10-5), we

have:

$$\begin{aligned}
\frac{dW_I^*}{d\chi^{g*}} &= \underbrace{\text{MRS}_0^* \frac{d(c_{J,0}^{i*} + Z_{J,0}^{i*})}{d\chi^{g*}}}_{\text{Direct Foreign Import Change}} + E_{Q_I} \left[\underbrace{\phi_s^* \text{MRS}_s^* \frac{dc_{J,s}^{i*}}{d\chi^{g*}}}_{\text{Real Debt Default Adjustment}} \right] \\
&+ E_{Q_I} \left[\underbrace{d \left(\frac{x_0^* Q_J^{i*}}{(1+\rho_I^*) p_{I,0}^*} - \frac{\phi_s^* Q_J^{i*} \gamma_{I,s}^* x_s^*}{p_{I,s}^*} \right)}_{\text{Real Debt Default Adjustment}} \right] \\
&- E_{Q_I} \left[\underbrace{d \left(\frac{x_0^* p_{J,0}^* (c_{J,0}^{i*} + Z_{J,0}^{i*})}{p_{I,0}^*} + \frac{\phi_s^* x_s^* p_{J,s}^* (c_{J,s}^{i*})}{p_{I,s}^*} \right)}_{\text{Real Import Expenditure Adjustment}} \right] \\
&- \underbrace{\frac{1}{\frac{\partial u_0^{i*}}{\partial c_{I,0}^{i*}}} \beta_I \pi_b \frac{d\chi^g \Delta_b^*}{d\chi^{g*}}}_{\text{Direct Default Penalty Adjustment}} .
\end{aligned}$$

B. Stylized Facts

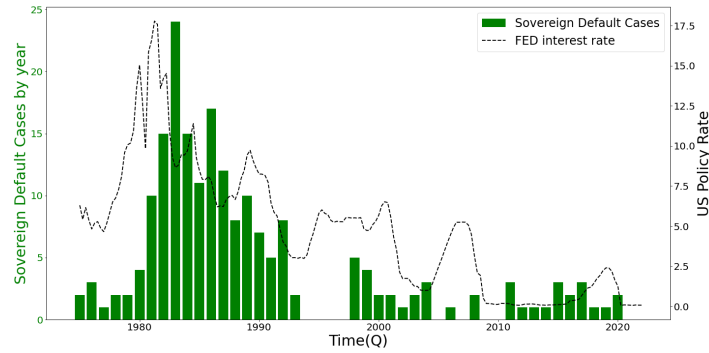
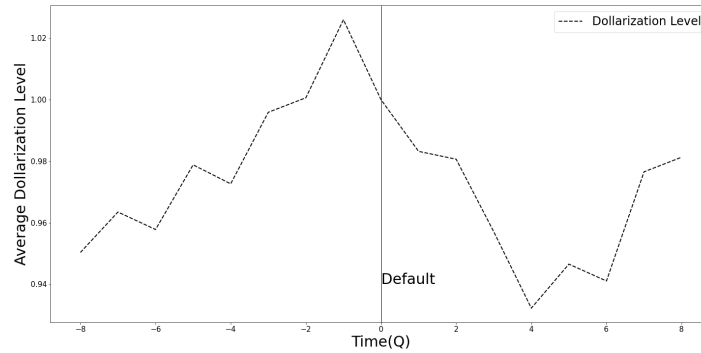


Figure 2.A: The Relationship Between US Policy Rate and Sovereign Default Cases

Note: The X-axis represents years from 1975 to 2021. The dashed line indicates the Fed policy rate. The green bar The data includes all the developing countries' default cases documented in [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#).

Sources: The FED policy rate is obtained from FED official data; Sovereign default cases are documented by [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#).

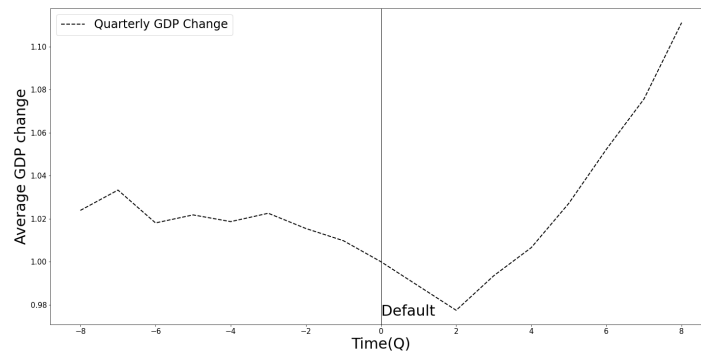
Figure 2.B: Quarterly Average Dollarisation Level Change around Default



Note: The X-axis represents the quarter time before and after default, with time 0 indicating the default date. The dashed line indicates the average dollarization level in a default case. We normalize the dollarization level on the announcement date to 1. The data includes all the EMEs default cases documented in Moody's(2021), [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#). The EMEs in our paper include all countries that is recognized as EMEs by at least one main international organization. The dollarization level is defined as the total US dollar debt divided by the total debt.

Sources: The debt data is obtained from BIS debt securities data; Sovereign default cases are documented by [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#). We include all EMEs sovereign default cases with available debt data.

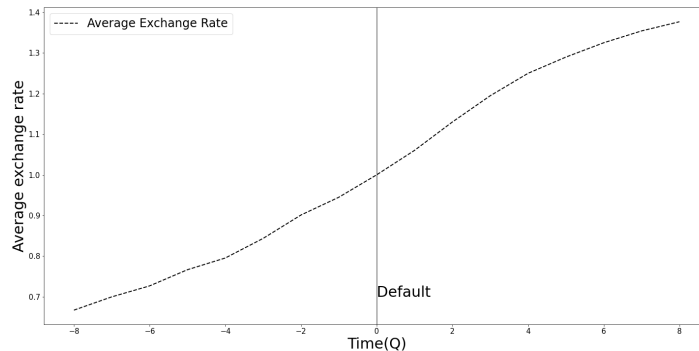
Figure 2.C: Quarterly GDP Change around Default



Note: The X-axis represents the quarter time before and after default, with time 0 indicating the default date. The dashed line indicates the average variation of GDP in a default case. We normalize the GDP on the announcement date to 1. The data includes all the EMEs default cases documented in [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#). The EMEs in our paper include all countries that is recognized as EMEs by at least one main international organization.

Sources: The debt data is obtained from OECD data; Sovereign default cases are documented by [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#). We include all EME's sovereign default cases with available quarterly GDP data.

Figure 2.D: Exchange Rate Dynamics around Default



Note: The X-axis represents the quarter time before and after default, with time 0 indicating the default date. The dashed line indicates the average nominal exchange rate in a default case. We normalize the nominal exchange rate on the default announcement date to 1. The data includes all the EMEs default cases documented in [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#). The EMEs in our paper include all countries that is recognized as EMEs by at least one main international organization. The nominal exchange rate is defined as the rate of EME currency to exchange for one US dollar.

Sources: The exchange rate data is obtained from BIS data; Sovereign default cases are documented by [Asonuma and Trebesch \(2016\)](#), and [Cruces and Trebesch \(2013\)](#). We include all EME's sovereign default cases with available exchange rate data.

C. Remark on the Transfer Paradox.

The Transfer Paradox, a concept grounded in general equilibrium theory, highlights how redistributive policies, including transfer payments, can unintentionally benefit recipients while harming providers. In our model, sovereign debt default can broadly be considered a transfer from U.S. households to domestic households, akin to a subsidy. Similar to the conventional Transfer Paradox, an optimal level of sovereign default does not necessarily improve welfare following a negative productivity shock: it depends on the relationship between the intertemporal substitution parameter and the intratemporal substitution parameter. Specifically, in this section, we set $\nu_I = \nu_J = 2.5$ and recalibrate the equilibrium with respect to the productivity level, as in [Figure 2.21](#).

As discussed in [Remark on Elasticity of Substitution](#), domestic and foreign goods are complementary in this case. A shortage of domestic goods due to the TFP shock leads to reduced demand for foreign goods. While default can relax the budget con-

straint by reducing the debt burden and increasing foreign consumption, the effect on social welfare remains limited due to lower marginal utility. This effect is not enough to compensate for the rise in external debt costs due to the anticipation of default risk in the first period. The results highlight the need for policymakers to evaluate the relationship between the main streams of domestic and import goods before considering sovereign default as an efficient policy to hedge TFP shock.

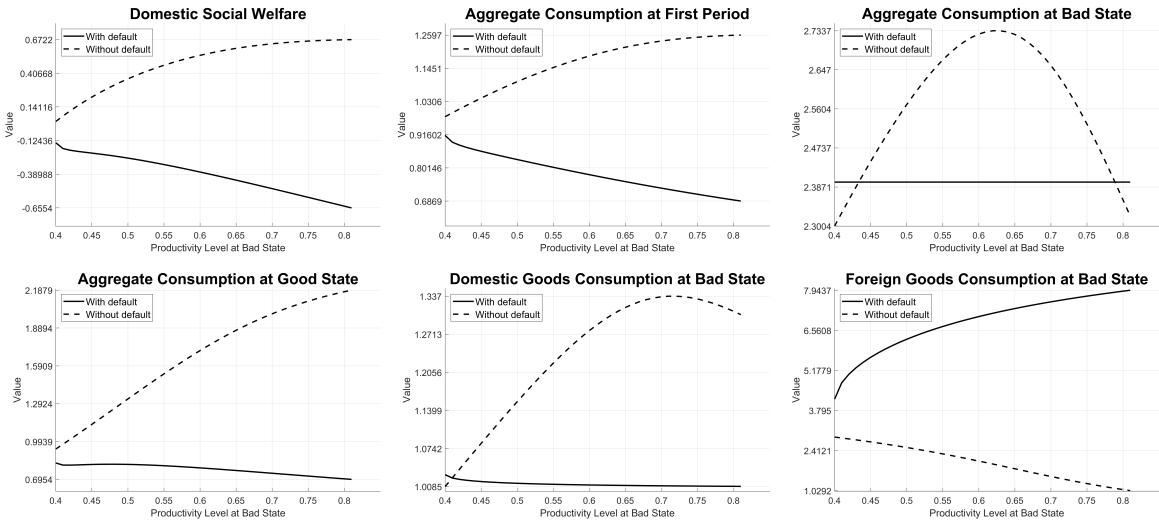


Figure 2.21: Exchange Rate Dynamics as a Function of Bad State Productivity Level

Chapter 3

EME Sovereign Risk Under U.S. Monetary Policy: The Role of Exchange Rates and Foreign Capital

EME Sovereign Risk Under U.S. Monetary Policy: The Role of Exchange Rates and Foreign Capital*

Abstract

This paper investigates how capital shares and reliance on imports as production inputs shape emerging-market (EME) sovereign default risk in response to U.S. monetary-policy shocks. I develop a small open-economy model with endogenous default and an explicit role for imported goods as inputs in production. Quantitatively, U.S. monetary tightening raises EME external borrowing costs, depreciates domestic currencies, and intensifies default risk. The magnitude of these effects depends on each economy's capital share and the share of imports in its production inputs. Economies that depend heavily on imported goods as production inputs face pronounced exchange-rate externalities because demand for these inputs is inelastic, which increases the cost of default and reduces default incentives. Moreover, I show that the default rate does not always increase as the external-debt-to-GDP level rises; it depends on the trade-off between the magnitude of exchange-rate externalities and debt-burden relief in economies with different levels of reliance on imported goods as production inputs.

Keywords: Sovereign debt restructuring; Sovereign default; Dollar-denominated debt; Exchange rate pricing; Global financial cycle; Imported capital inputs.

*This chapter is a single-authored paper. I thank Mingze Ma, Udara Peiris, Dimitrios P.Tsomocos, and Xuan Wang for providing helpful comments and suggestions.

3.1 Introduction

The global financial cycle, particularly U.S. monetary policy, plays a critical role in shaping the cost and risk of external debt in emerging market economies (EMEs). Empirical evidence indicates that U.S. monetary policy tightening significantly increases the default premium on the external debt of EMEs and is accompanied by depreciation of domestic currencies in EMEs (Bräuning and Ivashina, 2020; Bhattarai et al., 2020; Cristi et al., 2024). While Na et al. (2018) provide a theoretical model that rationalizes depreciation and default as optimal policies in response to a negative shock, an important question remains: How do the externalities of exchange rate depreciation affect EMEs’ incentives to default under a U.S. monetary policy shock, and how does reliance on imported capital goods and capital shares interact with these externalities?

To address these issues, I construct a small open-economy model that extends the literature on sovereign default and small open economies (Gali and Monacelli, 2005; Mendoza and Yue, 2012; Walsh, 2017) by incorporating two key features. First, motivated by Bianchi and Sosa-Padilla (2024)’s model—which captures both the externality costs of exchange-rate depreciation and the cost of sovereign default—I allow depreciation to generate additional externalities that raise the real value of external debt, thereby amplifying the costs of default. Second, I include a direct role for imported capital goods in the production function. My quantitative findings suggest that, on average, a 1% increase in the U.S. interest rate raises the default rate by about 0.5% and is accompanied by a 0.7% depreciation of the real exchange rate. I further identify a trade-off between the externality cost of depreciation and the welfare gains from default, showing that a higher capital share in production and greater demand for imported capital goods decrease the incentive to default because the exchange-rate externality is larger when such imports are critical for EMEs.

In my theoretical model, I assume that the domestic country has a representative household that consumes both domestic and foreign goods. This household can borrow

from the domestic market in domestic currency or receive U.S. dollar transfers from the government, which funds these transfers by issuing defaultable sovereign U.S. dollar debt in the international market. The household faces both a cash-in-advance constraint and budget constraints, and the production function uses capital goods as an input. The capital goods are composed of both foreign and domestic capital. The domestic central bank sets the interest rate according to a Taylor rule-based monetary policy. Under U.S. monetary policy shocks, the domestic economy encounters higher external borrowing costs and reduced external demand. This framework enables us to investigate how U.S. monetary policy shocks propagate through EMEs at various levels of imported capital goods, ultimately influencing their borrowing costs, default probabilities, and social welfare.

In this small open economy model, the international sovereign external debt allows for default, subject to a non-pecuniary penalty scaled by the real value of the outstanding debt, as discussed in Peiris and Tsomocos (2015); Goodhart et al. (2018). I assume that the default penalty term is an exogenous parameter, capturing the strictness of the default penalty imposed by creditors and the international market. This non-monetary default penalty reflects both the reputational impact of sovereign debt on EMEs (Eaton and Gersovitz, 1981; Cole and Kehoe, 2000) and the potential costs associated with exclusion from international financial markets (Gelos et al., 2011; Cruces and Trebesch, 2013). The depreciation of the domestic currency increases the real value of external debt in terms of domestic goods, thereby raising the non-pecuniary penalty. This channel captures the exchange rate-driven externality in both the default cost and risk.

In addition, to reflect the rarity of default, consistent with the discussion in Goodhart et al. (2018), I define an occasionally binding constraint on the default-on-the-verge condition. I assume that no default is the optimal choice for emerging market sovereigns in the steady state, while a sharp negative external shock can shift the regime to a partial default environment, making default the optimal choice for domestic sovereign debt.

Through a quantitative analysis of the model, I investigate how the share of foreign capital and variations in debt-to-GDP ratios affect the default rate in response to a U.S. monetary policy shock.

First, under a benchmark scenario aligned with average EME moments, I show that U.S. monetary policy spillovers affect default risk and real economic activity through both financial and exchange rate channels. This increased default risk arises mainly from two sources: (i) a direct increase in borrowing costs, driven by the pass-through of higher U.S. interest rates to default incentives and external debt costs via a no-arbitrage bond pricing function, and (ii) an exchange rate effect, in which contractionary U.S. monetary policy depreciates the domestic real exchange rate, elevating the external debt burden and reducing external demand from the US. This would reduce the imported capital goods in the domestic economy, thereby amplifying the benefits of default to free up resources for consumption.

More importantly, my findings show that the relationship between sovereign default risk and the exchange rate channel is significantly influenced by the share of foreign capital in production and the corresponding imported-capital-to-GDP ratio. My calibration suggests that a 10% increase in the capital share, accompanied by a corresponding rise in the imported-capital-to-GDP ratio, reduces the impulse response of the default rate to a U.S. monetary policy shock by more than 30%. This underscores the importance of capital share and reliance on foreign goods as production input as key channels in characterizing the impact of U.S. monetary policy shocks on default risk.

In the conventional literature, a higher negative income shock leads to a higher incentive to default (Eaton and Gersovitz, 1981; Arellano, 2008). However, when imported capital goods are incorporated into the capital accumulation function, as shown in my results, the decrease in capital inflow generates further depreciation of the exchange rate due to the reduced supply of U.S. dollars. When the capital share is high, the higher cost of reducing capital investment from abroad would generate a less elastic

demand for U.S. dollars in response to US monetary policy, despite the strong U.S. dollar. In this case, the demand for U.S. dollars would be less affected, leading to a higher depreciation value. The externality of the exchange rate, as assumed by the model, would induce domestic government defaults less in the external debt.

Moreover, the response to U.S. monetary policy shocks differs markedly between low external debt and high external debt environments. As the external debt-to-GDP ratio increases from 10% to 100%, the impulse response of exchange rate depreciation intensifies due to the higher demand for U.S. dollars to repay external debt. In high external debt environments, a greater capital share raises the economy's vulnerability to U.S. monetary policy shocks. Tightening U.S. monetary policy triggers higher import expenditures and outflows of foreign capital, leading to a sharper depreciation of the exchange rate. The domestic interest rate increases, following the U.S. interest rate, in an effort to stabilize the economy. The increase in domestic interest rates and currency depreciation decreases social welfare, increases the incentive for default relative to the externality cost of exchange rate depreciation, and thus raises the default rate when both external debt and capital share are high.

In contrast, for an economy with a low capital share, an increase in external debt has limited or even positive impacts on social welfare in response to U.S. monetary policy shocks. This is attributed to reduced exposure to expenditure on imports and reduced dependence on foreign goods as production input. In this case, external debt increase reduces the default incentive because exchange rate externalities are greater than the benefit from stabilizing social welfare.

This paper is closely related to the first paper in this thesis. I extend the two-period framework to an infinite-horizon model. Instead of evaluating the welfare effects of sovereign debt restrictions in EMEs, I explore the incentives for default in terms of exchange rate externalities and capital share. My research provides important policy implications for EMEs by highlighting the necessity of evaluating exchange rate

externalities and capital composition when implementing debt restructuring.

My results are closely related to the literature on sovereign default. I build on the foundational work of [Eaton and Gersovitz \(1981\)](#), [Aguiar and Gopinath \(2006\)](#), and [Arellano \(2008\)](#), which developed quantitative models to examine the relationship between default risk and output fluctuations. The domestic monetary environment in my model is close to the foundational framework proposed in [Gali and Monacelli \(2005\)](#). The default penalty setup stems from the foundation work of [Dubey et al. \(2005\)](#), and is used in [Goodhart et al. \(2018\)](#) and [Wang \(2021\)](#). I contribute to this strand of research by investigating how exchange rate externalities interact with sovereign default decisions and introducing a production function that depends on foreign capital.

My paper also contributes to the literature investigating the transmission of U.S. monetary policy to EMEs. [Neumeyer and Perri \(2005\)](#) provide evidence that the business cycle in Argentina has been largely impacted by exogenous interest rate shocks. [Uribe and Yue \(2006\)](#) show that U.S. interest rate shocks affect domestic aggregate economic activity through their impact on country spreads, both empirically and theoretically. Building on these foundations, several studies have examined the mechanisms through which U.S. monetary policy impacts the business cycle in EMEs. This extensive literature explores the spillover effects of U.S. monetary policy on EMEs through the exchange rate channel ([Bauer and Neely, 2014](#); [Neely, 2015](#)), financial markets ([Gilchrist et al., 2019](#)), macroeconomic fundamentals ([Mishra et al., 2014](#)), and different types of shocks ([Hoek et al., 2020](#)). [Johri et al. \(2022\)](#) provide a detailed analysis of how default probabilities in emerging markets are sensitive to changes in U.S. interest rates, demonstrating that uncertainty in monetary policy can significantly increase the rate of sovereign default. Their findings suggest that tighter U.S. monetary policy, by increasing borrowing costs and shifting capital flows, amplifies default risks under certain debt conditions. This paper contributes to this strand of literature by investigating how the interactions between the exchange rate channel, foreign investment, and capital allocation affect default risk in response to U.S. monetary policy shocks.

My results also relate to the literature discussing trade openness and default incentives. Starting with the research by [Ghironi and Melits \(2005\)](#), which shows that trade openness can enhance economic resilience, [Mendoza and Yue \(2012\)](#) support this analysis by providing a foundational framework linking trade openness to reduced default incentives. They posit that greater integration into international markets enhances a country's ability to stabilize its economy, increases the cost of default, and thereby lowers the likelihood of default. Additionally, [Serfaty \(2024\)](#) examines the complex interplay between sovereign default and international trade dynamics, highlighting how an EME default can disrupt trade flows, affect exchange rates, and how higher trade openness reduces the incentive to default. I contribute to this strand of literature by investigating how different levels of foreign capital interact with external debt levels and affect the incentive to default through the exchange rate and international trade channels.

The rest of the paper is organized as follows, the second section describes the model setup and equilibrium conditions. The third section calibrates the model to match empirical moments and analyzes the results. The fourth section concludes.

3.2 Small Open Economy Model

In this section, I construct a small open economy model with infinite horizons to quantify the impact of sovereign default on social welfare in response to a U.S. monetary policy shock. The analysis focuses on a domestic country (Country I) that engages in trade with the rest of the world. I assume the presence of a representative household in the domestic economy. This household consumes both domestic and foreign goods, borrows from the domestic central bank, and issues foreign debt. To simplify the framework, I consolidate the decisions of the domestic government into the representative household. In the model, the aggregate external debt in the domestic household equals the sovereign external debt level. I assume that the government transfers all external

debt revenue to households and subsequently imposes a lump-sum tax, denominated in U.S. dollars, on households in the following period to repay the sovereign debt. In this paper, I use “sovereign external debt” and “external debt” interchangeably to refer to the same concept.

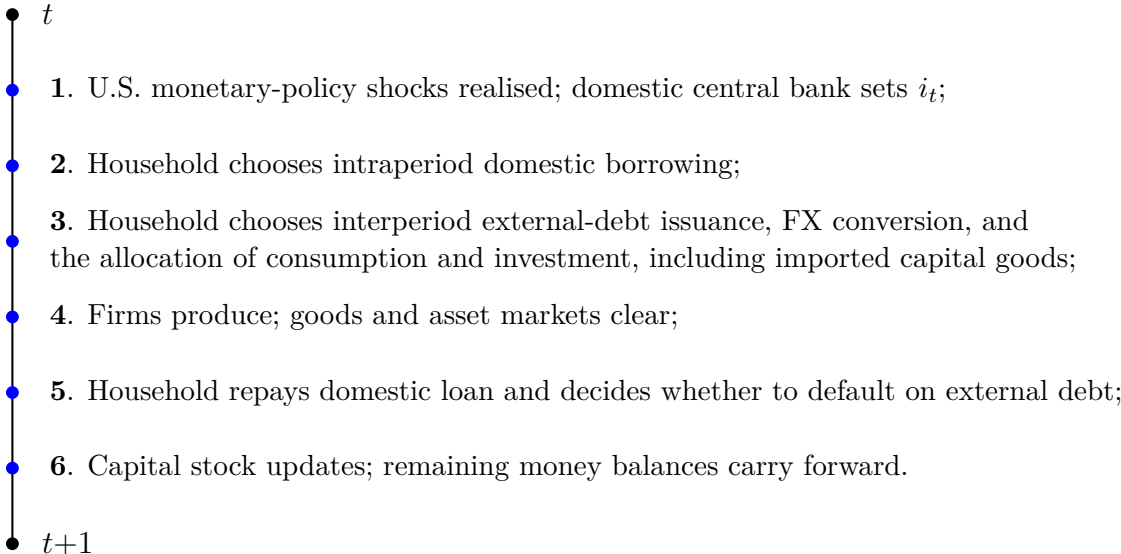


Figure 3.1: Timeline of the Dynamic Model

Figure 3.1 summarises the timing within a single period. First, exogenous shocks—most importantly the U.S. interest-rate shock—are realised, and the domestic central bank sets its policy rate. The representative household then decides how much to borrow domestically, how much interperiod external debt to issue, and how much foreign exchange to obtain so that it can purchase both domestic and imported capital goods. The household produces using the capital stock carried over from the previous period, and goods and asset markets clear, pinning down the exchange rate. Before the period ends, the household repays its domestic loan and services last period’s external debt, subject to possible default. Finally, capital accumulation and any remaining money balances carry over as the state variables for the next period.

3.2.1 Domestic Household

The household maximizes its utility, denoted by U , considering goods consumption and a non-pecuniary penalty for external debt default. This non-pecuniary default penalty is expressed as a convex function of the real value of sovereign external debt subject to a parameter σ_b , multiplied by a penalty parameter Ω_t . Formally, the utility function for the representative household is represented as

$$U = \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{(C_t)^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} - \frac{1}{1 + \sigma_b} \Omega_t \left(\chi_t + \frac{\max(\mathcal{D}_t \mathcal{E}_t B_{t-1}^*, 0)}{P_t} \right)^{1+\sigma_b} \right) \right], \quad (3.1)$$

where β is the subjective discount factor, $\sigma > 0$ is the intertemporal elasticity of substitution in consumption. Households consume a composite good C_t composed of domestic goods $C_{d,t}$ and foreign goods $C_{f,t}$. I assume a constant elasticity of substitution (CES) aggregator and C_t is defined as:

$$C_t = \left(\iota^{\frac{1}{\nu}} (C_{d,t})^{\frac{\nu-1}{\nu}} + (1 - \iota)^{\frac{1}{\nu}} (C_{f,t})^{\frac{\nu-1}{\nu}} \right)^{\frac{\nu}{\nu-1}}, \quad (3.2)$$

where $\nu > 0$ is the elasticity of substitution between domestic and foreign goods. P_t denotes the domestic consumer price index(CPI), which equals to

$$P_t = \left(\iota (P_{d,t})^{1-\nu} + (1 - \iota) (\mathcal{E}_t P_{f,t})^{1-\nu} \right)^{\frac{1}{1-\nu}}, \quad (3.3)$$

where $P_{d,t}$ is the price of the domestic good, denominated in domestic currency, and $P_{f,t}$ is the price of the foreign good, denominated in the dominant currency, which is the U.S. dollar. \mathcal{E}_t denotes the nominal exchange rate. I normalize the price of foreign goods, $P_{f,t}$ to be 1. The parameter $1 - \iota \in (0, 1)$ represents the openness of the economy.

The default penalty term, Ω_t , represents the shadow cost of default, reflecting the severity of the penalty for defaulting. I assume $\Omega_t = \bar{\Omega}$, which is constant over time, following the setup used in [Dubey et al. \(2005\)](#). This non-monetary default

penalty accounts for both the reputational consequences of sovereign debt for EMEs (Eaton and Gersovitz, 1981; Cole and Kehoe, 2000) and the potential cost of exclusion from international financial markets (Gelos et al., 2011; Cruces and Trebesch, 2013). Goodhart et al. (2018) propose a pro-cyclical default penalty term, indicating that the penalty depends on variations in macroeconomic indicators and economic situations. Since my analysis focuses on the exchange rate externality, I simplify the term to isolate the impact of exchange rate fluctuations on the default cost. The non-pecuniary default cost of the domestic country is expressed as the product of the default penalty term Ω_t and a convex function of the real value of the external debt, given by:

$$\frac{1}{1 + \sigma_b} \Omega_t \left(\chi_t + \frac{\max(\mathcal{D}_t \mathcal{E}_t B_{t-1}^*, 0)}{P_t} \right)^{1 + \sigma_b},$$

where χ_t is a positive constant ensuring that the no-default regime can be achieved in equilibrium. I assume $\sigma_b > 0$, indicating that the cost is a convex function of the real value of external debt. The default rate \mathcal{D}_t represents the proportion of the external debt that the government defaults in the equilibrium. This is interpreted as the default rate in the optimal conditions of this paper. In this paper, I use the terms “default rate” and “default probability” interchangeably throughout the analysis.

At time t , households are subjected to a cash-in-advance constraint and resource constraints:

$$P_{d,t} C_{d,t} + \mathcal{E}_t P_{f,t} C_{f,t} \leq M_{t-1} + T_t + Q_t B_t. \quad (3.4)$$

As shown in equation (3.4), at the beginning of period t , the household starts with domestic currency holdings M_{t-1} and receives a government lump-sum transfer T_t . The representative household can also obtain (or issue) an intra-period domestic loan B_t at a price Q_t , which can be used to purchase domestic and foreign goods for consumption. Note that $1/Q_t$ equals the nominal interest rate set by the domestic central bank. In my model, $M_t = M_{t-1} + T_t$, assuming the government controls the money supply

through lump-sum taxation. The optimal allocation of expenditure between domestic and foreign goods in equilibrium, derived from the first-order conditions (FOC) of $C_{d,t}$ and $C_{f,t}$, is given by:

$$C_{d,t} = \iota \left(\frac{P_{d,t}}{P_t} \right)^{-\nu} C_t; \quad C_{f,t} = (1 - \iota) \left(\frac{\mathcal{E}_t P_{f,t}}{P_t} \right)^{-\nu} C_t. \quad (3.5)$$

The domestic and foreign consumption depend on the relative price between the foreign goods and domestic goods and the openness parameter ι . The optimal allocation function indicates $P_{d,t}C_{d,t} + \mathcal{E}_t P_{f,t}C_{f,t} = P_t C_t$. Accordingly, the cash-in-advance constraint can be rewritten as:

$$P_t C_t \leq M_{t-1} + T_t + Q_t B_t. \quad (3.6)$$

Furthermore, the household is subject to a budget constraint expressed in terms of domestic currency.

$$M_t + P_{d,t}C_{d,t} + B_t + P_{d,t}I_{d,t} + P_{d,t}\Phi_{d,k}(K_t) + F_t = T_t + Q_t B_t + M_{t-1} + P_{d,t}Y_t. \quad (3.7)$$

As shown in equation (3.7), domestic households have domestic monetary resources that include the domestic currency holdings from the previous period M_{t-1} , a domestic loan B_t from the central bank at price Q_t , government transfers T_t , and the sales revenue from production goods Y_t . These resources are used to purchase domestic goods for consumption $C_{d,t}$ at price $P_{d,t}$, to repay the domestic debt B_t at the end of the period, to invest domestic capital $I_{d,t}$ as investment and to allocate F_t to the foreign exchange market for exchanging into U.S. dollars. The adjustment of capital away from the steady state is subject to an adjustment cost function $\Phi_d(K_t)$. The rest M_t is held and carried forward into period $t + 1$.

$$P_{f,t} (C_{f,t} + I_{f,t} + \Phi_{f,k}(K_t)) + B_{t-1}^* (1 - \mathcal{D}_t) = \frac{F_t}{\mathcal{E}_t} + Q_t^* B_t^* - Q_t^* \Phi_b(B_t^*). \quad (3.8)$$

Equation (3.8) is denominated in U.S. dollars. The purchase of foreign capital as production factors can be financed through external debt denominated in U.S. dollars. The domestic household issues external debt to acquire U.S. dollars from the international market at the price Q_t^* . It uses the funds obtained from the foreign exchange market, $F_t/\mathcal{E}t$, and U.S. dollars from external debt, $Q_t^*B_t^*$, to purchase foreign goods $C_{f,t}$ for consumption and $I_{f,t}$ for foreign investment.

The foreign investment $I_{f,t}$ represents the capital contributed by foreign investors, reflecting the inflow of resources from external sources into the domestic economy. This term specifically captures the reliance on imported goods as capital. In this paper, I use changes in $I_{f,t}$ to evaluate variations in imported capital goods in the domestic economy. Similarly, the adjustment of foreign capital is subject to an adjustment cost function $\Phi_f(K_t)$. Additionally, the adjustment of foreign bonds is subject to an adjustment cost $Q_t^*\Phi_b(B_t^*)$. The remaining funds are used to repay the previous period's external debt, subject to a default level \mathcal{D}_t .

Similar to the consumption aggregator, the aggregate investment is a CES function composed of domestic investment $I_{d,t}$, and foreign investment $I_{f,t}$, given by:

$$I_t = \left(\iota^{\frac{1}{\nu}} (I_{d,t})^{\frac{\nu-1}{\nu}} + (1-\iota)^{\frac{1}{\nu}} (I_{f,t})^{\frac{\nu-1}{\nu}} \right)^{\frac{\nu}{\nu-1}}, \quad (3.9)$$

Therefore, parallel to the optimal consumption goods equation in the equilibrium, I have:

$$I_{d,t} = \iota \left(\frac{P_{d,t}}{P_t} \right)^{-\nu} I_t; \quad I_{f,t} = (1-\iota) \left(\frac{\mathcal{E}_t P_{f,t}}{P_t} \right)^{-\nu} I_t. \quad (3.10)$$

The evolution of capital follows a standard law of motion, given by:

$$K_{t+1} = I_t + (1-\gamma)K_t, \quad (3.11)$$

where γ is the depreciation rate of capital in EMEs. The aggregate capital is used for

production, the domestic production function is given by:

$$Y_t = A_t(K_t)^\alpha, \quad (3.12)$$

where $A_t = \bar{A}$. The variable \bar{A} denotes the level of technological efficiency. In this model, I assume that labor does not explicitly enter the production process by combining it with technology and thus absorbing its effect into an 'augmented productivity' term. This approach helps isolate the role of capital dynamics in domestic production.

I define the aggregate adjustment cost function $\Phi_K(K_t)$ and $\Phi_{B^*}(B_t^*)$ as

$$\Phi_k(K_t) = \frac{\Psi_k}{2} \left(\frac{K_t}{\bar{K}} - 1 \right)^2 \bar{K}; \quad \Phi_b(B_t^*) = \frac{\Psi_b}{2} \left(\frac{B_t^*}{\bar{B}^*} - 1 \right)^2 \bar{B}^*, \quad (3.13)$$

where \bar{K} represents the capital level at the steady state, and \bar{B} represents the external debt level at the steady state. The adjustment cost for domestic capital and foreign capital is given by

$$\Phi_{d,k}(K_t) = \iota \left(\frac{P_{d,t}}{P_t} \right)^{-\nu} \Phi_k(K_t); \quad \Phi_{f,k}(K_t) = (1 - \iota) \left(\frac{\mathcal{E}_t P_{f,t}}{P_t} \right)^{-\nu} \Phi_k(K_t).$$

The domestic goods market clearing condition indicates $Y_t = C_{d,t} + X_t + I_{d,t} + \Phi_{d,k}(K_t)$, where X_t is the external demand from foreign countries, defined as:

$$X_t = \xi \left(\frac{P_t}{\mathcal{E}_t P_{f,t}} \right)^{-\phi} \frac{1}{1 + i_t^*}, \quad (3.14)$$

where ξ is an exogenous external demand coefficient, ϕ measures the elasticity of external demand, and i_t^* represents the nominal U.S. interest rate. The parameter ϕ corresponds to the Armington elasticity of the rest of the world. I assume that a higher U.S. interest rate reduces the aggregate demand of foreign households for domestic output. The foreign exchange market clearing condition is given by $P_{d,t} X_t = \mathcal{E}_t F_t$.

I write the cash-in-advance constraints and the budget constraints in real terms

and relative prices to calculate the results under a positive inflation rate target. I first define the real exchange rate S_t as

$$S_t = \frac{\mathcal{E}_t P_{f,t}}{P_t},$$

and the terms of trade Θ_t as

$$\Theta_t = \frac{\mathcal{E}_t P_{f,t}}{P_{d,t}}.$$

According to the definition of the relative prices, the cash-in-advance constraint could be expressed in real terms by dividing both sides of the cash-in-advance constraint by the price index P_t ,

$$C_t = \frac{m_{t-1}}{1 + \pi_t} + \tau_t + Q_t b_t, \quad (3.15)$$

where π_t is the domestic inflation rate, defined as $\pi_t = P_t/P_{t-1} - 1$, $m_{t-1} = M_{t-1}/P_{t-1}$ represents the real money balance from the previous period, $\tau_t = T_t/P_t$ is the lump-sum tax transfer in real term, and $b_t = B_t/P_t$ is the real value of domestic loans. According to the flow of money function, the aggregate money held at the end of period t in real terms equals the aggregate consumption, C_t , such that $C_t = m_t$.

When the domestic interest rate is positive, the cash-in-advance constraint inequality binds ¹. I combine the domestic currency budget constraint with the U.S. dollar budget constraint. By dividing through by the price index P_t , I derive the following period budget constraint expressed in real terms, incorporating the terms of trade and the real exchange rate:

$$\begin{aligned} m_t + C_t + b_t + I_t + \Phi_k(K_t) + \frac{S_t b_{t-1}^* (1 - \mathcal{D}_t)}{1 + \pi_{t+1}^*} \\ = \tau_t + Q_t b_t + S_t Q_t^* (b_t^* - \Phi_b(B_t^*)) + \frac{m_{t-1}}{1 + \pi_t} + \frac{S_t}{\Theta_t} A_t K_t^\alpha, \end{aligned} \quad (3.16)$$

¹For a detailed proof, please refer to [Walsh \(2017\)](#).

where π_{t+1}^* represents the inflation rate in the foreign country. I assume that the price index in the foreign country remains constant over time, implying $\pi_{t+1}^* \equiv 0$ in the model.

3.2.2 Equilibrium Conditions and Discussions

In equilibrium, the intratemporal optimality condition generates the standard Euler equation, where

$$Q_t = E_t \left[\beta \frac{1}{(1 + \pi_{t+1})} \left(\frac{C_{t+1}}{C_t} \right)^{-1/\sigma} \right]. \quad (3.17)$$

In the steady state, the $\beta = Q(1 + \bar{\pi})$, where $\bar{\pi}$ equals to the inflation target set by the domestic central bank. Equation (3.17) can be log-linearize around the steady state and rewrite as:

$$\hat{c}_t = E_t[\hat{c}_{t+1}] - \sigma \left(\hat{i}_t - E_t[\hat{\pi}_{t+1}] \right), \quad (3.18)$$

where lower letters with hat represent the log deviations of the corresponding variables from their respective steady-state levels. The Euler equation of the production factor from the FOC indicates:

$$1 + \Psi_K \left(\frac{K_{t+1}}{\bar{K}} - 1 \right) = E_t \left[\beta \frac{Q_{t+1}}{Q_t} \left(\frac{C_{t+1}}{C_t} \right)^{-1/\sigma} \left(\frac{S_{t+1}}{\Theta_{t+1}} A_{t+1} \alpha (K_{t+1})^{\alpha-1} + 1 - \gamma \right) \right]. \quad (z)$$

Assume the international investors are risk-neutral, following a no-arbitrage condition, in equilibrium, the price of the external debt equals:

$$Q_t^* = \frac{1}{1 + i_t^*} E_t[1 - \mathcal{D}_{t+1}], \quad (3.19)$$

where i_t^* represents the interest rate on risk-free U.S. debt in the international market. Equation (3.19) indicates the external debt of the domestic country depends on the expected default risk. The log deviations of the external debt price could be derived

as: ²

$$\hat{q}_t^* = -\hat{i}_t^* - E_t[\hat{\delta}_{t+1}]. \quad (3.20)$$

In this framework, the risk premium of the domestic external debt arises solely from the rate of default in the next period. In the absence of default risk, where $E_t[\mathcal{D}_{t+1}] = 0$, Q_t^* would equal the price of a risk-free U.S. bond.

In my model, the standard uncovered interest parity (UIP) doesn't hold due to two key frictions. First, there is a duration mismatch between domestic and foreign debt. The domestic interest rate corresponds to a short-term intraperiod loan, whereas the external debt is typically long-term inter-period debt. This is consistent with empirical evidence showing that the external debt of EMEs generally has a longer duration (Sánchez et al., 2018). The exchange rate dynamics in this setup must account for the short-term domestic interest rate and future inflation. Second, the risk premium associated with domestic external debt, coupled with adjustment costs for bond capital, creates additional friction. These frictions prevent the free movement of funds, increase the associated risk premium, and amplify deviations from UIP. In my model, the interactions between the domestic interest rate, the U.S. interest rate, and the real exchange rate in equilibrium are derived from the optimal conditions and are formally expressed in the equation below:

$$Q_t^* \left(1 - \Psi_B \left(\frac{B_t}{B} - 1\right)\right) = E_t \left[\beta \frac{Q_{t+1}}{Q_t} \left(\frac{C_{t+1}}{C_t}\right)^{-1/\sigma} \frac{S_{t+1}}{S_t} \frac{1}{1 + \pi_{t+1}^*} \right]. \quad (3.21)$$

According to equation (3.21), in the steady state, assuming the real exchange rate is constant then the depreciation speed of the domestic currency $\mathcal{E}_t/\mathcal{E}_{t-1}$ is the same as the domestic inflation, then $Q_t^* = \beta/(1 + \pi_{t+1}^*)$. Combine this condition with no arbitrage condition of the external debt pricing function, I have in the steady state, the default

²Since defaults are rare, I assume that the default rate is zero in the steady state. For a more general case, $\hat{q}_t^* = -\hat{i}_t^* + \ln\left(\frac{E_t[1-\mathcal{D}_{t+1}]}{1-\mathcal{D}}\right)$.

rate $\mathcal{D} = 1 - \beta/\beta^*$, where I assume β^* is the subjective discount factor in the foreign country and $\beta^*(1 + i_t^*) = 1 + \pi_{t+1}^*$. I can rewrite the equation (3.21) in a log-linearize form around the steady state as:

$$\left(E_t[\hat{i}_{t+1}] - E_t[\hat{\pi}_{t+1}]\right) - \left(\hat{i}_t^* - E_t[\hat{\pi}_{t+1}^*]\right) - E_t[\hat{\delta}_{t+1}] - \Psi_B \hat{B}_t = E_t[\hat{s}_{t+1}] - \hat{s}_t. \quad (3.22)$$

According to equation (3.22), the change in the real exchange rate around the steady state deviates from the standard UIP due to capital control costs, default risk, and fluctuations in the short-term domestic interest rate and inflation. A higher future default probability would depreciate the current period's real exchange rate while reducing the rate of depreciation in the future, consistent with the paper [Na et al. \(2018\)](#).

Finally, in equilibrium, the default on the verge condition indicates:

$$\Omega_t(\chi_t + S_t b_{t-1}^* \mathcal{D}_t)^{\sigma_b} = Q_t(C_t)^{-1/\sigma}, \quad (3.23)$$

where the marginal cost of default is represented on the left-hand side, which is lower when the domestic currency is strong and external debt levels are low in equilibrium. On the right-hand side, the marginal benefits of default are represented, which are higher in a low-interest-rate and low-consumption (bad) state. The model contains multiple equilibria, as discussed in [Goodhart et al. \(2018\)](#).

In this paper, I focus on analyzing the equilibrium where the steady-state default rate is equal to zero, capturing the empirical observation that sovereign default events are rare. To ensure this, I assume that the default penalty, Ω , is sufficiently high to exceed the steady-state marginal benefits of default, and that $\chi_t > 0$, ensuring that zero default occurs in the steady state. Specifically, I assume that $\Omega_t \chi_t$ is higher than the steady-state marginal benefits of default, making no sovereign default the optimal condition in the steady state.

The model includes an occasionally binding constraint, where partial default becomes optimal under severe conditions. A large negative shock, such as a sharp U.S. monetary policy shock, significantly reduces domestic aggregate consumption, which increases the marginal benefits of default. Thus, the previously non-binding constraint on default becomes binding, and partial default becomes an equilibrium response to the negative shock. This setup captures both the rarity of sovereign default under normal conditions and the possibility of default under a large external shock.

3.2.3 Monetary Policy

The domestic country is subject to external U.S. monetary policy shocks. Following the framework in [Fernández-Villaverde et al. \(2011\)](#) and [Johri et al. \(2022\)](#), I assume that the U.S. interest rate, denoted as i_t^* , faced by domestic households evolves as:

$$i_t^* = \bar{i}^* + \epsilon_t^*,$$

where \bar{i}^* represents the steady-state U.S. interest rate, reflecting the long-term average level of the U.S. interest rate, and ϵ_t^* captures deviations from this steady-state caused by monetary policy shocks. The law of motion of the monetary policy shock follows a first-order autoregressive process:

$$\epsilon_t^* = \rho^* \epsilon_{t-1}^* + \mu_t^*,$$

where $\rho^* \in [0, 1)$ is the persistence parameter that determines how much of the current monetary shock ϵ_t^* carries over to subsequent periods. The term μ_t^* represents unanticipated shocks to U.S. monetary policy at t , with $\mu_t^* \sim \mathcal{N}(0, \sigma_{\mu^*}^2)$.

Finally, the domestic central bank sets the domestic nominal interest rate, i_t , according to a standard Taylor rule, which links monetary policy to deviations of inflation, output, and real exchange rate from their respective steady states. The Taylor rule is

specified as:

$$\frac{1 + i_t}{1 + \bar{i}} = \left(\frac{1 + i_{t-1}}{1 + \bar{i}} \right)^{\rho_i} \left(\left(\frac{1 + \pi_t}{1 + \bar{\pi}} \right)^{1 + \phi_\pi} \left(\frac{y_t}{\bar{y}} \right)^{\phi_y} \left(\frac{S_t}{\bar{S}} \right)^{\phi_s} \right)^{1 - \rho_i}, \quad (14)$$

where $1 + \bar{i}$ represents the steady-state domestic interest rate. The price Q_t of the domestic loan is given by $\frac{1}{1 + i_t}$. In this framework, according to the Euler equation (3.17), the steady-state interest rate is determined by the household's discount factor, yielding $1 + \bar{i} = (1 + \bar{\pi})/\beta$. The parameters $\phi_\pi > 1$, $\phi_s > 0$, and $\phi_y > 0$ are Taylor rule coefficients, representing the central bank's responsiveness to deviations in inflation, output, and real exchange rate, respectively.

3.3 Quantitative Analysis

In this section, based on the model proposed in Section 2, I calibrate the model to analyze how a U.S. monetary policy shock affects the domestic economy's incentive to default and how the capital level and foreign investment level influence the incentive to default in response to a U.S. monetary policy shock.

I calibrate the key parameters of the model to align with the empirical values documented in [Mendoza and Yue \(2012\)](#), [Bajzik et al. \(2020\)](#), [Gilchrist et al. \(2019\)](#), and [Johri et al. \(2022\)](#), while assigning standard values to the remaining parameters.³ Table 3.1 provides an overview of the calibrated parameters, their values, and the target moments or sources. This calibration ensures that the model parameters are consistent with observed data and standard theoretical benchmarks, allowing the model to produce results that align with the empirical behaviour of emerging economies.

I set the US interest rate to a standard value of 0.01% and calibrate the domestic discount factor, $\beta = 1/1.01$, to ensure that the steady-state default rate equals 0. The annualized inflation rate is assumed to be 6%, consistent with the IMF's estimates for

³[Johri et al. \(2022\)](#) use quarterly frequency data from a group of 13 emerging economies for the years 1994–2008 to estimate the moments of the corresponding statistics.

emerging and developing markets. The share of domestic goods, $\iota = 0.62$, is based on the estimates provided by [Mendoza and Yue \(2012\)](#), reflecting the openness of the economy. Household risk aversion is calibrated to $1/\sigma = 2$. The Armington elasticity, ν , is set to 1.83, which corresponds to the mean value for developing countries. The external demand elasticity of the global economy is assumed to match that of developed countries, estimated at 1.24, as documented by [Bajzik et al. \(2020\)](#). The autocorrelation of U.S. monetary shocks, $\rho_r = 0.908$, is calibrated based on the estimates in [Johri et al. \(2022\)](#).

The weights in the Taylor rule are set as $\phi_\pi = 1.5$ and $\phi_y = \phi_s = 0.025$, which are standard values indicating the central bank's responsiveness to inflation and output and real exchange rate deviations, respectively. The external demand $\xi = 2.86$ is calibrated to match an external-debt-to-GDP ratio of 44%, as estimated by [Johri et al. \(2022\)](#). The depreciation rate of capital is set at 0.025, corresponding to an annualized value of 10%. The adjustment costs of both capital Ψ_I and bonds Ψ_B are set at 100, which interprets the adjustment in percentage terms.

The default penalty $\bar{\Omega} = 0.1$ and constant χ is calibrated to capture the EME external debt cost increase in response to U.S. monetary policy shocks, as documented in [Gilchrist et al. \(2019\)](#). I set the convex coefficient σ_b to 1.

In the benchmark calibration, I set the capital share $\alpha = 0.35$ and changed the capital share to evaluate how different levels of capital share and foreign investment influence default decisions in response to a U.S. monetary policy shock.

Table 3.1: Calibration and Target Values of Model Parameters

Parameters	Calibration Value	Target Value
U.S. interest rate	$i_t^* = 0.01$	Standard Value
Discount factor	$\beta = 1/1.01$	Steady State No Default
Share on domestic goods	$\iota = 0.62$	Mendoza and Yue (2012)
Household risk aversion	$\sigma = 0.5$	Standard Value
Substitution elasticity	$\nu = 1.83$	Bajzik et al. (2020)
US Monetary Shock autocorrelation	$\rho_r = 0.908$	Johri et al. (2022)
Capital Share	$\alpha = 0.35$	Benchmark Value
Weight in Taylor rule	$\phi_\pi = 1.5; \phi_s = \phi_y = 0.025$	Standard Value
External Demand	$\xi = 2.86$	Debt/GDP 44%
Productivity Level	$\bar{A} = 1$	Standard Value
Domestic Inflation	$\bar{\pi} = 0.015$	Annualized Inflation 6%
Default penalty	$\bar{\Omega} = 0.1, \sigma^b = 1, \chi = 0.71^{1/\sigma^b}$	Gilchrist et al. (2019)
External Demand Elasticity	$\phi = 1.24$	Bajzik et al. (2020)
Capital Depreciation	$\delta = 0.025$	Annualized 10%
Adjustment Cost	$\Psi_I = \Psi_B = 100$	Adjustment in Percentage

3.3.1 Static Analysis

First, I conduct a static analysis to examine how steady-state equilibrium allocations change with varying external debt levels in economies with different capital share coefficients α . Figure 3.2 plots the static analysis of the steady state with respect to different values of the external debt-to-GDP level. I change the value of the external demand coefficient ξ to simulate economies with different external debt-to-GDP ratios. The results are shown in Appendix, Figure 3.A. Higher external demand leads to a greater level of external debt because a country with higher exports can sustain a higher level of external debt. The red dot indicates the benchmark result, corresponding to the parameter space and moment matching shown in Table 3.1. The values in the figures for this section are normalized by dividing them by the benchmark result.

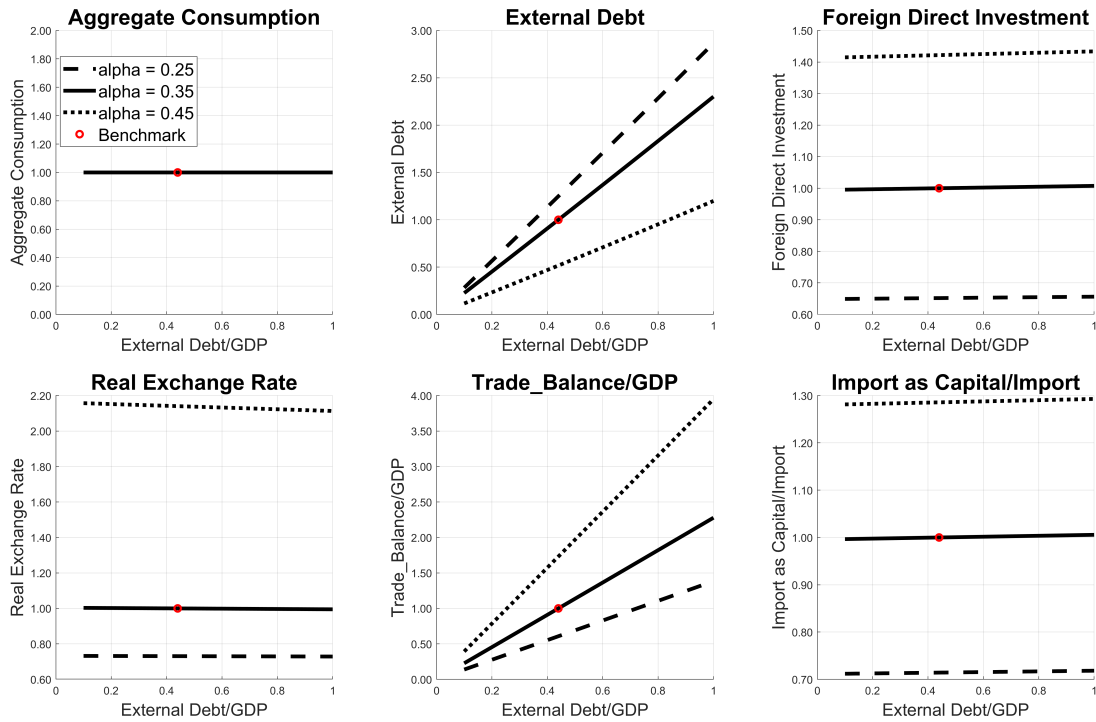


Figure 3.2: Static Analysis of Endogenous Variables with Different Capital Shares and Debt-to-GDP Ratios

For each subfigure, the x-axis represents the external debt-to-GDP level, and the y-axis represents the value of the corresponding endogenous variable relative to the benchmark. The three lines represent α values of 0.25, 0.35, and 0.45, as shown in the legend, which corresponds to the share of capital in production.

According to Figure 3.2, a higher capital share leads to a larger proportion of foreign capital in total imports, indicating that a greater portion of imports is allocated to production. This increased demand for imports in production raises the total level of foreign capital, which is interpreted as reliance on foreign goods in my model. The higher level of imports further results in a depreciation of the domestic currency and induces a higher trade balance. The improved trade balance reduces the external debt demand to finance expenditures, particularly for capital goods.

In addition, the aggregate consumption level in my model does not change signifi-

cantly with respect to the capital share. This suggests that the capital share primarily influences the economy by altering the composition of imported goods, the real exchange rate, and trade openness without affecting the total social welfare. Moreover, the external debt-to-GDP ratio has a limited effect on the investment level and imported capital goods, but primarily affects the economy through the external debt and trade balance terms. A higher external debt-to-GDP ratio indicates higher export demand and an increasing trade balance.

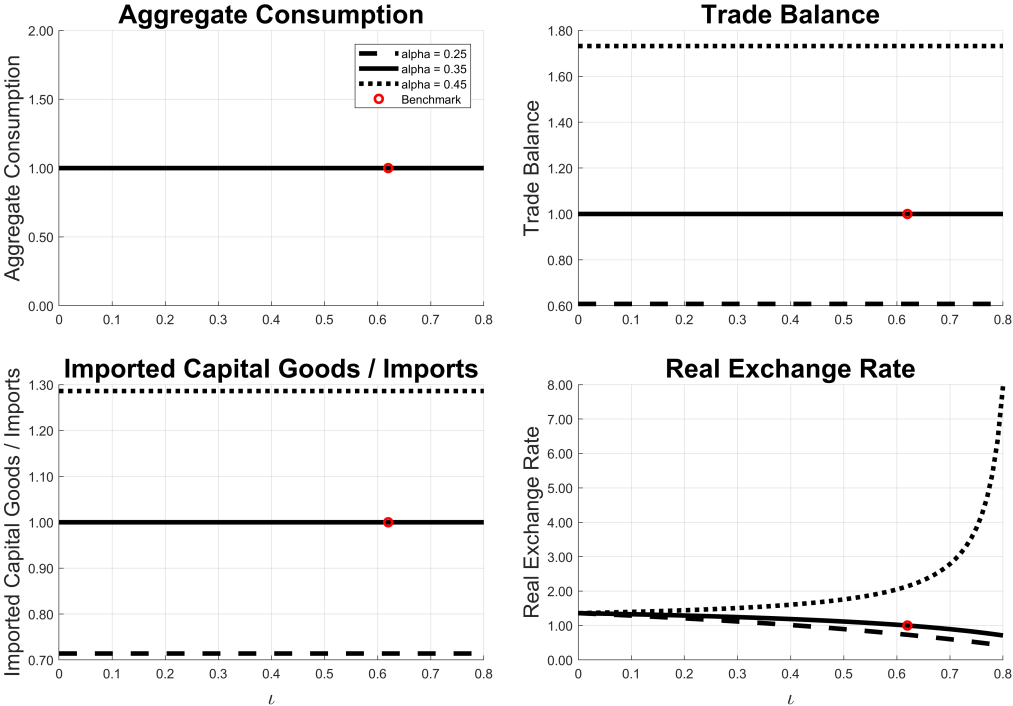


Figure 3.3: Static Analysis of Endogenous Variables with Different Capital Shares α and Trade-Openness Coefficient ι

In my model, both the trade-openness coefficient ι and the capital share α determine the total volume of imported goods, especially imported capital goods. To isolate the effect of trade openness in the investment bundle on sovereign default, I conduct the static experiment summarised in Figure 3.3. For each value of capital share α , I carry out a static experiment in which trade-openness coefficient ι varies from 0 (all investment goods imported) to 0.8 (predominantly domestic investment goods), while

the external-debt-to-GDP ratio and all other parameters are kept at their benchmark values reported in Table 3.1.

Figure 3.3 shows that the trade-openness weight ι plays only a secondary role in my model in shaping the component of imported goods once the capital share α is fixed. Aggregate consumption (upper-left panel) is essentially flat as ι increases from 0 to 0.8, indicating that steady-state utility depends on the marginal product of capital rather than on the relative share of imported versus domestic goods. The composition of imports shares similar results. The share of imports that are channelled into capital formation (lower-left panel) is horizontal in ι yet clearly separated by the three α curves; a larger capital share raises this ratio of import goods as capital regardless of the openness parameter. The trade balance and the real exchange rate follow the same pattern: a higher α leads to larger trade surpluses and a weaker currency, even when most capital goods are produced at home. Therefore, capital share α —through the inelastic demand for imported capital—drives both the steady-state allocations and the exchange-rate externality, while the trade-openness coefficient ι plays only a minor role in the model.

3.3.2 Impulse Response Analysis

The static analysis examines how the domestic economy changes with respect to different external debt levels and capital share values. Building on these insights, I further examine the impact of U.S. monetary policy shocks on sovereign default risk under different capital share values and external debt values. Figure 3.4 presents the impulse response of the domestic economy to a 50 bps increase in the U.S. monetary policy shock under different capital shares.

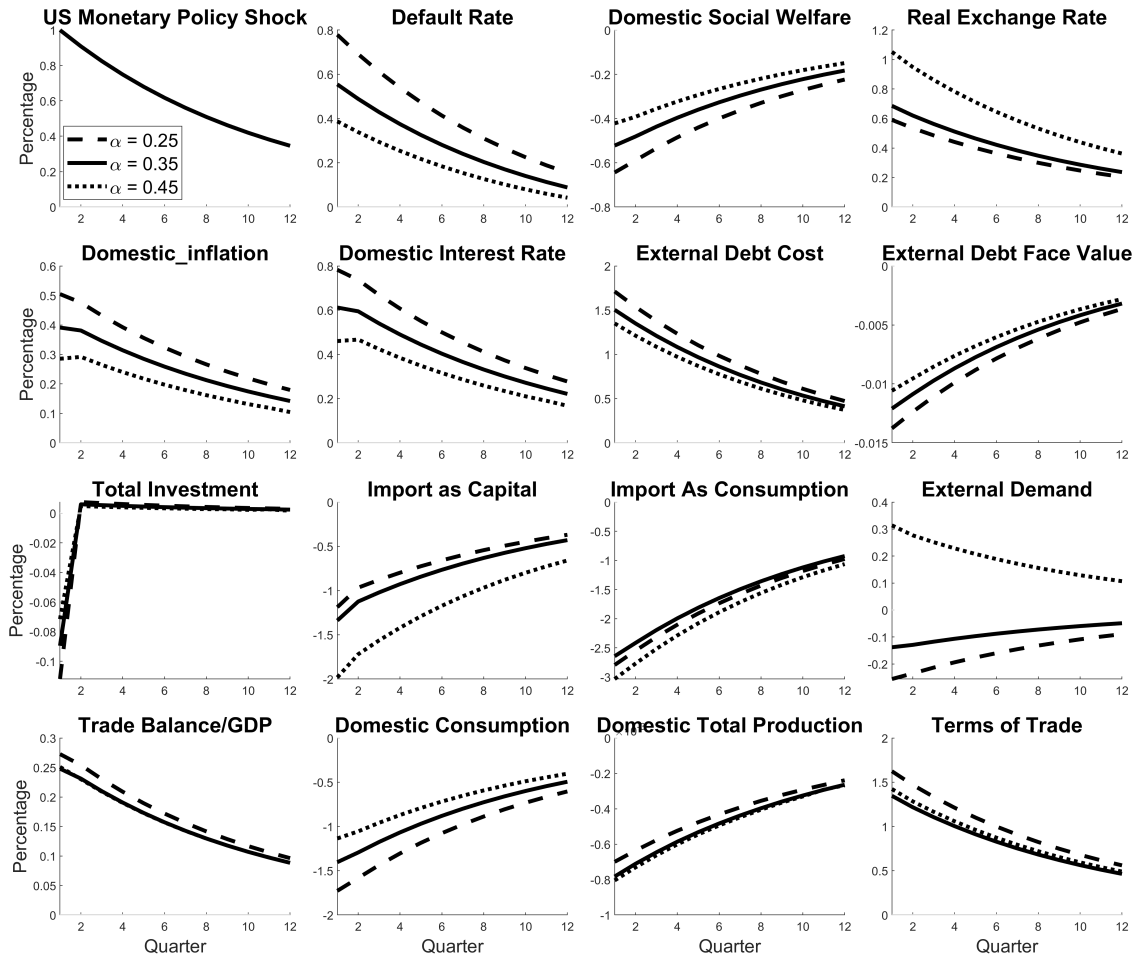


Figure 3.4: Impulse Response of 1% US Monetary Policy Shock

For each subfigure, the horizontal axis represents the quarters after the monetary policy shock, and the vertical axis represents the percentage change relative to the steady-state value of the corresponding endogenous variables following a 50-basis-point (bps) U.S. monetary policy shock. The results are normalized by dividing the values by 0.5 to illustrate the effects of a 1-percentage-point change in the U.S. interest rate. The dashed line, solid line, and dotted line represent the impulse response under different capital shares, where the capital share equals 0.25, 0.35, and 0.45, respectively.

As discussed in the default-on-the-verge condition Equation (3.23), in the calibration results, I assume that the default penalty term Ω is 2.5% higher than the value of $\bar{\Omega}$ corresponding to the marginal benefits of default for an on-the-verge no-default equi-

librium. In this case, a small monetary policy shock would not induce a large enough negative effect on domestic aggregate consumption to push the marginal benefits of default beyond the costs, and the equilibrium still holds for the no-default regime. As shown in Figure 3.C, no default remains the optimal choice for the domestic government when the domestic economy faces a 1bps U.S. monetary policy shock.

When the economy faces a large U.S. monetary policy shock, equal to 50bps, the sharp decrease in domestic social welfare and the increase in the domestic interest rate cause the benefits of default to exceed the costs, making a positive default rate the optimal choice in equilibrium, as shown in Figure 3.4. In this regime, the default rate increases by 0.55% in response to a 1% increase in the U.S. monetary policy shock under the benchmark with a capital share of 0.35. This is accompanied by approximately a 0.5% decrease in social welfare and a 0.65% increase in the real exchange rate.

According to the pricing function of external debt, as shown in equation (3.19), the decrease in repayment amplifies the external debt cost to a level exceeding a one-to-one response to the U.S. monetary policy shock. The higher external debt cost and the depreciation of the real exchange rate further reduce domestic consumption and social welfare. Moreover, the shortage of foreign investment generates a supply shock to the domestic economy, leading to domestic inflation. To manage both inflation and the depreciation of the exchange rate, the domestic central bank must raise domestic interest rates, which aligns with the empirical findings documented in Kalemli-Özcan (2019).

This result provides the first channel that affects the default incentive in facing U.S. monetary policy shock. The increase in the U.S. interest rate raises the external debt cost for the domestic economy via the no-arbitrage pricing function of external debt, as shown in equation (3.19). This gives rise to an incentive for the domestic government to default as a way to compensate for the reduction in consumption caused by the tight budget constraint generated by the higher cost of debt.

More importantly, the impulse response changes significantly with different capital share values. The dashed line in each subfigure represents the impulse response corresponding to a capital share of 0.25, which is lower than the benchmark, while the dotted line represents the result for a capital share higher than the benchmark, equal to 0.45. The results show that the default rate increases more and domestic social welfare decreases more in response to the U.S. monetary policy shock when the capital share is lower. A 10% decrease in the capital share increases the impulse response of the default rate from 0.55% to 0.78%, while a 10% increase in the capital share reduces it to 0.39%.

This deciphers the second channel: the trade-off between exchange rate externalities and aggregate consumption via the default-on-the-verge condition and foreign capital investment. U.S. monetary policy leads to a lower external demand for domestic goods from the U.S., causing an outflow of capital from the EME market. A higher capital share implies a higher marginal cost of reducing capital and greater adjustment costs associated with decreasing foreign capital investment. This reduces the elasticity of imported capital goods demand in response to foreign exogenous shocks. The inelasticity of imported capital goods demand leads to a sharper depreciation of the exchange rate in response to a monetary policy shock. The significant depreciation of the exchange rate increases the marginal cost of default, which arises as an externality of the exchange rate. This externality decreases the incentive for the domestic government to default, thereby reducing the default rate of sovereign debt.

On the other hand, when the capital share is smaller, a larger portion of imports is used directly for consumption. The substitution between foreign goods and domestic goods is easier than for investment goods, which results in a larger decrease in social welfare and a higher marginal utility benefit from default. The substitution from foreign goods to domestic goods induces a greater decrease in total imports, which generates a lower rate of depreciation of the real exchange rate. The increased marginal utility, combined with a higher real exchange rate, amplifies the marginal benefits of default, thereby increasing the default rate of EME sovereign debt. This default is accompa-

nied by a sharp increase in domestic interest rates and high inflation, further reducing domestic social welfare.

For completeness, Figure 3.B in the appendix reports the impulse responses for an economy with a high-openness parameter ($\iota = 0.1$), implying greater reliance on international trade for both consumption and investment. Although the overall default response is larger, the mechanism across capital-share cases is unchanged, mirroring our main results. This aligns with the static findings that ι alters aggregate imports only marginally and therefore plays a secondary role—relative to α —in the default trade-off driven by imported capital.

These findings highlight the critical role and mechanisms of capital share in shaping the default rate and domestic social welfare in response to U.S. monetary policy shocks, particularly through its effects on the real exchange rate. Building on this understanding, I now examine the response of the default rate to U.S. monetary policy shocks under different external debt levels and capital shares.

3.3.3 Capital Share and External Debt

Figures 3.5 and 3.6 show the first-period impulse response of endogenous variables to a U.S. monetary policy shock under different external debt-to-GDP ratios and capital share environments. The x-axis represents the external debt-to-GDP values, while the y-axis represents the first-period impulse response in percentage points for the corresponding endogenous variables. The legends for the lines in Figures 3.5 and 3.6 are the same as those in the previous section.

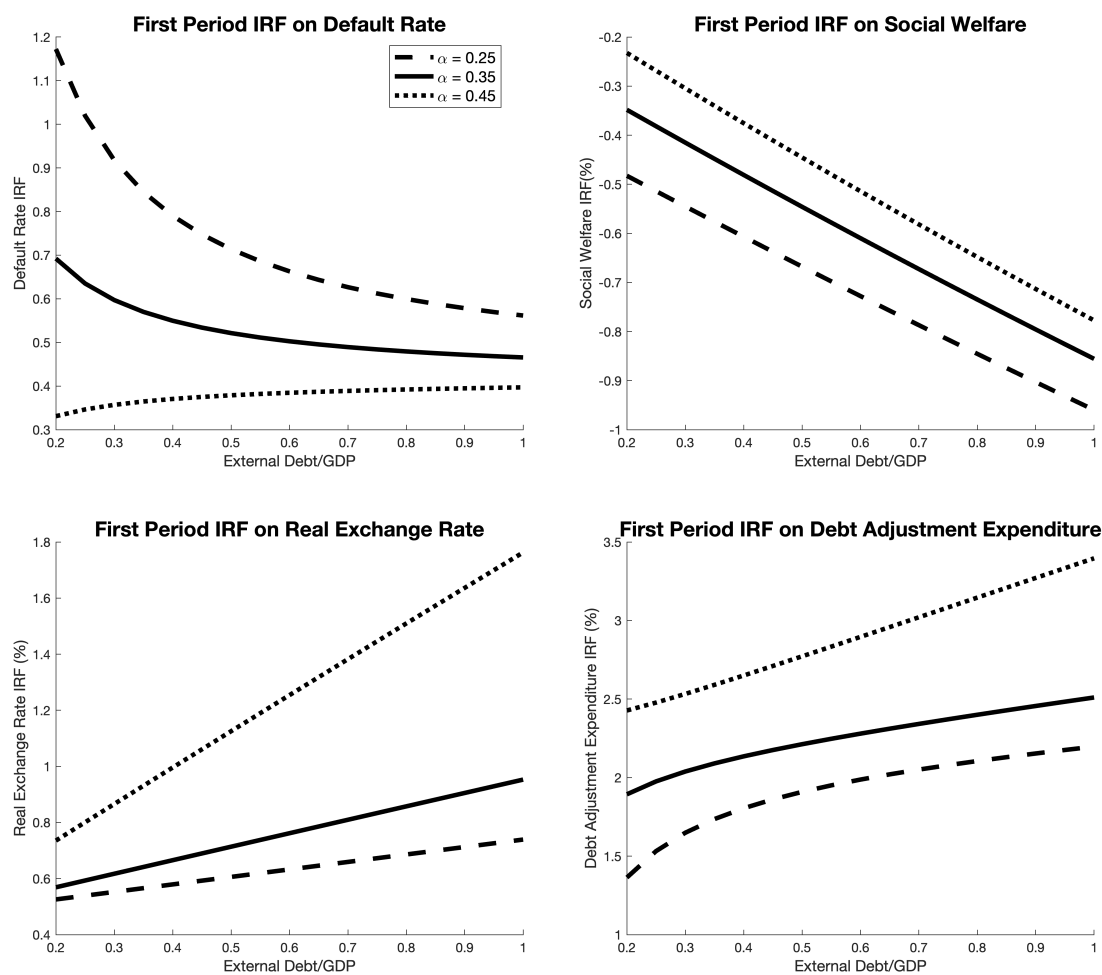


Figure 3.5: Impulse Response of 1% US Monetary Policy Shock under Different External Debt/GDP Level

The first subfigure in Figure 3.5 shows that different capital shares have distinct characteristics with respect to the default rate as the external debt level varies. Specifically, the default rate of an economy with a capital share below 0.35 decreases as external debt increases. My result contradicts the conclusions documented in the existing literature, which conclude that higher external debt-to-GDP levels are associated with higher default rates (Reinhart et al., 2003b; Mendoza and Yue, 2012). This discrepancy highlights the importance of the foreign investment channel in shaping the sovereign external debt default incentives of EMEs.

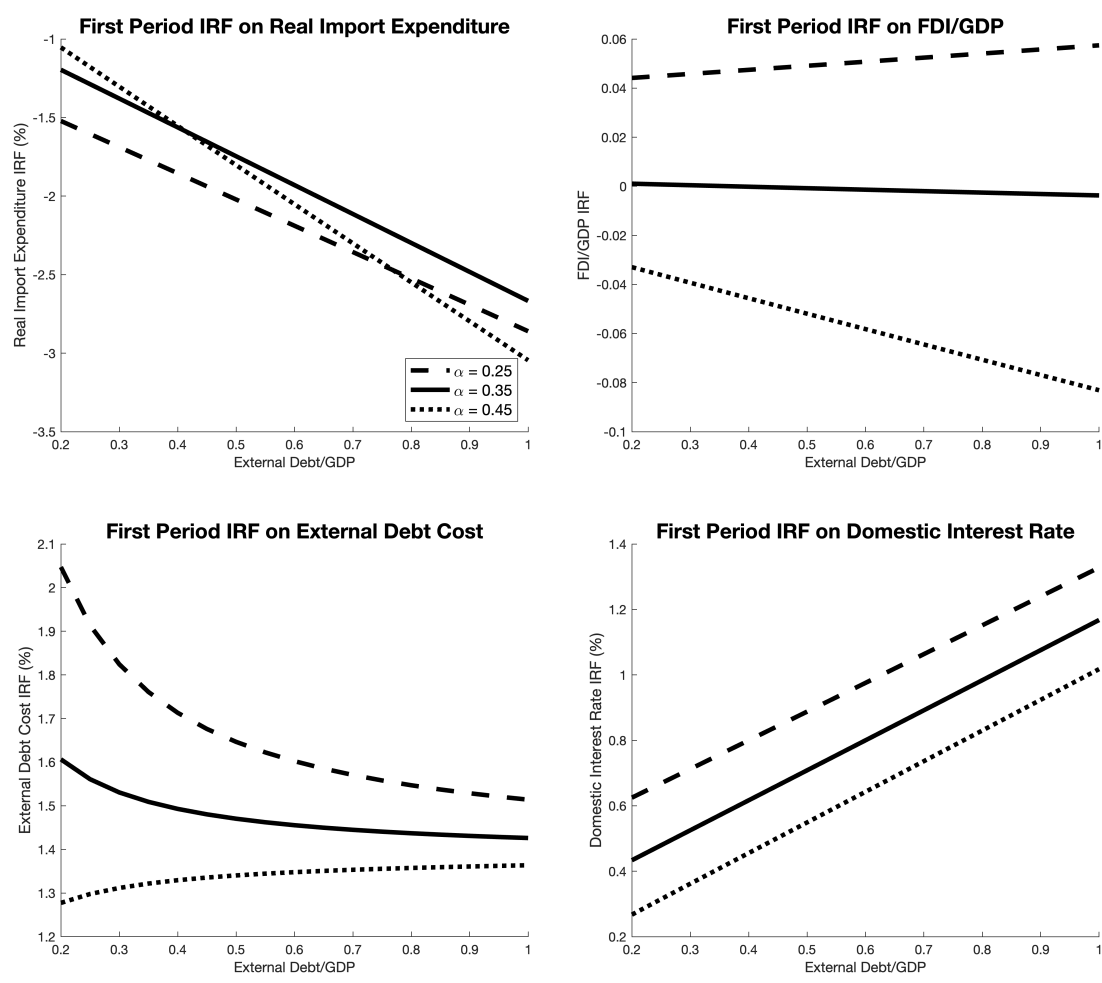


Figure 3.6: Impulse Response of 1% US Monetary Policy Shock under Different External Debt/GDP Level

As the external debt-to-GDP ratio increases, domestic exchange rate depreciation accelerates due to the higher demand for U.S. dollars to repay the debt, according to the static analysis. When the capital share is high, the inelastic demand of the domestic economy for investment amplifies the depreciation of the domestic currency. This depreciation of domestic currency increases the real value of the debt and induces externalities in the cost of default, which leads to a lower default rate in equilibrium. On the other hand, the depreciation of the domestic currency increases the real value of bonds and the cost of imports, as shown in the bottom-right subfigures in Figure

3.5 and the top-left subfigures in Figure 3.6. This leads to a sharp decrease in social welfare. When the capital share is high, the decrease in social welfare and the marginal benefits of default dominate the trade-off against the external debt default disincentive arising from exchange rate externalities.

When the capital share is low, the domestic economy does not rely heavily on external debt to finance investment, particularly imported capital goods. Consequently, a higher level of external debt has a smaller impact on aggregate consumption. In this scenario, the externality cost of the exchange rate dominates, so that higher real external debt levels result in a greater marginal cost of default, which in turn reduces the default rate as the external debt level increases.

The analysis in this section examines the first-period impulse response of key economic variables to a 1% U.S. monetary policy shock under varying external debt-to-GDP ratios and capital share environments. The results show that capital shares significantly influence default incentives and domestic economic responses to U.S. monetary policy shocks. Low capital shares induce higher exchange rate externality costs at high external debt levels, reducing default rates, while high capital shares amplify currency depreciation, increasing debt burdens, import costs, and social welfare losses, ultimately leading to higher default rates as an optimal choice.

3.4 Conclusion

The contribution of this paper is to explore the dynamics between exchange rate externalities, sovereign default risk, and foreign investment in response to U.S. monetary policy shocks.

I develop a small open economy model that incorporates endogenous default, exchange rate externalities, and the duration mismatch between domestic and external debt. The model is calibrated to match the moments of EMEs and offers insights into how different capital shares influence sovereign default incentives in response to U.S.

monetary policy shocks.

First, the results show that U.S. monetary shocks have a spillover effect on the domestic economy through the exchange rate and foreign investment channels. A tightening monetary policy shock induces a depreciation of the domestic currency, reduces domestic social welfare, decreases investment, and, in turn, leads to a higher default rate.

Next, I show that economies with higher capital shares and greater reliance on foreign investment experience greater exchange rate depreciation due to the inelasticity of demand for foreign investment. The increasing exchange rate externality increases the default cost and reduces the sovereign incentive to default.

Moreover, economies with a higher share of imports in production inputs are more likely to default when facing U.S. monetary policy shocks in a high external debt environment. In contrast, economies with lower capital shares experience less impact on social welfare under high external debt, and exchange rate externalities dominate. These results indicate a negative relationship between default rates and external debt levels for economies with low capital share and foreign investment. These findings have important policy implications, as they underscore the critical role of foreign capital and investment structures in shaping sovereign risk and highlight the trade-offs involved in managing external debt, exchange rate policies, and capital inflows under global financial cycles.

Appendix

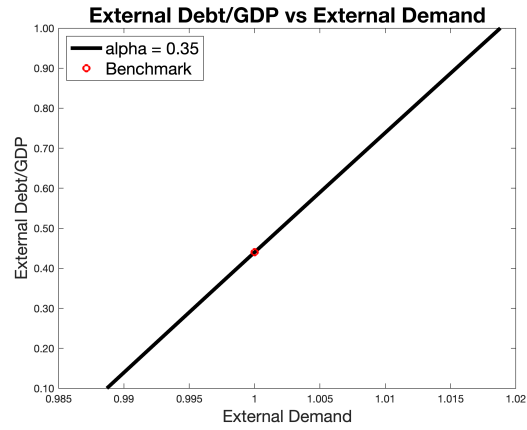


Figure 3.A: Static Analysis of Debt/GDP vs External Demand

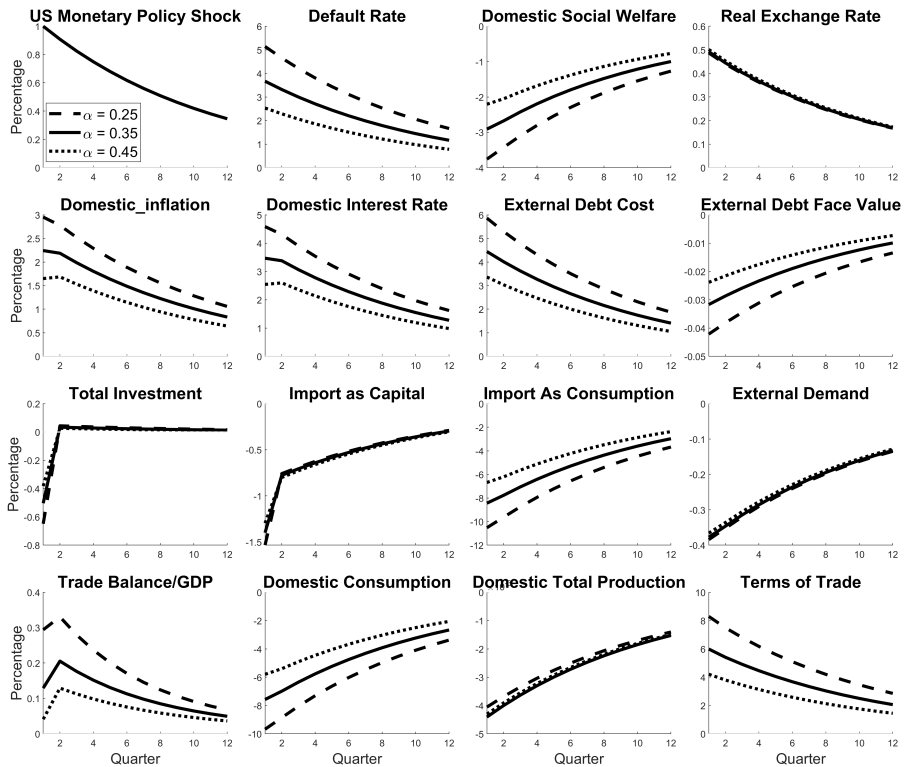


Figure 3.B: Impulse Response of 50 bps U.S. Monetary Policy Shock with $\iota = 0.1$
Note: The results are normalized to a 1% shock for comparison by multiplying the original impulse responses by 2.

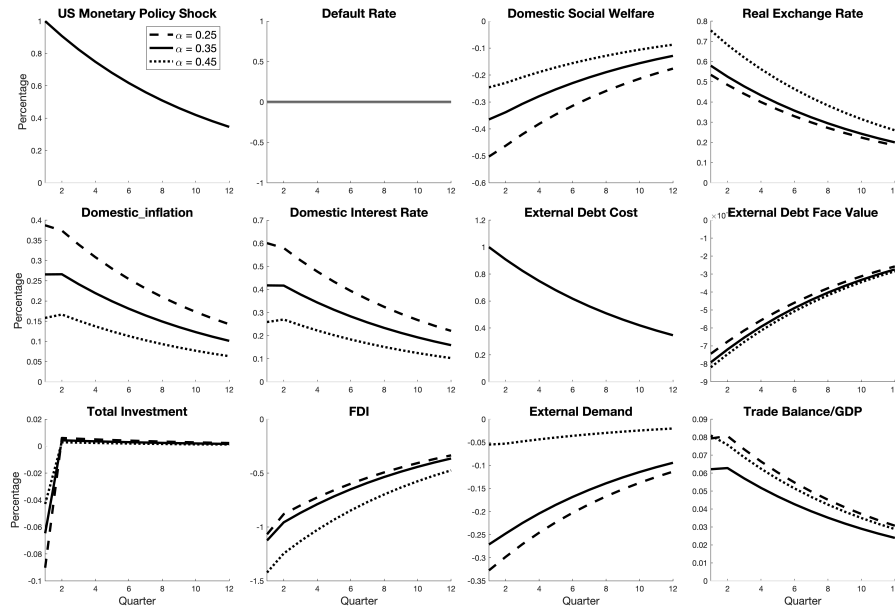


Figure 3.C: Impulse Response of 1 bps US Monetary Policy Shock

Note: The results are normalized to a 1% shock for comparison by multiplying the original impulse responses by 100.

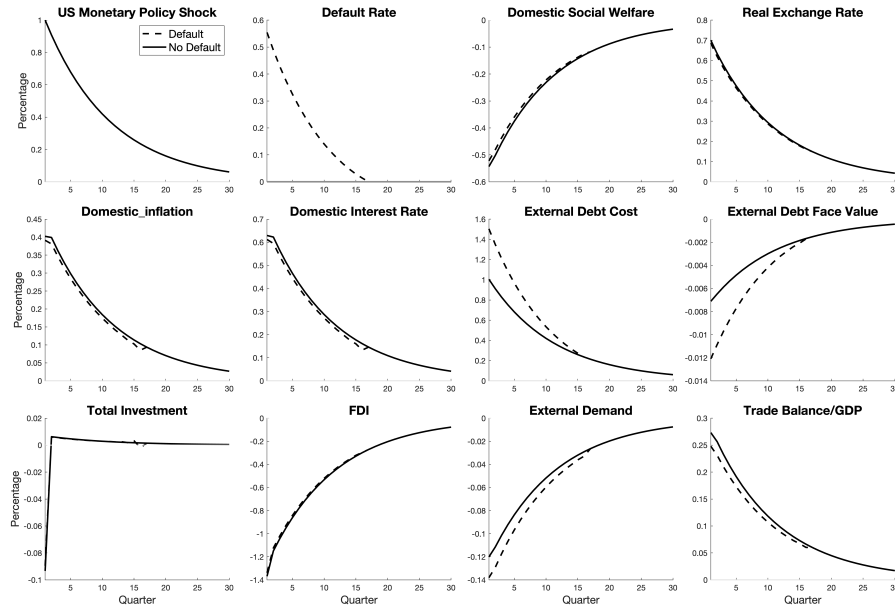


Figure 3.D: Impulse Response of 50 bps US Monetary Policy Shock: Default vs No-Default

Note: The results are normalized to a 1% shock for comparison by multiplying the original impulse responses by 2.

Chapter 4

Climate Change, Monetary Policy, and Price Stability

Climate Change, Monetary Policy, and Price Stability*

Abstract

Climate change affects the effectiveness of monetary policy, particularly in maintaining price stability. In a two-period theoretical model with heterogeneous agents, monetary policy, and climate externalities, we establish that a trade-off exists between climate change and inflation. In addition, lower interest rates for green investments enhance economic growth and aggregate social welfare when the carbon tax is not at the optimal level. Our analysis suggests that green monetary policy and carbon emission taxes are complementary rather than substitutes.

Keywords: Climate Change, Climate Risk, Green Monetary Policy, Carbon tax

*This chapter is derived from my joint work with Professor Dimitrios Tsomocos of Saïd Business School and St Edmund Hall, University of Oxford, and Professor Xuan Wang of Vrije Universiteit Amsterdam and the Tinbergen Institute.

4.1 Introduction

Climate change presents a new challenge for central banks (Schnabel, 2022). It affects price stability, the central bank's primary mandate, through both physical and transition risks. Recent literature suggests that physical risks negatively impact price stability (Faccia et al., 2021; Kotz et al., 2023; Ciccarelli and Marotta, 2024), whereas the effects of green transition policies, particularly carbon taxes, on price stability are not yet well understood.

While a hike in carbon taxes can result in a significant increase in energy prices, its effect on aggregate consumer price inflation has been broadly negligible (Konradt et al., 2024). Nevertheless, such policies affect price stability by causing large and persistent shifts in relative prices, thereby widening the divergence between headline and core inflation measures (Schnabel, 2021). This paper develops a stylized theoretical model to analyze the effects of climate change and carbon taxes, as well as their interaction with green monetary policy, on the central bank's mandate to achieve price stability and control inflation.

The theoretical results show that, first, climate change negatively affects price stability and inflation as supply shocks. Even with an optimal carbon tax, inflation remains higher than it would be in the absence of climate change damage. This underscores and confirms the importance for central banks to consider climate issues when evaluating monetary policy and inflation.

Second, we evaluate the trade-off of a green credit policy in an environment with a carbon tax. The green credit policy refers to a monetary policy implementing lower loan rates for green firms to incentivize green investments. Our numerical analysis suggests that the green credit policy can complement the carbon tax in controlling carbon emissions without increasing inflation when the tax is not stringent. However, when paired with strict carbon tax policies, the effectiveness of the green credit policy

becomes limited and may induce unexpected increases in inflation. The result implies that the policymakers of central banks must carefully implement green credit policies according to the magnitude of the carbon tax to avoid unexpected price instability.

Our model is a two-period framework inspired by the energy-economic models developed in the seminal works of [Acemoglu et al. \(2012, 2016a\)](#), [Golosov et al. \(2014\)](#), and [Barrage \(2020\)](#). We extend these frameworks by incorporating interest rates and fiat money into a heterogeneous agent environment. Our model identifies two types of firms: “brown” firms, which use dirty energy as a production factor and produce carbon emissions as a negative climate change externality, and “green” firms, which use clean energy to produce and generate zero carbon emissions. Our model allows the central bank to adopt a green credit policy, which provides green firms with a discounted loan rate to control emissions. This policy represents an aggressive and unconventional monetary approach to incentivize the transition from brown to green capital.¹ While reducing carbon emissions and increasing the stability of future Total Factor Productivity, this policy lowers the effective interest rate and may therefore result in higher contemporary inflation.

A distinctive feature of our framework is that monetary policy is non-neutral: changes in the nominal interest rate have real effects on investment, output, and the sectoral allocation of capital. This departure from the classical dichotomy stems from three interacting channels: (i) a cash-in-advance constraint forces investors to hold money balances before trade, so higher inflation effectively taxes liquidity; (ii) heterogeneous production technologies in the brown and green sectors convert the resulting shifts in consumption demand into non-proportional changes in factor prices and emis-

¹The Bank of Japan was the first among the central banks of developed countries to set a lower loan rate for green projects. The BOJ set the loan rate for climate projects at 0.1% in 2024, while the usual loan rate is above 1%. Since then, this so-called “Dual interest rate” policy for green investment has attracted growing attention. For instance, French President Emmanuel Macron said during the COP28 UN climate change conference in 2023 that the loan rate for brown firms should be higher than that of green firms so as to shift capital from brown to green. We investigate the impacts of a central bank’s green credit policy, especially designed to promote the transition from brown to green firms by offering the latter more preferential loan rates.

sions; and (iii) the heterogeneous-agent structure—captured by the relative weight w_I on investor utility in the social welfare function—amplifies redistributive wealth effects arising from movements in real money balances, thereby influencing aggregate saving and investment behaviour. By embedding this channel, the model allows us to study how conventional and “green” monetary tools interact with carbon taxation in a setting where interest rates and inflation are not neutral but are key determinants of real economic outcomes.

We start by analyzing our theoretical model in a benchmark setup that does not incorporate any climate regulatory policies, so as to explain the non-linear dynamics inherent in climate-related shocks to price stability and their transmission through macroeconomic and monetary channels. Our model identifies climate change as a potential source of supply shocks, shifting the supply curve downward, leading to higher future inflation and increased economic volatility.

Next, we incorporate the carbon tax—commonly referred to as a Pigouvian tax and widely regarded as the most efficient fiscal tool for addressing climate change (Nordhaus, 2007; Pindyck, 2013)—into our model. Existing climate economics models often overlook the effects of nominal rigidity stemming from the financial role of money. Our novel findings reveal that even with the optimal carbon tax, it: (1) remains insufficient to fully mitigate potential risks, and (2) generates an unintentional increase in inflation compared with the case without climate damage.

This side-effect arises from the interplay between climate-induced and financial frictions in a heterogeneous agent environment, preventing the economy from reaching a first-best solution. These findings emphasize the need for policymakers to consider financial channels and central bank policies when optimizing the carbon tax. In such a scenario, the optimal interest rate for monetary policy, though potentially lower than the optimal interest rate in a tax-absent scenario, still requires an increase compared to the no-climate-change case to accommodate the unhedged portion of possible climate

change shocks.

Moreover, we extend the model to consider a scenario where, due to the “tragedy of the horizon” issue highlighted by [Carney \(2015\)](#), the carbon tax may not reach its optimal level. In this case, the primary objective of central banks—maintaining the inflation rate—exhibits a non-monotonic relationship with the carbon tax. When the carbon tax is insufficient, an increase in the tax raises current prices due to higher energy costs while simultaneously lowering future prices as the severity of negative climate supply shocks diminishes. However, as the carbon tax continues to rise, inflation begins to face upward pressure. This upward pressure arises from the distortionary effects of the carbon tax, which reduce overall investment levels and offset the positive impact of lowering carbon emissions. Consequently, this leads to lower production levels in the future, resulting in higher prices in the second period.

Finally, we examine the potential benefits of implementing a green credit policy to achieve social welfare and maintain price stability. We demonstrate the effect of green credit policy in improving welfare in a second-best scenario. Numerical analyses suggest that discounting green bonds can complement carbon taxes in addressing climate change, mitigating credit market imperfections and carbon emission damages to enhance social welfare. Numerical analysis suggests that the green monetary policy yields the most significant improvement in social welfare when the carbon tax is insufficient. The higher production from less carbon emission further increases the aggregate supply and stabilizes inflation. However, as the carbon tax level rises, the magnitude of the improvement diminishes and induces an unexpected cost. Applying the green discount policy to green firms results in an effective interest rate² lower than the policy rate, which increases credit demand. This cost on the demand side in the money market exceeds the benefits from the supply side, leading to unexpected inflation. To counteract inflationary pressures, the central bank must raise the policy rate to offset the impact of

²The effective policy rate is simplified as the loan rate in our model, and the transmission channel between the policy rate and bank loan rates is beyond the scope of this paper.

the green policy. This underscores the trade-offs that central bank policymakers must consider when contemplating the implementation of a green monetary policy.

Our work is closely related to the literature investigating the impact of climate change on price stability and inflation. [Schnabel \(2021\)](#) argues that climate change has impacts on price stability via physical and transition risks. Regarding physical risks, [Faccia et al. \(2021\)](#) support this argument by showing that temperature significantly influences medium-term price developments via the physical risk channel. Similarly, [Kotz et al. \(2023\)](#) find a causal impact of climate change in exerting upward pressure on inflation over the short to medium term. [Cicarelli and Marotta \(2024\)](#) provide evidence that physical risks act as negative demand shocks, which affect price stability. On the other hand, transition policies also play a role in shaping price dynamics. [Känzig \(2023\)](#) find that a carbon policy shock in Europe raises energy prices and lowers emissions, with limited effects on core prices and no significant change in the policy rate. Additionally, [Del Negro et al. \(2023\)](#) and [Ferrari and Nispi Landi \(2024\)](#) develop New Keynesian models to investigate the effects of carbon pricing policies on inflation. They argue that the way carbon taxation affects inflation and price stability depends on expectations ([Hensel et al., 2024](#)), sectoral heterogeneity in emissions, and price stickiness. Our paper contributes to this strand of literature by analyzing whether climate change affects price stability, how the equilibrium interest rate is impacted, and the implications for inflation and the optimal design of green credit policies, considering interactions with carbon taxation.

Our work contributes to the literature discussing the role of central bank interventions in addressing climate change. [Annicchiarico and Di Dio \(2017\)](#), [Economides and Xepapadeas \(2018\)](#), [Dafermos et al. \(2018\)](#), and [Annicchiarico and Diluiso \(2019\)](#) are among the early contributors supporting the effectiveness of central bank monetary policies in addressing climate change within the framework of new-Keynesian models. [Spiganti and Comerford \(2017\)](#) provide an initial contribution by explicitly focusing on transition risk, analyzing the impact of disruptive climate policies within a model featur-

ing financial frictions, and discussing the effectiveness of various government measures in facilitating a smooth recovery. [Dafermos and Nikolaidi \(2021\)](#) empirically identify that the mix of green credit policies—the 'green supporting factor' (GSF) and 'dirty penalizing factor' (DPF)—is effective in modestly reducing climate-related physical financial risks while influencing credit provision and financial stability. Transition risks are small but manageable, especially when combined with green fiscal policies, which amplify the benefits of the DPF and balance the risks related to the GSF. [Giovanardi et al. \(2023\)](#) discuss the preferential treatment of green bonds in central bank collateral frameworks as a potential tool of environmental policy, whereas [Ferrari and Nispi Landi \(2024\)](#) and [Papoutsis et al. \(2021\)](#) investigate the potential effects and scope of green quantitative easing policies, outlining the conditions necessary for their success. [Carattini et al. \(2023\)](#) and [Oehmke and Opp \(2022\)](#) demonstrate how macroprudential and capital regulation can be optimally structured to mitigate transition risks in cases involving carbon taxes. [Annicchiarico et al. \(2024\)](#) emphasize how the monetary policy and the public's expectations shape the effect of climate policies on carbon emission.

Our work contributes to this strand of literature by first considering a direct green discount rate on the green loan rate instead of regulatory tools such as green capital requirements. The direct discount is regarded as a more aggressive green monetary policy tool, yet the associated risks remain unclear for policymakers. Additionally, our discount can also be broadly viewed as an endogenous effect of green regulatory policy, since [Macaire and Naef \(2023\)](#) empirically shows that green regulatory policies could facilitate green financing and reduce the cost of debt in green projects.

Finally, our project is also related to a strand of papers that discuss the interaction between carbon emissions and other financial or economic frictions. Previous studies, for instance, have investigated the optimal level of carbon taxes in the presence of imperfect financial markets ([Tirole, 2010](#); [Hoffmann et al., 2017](#); [Huang and Kopytov, 2023](#); [Allen et al., 2023](#); [Döttling and Rola-Janicka, 2024](#)), economic risks ([Cai and Lontzek, 2019](#); [Rising et al., 2022](#)), financial regulatory policies ([Döttling and Rola-](#)

Janicka, 2024) and fiscal policies (Barrage, 2020; van der Ploeg, 2023). The contribution of this paper is to examine the interactions between the carbon tax and green monetary policy, especially the “green dual interest rate”, with an emphasis on understanding the carbon tax’s impact on optimal monetary policy, inflation, and price stability. It offers a unique perspective to complement existing views on optimal carbon tax under economic frictions. Moreover, our paper suggests that green monetary policy may be an effective tool to help the transition towards green capital, in particular when the carbon tax is below the optimal level.

The paper is structured as follows: Section II presents the model setup and timeline. Section III outlines the model’s derivation and shows the competitive equilibrium. Section IV discusses the key propositions. Section V provides the numerical analysis. The concluding section summarizes the findings.

4.2 Model

In this section, we present the theoretical model that serves as the foundation of our analysis. The model incorporates an energy-economics block that draws on the works of Acemoglu et al. (2012), Acemoglu et al. (2016a), Golosov et al. (2014), and Barrage (2020). We extend the model and include nominal interest rates and fiat money.

4.2.1 Model environment

The model environment, sketched in Figure 4.1 and sequenced in Figure 4.2, features four representative agents: households, a competitive energy firm, two production sectors (brown and green), and a consolidated policy block that includes both the government and the central bank.

Households supply capital, purchase the final good, and hold outside money. The model distinguishes between two types of firms: brown firms and green firms. Both types of firms are owned by owner–managers who consume consumption goods. Brown

firms rely on dirty energy as a production input, resulting in carbon emissions—a negative externality that contributes to climate change. To promote the transition from brown to green firms and reduce carbon emissions, the central bank can implement a green credit policy by reducing the loan rate for green firms. However, this policy may present a risk to the central bank’s inflation target mandate. The primary contribution of our model is the introduction of money and the examination of the interaction between the central bank’s green monetary policy and the impact of climate change on the economy. Specifically, the model allows us to study the potential implications of the central bank’s policies on climate change mitigation and their potential effects on the stability of the financial system. By incorporating these variables, we can gain a deeper understanding of the dynamics of the economy in the context of climate change and monetary policy.

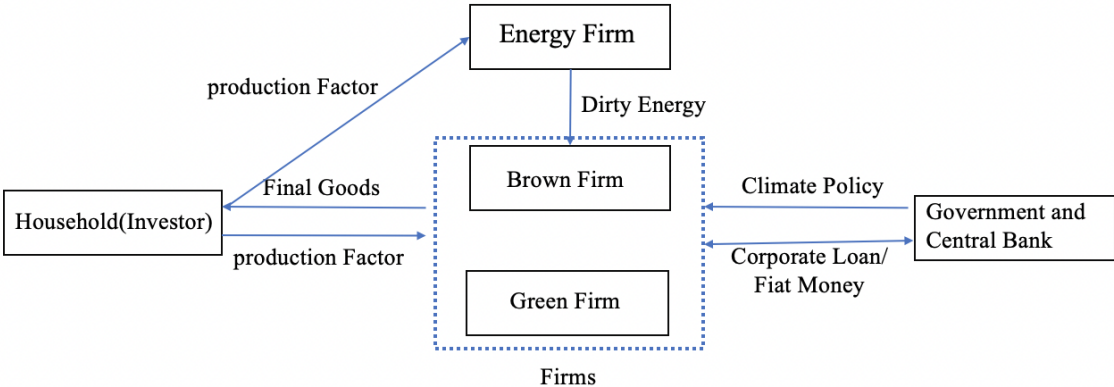


Figure 4.1: Model Structure

The timeline of our two-period model is shown in Figure 4.2. At $t = 0$, the government announces the carbon-tax schedule, while the central bank sets the policy rate and decides whether to grant a green-credit discount. Immediately afterwards ($t = 0^+$) firms obtain inter-period loans; if the central bank implements the green credit policy, green firms would borrow at a lower rate than brown firms. The energy firm produces dirty energy, brown and green firms manufacture goods, emissions occur, and carbon accumulates in the atmosphere. At $t = 1$, loans are repaid, households

consume, production takes place subject to climate damage, and all markets clear.

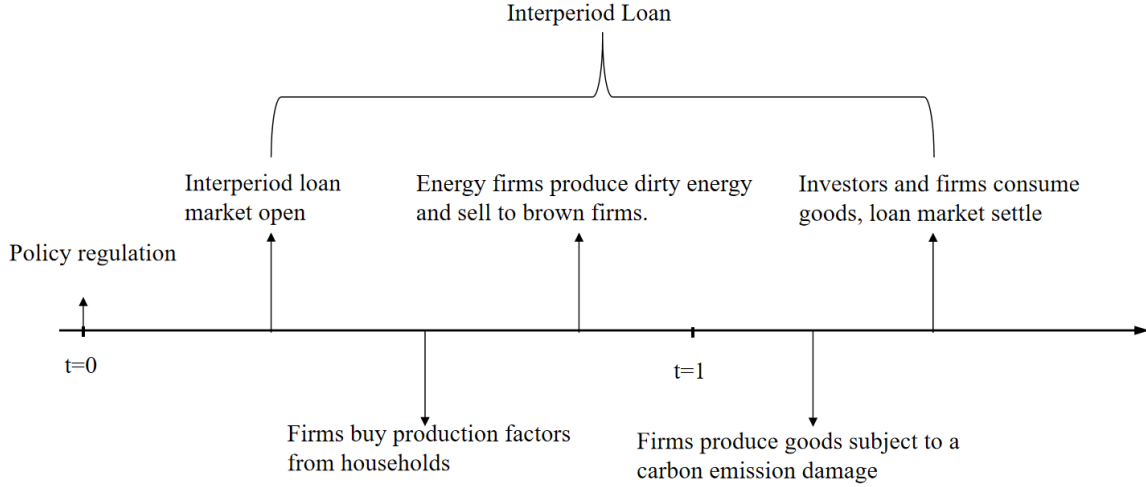


Figure 4.2: Timeline

4.2.2 Investors

We consider a two-period model involving a continuum of investors, each of a unit measure. Each investor is endowed with a quantity k of perishable consumption goods. These goods can either be consumed or traded. In the first period ($t=0$), each investor consumes c_0 of their goods and trades the remainder q_c to firms as a production factor. In the second period $t = 1$, investors consume the consumption goods c_1 , produced by the firms.

Investors gain utility from consumption but experience disutility from the impact of climate change. The utility function over the two periods is given by:

$$U(c_0, c_1) = \frac{c_0^{1-\sigma} - 1}{1-\sigma} + \beta \left(\frac{c_1^{1-\sigma} - 1}{1-\sigma} - \gamma_c D(\Theta) \right),$$

where σ is the coefficient of relative risk aversion, β is the discount factor, γ_c is the scale of utility loss from climate change, and $D(\Theta)$ represents the damage function related to the total carbon emission level Θ . We assume D is an increasing function of the carbon emission level Θ , and assume $\gamma_c > 0$, indicating that an increase in temperature results

in a decrease in utility.

The budget constraints for the investors are set as follows:

$$p_1 c_1 = p_0 q_c + m, \quad (4.1)$$

$$c_0 = k - q_c, \quad (4.2)$$

where p_0 and p_1 represent the prices of consumption goods at $t = 0$ and $t = 1$, respectively. m represents the initial endowment of money. The first equation indicates that the money spent on consumption in the second period is funded by the revenue from selling the production factor q_c and the initial money endowment m . The second equation states that consumption in the first period is the residual of the initial endowment after accounting for the goods traded to firms.

The investors' optimal consumption problem involves maximizing their utility subject to their budget constraints. The first-order conditions (FOCs) for this optimization yield:

$$\frac{U'(c_0)}{U'(c_1)} = \frac{\beta p_0}{p_1}.$$

The optimal conditions for the household are standard. The only difference from the standard model is the assumption that utility decreases due to the externality of climate change.

4.2.3 Final Goods firms

We assume that each firm is managed by an owner-manager who makes all production and investment decisions. These owner-managers consume a portion of the firm's output and are directly affected by the consequences of climate change.

There are two types of firms h , where h denotes the type of firm: either b for brown firms or g for green firms. In the first period, both types of firms issue bonds Q_h , with an

interest rate r_h , to buy non-consumable goods k_h , as a production factor from investors. Moreover, brown firms need to buy dirty energy θ , as an additional production factor, as described by [Acemoglu et al. \(2012\)](#) and [Acemoglu et al. \(2016a\)](#). In our model, dirty energy production is considered the sole source of carbon emissions and climate change ([Goloso et al., 2014](#)). Carbon emissions are a negative externality: higher emissions induce climate change damage, reduce production for both types of firms, and generate disutility for all agents. The scale of production loss from carbon emissions is represented by $D(\Theta)$. Here, Θ represents the total carbon emissions of the economy, defined as the aggregate value of carbon emissions from all brown firms. Furthermore, we assume that the brown firms and green firms have different productivity levels A_h , as described by ([Acemoglu et al., 2012](#)).

Brown Sector

Brown firms are managed by owner-managers who seek to maximize their utility. Brown firm owner-managers maximize the following utility function, which depends on their consumption—a share of the final output produced by the firm—and the disutility caused by climate change:

$$\max_{Q_b, \theta, k_b, c_b, q_b} \frac{c_b^{1-\sigma} - 1}{1 - \sigma} - \gamma_c D(\Theta),$$

where we assume owner-managers and investors have the same coefficient of relative risk aversion σ and disutility from climate damage $\gamma_c D(\Theta)$. In the first period, brown firms purchase dirty energy θ with price p_θ from energy firms and capital goods k_b with price p_0 from investors as production factors. The purchase of these production factors is constrained by loans $Q_b/(1 + r_b)$ from central banks.³

$$p_\theta \theta + p_0 k_b \leq \frac{Q_b}{1 + r_b} + T, \tag{4.3}$$

³The effect of financial intermediaries and banks on climate change is beyond the scope of this paper. Therefore, for simplicity, we assume that loans are directly provided by the central bank.

where T represents lump-sum transfer from the government. In the second period, the brown firms produce the final goods y_b using the production factors with the following production function

$$y_b = A_b(1 - D(\Theta)) \left(k_b^\alpha \theta^{1-\alpha}\right)^\gamma, \quad (4.4)$$

where A_b is the total factor productivity(TFP) of brown firm. The production function exhibits decreasing returns to scale, where α is the share parameter for capital input, and $\gamma \in (0, 1)$ scales the overall production function. The term $\alpha\gamma$ represents the output elasticity of capital. The climate damage function $D(\Theta)$ represents the scale of production loss attributable to the total carbon emissions Θ of the entire economy. Brown firm owner-managers sell a fraction of the final goods q_b to investors and consume the remaining portion c_b themselves. The revenue from the sale of goods is used to pay off the loans, expressed as:

$$q_b = y_b - c_b, \quad (4.5)$$

$$Q_b = p_1 q_b. \quad (4.6)$$

The maximization problem of brown firms using dirty energy implies:

$$\frac{\alpha\theta}{(1-\alpha)k_b} = \frac{p_1}{p_\theta}, \quad (4.7)$$

where the proportions of dirty energy are determined by the shared parameter and the relative price with respect to capital goods. Combined with the equation (4.4), we derive the output of brown firms as a function of prices and capital goods:

$$y_b = \left(\frac{(1-\alpha)p_1}{\alpha p_\theta}\right)^{(1-\alpha)\gamma} A_b(1 - D(\Theta))k_b^\gamma. \quad (4.8)$$

The FOC with respect to debt further determines the level of capital goods.

$$\frac{p_0(1+r_b)}{p_1} = \frac{\alpha\gamma y_b}{k_b}, \quad (4.9)$$

where $\alpha\gamma y_b/k_b$ captures the real return on capital goods k_b . Equation (4.9) implies that the real return to capital by the brown firms is equal to the loan rate minus the nominal inflation.

Green Sector

The green sector is analogous to the brown sector⁴, except we assume green firms do not require dirty energy as input to produce final goods. We assume the green firms have a different TFP A_g . The production function is outlined as follows:

$$y_g = A_g(1 - D(\Theta))k_g^\gamma. \quad (4.10)$$

The optimal investment decision of green firm owner-managers is determined by the loan rate, inflation rate, and the output elasticity parameter of capital, where

$$\frac{p_0(1 + r_g)}{p_1} = \frac{\gamma y_g}{k_g}. \quad (4.11)$$

The loan rate r_g for green firms can differ from the loan rate r_b for brown firms. The central bank can implement a green credit policy to provide a discount ϵ to the loan rate for green firms, making r_g lower than the policy rate. In this case, $1 + r_g = \epsilon(1 + r)$. This green credit policy is designed to incentivize investment in green firms by reducing their cost of capital.

Energy Sector

There is a competitive energy sector producing dirty energy Θ with a risk-neutral utility function. The sector maximizes its profit π_e by producing and selling energy. At $t = 0$, it purchases capital goods k_e from investors as production input. At $t = 1$, it produces energy using a linear production function with TFP ξ and sells it to brown firms at price p_θ . The government can impose an income carbon tax during the sale of the

⁴For details, please refer to [Appendix A](#)

energy.

$$p_0 k_e + \pi_e = p_\theta(1 - \tau)\Theta, \quad (4.12)$$

$$\Theta = \xi k_e. \quad (4.13)$$

4.2.4 Central Bank and Government

The central bank issues the reserve M and sets the policy rate r to maximize social welfare. Social welfare is defined as the aggregate of weighted individual utilities, formally represented by the social welfare function as:

$$W = w_I U_I + w_b U_b + w_g U_g, \quad (4.14)$$

where w_s represents the predetermined individual-specific welfare weight for agent s , and U_s represents the utility value for agent s , where $s \in \{I, b, g\}$.

To address climate change issues, there are two green policy instruments available for the government and the central bank. The government can levy a carbon tax τ on dirty energy to reduce carbon emissions. The central bank can implement climate-related monetary policy at the beginning of the first period by providing a discount ϵ to green firms. If the central bank implements this green discount policy, the loan rate for green firms will be lower than that for brown firms.

4.2.5 Carbon Emission and Climate Change

We assume climate damage is a function of temperature T , which depends on the exogenous initial condition S_0 and additional carbon emissions from dirty energy production Θ . Climate change damage is a monotonically increasing function of T , and temperature is a monotonically increasing function of Θ . Thus, we simplify the equation and directly express climate change damage as $D(\Theta)$. The function $D(\Theta)$ satisfies

the following properties:

$$\frac{\partial D(\Theta)}{\partial \Theta} > 0. \quad (4.15)$$

4.3 Competitive Equilibrium

The key results are analyzed based on a decentralized environment. The problem of heterogeneous agents defines a competitive equilibrium. To formally characterize this equilibrium, we provide the following definition.

4.3.1 Definition of Competitive Equilibrium

The Competitive Equilibrium is defined as an allocation $(c_0, c_1, c_b, c_g, k_b, k_g, k_e, \Theta, \theta, q_c, q_b, q_g, Q_b, Q_g)$ with prices (p_0, p_1, p_e) , given a set of policy tools $(r$ and $\tau)$, such that investors and firms maximize their utility function, subject to budget constraints, and market clearing conditions:

- Goods market: $q_g + q_b = c_1$.
- Factor market: $q_c = k_g + k_b + k_e$.
- Energy market: $\Theta = \theta$.
- Money market (Assume interest rates are the same across firms): $1 + r = \frac{Q_g + Q_b}{M}$.

4.3.2 Analytical Solutions of Competitive Equilibrium

To obtain analytical solutions, we set the coefficient of relative risk aversion σ equal to 1, resulting in the logarithmic utility function as a special case. The analytical solution for a competitive equilibrium, given a set of policies—interest rate (r) and tax (τ) —is illustrated below.

The investment level in equilibrium can be represented by the following exogenous

parameter variables, formally expressed as:

$$k_b = \frac{k\alpha}{((1 - \tau(1 - \alpha)) + \delta(\tau)\alpha)(2 + r)}, \quad (4.16)$$

$$k_g = \delta(\tau)k_b, \quad (4.17)$$

$$\Theta = (1 - \tau)\xi \frac{1 - \alpha}{\alpha} k_b, \quad (4.18)$$

$$k_e = (1 - \tau) \frac{1 - \alpha}{\alpha} k_b, \quad (4.19)$$

where $\delta(\tau) = (\alpha \frac{A_b}{A_g})^{\frac{1}{\gamma-1}} ((1 - \tau)\xi \frac{1 - \alpha}{\alpha})^{\frac{(1-\alpha)\gamma}{\gamma-1}}$. From equation (4.16) to (4.19), the investment level of the economy is a monotonically decreasing function of the interest rate. A higher interest rate reduces the overall investment level in the economy due to the increased cost of capital. This effect is consistent across various sectors, including brown and green firms, as well as energy producers, each of which will experience a decline in investment at different scales in response to the interest rate hike.

The output value of the brown firm y_b and the green firm y_g in equilibrium can be represented as a function of the capital goods, formally expressed as:

$$y_b = A_b(1 - D(\Theta))((1 - \tau)\xi \frac{1 - \alpha}{\alpha})^{(1-\alpha)\gamma} (k_b)^\gamma, \quad (4.20)$$

$$y_g = A_g(1 - D(\Theta))k_g^\gamma. \quad (4.21)$$

As shown in (4.20) and (4.21), the decline in investment due to a higher interest rate directly reduces the equilibrium investment, thus lowering the overall output level. Regarding the relative investment level and output level between green and brown firms, the ratio of green capital to brown capital equals $\delta(\tau)$. Since $\frac{\partial \delta(\tau)}{\partial \tau} > 0$, our model indicates that a strict carbon tax imposed by the government would shift capital from brown firms to green firms. In addition, (4.18) shows that the production of dirty energy decreases with a stricter carbon tax policy.

The price level in the competitive equilibrium could be represented as the following

function:

$$p_0 = \frac{(2+r)m}{rk}, \quad (4.22)$$

$$p_1 = \frac{(1+r)p_0k_g}{\gamma y_g}, \quad (4.23)$$

$$p_\theta = \frac{p_0k_e}{(1-\tau)\theta}. \quad (4.24)$$

The prices of goods across periods, including fossil fuels are negatively related to the interest rate. The price of consumption goods in the first period is more sensitive to changes in the interest rate. The price of dirty energy increases with respect to the carbon tax τ ; a higher carbon tax will lead to a higher price of dirty energy. We define the inflation of the economy as $\pi = p_1/p_0$, reflecting the price dynamics between periods.

Equations (4.16)–(4.24) make it clear that neither the nominal interest rate nor the inflation rate is neutral in our model. A change in the policy rate r alters inflation π , which in turn reshapes the allocation of capital and the aggregate level of output. This non-neutrality arises for two reasons. First, the cash-in-advance constraint forces investors to hold money balances before trade takes place; a higher gross inflation rate π therefore acts as an implicit tax on real money balances, raising the marginal cost of present consumption relative to future consumption and inducing a contraction in aggregate demand. Second, sectoral technology differences and the endogenous price of dirty energy p_θ amplify the effect through firms' first-order conditions: a higher nominal rate r increases the intertemporal discount factor, depresses capital accumulation in both brown and green firms, and—because the two sectors display different elasticities of substitution—generates non-proportional reallocations of capital and emissions.

The consumption allocations of investors and firms in equilibrium can be repre-

sented in terms of output and capital investment, formally expressed as:

$$c_0 = \frac{k(1+r)}{(2+r)}, \quad (4.25)$$

$$c_1 = \frac{k(\gamma A_g(1-D(\Theta))(\delta(\tau)k_b)^{\gamma-1})}{(2+r)}, \quad (4.26)$$

$$c_g = (1-\gamma)y_g, \quad (4.27)$$

$$c_b = (1-\gamma + \tau\gamma(1-\alpha))y_b. \quad (4.28)$$

As shown in equation (4.25), investors' consumption in the first period depends only on the interest rate. An interest rate hike reduces the investment level, leaving more consumption goods available for investors. Second-period consumption, c_1 , decreases with a higher interest rate. In our model, climate damage directly affects second-period consumption, as shown in (4.26). This indicates that, in our model, disutility for investors arises not only from an exogenous disutility term, γ_c , but also from an endogenous reduction in second-period consumption.

From equations (4.27) and (4.28), firm consumption is aligned with the trend of the corresponding final goods output and scales according to a function dependent on the production parameters. In addition, in a competitive equilibrium with a higher carbon tax policy, the brown firms consume a larger portion of their output. The higher tax level will lower the share of brown debt issuance in equilibrium so that a greater proportion of wealth goes into final good consumption instead of brown capital inputs for production.

In summary, the analytical solution for the competitive equilibrium with respect to any given set of policy values indicates that the interest rate and carbon taxes are two key determinants of equilibrium allocations. The next section examines the interaction between the optimal carbon tax and interest rate, focusing on their effects on the economy and the trade-offs policymakers face.

4.4 Optimal Interest Rate and Carbon Pricing

To derive the optimal policies under the heterogeneous competitive equilibrium with climate externalities, we consider the government choosing the carbon tax and the central bank setting interest rates simultaneously to maximize social utility. We focus on analyzing how the optimal interest rate and the corresponding inflation change as climate change and carbon tax are incorporated into the evaluation framework.

4.4.1 Baseline Model: No Climate Damage

We first analyze a baseline model where the climate damage function D is set to 0. In this case, the introduction of a positive carbon tax is not an optimal government policy, indicating that $\tau = 0$. Then, the model simplifies to a basic heterogeneous agent model with a credit market.

Proposition 1: *In the baseline model, the optimal interest rate $r_{base}^* > 0$. The optimal interest rate r_{base}^* is a function of the investor's utility weight w_I and the production elasticity parameter γ , formally given by:*

$$(1 + r_{base}^*) = \frac{w_I}{\gamma}. \quad (4.29)$$

Proof: see [Appendix Proof of Propositions 1](#).

This proposition indicates that the optimal interest rate in our baseline model is positive instead of zero, which contradicts the conventional Friedman Rule ([Friedman, 1969](#)).⁵ In this model, on one hand, from equations (4.16) to (4.21), an increase in the interest rate from zero to positive raises the cost of capital, thus decreasing total investment and production levels, which in turn reduces social welfare. On the other hand, a positive interest rate lowers the price of goods in the second period and increases

⁵In [Friedman \(1969\)](#) and subsequent papers advocating his theory, it is argued that the welfare-maximizing monetary policy should set the interest rate at zero or close to zero, thus removing the incentive to hold money.

the real value of outside money m , providing a positive wealth effect to investors. This wealth effect incentivizes investors to consume more in the first period, thereby increasing social welfare. Optimal social welfare and the interest rate are achieved when the positive marginal wealth effects equal the negative marginal effects from production shrinkage.

4.4.2 The Impact of Climate Change on Optimal Interest Rate

Next, we assume that the climate damage function is not negligible. The climate damage D is an increasing function of carbon emissions. We focus on analyzing how the damages from climate change, resulting from carbon emissions, impact the equilibrium. Initially, the carbon tax is set to zero, thus creating an environment where the interest rate is the only available policy tool.

Proposition 2: *Suppose $D(\Theta) > 0$ and $\tau = 0$, the optimal interest rate $r_{\tau=0}^*$ is higher than the baseline case interest rate r_{base}^* , formally given by:*

$$(1 + r_{\tau=0}^*) > \frac{w_I}{\gamma}. \quad (4.30)$$

Proof: see [Appendix D, Proof of Propositions 2](#).

In this case, a higher interest rate is associated with lower energy input and reduced climate change damage, which benefits social welfare. Therefore, the marginal benefit of the interest rate relative to the baseline case increases, ultimately converging to a higher optimal interest rate, as shown in [Proposition 2](#). The magnitude of the shift in the optimum interest rate depends on how serious the climate damage will be to the economy. The higher the level of climate damage or the more sensitive dirty energy production is to the interest rate, the more pressing the demand for a higher interest rate in controlling climate damage. In addition to this demand for an interest rate rise to cut down brown capital input and carbon emissions, climate damage would also impact the equilibrium price function—which is the central bank’s main mandate.

Lemma 1: Suppose $D(\Theta) > 0$ and $\tau = 0$. Given an interest rate r , the inflation rate $\pi_{\tau=0}$ in equilibrium satisfies $\pi_{\tau=0} > \pi_{base}$. In addition, the inflation $\pi_{\tau=0}$ is more sensitive to the interest rate: $|\frac{\partial \pi_{\tau=0}}{\partial r}| > |\frac{\partial \pi_{base}}{\partial r}|$, where π_{base} represents the inflation in equilibrium given the same r when $D(\Theta) = 0$ and $\tau = 0$.

Proof: see [Appendix D, Proof of lemma 1](#).

If the central bank keeps the policy rate the same as the baseline case, since $\tau \equiv 0$, according to the equations from (4.16) to (4.19), the investment level across two cases remains at the same level. However, the total production would shrink as a result of climate change damage $D(\Theta)$. This would then have a negative effect on the supply side due to climate damage, increasing the inflation in the equilibrium shown in [Lemma 1](#). Higher inflation in the equilibrium indicates the cost of climate change on price stability. This provides an important policy implication for central bank policymakers: if they implement a monetary policy without considering climate change, it might cause negative supply shocks stemming from climate change that make the inflation rate shift upwards from its target.

To derive the analytical solution, from now on, we assume the damage function is an exponential function, as proposed in [Golosov et al. \(2014\)](#). Specifically, it is defined as:

$$1 - D(\Theta) = 1 - (1 - e^{-d\Theta}) = e^{-d\Theta},$$

where d is a damage parameter. By plugging this damage function into the equations in [Appendix D](#), we derive the analytical solution for the optimal interest rate as:

$$1 + r_{\tau=0}^* = \frac{\delta_1 - \gamma + w_i + \sqrt{(\delta_1 - \gamma)^2 + 2(\delta_1 + \gamma)w_i + w_i^2}}{2\gamma} > r_{base}^*, \quad (4.31)$$

where $\delta_1 = \frac{k(1-\alpha)d\xi}{(1+\alpha\delta(0))}$.

The analytical solution for the optimal interest rate, as shown in (4.30), is a function of exogenous parameters. It highlights that the optimal interest rate increases

relative to the baseline when climate damage is incorporated into the model. The quantitative magnitude of this increase depends on the utility weight, production parameters, and climate damage coefficient, which will be discussed further in the numerical simulation section.

4.4.3 The interactions between Carbon Tax and Interest Rate

In this section, we analyze the interactions between the carbon tax and the monetary policy rate. While previous literature has investigated the interactions between other fiscal policies and carbon tax in addressing climate change (Barrage, 2020; van der Ploeg, 2023), few papers have explored monetary policy in this context. Our heterogeneous agent framework extends this literature by analyzing the joint determination of optimal carbon taxes and interest rates in a competitive equilibrium with climate externalities.

In this section, we assume the central government sets a non-negative carbon tax ($\tau \geq 0$) to address the issue of climate change. The focus is on understanding how the optimal monetary policy and the corresponding inflation rate change in response to the carbon tax. We first quantify the changes in the optimal level of monetary policy in an economic environment with positive climate damage and a carbon tax.

Propositions 3: *Suppose $D(\Theta) > 0$ and $\tau > 0$, the optimal interest rate $r_{\tau \geq 0}^*$ lies between r_{base}^* and $r_{\tau=0}^*$. Formally,*

$$r_{base}^* \leq r_{\tau \geq 0}^* \leq r_{\tau=0}^*. \quad (4.32)$$

Proof: See [Appendix D](#), proof of Propositions 3.

The right inequality holds when $\tau = 0$, where the problem reduces to the no-tax case. The left inequality holds when $\tau = 1$. In this scenario, the use of dirty energy will shrink to zero, resulting in zero carbon emissions and consequently, zero climate

damage. If the carbon tax is between 0 and 1, the use of dirty energy and carbon emissions will drop compared to the no-tax case due to the higher energy price. In this scenario, the marginal benefits of a higher interest rate in reducing carbon emissions decline accordingly. However, since the usage of dirty energy is still non-negligible, there are benefits to the economy from the interest rate being higher than in the baseline case.

Propositions 4: *Suppose $D(\Theta) > 0$ and $\tau > 0$, given the exogenous parameter space, there exists a threshold $\bar{\tau} \in \mathbb{R}^+$ such that*

$$\frac{\partial \pi_{\tau \geq 0}}{\partial \tau} = \begin{cases} < 0, & \text{if } \tau \leq \bar{\tau}, \\ > 0, & \text{if } \tau > \bar{\tau}, \end{cases}$$

where $\pi_{\tau \geq 0}$ represents the inflation in equilibrium when $D(\Theta) > 0$ and $\tau \geq 0$.

Proof: See [Appendix D, proof of Propositions 4](#).

This proposition illustrates how the tax rate affects the equilibrium price level. It indicates that the tax rate has a non-monotonic relationship with inflation. Intuitively, when the tax is low, an increase in the tax would raise the first-period price due to higher energy costs and lower the second-period price as a result of a positive supply shock stemming from reduced climate damage. However, when the tax is higher than the optimal level, a further increase in the tax would reduce the input of energy and offset the positive effect from reduced climate damage, leading to a lower production level and a higher second-period price, i.e., higher inflation. This proposition provides a direct link between inflation and the carbon tax. It indicates the importance of evaluating the distortionary effects of the carbon tax on inflation.

4.5 Green Credit Policy and Numerical Solution

In this section, we propose that the central bank implement a unique green credit policy to address the climate change issue. This green credit policy is equivalent to

a dual-interest rate policy. Green firms that utilize clean energy are eligible for a discount $\epsilon \in (1/(1+r), 1)$ on the loan rate. We assume the green credit policy ϵ is a complementary second-order policy: for a given level of tax and interest rate, the central bank chooses a level of green discount policy that maximizes social welfare. In this setup, the green interest rate r_g is defined as $1 + r_g = (1 + r)\epsilon$.

This green credit policy could incentivize green firms to invest more, assist in shifting capital from brown capital to green capital, and reduce carbon emissions. However, this policy is not without cost. It raises the price level. The effective interest rate of the whole economy, calculated as the weighted average of the cost of capital, is a weighted average of the interest rates of green firms r_g and brown firms r_b . This effective interest rate would be lower than the policy rate r . The price functions (4.22) and (4.23) indicate that a lower effective interest rate will increase the price level in both periods, raising concerns about inflation.

4.5.1 Numerical Analysis

To quantify the impact and trade-offs associated with the green credit policy, we conduct a numerical simulation. The second period in our model corresponds to 25 years, spanning from 2025 to 2050, aligning with the timeline of the Paris Agreement to achieve net-zero emissions in 2050. We set the utility preference parameter to $\sigma = 1$, reducing the utility function to a logarithmic form consistent with our theoretical equilibrium analysis.⁶ Climate damage is calibrated at $d = 0.08$ and $\gamma_c = 0.01$, representing an output loss of 1.74% when an optimal carbon tax is implemented. Following Acemoglu et al. (2012), productivity parameters are set to $A_b = 1.2$ and $A_g = 1$, with the energy sector productivity factor equalized to that of green firms ($x_i = 1$). Output elasticities are set at $\alpha = 0.9$ and $\gamma = 0.7$. The outside money parameter is calibrated at $m = 100$, corresponding to an annualized inflation rate of 5%. The subjective discount factor is

⁶Results remain robust under more general utility specifications. See [Appendix E](#) for robustness checks with $\sigma = 2$.

defined as $\beta = 0.985^{25}$, consistent with standard values in the literature. Lastly, utility weights are calibrated as $W_I = 0.8$, $W_{I,b} = 0.1$, and $W_{I,g} = 0.1$, targeting an annualized policy rate of approximately 1%.

Table 4.1: Parameterization

Parameters	Calibration Value	Target Value
Preferences	$\sigma = 1$	Log Utility function
Climate damage	$d = 0.08, \gamma_c = 0.01$	Social Welfare loss 1.74%
Productivity	$A_b = 1.2, A_g = 1, x_i = 1$	Acemoglu et al., 2012
Output elasticity	$\alpha = 0.9, \gamma = 0.74$	Acemoglu et al., 2016
Outside Money	$m = 100$	Annualized inflation 5%
Subjective discount	$\beta = 0.985^{25}$	Standard Value
Utility weight	$W_I = 0.8, W_{I,b} = W_{I,g} = 0.1$	Annualized interest rate 1%

We first run a simulation to evaluate the interactions between the carbon tax and the monetary policy rate r . In Figure 4.3, the x-axis represents the carbon tax rate, ranging from 0 to 1, while the y-axis represents the social utility as a ratio of the optimal social utility without climate damage. The black solid line represents the baseline case, where the climate damage $D(\Theta)$ equals 0.

The optimal carbon tax for this case, indicated by the red dot, is 0, as expected. The dashed black line represents the case with climate change but the central bank does not incorporate climate disruptions in its monetary policy framework and keeps the policy rate at the baseline level. In this case, without a carbon tax, social welfare loss exceeds 3.5%, as a result of climate damage. Introducing a carbon tax results in a large marginal increase in social welfare when the tax rate is on the low end, demonstrating strong marginal benefits in reducing carbon emissions and climate damage. However, the marginal increase in social welfare becomes zero when the tax rate equals 80% ⁷, after which the social welfare starts to decrease, because the marginal cost of taxes from reducing investments surpasses the marginal benefits of less climate damage.

⁷literature typically expresses carbon taxes in absolute terms (e.g., dollars per ton of carbon emissions). For perspective, given coal priced at approximately \$75 per ton and a carbon content of 71%, a carbon price of \$104 per ton is implied. An optimal tax between \$50–\$150 per ton translates to a tax rate ranging from 50%–150% of coal price

In addition, the dashed grey line represents a scenario where we increase the policy rate and vary carbon taxes. This scenario illustrates a situation where the central bank incorporates climate risks into the evaluation model and sets the policy rate significantly higher than the baseline model to reduce brown investment and mitigate climate change. As shown in the figure, even if monetary policy accounts for climate risks and increases the policy rate accordingly to reduce carbon emissions, the benefits to social welfare are very limited compared to the case when policy rate is kept at the baseline level. This indicates the ineffectiveness of conventional monetary policy mitigating climate change.

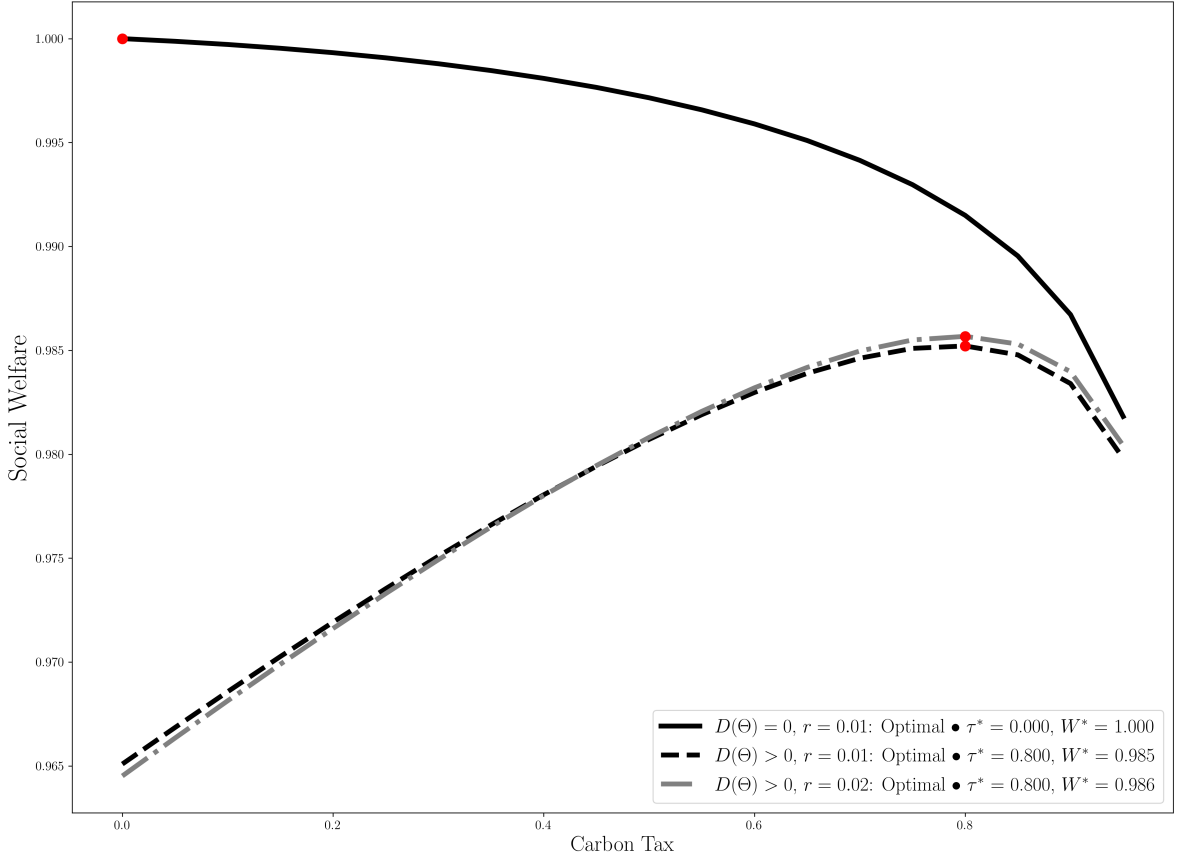


Figure 4.3: Social welfare as a function of carbon taxes and the policy rate

Note. The figure above plots social welfare as a function of the carbon tax rate under different monetary policy assumptions. The x-axis reports the carbon tax rate ranging from 0 to 1, while the y-axis shows social welfare normalized by the optimal social welfare without climate damage. The solid black line denotes the baseline case with no climate damage. The dashed black line shows the case with climate damage and a fixed policy rate. The dashed grey line represents the case with climate damage and a higher policy rate. The red dot marks the welfare-maximizing carbon tax level in each case.

Figure 4.4 illustrates the optimal policy rate when considering climate damage. In this figure, the horizontal axis represents the interest rate r , and the vertical axis shows the social welfare of the corresponding equilibrium normalized by the optimal social utility without climate damage. The black solid line represents the baseline model with no climate damage and no carbon tax, with the optimal interest rate of 1%. After introducing climate damage, as illustrated by the dashed black line, the optimal interest rate significantly exceeds the baseline case and stands at a staggering 4.2%, but its positive effects on social welfare are minimal. The social welfare loss remains above 1.8% even when the central bank chooses a welfare-maximizing monetary policy. This suggests that monetary policy alone is ineffective in mitigating climate damage.

However, as illustrated by the dashed grey line, if there is a reasonable level of carbon tax,⁸ the optimal interest rate is now much lower than second case, but much closer to the baseline case. This suggests that carbon taxation is the more effective tool to address carbon emissions compared to monetary policy. When there is a reasonable level of carbon tax, the rise in the interest rate to maximize social welfare and stabilize prices does not need to be substantial, unlike the previous case with no carbon taxes. Comparing this result with that in Figure 4.3, we find the optimal tax level is not sensitive to the interest rate, but the optimal interest rate is very sensitive to the carbon tax rate. This underscores the central role of carbon taxation in climate mitigation, highlighting its relative effectiveness over conventional monetary policy.

⁸We take the reasonable carbon tax rate as the optimal carbon tax rate when the policy rate is at the baseline model level of 1%. We choose this as the reasonable tax level because the baseline interest rate more or less aligns with the real-world scenario when the central bank does not actively mitigate climate change.

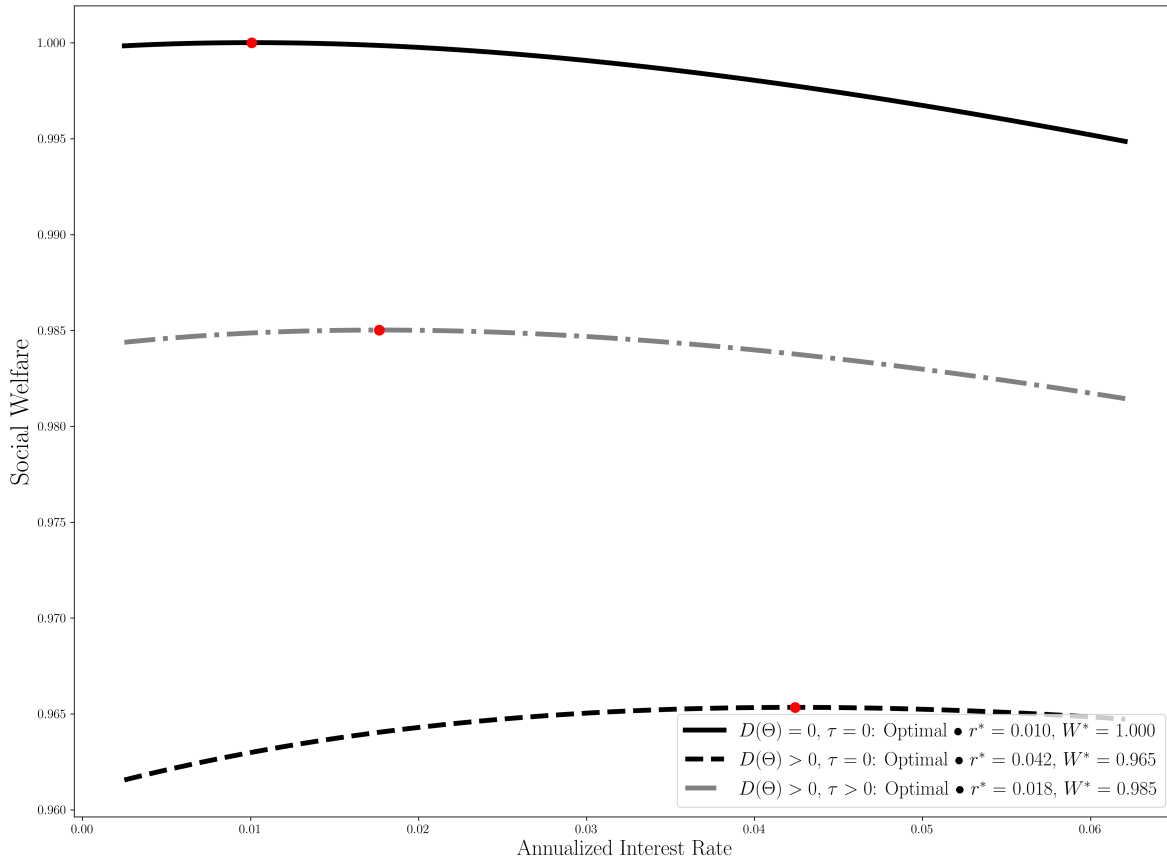


Figure 4.4: Social Welfare as a function of interest rate in three cases

Note. The figure above plots social welfare as a function of the interest rate across three cases. The x-axis shows the interest rate, and the y-axis presents normalized social welfare. The solid black line represents the baseline case with no climate damage. The dashed black line incorporates climate damage with optimized monetary policy while no carbon tax. The dashed grey line shows the case with climate damage and a fixed carbon tax. The red dot marks the welfare-maximizing interest level in each case.

Next, we illustrate how carbon taxes impact future inflation and price stability. Figure 4.5 depicts the equilibrium relationship between the carbon tax rate (x-axis) and the future annualized inflation (y-axis). The solid line represents carbon taxes' negative effect on inflation when we assume away climate disruptions in the economy. A higher tax would distort the economy, reduce investment, and cause a supply shortage of final goods production in the second period, leading to higher inflation. However, if carbon damage exists in the economy, the benefits of the carbon tax would increase the production of goods in the second period, leading to a sharp decrease in inflation before reaching the optimal tax level. This demonstrates the benefits of the carbon tax;

although the carbon tax is not aimed at price stability, it contributes to price stability through a supply channel.

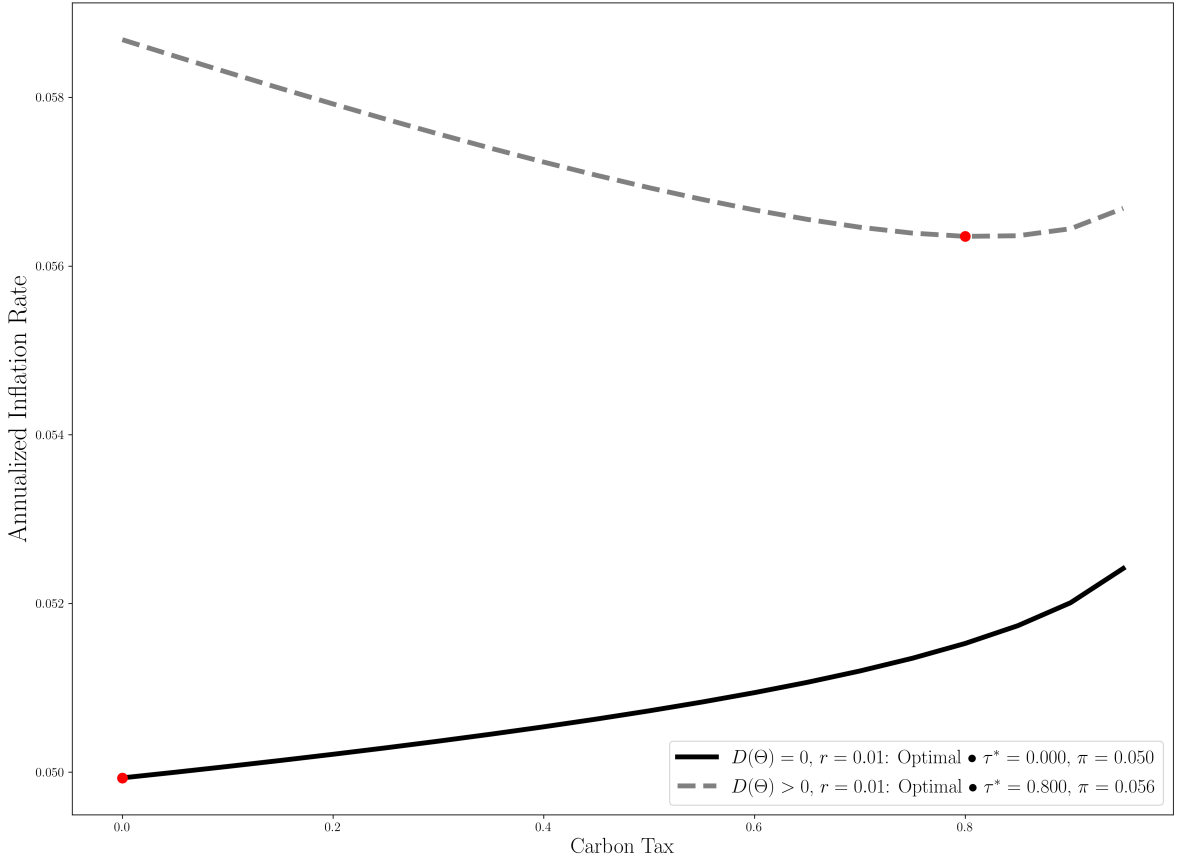


Figure 4.5: Inflation as a function of tax in two cases

Note. The figure above plots the impact of carbon taxes on inflation. The x-axis displays the carbon tax rate, and the y-axis shows the annualized inflation rate. The solid line represents the case without climate damage. The dashed line includes climate damage. The red dot marks the the inflation rate level when the carbon tax is set at optimal level. The comparison highlights that carbon taxes are more effective than interest rate adjustments in restoring welfare.

4.5.2 Numerical Solution: Dual Interest Rate Case

In this subsection, we introduce the green credit policy to the economy. We assume the central bank can implement a green credit policy that provides a discount ϵ to the green debt rate r_g . The ϵ ranges from 0 (indicating a free loan) to 1 (indicating no discount). We run the following numerical simulation to test whether this green credit policy could mitigate climate damage contingent on the carbon tax level and whether

it has a negative effect on inflation as discussed.

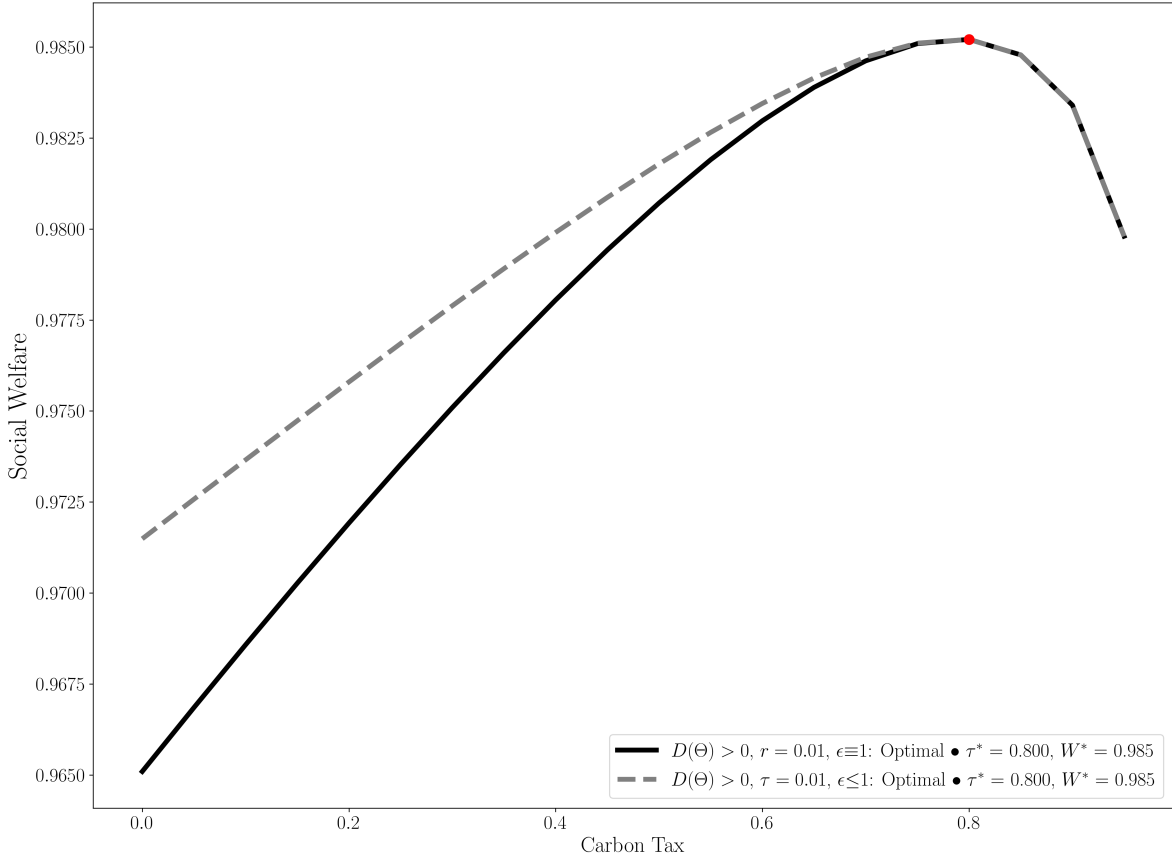


Figure 4.6: Simulation Results for the Green Credit Policy Case - Social Welfare

Note. The figure above compares social welfare under different green credit policy scenarios. The x-axis reports the carbon tax rate, and the y-axis shows social welfare in equilibrium. The black line shows benchmark results without green credit. The grey line incorporates a green credit policy. The gap between the lines reflects the welfare gains from implementing green credit when carbon taxes are below optimal.

We test the effect of the green credit policy on social welfare with different carbon tax levels. In Figure 4.6, the x-axis represents the carbon tax level while the y-axis shows the corresponding equilibrium social utility. The black line represents the benchmark results shown in Figure 4.3, where the central bank and the carbon tax policies are at their best possible combinations. The grey line assumes the interest rate remains the same but the green credit policy is implemented to address the climate change issue. The differences between these lines allow us to evaluate how the green credit policy increases social welfare with the same level of carbon tax and monetary policy

rate. Figure 4.7 documents the optimal annualized interest rate for green firms in equilibrium. The interest rate for green firms is bounded by the zero lower bound and cannot exceed the policy rate level of 0.01.

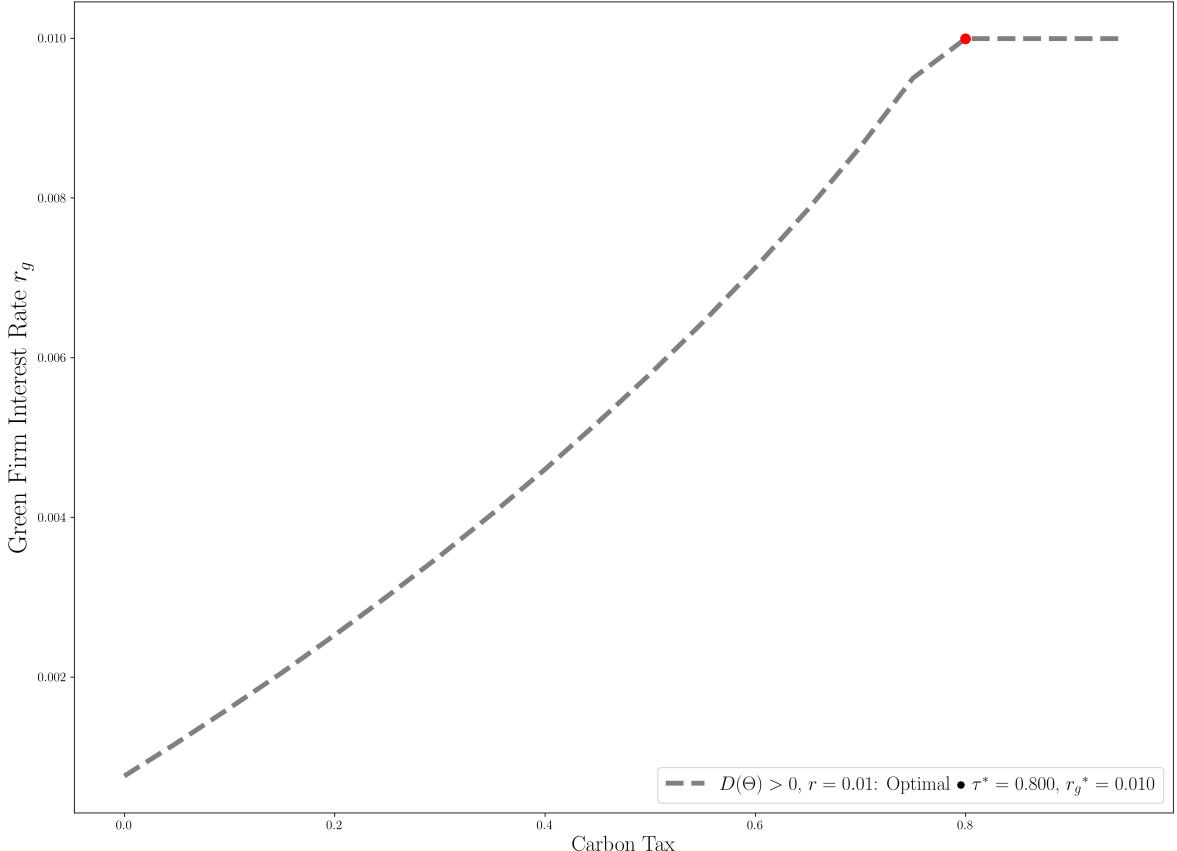


Figure 4.7: Simulation Results for the Green Credit Policy Case - Discount Rate

Note. The figure presents the equilibrium interest rate for green firms under the green credit policy. The x-axis denotes the carbon tax rate, and the y-axis reports the annualized interest rate for green firms. The results show that the green interest rate hits the zero lower bound when carbon taxes are low but converges to the policy rate when taxes are high.

When the energy tax is significantly below the optimal level, a zero loan rate for green firms is the optimal choice for the green credit policy. It is noteworthy that the zero lower bound limits the effectiveness of green monetary policy, otherwise the optimal interest rate for the green firm would be below zero. This green credit policy has a substantial effect on social welfare when the energy tax is insufficient. For example, when the carbon tax is below 0.1, the zero-green loan policy can improve social welfare by two percent. A lower cost of capital for green firms shifts investment from

brown to green sectors, thereby decreasing carbon emissions and mitigating climate damage. This finding has significant policy implications, as scholars have argued that the current carbon tax policy is far below the optimal level due to the "tragedy of the horizon" and political issues (Carney, 2015; Hansen, 2022). Implementing a green credit policy with a lower loan rate for green firms can help mitigate these challenges by directly incentivizing environmentally friendly investments, reducing carbon emissions, and enhancing social welfare.

The advantages of the green credit policy decay to zero when the carbon tax is at a high level. As the tax increases, the marginal cost of dirty energy decreases, and the marginal benefits of the interest rate discount for green firms diminish significantly. Conversely, inflation and the high marginal investment value for brown firms cause the marginal cost of a lower rate for green firms to increase. After the tax surpasses a threshold, the optimal green firm rate converges to the policy rate. This indicates that the green credit policy cannot provide additional value to the economy when the carbon tax is at a sufficiently elevated level. This underscores the fact that green credit policies are only useful when the carbon tax is not at the optimal level and can only serve as an auxiliary policy to address climate issues.

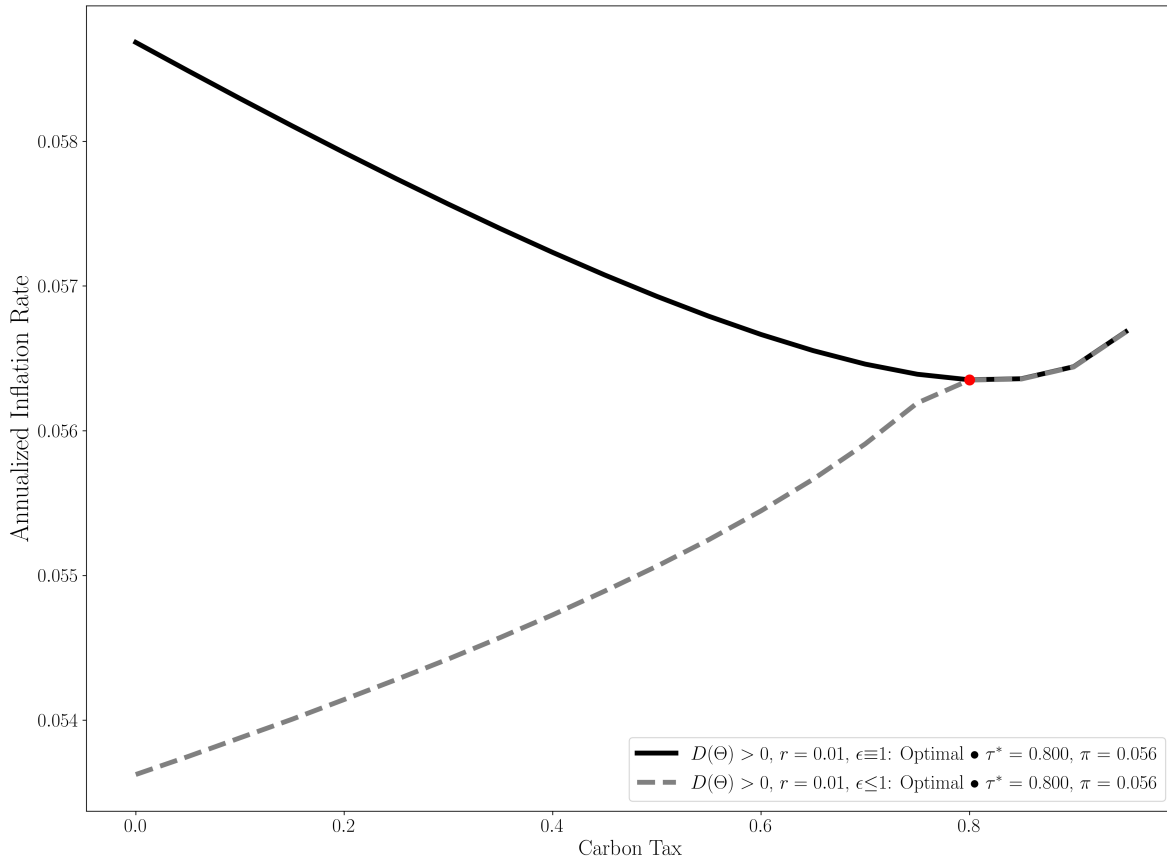


Figure 4.8: Simulation Results for the Green Credit Policy Case - Price1

Note. The figure above shows the inflation response to the green credit policy across varying carbon tax levels. The x-axis indicates the carbon tax rate, and the y-axis presents the annualized inflation rate. The black line is the benchmark without green credit, and the grey line includes green credit. The figure shows that green credit helps reduce inflation when carbon taxes are low, but the effect diminishes as the tax increases.

A major concern for the green credit policy is its potential negative effect on inflation and price stability. Therefore, in Figure 4.8, we examine how inflation changes when the green credit policy is introduced. As before, the black line represents the benchmark result, while the grey line represents the case with the green credit policy. Compared to the benchmark case, the inflation rate drops with a zero-interest green rate. This indicates that the higher production from the supply side compensates for the cost of a lower effective interest rate on the demand side, inducing a decrease in inflation. This drop in inflation is favorable for policymakers as they achieve the climate objective while maintaining their main inflation target. However, this inflation

gap shrinks and converges to zero as the tax increases. It indicates that the benefits from higher production on inflation diminish as the tax increases. It is important to note that if the central bank policymaker implements an aggressive green credit policy when the carbon tax is high, it will cause an unexpected rise in inflation. This deviates from the central bank's main mandate and is not favorable for achieving its objective of maintaining stable prices.

In summary, the green credit policy offers a potential solution for the central bank to tackle the challenge of climate change. However, the effectiveness of such a policy not only relies on the damage parameter and the stance of conventional monetary policy but is also heavily influenced by the current carbon tax level. Therefore, it is essential for policymakers to consider the carbon tax level and its interactions with green monetary policy and develop a contingent policy accordingly.

4.6 Conclusion

This paper provides a theoretical framework with policy implications for central bankers to incorporate climate change considerations into their evaluation processes.

First, our analytical solutions indicate that climate change and transition policy, especially the carbon tax, have an unexpected and significant effect on inflation and price stability. This result underscores the necessity for the central bank to incorporate climate change issues into its policy evaluation framework.

Next, our results indicate that implementing a green debt discount as part of a green monetary policy is a feasible approach to ensuring sustainable economic growth and environmental sustainability. However, the effectiveness of these green policies heavily depends on climate damage parameters and carbon tax levels. Green credit policies can serve as a sub-policy to support the carbon tax policy when the carbon tax level implemented in the economy is insufficient to control carbon emissions. On the other hand, when tax measures are sufficient to reduce carbon emissions, an ag-

gressive green credit policy has only a limited impact on increasing social welfare and further reduces the effective policy rate, leading to higher inflation. Therefore, policy-makers must implement green credit policy cautiously to avoid unexpected inflationary pressure. This result provides policy implications for central bankers when designing optimal green monetary policies to address climate change issues.

Appendix

A. Model

The model structure for green firms:

The green firm owner maximize the following objective function:

$$\max_{Q_g, k_g, c_g} \frac{c_g^{1-\sigma} - 1}{1-\sigma} - \gamma_c D(\Theta),$$

subject to the following budget constraints:

$$p_0 k_g = \frac{Q_g}{1+r_g}.$$

$$Q_g = p_1 q_g.$$

$$q_g = (y_g - c_g).$$

$$y_g = A_g(1 - D(\Theta))k_g^\gamma.$$

Where,

$Q_g \equiv$ Face value of green firm's bond;

$k_g \equiv$ Capital input of green firm;

$q_g \equiv$ Goods sold by the green firm to investors;

$c_g \equiv$ Consumption of green firm;

$y_g \equiv$ Goods produced by green firm;

$\gamma \equiv$ Output Elasticity of capital input.

B. First Best Solution

In the first-best equilibrium, the objective function for the representative agent is:

$$\text{Social utility} = w_I(U_{Investor}) + w_b(U_{Brown}) + w_g(U_{Green}),$$

subject to the aggregate budget constraints:

$$\begin{aligned} c_0 + k_b + k_g + \frac{\Theta}{\xi} &= e. \\ c_1 + c_b + c_g &= A(1 - D(\Theta)) \left(k_b^\alpha \Theta^{1-\alpha} \right)^\gamma + A(1 - D(\Theta)) k_g^\gamma. \end{aligned}$$

The Lagrangian problem is written down as:

$$\begin{aligned} \mathcal{L} &= w_I(U_{Investor}) + w_b(U_{Brown}) + w_g(U_{Green}) \\ &+ \lambda_1 \left(e - c_0 - k_b - k_g - \frac{\Theta}{\xi} \right) \\ &+ \lambda_2 \left(A(1 - D(\Theta)) \left(k_b^\alpha \Theta^{1-\alpha} \right)^\gamma + A(1 - D(\Theta)) k_g^\gamma - c_1 - c_b - c_g \right), \end{aligned}$$

where λ_1, λ_2 are the lagrangian multiplier, FOC derives:

$$\underbrace{w_I U'_{Investor}(c_0)}_{\text{Marginal Utility at } t=0} = \lambda_1, \quad (4.33)$$

$$\underbrace{w_I U'_{Investor}(c_1) = w_b U'_{Brown}(c_b) = w_g U'_{Green}(c_g)}_{\text{Marginal Utility at } t=1} = \lambda_2, \quad (4.34)$$

$$\underbrace{\frac{w_I \gamma c D'(\Theta) + \lambda_1 \frac{1}{\xi} + \lambda_2 \left(A D'(\Theta) \{ (k_b^\alpha \Theta^{1-\alpha})^\gamma + k_g^\gamma \} \right)}{\lambda_1}}_{\text{Marginal decrease of utility from energy usage}} = \underbrace{\frac{\lambda_2 \left(A(1 - D(\Theta)) (1 - \alpha) \gamma (k_b^\alpha \Theta^{1-\alpha})^\gamma \frac{1}{\Theta} \right)}{\lambda_1}}_{\text{Marginal increase of utility from energy usage}}, \quad (4.35)$$

$$\lambda_1 = \lambda_2 \alpha \gamma A(1 - D(\Theta)) \left(k_b^\alpha \Theta^{1-\alpha} \right)^\gamma \frac{1}{k_b}, \quad (4.36)$$

$$\lambda_1 = \lambda_2 \gamma A(1 - D(\Theta)) k_g^\gamma \frac{1}{k_g}, \quad (4.37)$$

where (4.35) outlines the marginal costs and advantages of producing energy. The right-hand side, which is the marginal benefit, equals the utility-weighted production increase from one additional unit of energy as input. The left-hand side, which is the marginal costs, consists of three terms: 1. utility weighted less consumption in the first period because of higher energy input. $\frac{1}{\xi}$ ¹⁰, 2. utility weighted direct climate damage to utility from higher energy use, 3. utility weighted climate damage to production ($\frac{\lambda_2}{\lambda_1} (AD'(\Theta)\{(k_b^\alpha \Theta^{1-\alpha})^\gamma + k_g^\gamma\})$). The social cost of dirty energy or Pigouvian tax τ^* could be decomposed into two terms (Barrage, 2021) $\tau^{\text{Pigou, Y}}$ and $\tau^{\text{Pigou, U}}$:

$$\text{production damages} \quad \tau^{\text{Pigou, Y}} = \frac{\lambda_2}{\lambda_1} (AD'(\Theta)\{(k_b^\alpha \Theta^{1-\alpha})^\gamma + k_g^\gamma\}). \quad (4.38)$$

$$\text{utility damages} \quad \tau^{\text{Pigou, U}} = \frac{1}{\lambda_1} w_I \gamma_c D'(\Theta), \quad (4.39)$$

where λ_2 and λ_1 are the shadow price (or marginal utility) of period 1 and period 2 constraint respectively. Combined with equation (4.33) and (4.34), we have:

$$\text{Production damages Tax} \quad \tau^{\text{Pigou, Y}} = \frac{U'(c_0)}{U'(c_1)} (AD'(\Theta)\{(k_b^\alpha \Theta^{1-\alpha})^\gamma + k_g^\gamma\}). \quad (4.40)$$

$$\text{Utility damages Tax} \quad \tau^{\text{Pigou, U}} = \frac{1}{U'(c_0)} \gamma_c D'(\Theta). \quad (4.41)$$

C. Competitive Equilibrium

By rearranging the budget constraint and the first-order conditions (FOCs), we derive the allocation solutions as shown in the main text.

¹⁰It could also be explained as cost of production because of less capital input

D. Optimal Interest rate and Carbon Pricing

The Social Utility Function could be derived as:

$$\begin{aligned}
\text{Social Utility} &= w_I(\log(c_0) + \log(c_1)) + w_b \log(c_b) + w_g \log(c_g) \\
&= w_I \left(\log\left(\frac{k(1+r)}{(2+r)}\right) + \log\left(\frac{k\gamma y_g}{k_g(2+r)}\right) \right) + w_g \log((1-\gamma)y_g) \\
&\quad + w_b \log\left((1-\gamma + \tau\gamma(1-\alpha))\frac{y_g}{\delta(\tau)\alpha}\right) \\
&= w_I[\log(1+r) - 2\log(2+r) - \log(\delta(\tau)) - \log(k_b)] + \log(1 - D(\Theta)) + \gamma \log(\delta(\tau)) \\
&\quad + \gamma \log(k_b) - w_b \log(\delta(\tau)) + w_b \log((1-\gamma + \tau\gamma(1-\alpha)) + \text{constant} \\
&= w_I(\log(1+r) - 2\log(2+r) + (\gamma - w_I)\log(k_b) + \log(1 - D(\Theta))) \\
&\quad + w_b \log((1-\gamma + \tau\gamma(1-\alpha)) + \text{constant} \\
&= w_I(\log(1+r) - 2\log(2+r)) - (\gamma - w_I)\log(2+r) \\
&\quad - (\gamma - w_I)\log((1-\tau(1-\alpha)) + \delta(\tau)\alpha) \\
&\quad + \log(1 - D(\Theta)) + w_b \log((1-\gamma + \tau\gamma(1-\alpha)) + (\gamma - w_b)\log(\delta(\tau)) + \text{constant},
\end{aligned}$$

where $\delta(\tau) = \left(\alpha \frac{A_b}{A_g}\right)^{\frac{1}{\gamma-1}} ((1-\tau)\xi)^{\frac{1-\alpha}{\alpha}} \frac{(1-\alpha)\gamma}{\gamma-1}$.

Proof of Propositions 1

For the baseline case, we assume there is no climate damage in the economy, thus the carbon tax is not necessary to introduce. In this case, the $D(\theta) \equiv 0$ and $\tau = 0$.

Taking the derivative of social utility with respect to the interest rate r , we have:

$$\begin{aligned}
\frac{\partial(\text{Social Utility})}{\partial r} &= \frac{w_I}{1+r} - \frac{w_I + \gamma}{2+r} = \frac{w_I - (1+r)\gamma}{(1+r)(2+r)} \\
&\implies (1+r_{\text{base}}^*) = \frac{w_I}{\gamma}.
\end{aligned}$$

Proof of Propositions 2 In this case, we assume $D(\theta) > 0$ and $\tau = 0$. Taking the derivative of social utility with respect to the interest rate r , we have:

$$\frac{\partial(\text{Social Utility})}{\partial r} = \frac{w_I}{1+r} - \frac{w_I + \gamma}{2+r} - \left(\underbrace{\frac{\frac{\partial D}{\partial \Theta} \frac{\partial \Theta}{\partial r}}{1 - D(\Theta)}}_{\text{Marginal Climate damage} < 0} \right) \quad (4.42)$$

$$\implies (1 + r_{\tau=0}^*) > \frac{w_I}{\gamma}. \quad (4.43)$$

Proof of Lemma 1

Consumption goods prices equal to

$$p_0 = \frac{(2+r)m}{rk}, \quad (4.44)$$

$$p_1 = \frac{(1+r)p_0 k_g}{\gamma y_g}. \quad (4.45)$$

Therefore, the inflation π_{base} equals to:

$$\pi_{\text{base}} = \frac{p_1}{p_0} = \frac{(1+r)}{\gamma A_g k_g^{\gamma-1}} = \frac{(1+r)}{\gamma A_g (\delta k_b)^{\gamma-1}} = \frac{(1+r)}{\gamma A_g (\delta \frac{k\alpha}{(1+\delta\alpha)(2+r)})^{\gamma-1}} = \frac{(1+r)(2+r)^{\gamma-1}}{\gamma A_g (\delta \frac{k\alpha}{(1+\delta\alpha)})^{\gamma-1}}. \quad (4.46)$$

Regarding the second case, the

$$\pi_{\tau=0} = \frac{(1+r)(2+r)^{\gamma-1}}{\gamma A_g (1 - D(\Theta)) (\delta \frac{k\alpha}{(1+\delta\alpha)})^{\gamma-1}} > \pi_1, \quad (4.47)$$

since $(1 - D(\Theta)) < 1$, we have $|\frac{\partial \pi_{\tau=0}}{\partial r}| > |\frac{\partial \pi_{\text{base}}}{\partial r}|$.

Proof of Proposition 3 In this case, we assume the carbon tax is positive,

The interaction term in the utility function is

$$\log(1 - D(\Theta)) = -d\Theta = -d(1 - \tau)\xi \frac{1 - \alpha}{\alpha} \frac{k\alpha}{((1 - \tau(1 - \alpha)) + \delta(\tau)\alpha)(2 + r)}.$$

As proved before, $\frac{\partial \Theta}{\partial \tau} < 0$. The marginal climate damage terms in **Proof of Proposition 3** become less negative, and therefore the optimal $r_{\tau \geq 0}^*$ is equal or smaller than $r_{\tau=0}^*$.

Proof of Proposition 4 Plug in the solution of the endogenous variables into the inflation function, we have:

$$\pi = \frac{(1+r)(2+r)^{\gamma-1}}{\gamma A_g (1 - D(\Theta)) (\delta(\tau) \frac{k\alpha}{(1-\tau(1-\alpha) + \delta(\tau)\alpha)})^{\gamma-1}}. \quad (4.48)$$

E. Numerical Robustness Check

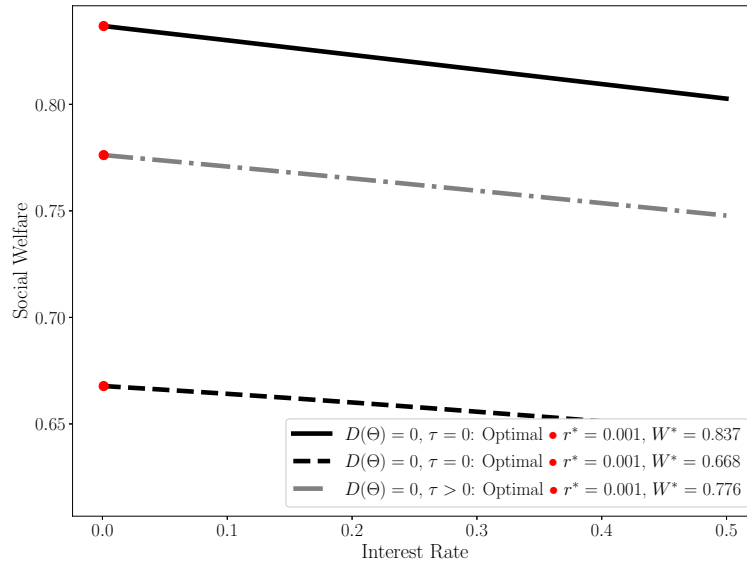


Figure 4.9: Social Welfare as a Function of Carbon Tax in Three Regimes with $\sigma = 2$

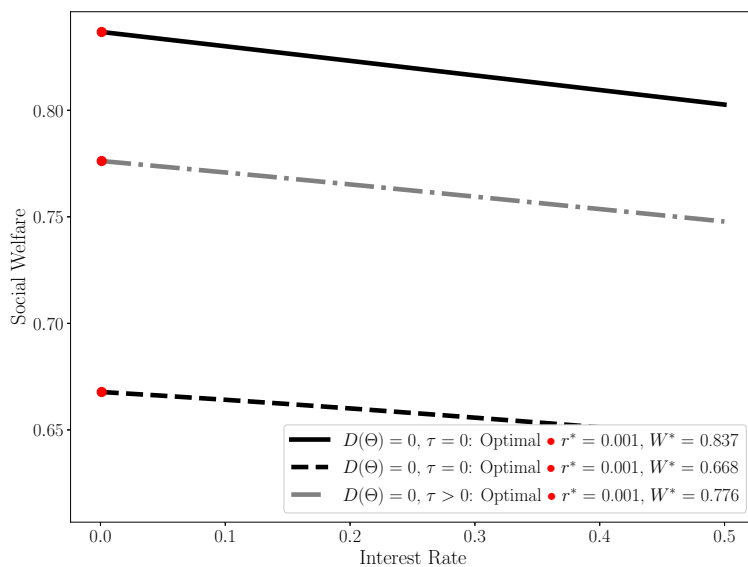


Figure 4.10: Social Welfare as a Function of Interest Rate in Three Regimes with $\sigma = 2$

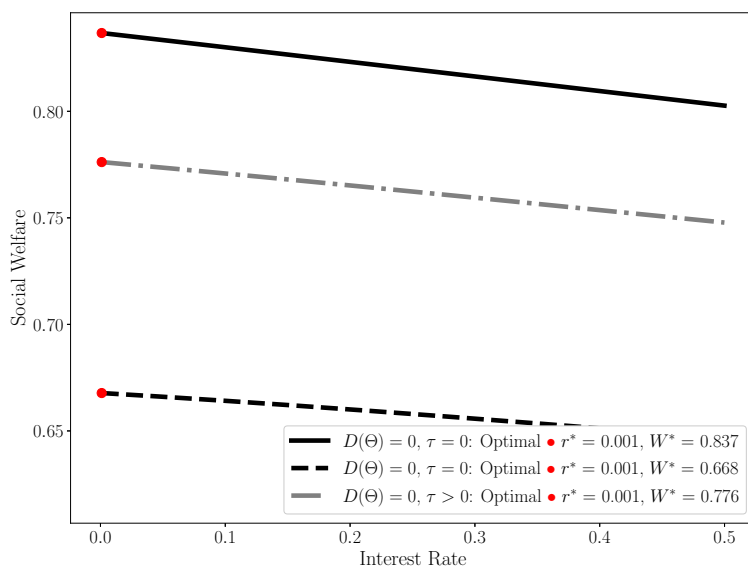


Figure 4.11: Inflation as a Function of Carbon Tax with $\sigma = 2$

Chapter 5

Dynamic Knowledge Graph Asset

Pricing

Dynamic Knowledge Graph Asset Pricing*

Abstract

The macro-finance system stands as a complex network. We model this system in a Large-Language-Model-based (LLM) dynamic knowledge graph using the entire corpus of the Wall Street Journal from 1999 to 2023. We identify a constellation of systematic themes, such as economic growth and technology. A novel network-based measure named polar centrality is introduced to quantify the systematic importance of corresponding theme factors to the whole economy. We apply an asset pricing model to validate our structural theme factors as reliable proxies for state variables in the unconditional ICAPM framework. Our theme indexes inherently account for the time-varying importance of different macro themes. They demonstrate forecasting competency for future economic activities, unconditional pricing power in the cross-section, and incremental contribution to the stock market factor zoo. The LLM-powered graph AI system unveils a new thematic factor lens that represents the financial system with high resolution.

Keywords: Knowledge graph, Large language model, Cross-sectional asset-pricing, ICAPM, Factor model, Graph theory, Generative AI, Factor zoo

*This chapter is derived from my joint work with Xiaohui Li. The views presented in this article are those of the authors and do not necessarily represent those of the authors' affiliations. We are grateful to Amir Amel-Zadeh, Dimitrios P.Tsomocos, Jiri Knesl, Shumiao Ouyang, and Francesco Sanna Passon for their invaluable comments.

5.1 Introduction

The sophisticated interactions between macroeconomic indicators and financial markets present the macro-finance system as a complex network in nature (Acemoglu et al., 2016b). The network is instrumental in understanding the dynamics of economic shocks and the bidirectional influence between the economy and financial markets. Despite a grounded theoretical foundation, measuring the multi-dimensional state variable of the economy within this network remains an active challenge.

This paper introduces an Artificial Intelligence methodology - Dynamic Knowledge Graph - to model the macro-finance network system. We utilize a fine-tuned Large Language Model (LLM) to process an extensive news corpus (Li, 2023). Our knowledge graph model processes the extensive news dataset to assess the state of the economy. We propose that the theoretical macro-finance network can be effectively represented through a news-based dynamic knowledge graph, leveraging the generative capabilities of LLM. We hence develop network topology-based indexes, termed “polar centrality”, to quantify the impact of various economic state variables on asset markets within the Intertemporal Capital Asset Pricing Model (ICAPM) framework by Merton (1973). Our index, which measures the systematic importance of each factor, uniquely provides a proxy for state variables that inherently account for their time-varying relationship with the whole economy. We provide empirical evidence that our polar centrality indexes have unconditional predictive power for future economic activities, are unconditionally priced with a positive risk premium, and contribute to the factor zoo as macro factors.

Traditional macroeconomic data holds inherent measurement errors and delays (Chang and Li, 2018), compounded by the rapidly evolving and increasingly high-dimensional nature of economic variables. Recent advancements in Generative AI, characterized by the surge of alternative data sources, offer a new paradigm that uses AI to convert unstructured data into structured macroeconomic indicators.

Our method combines insights from economic themes with a structural analysis provided by the dynamic knowledge graph, proposing a new AI-powered framework for modeling and analyzing the macro-finance system through a data-driven approach. This methodology shifts Natural Language Processing (NLP) from a primarily frequency-based text analysis (Baker et al., 2016; Cohen et al., 2020; Caldara and Iacoviello, 2022) to a generative AI paradigm for processing financial text data, including tasks like Named Entity Recognition (NER), Entity Linking (EL), Entity Disambiguation (ED), and Aspect-based Sentiment Analysis (ABSA), all performed by a single LLM with various prompts. Furthermore, we have developed a fine-tuned 7-billion parameter Large Language Model, leveraging self-instruction techniques proposed by Wang et al. (2022) to learn from OpenAI’s GPT-4 (Achiam et al., 2023), to construct a financial knowledge graph from more than 400,000 financial news articles over the past 25 years.

With the principle “things, not strings”, the introduction of modern Knowledge Graphs (KGs) by Google in 2012 marked a shift from keyword-based search to semantic, context-aware machine understanding (Fensel et al., 2020). Since then, the development of KGs has greatly advanced, expanding into various sectors, including recommendation (Wang et al., 2018, 2019) and question-answering (Bordes et al., 2015) systems, and others. However, KGs in finance have remained relatively underdeveloped, particularly compared to the established field of Financial NLP (Gentzkow et al., 2019). This work explores the potential of dynamic KGs in asset pricing. Our dynamic KG not only models real-world entities with precision but also captures the dynamic nature of each entity in a structured manner.

News attention measure, as documented by Bybee et al. (2023), can be derived from newspaper data to price assets. However, the attention itself fails to capture the sentiment of state variables. For example, the FOMC announcement could be interpreted as both dovish and hawkish tones (Cieslak and McMahan, 2024), each impacts the financial market in a different way, suggesting that sentiment is necessary to capture the effect of different macro concepts on the market.

In our study, we introduce a novel graph-based metric denoted as polar centrality, which integrates the network topology-based Katz centrality measure with entity-based sentiment analysis to evaluate the state variables of thematic factors systematically identified by our structured KG. We develop 125 thematic indexes material to our macro-finance network system, covering a wide range of macroeconomic states from Economic Growth and Consumer Spending to emerging themes like Artificial Intelligence and Cryptocurrency.

To evaluate whether our theme indexes have significant effects on asset returns, we apply an empirical test model based on the Integrated Consumption-based Asset Pricing Model (ICAPM) (Merton, 1973) framework. According to ICAPM, an asset's expected return should be linked not only to its covariance with market returns but also to state variables that can predict future consumption or economic growth. Within this framework, the stochastic discount factor (SDF) is approximated as a linear function of innovations in various factors, including the market portfolio and latent state factors.

Building on this theoretical foundation, our analysis focuses on evaluating the polar centrality index associated with the structural theme of the economy. These indexes capture the importance of related economic themes to the overall economy and are, therefore, more appropriate candidates for proxies of state variables. We select 59 out of 125 themes based on two simple criteria: having fewer missing values and a higher average systematic importance value.

First, we present empirical evidence demonstrating that our selected polar centrality indexes have strong predictive power for future economic activities. We start by running a monthly frequency single predictor regression across different horizons. This regression evaluates the predictive power of our polar centrality index on two proxies for future economic activity: industrial production growth and real consumption per capita growth. Next, we incorporate our polar centrality indexes into the baseline model, which includes three proxies for state variables widely used in the literature

(Gilchrist and Zakrajšek, 2012; Boons, 2016; Boons et al., 2020), to evaluate the robustness of the predictive power of our polar centrality indexes.

Our results show that most of our economic structural indexes have consistent predictive power for both consumption growth and industrial production growth across different horizons. For instance, the polar centrality index for the financial sector has an R^2 of 0.169 and 0.135 in the single index prediction regression for predicting the future six months' real consumption per capita growth and industrial production growth, respectively. This predictive power remains robust after controlling for state variables that have been used in past literature. When our indexes are included in a baseline model, which incorporates three state variables used in past literature, the adjusted R^2 increases from the baseline values of 0.168 to 0.249 for predicting consumption expenditure growth and from 0.070 to 0.186 for predicting industrial production growth. Additionally, the coefficients in the multiple regression are very close to those in the single regression, indicating that our index provides incremental value that is almost orthogonal to the state variable model used in past literature.

Second, we test whether exposure to our index factor is priced in the cross-section of asset returns. Testing non-tradable factors, such as our thematic indexes, encounters challenges due to omitted factors and measurement errors. These issues are addressed by using the three-pass estimators model (GX model) proposed by Giglio and Xiu (2021) to assess the risk premium of our thematic index. The GX model projects our non-tradable factors onto the latent factor space extracted by the principal component from the asset return matrix. This methodology provides an unbiased and more robust estimation of the risk premium for non-tradable factors. We estimate the risk premium of our polar centrality index using monthly equity portfolios sorted by 212 characteristics, as described in Chen and Zimmermann (2021). The testing period spans from 2000 to 2022.

The risk premium testing results indicate that 20 of our centrality indexes are

priced in the cross-sectional test with a positive and significant risk premium. Since sentiment determines the direction of the centrality index, all significant factors exhibit a positive risk premium. This result verifies the effectiveness of our polar centrality index in capturing economic activities that systematically affect the equity market. For instance, according to our results, a one-unit beta exposure to the oil index is compensated with a 116 basis points monthly return. Although there is a consensus that oil impacts the equity market (Ready, 2018; Azimli, 2020; Gao et al., 2022), no index has been able to unconditionally capture the risk premium of oil shocks. This highlights the unique capability of our polar centrality index to consistently capture the effect of macro themes on the economy and stock market.

Although the ICAPM does not explicitly define state variables, previous studies have developed sign restriction criteria as a necessary condition for a factor to be considered a potential risk factor. A state variable with positive (or negative) predictability for future economic conditions should lead to a corresponding positive (or negative) risk premium (Boons, 2016). Our empirical evidence from the prediction tests and risk premium estimations supports these sign restriction criteria and demonstrates that our indexes could effectively serve as proxies for state variables within the ICAPM framework.

Finally, we test the contribution of our polar centrality indexes as a macro factor to asset pricing. We employ the “two-pass regression with double-sorted Lasso” (FGX) methodology proposed in Feng et al. (2020) to examine the marginal contribution of our polar centrality indexes to the existing factor zoo. The FGX methodology uses a double-sorted Lasso approach to address the high-dimensionality of the factor zoo issue while accounting for the omitted factor bias problem. This methodology is appropriate for non-tradable factors and can independently test candidate factors, thus fulfilling the requirements for our evaluation.

The results of the contribution test indicate that several of our theme indexes,

such as Oil, China, Manufacturing, Economic Growth, Economic Recovery, Financial Conditions, and Economic Outlook, significantly contribute to the existing factor zoo with positive loadings, It is notably important that although the stock market, US economy, global economy, and some other indexes show significant risk premiums in the test, they have no significant SDF loadings after controlling for existing factors. This indicates that not all the indexes from our dynamic knowledge graph contain substantial new information not captured by past factors, and some information appears redundant. Nevertheless, the contribution of some of our indexes to asset pricing still highlights the effectiveness of our dynamic knowledge graph method in innovatively developing macro factors that track the time-varying systematic importance of different macro themes.

Our work contributes to at least two strands of asset pricing literature. First, we contribute to the literature on identifying potential state variables within the ICAPM framework. Since the development of the ICAPM model (Merton, 1973), identifying interpretable state variables within this framework has been a popular topic. Many studies attempt to use macroeconomic factors as state variable proxies (Chen et al., 1986; Ferson and Harvey, 1991; Petkova, 2006). Yet, a growing number of academic works question whether a risk premium for state variable exposure in the equity market council with macro-finance theory.

On one hand, Lewellen and Nagel (2006) and Maio and Santa-Clara (2012) argue that traditional state variables show inconsistencies between time-series predictions and cross-sectional observations at the portfolio level, violating the ICAPM framework's assumptions. On the other hand, Boons (2016) claims that consistency holds for conventional proxies for state variables when tested at the individual asset level. More recently, Boons et al. (2020) suggest that time-varying risk premiums, due to changing predictive power over time, are the main reason for inconsistent results in consistency tests. However, if this is correct, the time-varying nature of state variable risk premia complicates the accurate estimation of the associated risk premium.

Our paper fills this gap by providing polar centrality indexes as a robust proxy for state variables. We show that the direction of the significant risk premiums of our polar centrality indexes, estimated using a group of portfolio assets, aligns with the direction of how these variables forecast macroeconomic growth over time. This approach addresses the noted inconsistencies, even when testing with portfolio assets. More importantly, our polar centrality index accounts for the time-varying importance between specific themes and the overall economy. This allows for the estimation of the risk premium of state variables in a simple, unconditional asset pricing setup.

Our paper also relates to and contributes to the literature applying textual analysis methodology in finance, particularly studies that use NLP methodologies to extract signals and narratives from financial news data (Loughran and McDonald, 2020; Kelly et al., 2023; Ash and Hansen, 2023). Previous literature has employed textual analysis models, including dictionary list counts (Gentzkow and Shapiro, 2010; Baker et al., 2016), or LDA (Latent Dirichlet Allocation) with word-embedding models (Bybee et al., 2024; Hirshleifer et al., 2025; Bybee et al., 2023), to extract attention-based topics or uncertainty indexes from newspaper data. These studies demonstrate the predictive and explanatory power of such new indexes for the economy and stock market. We contribute to the attention-based topic modeling papers by constructing a dynamic knowledge graph. This dynamic knowledge graph, based on real-world financial entities, provides a more structured view compared to traditional text-based methods that solely rely on the attention given to a topic.

Additionally, a line of research uses sentiment analysis methodologies to construct sentiment indexes from newspapers (Shapiro et al., 2022; Macaulay and Song, 2023; van Binsbergen et al., 2024), which also have predictive power for economic indicators such as GDP growth and consumer confidence. In our paper, we integrate sentiment with graph centrality by constructing a composite index. The composite index presents a more nuanced view of the impact of news, taking both its prominence and its content into consideration.

The rest of the paper is organized as follows. Section 5.2 describes the AI model used in generating the financial knowledge graph. Section 5.3 describes our methodology for generating the thematic indexes. Section 5.4 tests our indexes in asset pricing models. Finally, Section 5.5 concludes with a summary and concluding statements.

5.2 Financial Dynamic Knowledge Graph with LLM

We employ a specialized large language model (LLM) introduced by Li (2023) to process and summarize the extensive Wall Street Journal (WSJ) text corpus, aiming to compile a structured financial dynamic knowledge graph (KG) dataset spanning over 20 years. This section outlines our proposed generative AI pipeline for developing the news-based KG and provides details about the LLM.

5.2.1 Dynamic Knowledge Graph

KGs have become an important data-driven methodology for extracting structured and semantic information from unstructured data in the recent decade. KGs are a graph-based data structure consisting of two essential elements: node and edge. In KG, nodes represent entities with real meaning, and edges refer to the relationships between these entities (Ji et al., 2021). The entity in the KG reflects a significant improvement over keyword- or term-based techniques in natural language processing (NLP). The traditional keywords represent characters or words that may not have intrinsic meaning, while entities represent identifiable objects or concepts that are well-defined. The edges in the KG further embed entities within a rich network of relationships and attributes (Kejriwal and Szekely, 2017). The differences between KG and conventional NLP bring with them a semantically deeper and more expressive form of information, allowing Knowledge Graphs to structure information from a variety of sources in terms of clearly defined entities and, therefore, capture rich contextual information regarding their interrelationships and descriptors.

The formal mathematical definition of a KG is $\mathcal{G} = \{E, R, F\}$, where E , R , and F represent the sets of entities, relations, and facts, respectively. The set E comprises different entities. The set R comprises heterogeneous relationships that identify the linking types between entities. The fundamental structure of a KG is the triplet $(s, r, o) \in F$, where s is the source entity, r is the relation, and o is the object entity. For instance, the triplet $(OpenAI, Invent, ChatGPT)$ represents a relation between source entity OpenAI and object entity ChatGPT through the relation “Invent.” By combining entities with a relation, a single fact statement is constructed through such a triplet. By combining such triplets, a rich Knowledge Graph is constructed, providing an overall picture of represented knowledge in a structured form.

Real-world KGs are dynamic, evolving with new information while discarding outdated information. To account for the dynamic nature of the relationships between different entities, the concept of a Temporal knowledge graph(TKG) was introduced. In a directed, multi-relational TKG, each edge is tagged with a discrete time stamp. An edge can be represented by a 4-tuple (s, r, o, t) , where s represents the subject entity, r is the relation type of the edge, o is the object entity, and t is the time stamp. In TKGs, each edge is associated with a time stamp t identifying the time for which a relationship between two entities is valid. This expressive temporal tagging enables fine-grained temporal inference and facilitates the recognition of dynamic patterns and trends (Peng et al., 2023). A dynamic knowledge graph(DKG) consists of a sequence of TKGs across time (Li, 2023). The dynamic graph $\mathcal{G}_{0:t}$ can be viewed as the union of its time-sliced subgraphs \mathcal{G}_τ , formally represented as $\mathcal{G}_{0:t} = \bigcup_{\tau=0}^t \mathcal{G}_\tau$. Figure 5.1 shows the structure of the dynamic knowledge graph develops as a sequence of TKGs. In this paper, we use the DKG concept described above to capture the time-evolving macro-finance system. We propose a finance event-centric DKG that focuses on the identification, representation, and integration of events related to financial activity. Our finance event-centric DKG could not only capture the static relationships between entities in the macro-finance world (e.g., ownership, affiliation) but also dynamically

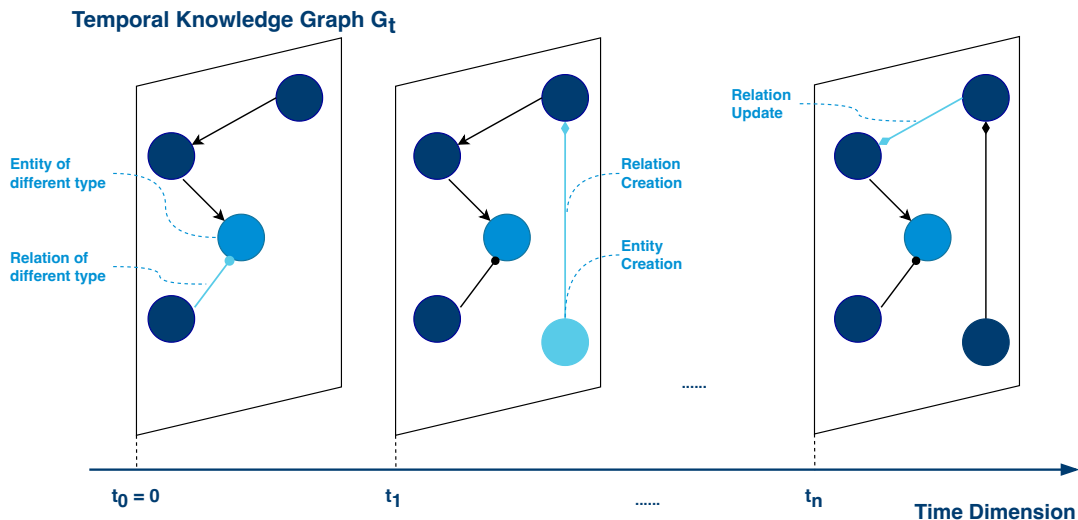


Figure 5.1: Temporal Dynamics in a Dynamic Knowledge Graph

models the influence of macro-financial events on those entities over time.

5.2.2 Generative Knowledge Graph Construction Using Large Language Model

In this section, we detail the methodology for constructing the DKG model proposed above. Generative Knowledge Graph Construction (KGC) represents the pipeline for generating knowledge graphs from unstructured and semi-structured information. KGC involves leveraging a large language model (LLM) to extract entities and the relationships between them from textual data through specific prompts and then combining this information into triplets. Traditional approaches to KGC have encountered issues such as error propagation and poor adaptability in dealing with a range of tasks. The development of LLMs has led to the proposal of a new model for generative KGC, which significantly improves upon existing methodologies.

Figure 5.2 offers an illustrative example of this generative KGC pipeline. The KGC begins with the use of the LLM to derive KG triplets from financial news articles. We predefined the relationship and triple types to reduce noisy. There might be multiple triplets in each documents and we only keep the triplets that meet our pre-defined

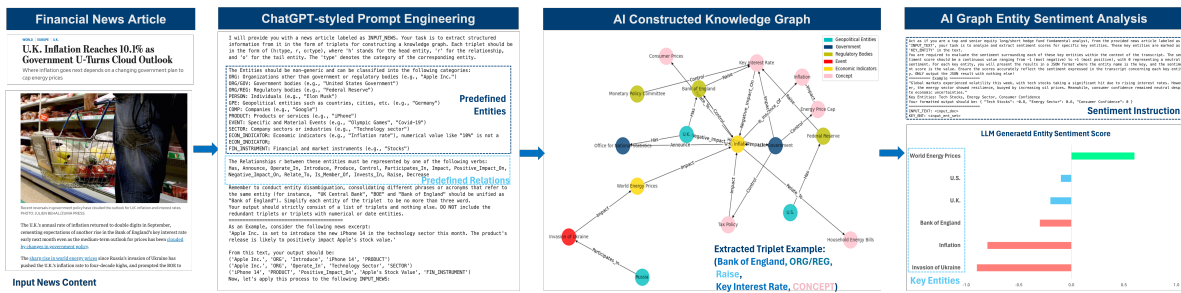


Figure 5.2: Generative Knowledge Graph Construction and Processing Pipeline

requirements.

The next stage is entity disambiguation processing. Entity Disambiguation (ED) is a technique utilized for proper entity identification mentioned in a text, particularly in cases when terminology holds uncertain meanings. Traditional ED approaches have utilized a variety of techniques for natural language processing (NLP), including algorithmic approaches, feature engineering, and rule-based approaches, all for exploiting contextual information about uncertain terms and effectively mapping them with respective entities in a knowledge base.

Embedding-based LLMs, including BERT (Devlin et al., 2018) and MPNet (Song et al., 2020), present a new ED approach through exploiting rich semantic information present in their embeddings. Unlike conventional techniques that rely on expert-designed features and external knowledge bases, LLMs have the potential to make correct entity references directly out of the text, leveraging contextual information present in their pre-trained forms. In this paper, we utilize the Sentence-Transformer model to produce entity embeddings and cluster entities into coherent groups with a cosine similarity value over 95%. Figure 5.E visualizes the 3D embeddings for the entity group “Google Inc.” in comparison with other randomly sampled unrelated entities. The dimensionality of these embeddings is effectively reduced using the UMAP algorithm (McInnes et al., 2018), a technique renowned for its proficiency in preserving both local and global data structures within lower-dimensional spaces. The entities related to “Google Inc.”, such as “Google Inc”, “Alphabet Inc.”, or “Google LLC” etc., are

grouped together as one entity cluster and all transformed into “Google Inc.” that has the highest counts within the total KG. We leave the supplementary details on embedding-based LLM in Appendix C.

5.2.3 Aspect-Based Sentiment Analysis

Sentiment analysis is the final step in our KCG pipeline. Sentiment analysis can be categorized into document, sentence, and aspect levels, depending on the granularity of the text being analyzed. While document- and sentence-level analyses yield an overall estimation of sentiment, they fail to account for cases where different paragraphs in a document express conflicting sentiments for an entity. For instance, a piece of news might have a positive sentiment about inflation while a negative sentiment about the Federal Reserve’s high interest rates. This limitation of the document- and sentence-level analyses indicates the necessity to introduce Aspect-Based Sentiment Analysis (ABSA) to evaluate the sentiment. ABSA provides a more comprehensive and accurate evaluation of sentiment at the aspect level. In our KG, the aspect level is equivalent to the entity level.

In our application, given a news article, there are various entities of different contexts and sentiments. We propose using the LLM to identify a sentiment score for each of the entities. As shown in Figure 5.2, our sentiment analysis prompt takes both the source document and entities identified in the initial stages, finally producing a structured output that encapsulates the sentiment associated with each entity. The ASBA prompt can be seen in the Appendix B.

5.2.4 Specialized Large Language Models with Supervised Fine-tuning

While pre-trained LLMs are powerful in general language understanding, these models might not be optimal for a specific downstream task. To optimize the performance of

LLMs for a specific task, supervised fine-tuning has emerged as a fundamental technique. Specifically, Yu et al. (2020) shows the effectiveness of fine-tuning in improving the performance of LLMs in the KGC pipeline. In this subsection, we discuss LLM fine-tuning and detail the mathematical formula.

The fine-tuned methodology can be expressed in a mathematical formula. Given a sequence of text tokens $X = \{x_1, x_2, \dots, x_N\}$, the objective of a generative LLM is to maximize the likelihood of generating this sequence. The objective function is:

$$\max_{\theta} \log P(X; \theta) = \sum_{t=1}^N \log P(x_t | x_1, x_2, \dots, x_{t-1}; \theta),$$

where *token* denotes a unit of text that has been extracted from the original text during the LLM tokenization process. Tokens form the basis for language models in both training and inference operations. The generating function, represented with f_{θ} , is defined in terms of its parameterization with θ and can be represented as:

$$x_t = f_{\theta}(x_1, x_2, \dots, x_{t-1}; \theta),$$

where x_t is the token generated by f_{θ} , and θ are the parameters of the neural network model optimized during training. Supervised fine-tuning of generative LLMs can be formulated as the following optimization problem:

$$\min_{\theta} \sum_{i=1}^n \mathcal{L}_{\text{NLL}}(y_i, f_{\theta}(x_i)),$$

where \mathcal{L}_{NLL} is the Negative Log-Likelihood loss function, x_i are the input text tokens of a fine-tuning dataset, y_i are the corresponding human or more advanced LLM-generated responses, $f_{\theta}(x_i)$ is the text sequence generated by the model when given x_i as input.

This approach leverages the generative powers of LLMs with the structured knowledge representation in graphs, facilitating large-scale automated knowledge graph construction without intense human effort.

5.2.5 News-based Financial Dynamic Knowledge Graph Dataset

In this study, we develop a Financial Knowledge Graph (FinKG) dataset leveraging LLM, constructed from the full news article datasets of the Wall Street Journal (WSJ). We choose WSJ because it is widely recognized as one of the most authoritative news sources for comprehensive coverage of financial news and market-relevant information. Our methodology capitalizes on the extensive content of complete news articles, enabling the use of LLMs to extract structured data. This approach differs from conventional finance literature that depends on the manual summarization of news headlines or abstracts like Baker et al. (2016). We extract the full spectrum of information contained within the financial news articles.

The daily-frequency news dataset we collect consists of all articles published in WSJ from January 1999 through December 2023. Since we only focus on economic news, we exclude articles with subject tags corresponding to predominantly non-economic content such as sports, leisure, and arts, and exclude articles that contain data tables with little supporting text. Our final data set consists of 427,158 articles.

Next, we leverage the introduced generative knowledge graph construction pipeline to construct the dynamic knowledge graph. At the core of our approach lies the ICKG (Integrated Contextual Knowledge Graph Generator), an instruction-following LLM of seven billion model parameters, which has been made available for academic research¹ by Li (2023). This model is fine-tuned on a high-quality supervised dataset generated by the state-of-the-art but close-sourced GPT-4 AI model (Achiam et al., 2023). Such inheritance empowers ICKG with GPT-4’s aptitude for automated knowledge graph construction and aspect-based sentiment classification, facilitating the generation of real-world, large-scale knowledge graphs. The model’s fine-tuning and inference processes were executed on a cloud-based GPU server, equipped with eight NVIDIA A100 GPUs with 40GB of memory each. The implementation details are shown in

¹Access the ICKG LLM at: <https://huggingface.co/victorlxh/ICKG-v3.2>

Appendix B.

We further refine the raw knowledge graph triplets through the ED methodology by employing a Sentence-Transformer model (Reimers, 2019). Next, we implement a rolling-window filtering mechanism. At the end of each month, starting from 2001, entities documented more than five times in the preceding year were retained as *active entities*. This rolling-window framed process enables the exclusion of infrequent, and thereby potentially irrelevant, entities without including any look-ahead information. Triplets featuring entities not classified as active were systematically removed from the dataset.

A significant feature of our FinDKG, in contrast to conventional graphs, is its incorporation of complex relationships between entities. We develop a set of 15 predefined relationships designed to cover key relations in the worldwide financial news environment. As seen in Table 5.A in Appendix A, important relations such as *relate_to* and *impact* serve as building blocks for representing importance and cause-effect relations. In addition, taking advantage of LLM’s inbuilt Named Entity Recognition (NER) feature enables distinguishing specific entity types out of a predefined range of 12 categories, including important *PERSON*, abstract *CONCEPT*, and significant *EVENT*, discussed in detail in Table 5.B.

Figure 5.A shows the monthly count of the triplets of our LLM-generated FinDKG. The count of knowledge graph triplets closely track the count of news articles. On average, each article contributed to the generation of 7.1 active triplets, underscoring the efficiency of our methodology in translating textual data into enriched structured knowledge. Table 5.C summarizes the statistics of the knowledge graph dataset. In total, there are 3,028,055 active triplets extracted, covering 58,848 unique entities.

5.3 The Dynamic Network of Macro-Finance

The financial dynamic knowledge graph models in this paper capture the complex macro-finance network system. We cover a wide range of financially related entities and build a knowledge graph to capture their complex and dynamic relationships. This section aims to systematically dissect the network, describing the detailed methodology for constructing thematic factors.

Our methodology constructs Temporal Knowledge Graphs (TKGs) on a weekly frequency. These TKGs are built using a one-month rolling window, incorporating knowledge graph triplets extracted from newspaper data described in the previous section. To capture the systematic importance of entities in the KG, which serve as a proxy for their impact on economic growth, we construct a thematic index to quantify the importance of entities.

5.3.1 Identifying Systematic Important Network Themes

To quantify the importance of entities, we leverage the centrality measure, a key quantitative methodology in identifying the systematic importance of nodes in network analysis. Mathematically, for a graph $G = (V, E)$ consisting of nodes V and edges E , we have adjacency matrix A defined such that $A_{ij} = 1$ if an edge exists between nodes i and j , and $A_{ij} = 0$ otherwise. The centrality measure gives a relative ranking score x for each node that quantifies its importance within the graph.

Degree centrality stands as the benchmark measure. Degree centrality is based on the frequency of edges and is simple to calculate. For a node v , degree centrality x^{Degree} equals the number of edges $C_D(v)$ linked to the node, which is the sum of inbound edges $\sum_{i \in V} A_{iv}$ and outbound edges $\sum_{j \in V} A_{vj}$, then normalized so that the degree centrality

sum to one, formally:

$$C_D(v) = \sum_{i \in V} A_{iv} + \sum_{j \in V} A_{vj};$$
$$x^{Degree} = \frac{C_D}{\sum_{u \in V} C_D(u)}.$$

This metric is a benchmark estimate of a node's value, using only the direct count of links, similar to bag-of-words model in analyzing documents.

The eigenvector centrality x^{Eigen} generalizes the concept of degree centrality in terms of not only the count but also the quality of relations. This measure works under the principle that being connected to a high-ranked node has a larger impact in contributing to a node's overall value, and this can be represented in the following equation:

This metric is a benchmark estimate of a node's value, using only the direct count of links, similar to the bag-of-words model in analyzing documents.

The eigenvector centrality x^{Eigen} generalizes the concept of degree centrality in terms of not only the count but also the quality of relations. This measure works under the principle that being connected to a high-ranked node has a larger impact in contributing to a node's overall value, and this can be represented in the following equation:

$$Ax^{Eigen} = \lambda x^{Eigen}, \tag{5.1}$$

where λ represents the largest eigenvalue of the matrix A . Building upon eigenvector centrality, implementations such as Google's PageRank and Katz centrality expand on a more sophisticated evaluation of a node's impact in a network. Katz centrality extends the eigenvector centrality with an additional attenuation parameter α together with the eigenvector β , such that one can include consideration for the impact of indirect ties while keeping the main ideas of eigenvector centrality. The mathematical expression

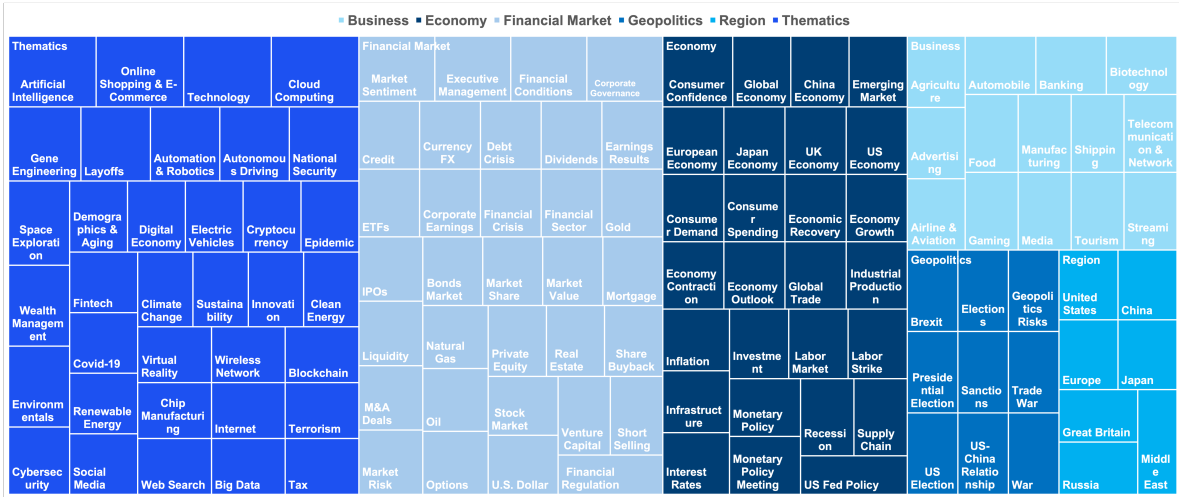


Figure 5.3: LLM Identified Themes

for Katz centrality is defined as:

$$x_i^{Katz} = \alpha \sum_{j=1}^N A_{ij} x_j^{Katz} + \beta, \quad (5.2)$$

where x_i^{Katz} is the Katz centrality of node i . The Katz centrality measure captures the indirect connections within the network and penalizes distant connections between nodes through the attenuation factor α . As α approaches zero, Katz centrality converges to the benchmark degree centrality. The inclusion of both direct and indirect connections in the Katz measure mirrors the contextual text analysis in document processing beyond bag-of-words approach. We choose to use Katz centrality to measure the entity node’s importance.

Utilizing Katz centrality, we generate a temporal entity ranking at each point in time. Figure 5.B and 5.C plot the subgraph including only the top 15 entities of each entity category defined in Table 5.B. In 2020, the COVID-19 pops up as the dominant event-categorized entity, while in 2023, interest rates and inflation become focal points of the financial system.

Each week, we collect the top 15 entities across each entity group ranked by Katz centrality, creating a comprehensive set of entities that play a significant role in driving

the dynamics of the financial knowledge graph. We employ embedding-based LLMs to identify topic clusters among these entities, thus delineating thematic topics that encompass entities with contextual similarities. For instance, entities such as Artificial Intelligence, Generative AI, ChatGPT, and AlphaGo are all categorized under the “Artificial Intelligence” theme. Throughout the entire dataset, we have identified 125 distinct themes, which are classified into six general categories: Business, Economy, Financial Market, Geopolitics, Region, and Thematics. The list of all themes is shown in Figure 5.3 Overall, these themes cover the whole macro-financial system, and their topics range between macroeconomic shocks and general theme considerations.

By leveraging the embeddings from the LLM, we can dynamically incorporate new entities into an existing theme based on the cosine similarity of their embeddings. Specifically, if the cosine similarity score of an entity’s embedding with a theme’s embedding exceeds 90%, the entity is classified into that theme’s cluster. Our dynamic model is, therefore, more adaptive than the Latent Dirichlet Allocation (LDA) approach (Bybee et al., 2024), as our themes can evolve with the flow of new entities. This approach also allows a single entity to be classified into multiple embedding-based themes. It ensures a more comprehensive and denser theme space. Further implementation details of our topic clustering algorithm are provided in Appendix C.

5.3.2 Quantifying State Variable of Theme

After identifying themes within our KG based on a LLM, we quantify the importance and sentiment of these themes in this section. We begin this process by calculating each theme’s aggregate centrality within the network. We select the maximum Katz centrality score from all associated entities within a theme. Formally, for a theme m consisting of N entities, each with a Katz centrality x_e^{Katz} , the theme’s centrality, λ_m^t , is given by:

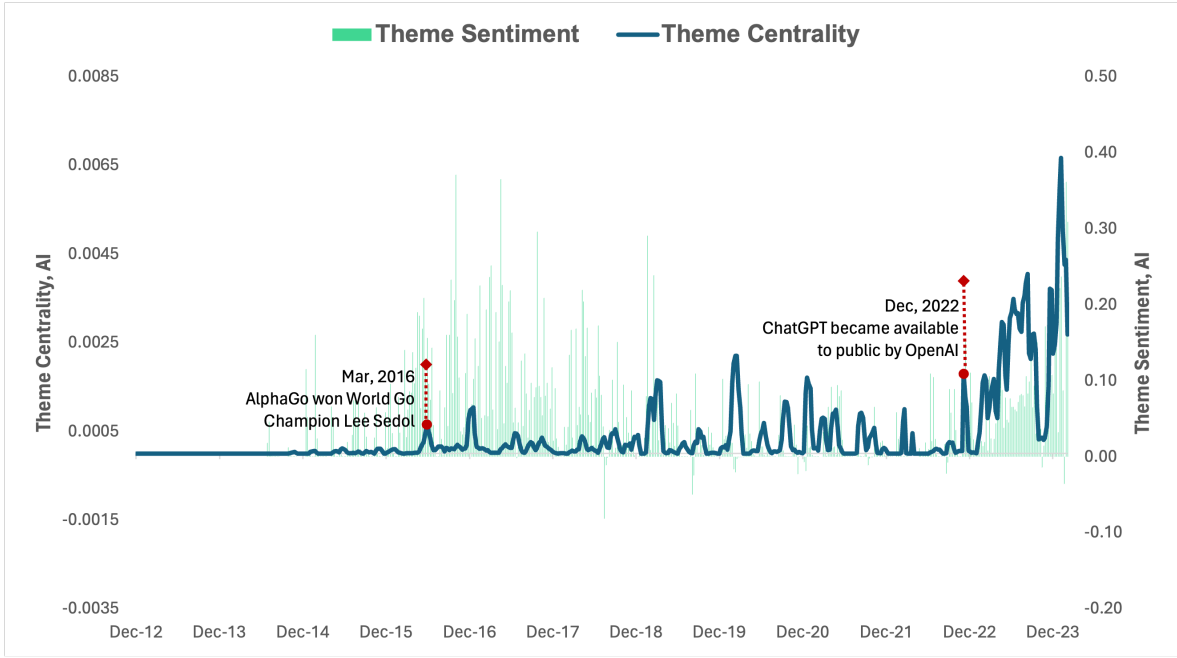


Figure 5.4: Centrality and Sentiment Index of the AI Theme

$$\lambda_m^t = \max_e(x_e^{\text{Katz}}). \quad (5.3)$$

Figure 5.4 shows the centrality measure of the AI theme over time. Our measure captures its growing impact with the introduction of AlphaGo in 2016. It becomes even more significant in the ChatGPT era, marking a substantial influence of AI on the macro-finance network. More importantly, we note that this impact is inherently polar, potentially exerting both positive and negative effects on the system. Here, we utilize sentiment scores derived from our LLM, ranging from -1 to +1 for each entity within a news document. We calculate the sentiment s_t^m for theme m by averaging the sentiment scores of entities associated with that theme over one week. Figure 5.4 presents the sentiment trend for the AI theme. The sentiment value for the AI theme is generally positive despite occasional concerns related to AI risks and side effects.

Previous studies document a general negativity bias in financial news reporting (Damstra and Boukes, 2021; Gentzkow and Shapiro, 2006; van Binsbergen et al., 2024).

Figure 5.D plots our average entity-level LLM-based sentiment. The raw sentiment confirms the documented negative bias in estimates of economic sentiment derived from news data. To mitigate this bias, we adjust the original sentiment metrics by orthogonalizing them with respect to the average sentiment. As a result, the net sentiment no longer exhibits a long-term downward trend while still capturing intrinsic business cycle variations (see Figure 5.D). This adjusted sentiment measure will be used throughout our empirical analysis.

Finally, we propose a new centrality metric, polar centrality, that accounts for both the magnitude of network impact and its polarity. Formally, for theme m at time t , the polar centrality is defined as:

$$z_t^m = \text{EWM}(e^{\lambda_t^m} \times \tilde{s}_t^m, 7d), \quad (5.4)$$

where $e^{\lambda_t^m} \in [1, +\infty)$ represents the network amplifying factor of theme m 's impact on the system, \tilde{s}_t^m represents the adjusted sentiment of the theme, $\text{EWM}(\cdot)$ represents the exponential weighted moving average function. When a theme has zero graph centrality ($\lambda_t^m = 0$), the polar centrality aligns with the sentiment index. We employ a weekly Exponential Weighted Moving (EWM) average for polar centrality to mitigate weekly seasonal effects. Figure 5.F showcases the polar centrality time series for the AI theme in recent years, including its one-month moving average.

Figure 5.5 displays the historical Katz centrality and polar centrality indices for various themes. Themes like Oil and Economic Growth exhibit polar values, underscoring the thematic polarity. In addition, emerging themes such as Covid-19, despite their brief history, have had a substantial impact during specific periods, e.g., in 2020. Table 5.D and 5.E present the descriptive statistics and correlation for a subset of nine illustrative themes.

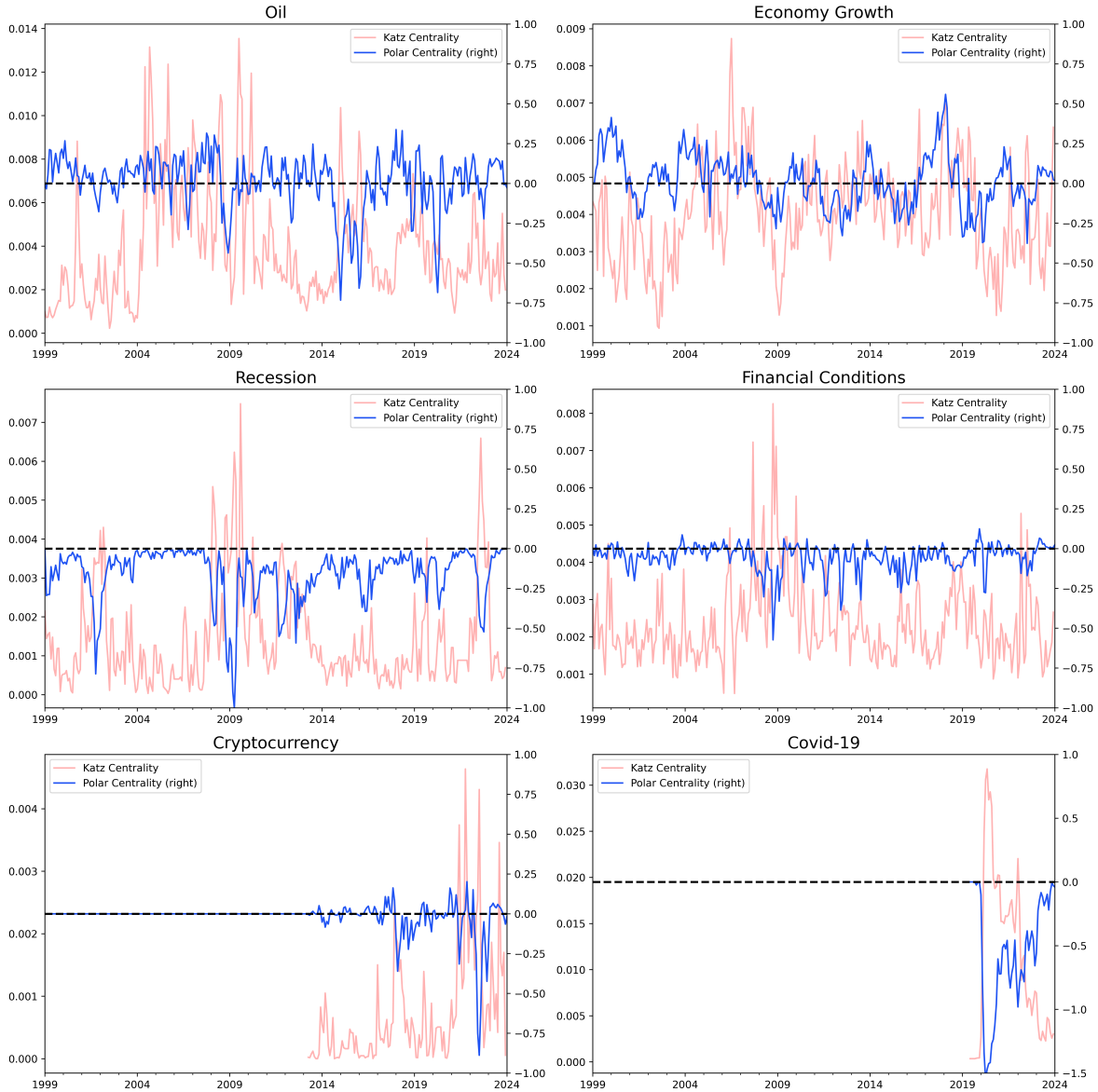


Figure 5.5: Theme Polar Centrality Monthly Indexes

Note: The red lines show the one-month moving average Katz centrality indexes. The right vertical axis lists the values of the polar centrality for each theme, and the blue lines represent the one-month moving average polar centrality indexes.

5.4 Asset Pricing Test and Methodology

To test the relationship between our network polar centrality indexes and stock returns, we develop a methodology grounded in the principles of the Integrated Consumption-based Asset Pricing Model (ICAPM). The centrality of aggregate consumption to asset pricing follows directly from the intertemporal Euler equation. In representative-agent economies (Lucas Jr, 1978; Breeden, 1979), the stochastic discount factor (SDF) is proportional to the intertemporal marginal rate of substitution, $m_{t+1} = \beta u'(C_{t+1})/u'(C_t)$. Following this Euler equation, Cochrane (2009) shows that, within the ICAPM framework, the stochastic discount factor (SDF) can be approximated to first order as a linear function of the innovation of a group of factors, including the market portfolio and latent state factors that can forecast future consumption or wealth:

$$m_{t+1} = 1 - b'v_{t+1}, \quad (5.5)$$

where $v_{t+1} = f_{t+1} - E_t(f_{t+1})$. While the ICAPM model does not explicitly identify the state variables, past literature (Maio and Santa-Clara, 2012; Boons, 2016) develop a sign restriction criteria as a necessary condition for a potential factor to be considered a risk factor within the ICAPM framework. This sign restriction suggests that a state variable with positive (negative) predictability for future economic prospects should correspondingly lead to a positive (or negative) risk premium. This restriction is consistent with the theoretical model: within the framework of the ICAPM model, an asset that has a higher exposure to a state variable with a positive prediction loading earns a higher return in favorable states when marginal utility is low. Consequently, this stock should be compensated with a positive expected return, indicating that the exposure to the associated state variable should carry a positive risk premium. A substantial body of evidence shows that asset returns are priced by their covariance with aggregate consumption growth and with state variables that forecast future consumption growth. (Hansen and Singleton, 1983; Parker and Julliard, 2005; Savov, 2011).

5.4.1 From Theme Index Shocks to ICAPM State Variables

Our polar-centrality indexes are designed to capture how different facets of latent state variables influence expected consumption growth and asset returns. An innovation in a theme index aggregates economy-wide information that appears before conventional macro releases. Because these news shocks are forward-looking, they shape investors' expectations about future consumption and production, and should earn systematic risk premia.

For instance, the Oil Index is one of the most prominent indices in our knowledge-graph system. Oil links the supply and demand sides of the economy: it is an essential production input for firms and absorbs a sizable, price-inelastic share of household income. News of an oil-supply shortage therefore has two macro-critical consequences: it lowers households' expected real consumption growth as fuel bills rise and pushes up producers' marginal costs, reducing future industrial output. Within the consumption-based asset-pricing framework, these changes increase the SDF, so assets whose cash flows covary with adverse oil news must command a lower risk premium. Empirical studies document the joint response of consumption and production to oil-supply shocks (Hamilton, 1983; Driesprong et al., 2008; Kilian, 2009), reinforcing the economic content of oil news as a valid ICAPM state variable.

The oil polar-centrality index measures the economy-wide importance of oil-related news and is weighted by contemporaneous market sentiment. A positive innovation in the oil index signals favourable supply news that lowers energy costs, supports future real consumption growth, and reduces marginal utility. Assets whose payoffs covary positively with the index therefore, have positive covariance with the SDF and, under the ICAPM sign-restriction of Maio and Santa-Clara (2012); Boons (2016), should earn a positive risk premium. The formal log-linear derivation linking the index to the SDF is provided in Appendix D.

We focus on evaluating the network polar centrality index associated with the

economy’s structural theme. These indexes are designed to measure the importance of the corresponding economic indicators to the whole economy and, by definition, are better candidates to be proxies for state variables. Therefore, we select the theme indexes based on two criteria. First, the theme index should have at least 90% valid values across the data sample. Second, the mean of the absolute value of the index should be higher than the median of the means of the absolute values of all indexes. These two criteria filter out theme indexes that only appear for a short period and those that do not have consistent, significant systematic importance to the economy. The number of indexes that are selected as candidate factors after filtering is 59. These 59 indexes contain most of the themes in the Economy and Financial Market categories.²

In this section, we assess the validity of our selected theme polar centrality index as a state variable in the ICAPM model. We conduct the test by first evaluating its time-series predictability and then examining its risk premium through a cross-sectional analysis. Next, we check whether our indexes satisfy sign restrictions. Finally, we test whether our indexes provide incremental value to the existing equity factor zoo.

5.4.2 Network Polar Centrality Index and Macroeconomic Activity

In this subsection, we evaluate the ability of our network-based thematic index to predict future macroeconomic activity.

Data and Methodology

To test the predictive power of our indexes on future economic activities, we conduct a time series regression as follows:

$$\Delta Y_{t,t+s} = \alpha + \psi W_t + \theta_k z_{k,t} + e_t, \quad (5.6)$$

²For the full list of selected themes, please refer to the tables in the Appendix.

where $z_{k,t}$ is the candidate state variable k 's value at time t and the θ_k is the corresponding prediction coefficient. The sign of θ_k indicates the forecasted direction of the state variable in relation to the macroeconomic indicators. W_t includes three variables that are used in previous literature (Petkova, 2006; Boons, 2016; Barroso et al., 2021) as state variables: The dividend yield (DY) on the CRSP value-weighted stock market index; the default spread (DS), which is calculated as the difference in yield between long-term corporate bonds rated BAA and those rated AAA; and the term spread (TS), which is determined by the difference in yield between ten-year and one-year Treasury bonds. The state variables' predictive coefficients are represented by ψ . $\Delta Y_{t,t+s}$ represents the growth of one of the macroeconomic indicators from t over the next s months. For instance, when $s = 3$, $\Delta Y_{t,t+s}$ calculates the quarterly growth of the macroeconomic indicators. Following the methodology in Boons (2016) and Barroso et al. (2021), the seasonally adjusted per capita in real consumption expenditures on nondurables and services, and industrial production are the two candidates for Y_t . These two macro indicators capture the consumption, output, and economic situation in the United States. The data sample matches the timespan of WSJ news data, covering 24 years, which contains 288 monthly observations from 2000 to 2023. The macroeconomic indicators and bond yield data are collected from the FRED Dataset.

Single Index Predictive Regressions

First, we conduct an unconditional single-variable time series regression to assess the predictability of our Polar Centrality index with respect to the macroeconomic indicators. In this case, the state variables W used in past literature are excluded from the regressions. We examine the predictability of our indexes for various future horizons, including [1, 3, 6, 12] months, which represent one month, one quarter, half a year (two quarters), and one year (four quarters), respectively. Furthermore, to correct for time series dependence and heteroskedasticity, the standard errors are adjusted using Newey-West standard errors (Newey and West, 1986). All variables are standardized so that

the R-squared of the regression equals the square of the coefficient.

We only conduct regressions for themes that have a non-zero polar centrality value across the period we cover, i.e., from 2000 to 2023. This filter excludes some emerging themes, such as Brexit and COVID-19. Even though these emerging themes might have significant and high R^2 levels of predictability—for instance, COVID-19 explains 40% of the variation in future Industrial Production Growth between 2020 and 2023—they are not appropriate to be used as proxies for state variables. The reason is that those emerging indexes usually only pop up for a short period of time. Therefore, for this analysis, we limit the scope to focus on analyzing the structural themes. Notably, our Polar Centrality Index, which embeds sentiment from news sources, ensures that a higher index value uniformly denotes a positive view. Therefore, we expect the majority of the predictive coefficients derived from our single predictive regressions to be positive, including themes traditionally associated with negatively perceived economic shocks, such as geopolitical risks and war.

The key results for the future six-month predictions are presented in Table 5.1, and the full results for all horizons are shown in the Appendix D.I. Table 5.1 exclusively presents the top 10 predictors, sorted by the R^2 values. All the theme indexes provided in Table 5.1 forecast economic growth with a statistically significant positive coefficient, corresponding to an adjusted R^2 ranging from 5.4% to 18.2%. These indexes, primarily locate in the financial market conditions and economic growth theme categories, have profound economic implications and show a strong capability for forecasting future industrial production growth. For instance, a higher polar centrality index on the Financial Sector theme predicts a higher level of Industrial Production in the next two quarters and explains 13.5% of the variation. This result aligns with economic theories³ suggesting that a positive sentiment within the financial sector, which substantially shapes the economic network, forecasts an increase in consumption and production in

³For example, Adrian et al. (2019) provides evidence showing that poor financial conditions are associated with higher conditional volatility and lower conditional mean of future economic growth.

Table 5.1: Predicting Six-month Future Macroeconomic Activity Using Theme Index

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.43***	3.92	0.182	Financial Sector	0.37**	2.32	0.135
Credit	0.42***	3.90	0.175	Manufacturing	0.34***	3.08	0.112
Financial Sector	0.41***	3.42	0.169	Economy Contraction	0.33***	3.02	0.112
E-Commerce	0.35***	2.61	0.124	Credit	0.33**	2.15	0.110
Economy Contraction	0.34***	2.99	0.116	Economy Growth	0.31***	2.96	0.098
Recession	0.33***	3.38	0.106	Economic Recovery	0.28***	3.12	0.078
Europe	0.31***	3.79	0.096	Automobile	0.27**	2.53	0.072
Economy Growth	0.31***	2.87	0.095	Stock Market	0.26*	1.90	0.066
Financial Crisis	0.30***	3.18	0.090	China Economy	0.25***	2.68	0.064
Investment	0.29***	2.75	0.084	Global Economy	0.23*	1.75	0.054

Note: This table presents the results of single-variable predictive regressions. The 59 selected thematic indexes are used to predict the six-month future growth of two macroeconomic indicators: industrial production log growth and real personal consumption expenditure per capita log growth. Only the top 10 predictors, sorted by R^2 , are presented in this table. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of COVID-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The results are consistent with the raw results. The values for all variables are standardized, such that for the single-variable regression, the R^2 is equal to the square of the regression slopes. For the full results, please refer to [Appendix D](#). The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

the subsequent quarters.

Furthermore, the R^2 values from our results exceed those of the three widely used proxies—Dividend Yield (DY), Default Spread (DS), and Term Spread (TS)—as cited in studies such as [Petkova \(2006\)](#), [Boons \(2016\)](#), and [Barroso et al. \(2021\)](#). Specifically, in [Boons \(2016\)](#), the unconditional prediction regression of single state variable predictors with respect to future two-quarter growth of industrial production has R^2 values ranging from approximately 2.5% to 6.0%. This comparison underscores the superior forecasting capability of our structural indicator in predicting future economic growth unconditionally.

In addition to the predictability of our theme index, the results across different horizons reveal the different characteristics of different themes. According to the tables in [Appendix D](#), most of the indexes explain the growth of macroeconomic indicators

over different horizons with consistent coefficients and R^2 . For instance, the foreign countries-related index, Japan and China, could consistently and significantly explain 2-4% of the future growth of industrial production across different horizons.

However, there are a small number of themes that show significant patterns across different prediction horizons. For instance, a higher value for the polar centrality index of oil has the highest predictive power among all indexes for the short-term, one-month future industrial production. The predictive power of the oil index decays after three months, and the prediction coefficient becomes insignificant, with a low R^2 for the next six to twelve-month growth predictions. The significant coefficient for the short-term prediction indicates that our polar centrality index of oil can capture the importance of oil to the entire economy. The measure of systematic importance, integrated with sentiment analysis, can aggregate oil's effects from different channels. These positive and significant prediction coefficients indicate a substantial contribution to the existing literature measuring how turbulence in the oil market affects the US economy (Kilian, 2014; Gao et al., 2022).⁴ In addition, the decay of predictive power for longer horizons demonstrates that the oil index only has a temporary effect on future economic growth. This temporary effect contributes to the debate about the effect of oil price shocks on real GDP growth. Our result provides empirical evidence supporting the argument that oil shocks or volatility do not directly affect total productivity but act as short-term disturbances that temporarily affect industrial production, GDP, or consumption growth (Barsky and Kilian, 2002; Gao et al., 2022). Furthermore, the insignificant coefficient in predicting consumption expenditure growth supports the evidence that the direct effect of oil on the demand side, including consumption expenditure, is mild (Kilian, 2014; Edelstein and Kilian, 2009).

There is also another strand of predictors that has better predictive power over

⁴To our limited knowledge, there is no unified oil index with unconditional predictive power developed by past literature. For instance, Kilian (2014) emphasizes the necessity of using the structural VAR model to distinguish between the demand and supply shocks of oil when analyzing its effects on the economy. Gao et al. (2022) develops an option-implied oil volatility risk measure, which captures the uncertainty of the economy and has good predictive power for future economic growth.

longer horizons. For instance, the credit theme index has an R^2 equal to 4.8% for the one-month prediction of consumption growth, increasing to 12.4% for three months, 17.5% for six months, and 22.2% for twelve months. Other financial conditions-related themes, such as the Financial Sector and Financial Regulation, follow a similar pattern. These results indicate that a strong index in the credit and financial intermediaries sector takes some time to transmit to consumption and industrial production. This finding contributes to our understanding of the lagged effects of financial indicators on economic performance, highlighting the importance of considering longer time horizons when evaluating the impact of financial conditions on the real economy.

Multiple Predictive Regressions

In the single-index predictive regression, half of our index demonstrates significant predictability. Moving forward, the analysis in this subsection expands upon this predictive framework by incorporating three additional state variables commonly used in the literature. This analysis aims to demonstrate that our index's predictability remains robust when considering other state variables and that they provide incremental contributions to existing models.

We start with a baseline model that includes only the three conventional state variables: dividend yield, default spread, and term spread. The baseline result is shown in Table 5.G. The adjusted R^2 for predicting consumption growth is 0.077, 0.171, 0.168, and 0.140 for the next $S = 1, 3, 6, 12$ months, respectively⁵. Similarly, the adjusted R^2 for predicting industrial production growth is 0.046, 0.063, 0.077, and 0.083 for the next $S = 1, 3, 6, 12$ months, respectively. These results indicate that the baseline model has some predictive power for the future growth of industrial production. However, the

⁵The adjusted R^2 is higher than the estimation in Barroso et al. (2021), where their adjusted R^2 equals 0.0711, 0.0938, and 0.1025 for one quarter (3 months), two quarters (6 months), and four quarters (12 months) ahead prediction, respectively. This is because the state variables have good predictive power for the decline in consumption after the financial crisis, which explains a large portion of the variation within this period. The coefficient for dividend yield flips the sign compared with their result but is consistent with Barroso et al. (2021) conditional regression, where the coefficient for dividend yield after the 2000s is significantly negative, especially around the financial crisis.

coefficients on dividend yield and default spread (DS) are not statistically significant, and the overall adjusted R^2 is not high, not even exceeding the R^2 of our single index prediction.

Next, we incorporate our polar centrality indexes into the model, one at a time, and conduct four-predictor regressions. The main findings for the six-month ahead predictions are displayed in Table 5.2, and the comprehensive results for all time horizons are in Appendix D.II. The four-predictor regression results demonstrate the robust forecasting capability of our indexes for predicting the future economic landscape, even when considering other state variables. The prediction coefficients are robust and significant after controlling for the three baseline coefficients. More importantly, the adjusted R^2 significantly improves for the predictors that have significant coefficients in the single index test. For instance, for the financial sector index, the adjusted R^2 increases to 0.186 from the baseline result of 0.070, indicating a more than 10 percentage point increase. This increase in R^2 demonstrates that our theme index provides substantial additional value to conventional state variables, even though both the three state variables and the financial sectors lie in the financial markets category.

The incremental value provided by our index stems from our innovative KG-based method. This method not only considers the systematic importance of each theme to the economy but also takes into account the relationships among themes. By employing this unique construction methodology, our index captures information that is orthogonal to conventional macro indicators and state variables, even though the three state variables and the financial sectors all lie within the financial markets category.

In summary, tests on the predictability of our theme polar centrality indexes, especially those with structural economic significance, demonstrate strong and robust predictive power for future economic growth. These indexes not only provide incremental value by incorporating the systematic importance of themes but also account for the different characteristics of various themes. As a result, our methodology captures

Table 5.2: Results of Multiple Predictive Regressions with Index Inclusion

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Baseline + Theme	Coeff.	T-Stats	R^2	Baseline + Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.42***	4.01	0.319	Financial Sector	0.37***	2.73	0.186
E-Commerce	0.34***	2.76	0.271	Credit	0.31**	2.24	0.150
Financial Sector	0.31***	2.98	0.249	Economy Contraction	0.30***	3.17	0.147
Inflation	0.29**	2.13	0.245	Manufacturing	0.28**	2.44	0.133
Credit	0.30***	3.20	0.241	Economy Growth	0.26***	2.90	0.122
IPOs	0.25***	2.60	0.215	Stock Market	0.24**	2.07	0.120
Europe	0.22***	3.54	0.210	China Economy	0.22***	2.58	0.116
Economy Contraction	0.22**	2.42	0.208	Japan Economy	0.24***	3.22	0.114
Japan	0.22***	3.01	0.206	Japan	0.22***	2.70	0.109
Technology	0.21**	2.28	0.204	Economic Recovery	0.22***	2.62	0.100
Baseline			0.168	Baseline			0.070

Note: This table presents the results of Multiple-variable predictive regressions. The 59 selected thematic indexes are added to the baseline three-predictor model one at a time to run four-predictor regressions to predict the six-month future growth of two macroeconomic indicators: real personal consumption expenditure per capita log growth and industrial production log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of COVID-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized. The R^2 equals the adjusted R^2 of the corresponding predictive regressions. Only the top 10 predictors, sorted by adjusted R^2 , are presented in this table. For the full results, please refer to [Appendix D.II](#). The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

unique information that enhances the accuracy and reliability of economic forecasts, distinguishing it from conventional macro indicators and state variables.

5.4.3 Risk Premium of the Theme Index

In this section, we examine whether assets with greater exposure to our theme index are priced and assess the consistency between time-series and cross-sectional tests.

Even though our index isolates the information and accounts only for the systematic impact of each index on the whole economy and pricing kernel, measurement errors still exist due to the nature of the text data. In addition, testing non-tradable factors, such as our theme indexes, is heavily affected by the issue of omitted factors. This

issue is fundamental yet significant in the evaluation of new factors' risk premiums, as theoretical frameworks tend to inherently lack the capacity to fully represent all the valid factors present in the economy. In this case, implementing the conventional Fama-MacBeth model might generate a biased estimation of the risk premium and reduce the efficiency of the estimation. To solve these issues, we leverage the three-pass estimators model (GX model) proposed in [Giglio and Xiu \(2021\)](#) to test the risk premium of our theme index.

Consider a general linear pricing model with p latent factors:

$$r_t = \beta f_t + u_t, \quad (5.7)$$

where r_t is the asset excess return, f_t represents the p latent factors that explain the asset returns, and β are the latent factor loadings. The term u_t is the idiosyncratic zero-mean error and has zero correlation with the factors. The f_t can be decomposed into a combination of the risk premium γ of the factor and a zero-mean innovations term v_t . Assume $\text{Cov}(v_t, u_t) = 0$, we have:

$$f_t = \gamma + v_t. \quad (5.8)$$

The $\epsilon_{t,k}$, which is our theme polar centrality index innovation for theme k is defined as $\epsilon_{t,k} = z_{t,k} - E[z_{t,k}]$ for topic k . We assume our centrality index innovation $\epsilon_{t,k}$ is a linear combination of the latent factors and satisfies the following equation:

$$\epsilon_{t,k} = \alpha + \phi_k v_t + e_t. \quad (5.9)$$

This equation projects our theme index on the unobservable latent factor space. The risk premium of our centrality index z , which is defined as the expected return of one unit exposure to the respective factor and zero to others, is revealed as $\phi_k \gamma$. However, since the f_t is a group of unobservable factors, they could not be observed in an empirical

test. To solve this problem, GX develop a three-pass estimator to identify the risk premium of factors without necessarily observing the latent factors. The methodology setup could be simplified as follows. Assume the test asset excess return matrix R is a $n \times T$ matrix, with n representing the number of test assets and T being periods for the test sample. The factor matrix Z is a $m \times T$, where m is the number of candidate factors.

1. Extract the first d Principal Components X from the excess return matrix R as a proxy for a linear transformation of the unobservable latent factor, formally expressed as $X = Gv_t$, and estimate the corresponding β loading for the component:

$$\hat{X} = [\hat{x}_1, \hat{x}_2, \dots, \hat{x}_d]; \quad (5.10)$$

$$\hat{\beta} = \bar{R}\hat{X}. \quad (5.11)$$

where \hat{x}_d is a $T \times 1$ vector representing the d^{th} asymptotic principal component⁶ of the excess return matrix R , and \bar{R} represents centralized mean return.

2. Run a cross-sectional regression to estimate the risk premium γ_X of the transformed latent factor X , which is equivalent to the second-stage regression in the Fama-Macbeth Test as:

$$\hat{\gamma}_x = (\hat{\beta}^T \hat{\beta})^{-1} \hat{\beta}^T \bar{r}, \quad (5.12)$$

where \bar{r} is an $n \times 1$ vector representing the average return for each test asset.

3. Run a time series regression to project the theme factors on the transformed latent factors space, and estimate the coefficient $\hat{\phi}$ as:

$$\hat{\phi} = \epsilon \hat{X}^T (\hat{X} \hat{X}^T)^{-1}. \quad (5.13)$$

⁶See [Bai and Ng \(2002\)](#)

4. Finally, the risk premium of the factor could be estimated as⁷:

$$\hat{\gamma}_z = \hat{\phi} \hat{\gamma}_x. \quad (5.14)$$

This methodology, which maps the candidate factor onto the space of latent pricing factors inferred from the cross-section of test-asset returns using a PCA method, mitigates the severity of issues related to omitted factors and measurement errors. Additionally, one advantage of the three-pass estimators is their ability to test factors independently, allowing for separate assessments of each factor. This feature is particularly beneficial for estimating the risk premium of an individual index, as the estimated risk premium for each index remains unaffected by the inclusion of other candidates in the model. The main limitations of this methodology are that the model assumes the risk premium and the factor loadings are constant over time. The constant factor loadings issue is usually mitigated by using asset portfolios as tests since the portfolio’s factor loadings are more stable over time. While the constant risk premium assumption fails for the state variables proposed by past literature (Boons et al., 2020; Kang and Pflueger, 2015; David and Veronesi, 2013), our index is designed to inherently capture the time-varying importance to the economy. Therefore, our index is expected to have an unconditional risk premium and satisfies the assumption if it is priced in the cross-section.

Empirical Test Data and Number of Latent Factor

We conduct our empirical tests on the indexes using equity portfolios sorted by 212 different characteristics, as described in Chen and Zimmermann (2021). The portfolio dataset includes $T = 276$ monthly observations for $n = 1272$ portfolios from 2000 to 2022.⁸ We choose portfolio-level assets instead of individual assets to assess the risk premium due to the GX method’s enhanced robustness at the portfolio level. This preference stems from the GX method’s assumption that both β and the linear trans-

⁷For consistency and asymptotic properties, please refer to Giglio and Xiu (2021)

⁸The latest version of the Chen and Zimmermann (2021) dataset only has portfolio data up to the end of 2022.

formation matrix ϕ remain constant over time, an assumption to which portfolio-level assets are inherently more resilient.

To align with the frequency of the predictability test in Section 5.4.2, we run the GX method with monthly frequency portfolio returns. Since our indexes are constructed by smoothing with a moving average, we use the innovation shock at the end of the month as our estimated value for ϵ . The $E[z_{t,k}]$ is estimated using a six-month rolling window to align with our main predictive tests. There are multiple ways of choosing the optimal number of latent factors P . For example, Bai and Ng (2002) and Giglio and Xiu (2021) evaluate how much of the variance is explained by the PCA with a penalty function, while Onatski (2010) and Lettau and Pelger (2020) choose the number of PCA based on the eigenvalue ratios. We keep the selection methodology simple, employing the methodology of Bai and Ng (2002) and attempting to choose the higher bound of the estimated number of factors.⁹ We further apply the bootstrap methodology to verify the optimal number of latent factors. We choose 8 as the optimal number of factors, and the bootstrap result is shown in Figure 5.G, Appendix E¹⁰.

Risk Premium Test Results

The risk premiums estimated using the three-pass estimators are shown in Table 5.3. We reapply the length filter to concentrate on themes with valid values for all periods. We present only the top 15 factors in the body text, sorted by the risk premium. The full results are presented in Table 5.I and Appendix E. All the top 15 indexes presented in Table 5.3 are statistically significant in predicting at least one of the two macroeconomic indicators with positive coefficients. Most of the candidate factors that are statistically significant in predicting macroeconomic activities are priced in the cross-section regression.¹¹ Specifically, one unit of exposure to our polar centrality

⁹As shown in the proof by Giglio and Xiu (2021), as long as the chosen number of latent factors is higher than the true value, the risk premium estimation will remain unbiased.

¹⁰Giglio and Xiu (2021) use 7 latent factors to generate their main results

¹¹According to the results in the appendix, 20 out of 59 indexes are priced in the cross-section with a significant risk premium value.

Table 5.3: GX Risk Premium and T-Statistics Estimation

Topic Index	Risk Premium (bps)	NW T-Statistics
Oil	116.36**	2.15
Stock Market	108.53**	2.06
US Economy	106.95**	2.52
Global Economy	76.49**	2.03
Recession	66.13**	2.20
Economy Growth	58.96*	1.83
Consumer Spending	56.13***	3.57
Financial Conditions	53.39**	2.40
Financial Crisis	52.01*	1.80
Economy Outlook	51.02***	3.11
Economic Recovery	50.28*	1.87
China	39.22	1.64
IPOs	38.57**	2.10
Manufacturing	36.69	1.39

Note: This table presents the risk premium test using GX methodology for each index using the 1272 portfolio as test assets. The risk premium column indicates the scaled factor risk premium of the candidate factor index, reflecting a unit beta exposure. They are normalized as bps return per month. The t-statistics reported are calculated using Newey-West standard errors with 12 lags. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW T-Statistics.

indexes, as represented in Table 5.3, is compensated for a high-risk premium ranges from 37 basis points (bps) per month for the manufacturing index to 116 bps per month for the oil index. These priced themes carry significant economic meaning and contribute to the existing literature investigating the relationship between macro uncertainty and the stock market. For instance, our result indicates that an asset with a one-unit exposure to our oil theme measure should be compensated with a 116 basis points (bps) return. The high-risk premium result of the oil index contributes to the literature investigating the impact of oil on the stock market. Previous studies have focused on distinguishing the effects of different types of oil events on the entire market or industry level, rather than considering the overall impact (Ready, 2018; Azimli, 2020; Gao et al., 2022). Our unconditional risk factor integrates these studies and provides a more comprehensive assessment of the overall impact of oil events on the stock market. Our robust unified and unconditional index could provide guidance for investors to hedge against oil risk.

In addition, consumption spending and consumer confidence indexes provide sub-

stantial value to the literature discussing the impact of consumption growth on cross-sectional returns. Past literature uses consumption growth shocks (Parker and Julliard, 2005; Yogo, 2006) and consumption growth volatility (Boguth and Kuehn, 2013) to capture the effect of consumption growth on the stock market. Boguth and Kuehn (2013) argue that consumer beliefs about future expected consumption growth are not priced in the cross-section, which contradicts theoretical models. Our consumer confidence index¹² uniquely captures the systematic part of belief information that impacts the economy and illustrates that consumer beliefs or confidence matter for asset prices and are priced in the cross-section with a 35 bps return per month. By doing so, we bridge the gap between theoretical predictions and empirical observations of consumption growth, as proposed by Boguth and Kuehn (2013).

The risk premium test and our analysis suggest that certain indexes, which reflect structural economic factors, serve as powerful predictors for future growth and are consistently incorporated into asset pricing models with the same sign. This consistency underscores their relevance in capturing essential economic dynamics that influence asset market behavior. Therefore, these factors could be considered as state variables in the ICAPM framework, highlighting their potential to provide valuable insights into the intertemporal trade-offs faced by investors.

5.4.4 Evaluating the Contribution of Network Polar Centrality to the Factor Zoo

In the previous section, the three-pass estimator demonstrates that 20 of our state variables are priced in the cross-sectional model. However, as discussed in Cochrane (2009), a priced factor does not necessarily add value in cross-sectional return pricing. For instance, the stock market index, which shows a very high and significant risk premium, might simply be a factor formed partly by components correlated with the market portfolio and partly by other factors. Although these factors potentially have

¹²Results are shown in Table 5.I

a significant high-risk premium, they do not provide additional prediction power in cross-sectional pricing. To demonstrate that our indexes offer additional information and provide incremental value to the existing factor zoo, the SDF loading, as shown in Equation (5.5), should be evaluated.

To evaluate the marginal contribution of our index factor, we face two major obstacles: omitted factors and low-dimensional time series portfolio returns compared to the large existing factor zoos. To address these issues while systematically evaluating the contribution of our index factors individually, we apply the “two-pass regression with double-selection Lasso” methodology proposed by [Feng et al. \(2020\)](#)(FGX).

The FGX methodology stems from the traditional Fama-MacBeth test but leverages a two-stage LASSO regression to select control factors that either have good explanatory power for the expected return or have a high correlation with the test factors. These two selection steps reduce the dimensionality of the control factor zoo while keeping the omitted variable bias at a low level. Analogous to the GX model for estimating risk premium, this test also assumes a constant loading for the test factors, which is satisfied by the nature of our theme indexes.¹³

The test assets are the same as in the previous session; we use the 1272 stock portfolios sorted by 212 different characteristics from [Chen and Zimmermann \(2021\)](#). The controlled factors are also the 212 factors described in [Chen and Zimmermann \(2021\)](#). These 212 factors include all those from [Hou et al. \(2015\)](#), [McLean and Pontiff \(2016\)](#), [Green et al. \(2017\)](#), and [Harvey and Liu \(2019\)](#) that are significant according to the replication in [Chen and Zimmermann \(2021\)](#). This factor set provides a comprehensive coverage of the factor zoo up to date.

The test period spans from 2000 to 2022 to maintain consistency. The penalty parameters for the first and second stage Lasso regressions are determined by averaging the results of 200 random seed 10-fold cross-validations. For each random seed, we select

¹³For more details about the model, please see [Appendix E](#) and [Feng et al. \(2020\)](#)

the penalty parameters based on the lowest mean square error for the test sample from the 10-fold cross-validation.

Table 5.4: Evaluating the SDF Loading of Candidate Factors

Theme	γ_z (bps)	T-Stats	# of Selected Control Factors
Oil	300.77***	3.55	61
China	168.85***	4.27	59
Manufacturing	150.24***	3.74	59
Economy Growth	198.23***	2.79	60
Economic Recovery	182.40***	3.57	72
Financial Conditions	151.45***	3.35	62
Economy Outlook	74.70**	2.06	60
Consumer Confidence	71.43	1.61	61
Real Estate	68.08*	1.93	64
Consumer Spending	60.47	1.58	59
US Economy	56.66	0.60	61
IPOs	54.06	1.64	59
Sanctions	37.12	0.96	59
Global Economy	26.11	0.33	130
Stock Market	19.71	0.20	60
Economy Contraction	2.98	0.10	65
Financial Sector	-8.45	-0.17	59
Credit	-10.46	-0.85	59
Financial Regulation	-30.73	-1.33	59
Financial Crisis	-61.78	-0.96	60
Labor Market	-121.45	-1.09	70

Note: This table presents the SDF loading estimation of our theme indexes using two-pass regression with double-sorted Lasso methodology. The control factors are the 212 factors described in [Chen and Zimmermann \(2021\)](#), and the test portfolios are the sorted portfolios from [Chen and Zimmermann \(2021\)](#). The test period spans from 2000 to 2022. The penalty parameters for the two-step lasso selections are chosen by averaging the 200 random seeds 10-fold cross-validations. The penalty for the first stage lasso equals to $\exp(-17.025)$. The second stage lasso penalty ranges from $\exp(-15.025)$ to $\exp(-24.025)$. The first column lists the theme index names. The second column, γ_z , indicates the scaled factor loading of the candidate factor index, reflecting a unit beta exposure. The third column, T-stat, provides the T-statistics for testing the null hypothesis that the factor loading is zero. The fourth column represents the total number of control factors selected by the two-stage lasso regression. The standard error of factor loading is estimated following the inference in [Feng et al. \(2020\)](#). Statistical significance levels are indicated as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results are shown in [Table 5.4](#). The first column shows the theme index name. The second column, γ_z , represents the scaled factor loading of the candidate factor index to represent a unit beta exposure. The third column, T-stat, represents the T-statistic for testing the null hypothesis that the factor loading is 0. The fourth column shows the control factors selected by the two stages of regression. Our methodology selects control factors ranging from 59 to 130¹⁴. According to the results shown, some of our indexes

¹⁴The number of selected control factors is slightly higher than those selected by [Feng et al. \(2020\)](#), but within a similar range.

provide significant contributions to the existing factor zoo. All the significant loadings have positive values, further substantiating that our indexes should be compensated by a positive premium, as sentiment measures control the direction.

The indexes for Oil, China, Manufacturing, Economic Growth, Economic Recovery, Financial Conditions, Real Estate, and Economic Outlook show significant estimations of the SDF loadings unconditionally. These significant factor loadings underscore the substantial contribution of our dynamic knowledge graph method to asset pricing by providing new macro factors with incremental value to the factor zoo. Although these themes have a widely acknowledged substantial effect on stock markets, as discussed above, it is challenging to measure the unconditional risk premium using traditional econometric techniques due to their time-varying importance to the economy. Our indexes, which capture the systematic importance of specific themes to the whole economy, address this problem and show incremental value in pricing asset returns.

It is also worth noting that the loading estimations for the Stock Market, US Economy, and Global Economy indexes are not statistically different from zero, despite showing high-risk premiums in the three-pass test. This result indicates that while some of our indexes are priced cross-sectionally, much of the information they provide is redundant and captured by existing factors. These factors remain useful for identifying new macroeconomic risk factors and assisting investors in hedging specific macroeconomic risks, but they do not provide additional information to pricing the cross-section of returns.

Overall, the asset pricing test demonstrates that the theme network polar centrality derived from our dynamic knowledge graph can effectively serve as state variables in the ICAPM model. Out of the 59 indexes, 20 exhibit substantial predictive power for future economic activity and are priced in cross-sectional asset pricing with a positive risk premium. Furthermore, although the majority of these 20 indexes are either redundant or explained by the existing factor zoo, 8 indexes provide incremental value

in pricing asset prices. These indexes offer a proxy for the systematic importance of macroeconomic factors to the economy that are challenging to measure using conventional methodologies. This underscores the potential of our dynamic knowledge graph in enhancing the understanding and measurement of macroeconomic risks.

5.5 Conclusion

This paper leverages dynamic knowledge graphs and LLMs to introduce innovative thematic factors for asset pricing. Our findings validate the significance of these thematic risk factors, which align with the ICAPM framework and are consistently factored into asset pricing models.

Our study aligns with and contributes to the growing body of literature in finance on the textual analysis of financial news data. Our generative AI approach extends beyond traditional textual analysis by employing an LLM framework, transitioning from a frequency-based method to the generative AI paradigm using prompt engineering. We leverage an advanced fine-tuned LLM to create a novel financial knowledge graph that models real-world entities and dynamically captures the relationships among them. The financial knowledge graph offers an alternative lens through which to view the financial system.

We further demonstrate the contribution of our knowledge graph to the asset pricing literature. Our paper particularly contributes to the literature on the ICAPM model. We introduce a novel measure derived from the knowledge graph that captures both the systematic importance of themes within the knowledge graph and the sentiment from the market. We use this polar centrality index as a proxy for state variables in the ICAPM model.

The introduction of state variable proxies based on a knowledge graph network bridges the research gap documented in prior studies, where state variables could only be applied in conditional asset pricing models. We claim that our innovative measures

can inherently capture the time-varying strength of the impact of macro themes on the entire economy and can predict the stock market and economic growth unconditionally. We show that the risk premiums for specific state variables are consistent with their predictive ability for macroeconomic growth, thus introducing a group of candidate state variables and shedding new light on the dynamic relationship between economic indicators and financial markets. Our paper identifies the potential of artificial intelligence and dynamic knowledge graphs in transforming macro-financial network system modelling.

Appendix 5.A. Financial Dynamic Knowledge Graph (FinDKG) Dataset

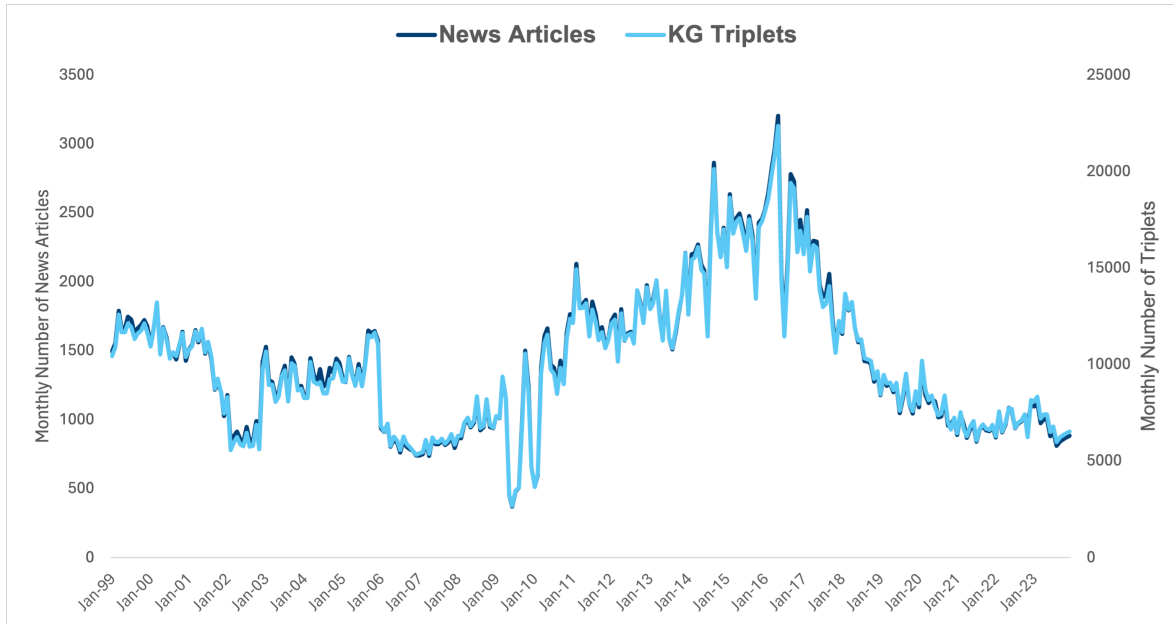


Figure 5.A: Financial Dynamic Knowledge Graph Counts

Relationship	Definition	Example (Edge)
Impact	Signifies a notable effect, either positive or negative, on a market trend, financial asset, or economic indicator tail entity.	(Brexit, Impact, European Union)
Relate_To	Points out a connection or correlation with a financial concept, sector, or market trend.	(ChatGPT, Relate_To, AI)
Has	Indicates ownership or possession of the tail entity.	(Google, Has, Android)
Announce	Refers to the formal public declaration of a financial event, product launch, or strategic move.	(Apple, Announce, iPhone 13)
Operate_In	Describes the geographical market in which a business entity conducts its operations.	(Tesla, Inc., Operate_In, China)
Introduce	Denotes the first-time introduction of a financial instrument, product, or policy to the market.	(Apple, Inc., Introduce, Vision Pro)
Produce	Specifies the entity responsible for creating a particular product, often in a manufacturing or financial product context.	(Pfizer, Produce, Covid-19 Vaccine)
Control	Implies authority or regulatory power over monetary policy, financial instruments, or market conditions.	(Federal Reserve, Control, Interest Rates)
Participate_In	Indicates active involvement in an event that has financial or economic implications.	(United States, Participate_In, G20 Summit)
Is_Member_Of	Denotes membership in a trade group, economic union, or financial consortium.	(Germany, Is_Member_Of, EU)
Invest_In	Specifies an allocation of capital into a financial instrument, sector, or business entity.	(Warren Buffett, Invest_In, Apple)
Raise	Indicates an increase, often referring to capital, interest rates, or production levels in a financial context.	(OPEC, Raise, Oil Production)
Decrease	Indicates a reduction, often referring to capital, interest rates, or production levels in a financial context.	(Federal Reserve, Decrease, Interest Rates)

Table 5.A: Definitions and Examples of Relationships in the Financial Dynamic Knowledge Graph (FinDKG).

Entity Category	Definition	Example
ORG	Organizations that are not governmental or regulatory bodies.	United Nations
ORG/GOV	Governmental bodies.	United States Congress
ORG/REG	Regulatory bodies involved in financial oversight.	Federal Reserve
GPE	Geopolitical entities like countries or cities.	United States
PERSON	Individual people often in influential or decision-making roles.	Jerome Powell
COMP	Companies across sectors.	Apple Inc.
PRODUCT	Tangible or intangible products or services.	iPhone
EVENT	Specific, material events that have financial or economic implications.	Brexit
SECTOR	Sectors or industries in which companies operate.	Technology Sector
ECON_INDICATOR	Non-numerical indicators of economic trends or states.	Inflation Rate
FIN_INSTRUMENT	Financial and market instruments.	S&P 500 Index
CONCEPT	Abstract ideas, themes, or theories.	Artificial Intelligence

Table 5.B: Definitions and Examples of Entity Categories in the Financial Dynamic Knowledge Graph (FinDKG).

Dataset	#Triplets	#Entities	#Relations	Temporal Interval
FinDKG	3,028,055	58,848	15	1 day

Table 5.C: Descriptive Statistics of the Financial Knowledge Graph Dataset

Appendix 5.B. Integrated Contextual Knowledge Graph Generator Instruction-following LLM

ICKG (Integrated Contextual Knowledge Graph Generator) is a specialized Large Language Model (LLM) refined from the open-source Vicuna-7B model (Zheng et al., 2024), itself built on Meta’s LLaMA 2.0 framework. ICKG has been specifically trained for knowledge graph construction, harnessing the advanced capabilities of the GPT-4 API for data generation. In initial tests for knowledge graph construction tasks, ICKG has shown superior performance compared to both GPT-3.5 and its base Vicuna-7B model, achieving results comparable to GPT-4 with the added advantage of efficient operation on consumer-grade GPUs.

For the training of ICKG, we created a Knowledge Graph Construction and Aspect-based Sentiment Analysis Instruction Dataset using the GPT-4 API. Starting with 8,000 news articles, we generated triplet responses and applied a rigorous quality filter to ensure the responses closely followed our prompts and produced a rich set of triplets, specifically discarding data points that generated fewer than five triplets per article. This method enhanced the quality of our fine-tuning dataset beyond the innate performance of GPT-4, leading to improved triplet extraction capabilities in the trained LLM. Next, we use another round GPT-4 API to generate the sentiment scores for the extracted entities of the same news articles.

The fine-tuning of Vicuna-7B models was executed using Hugging Face’s training environment, employing efficient GPU training strategies such as Int8 quantization. This fine-tuning phase, particularly on a 7B LLaMA model, spanned roughly 10 hours on a GPU server including eight A100 GPUs, each with 40GB of memory. The total cost for this computation on cloud-based GPU services was estimated to be under \$500, highlighting the economic efficiency of our approach.

The ICKG model is made publicly accessible¹. The prompt template for knowledge graph construction and aspect-based sentiment classification on ICKG is specified in online website¹.

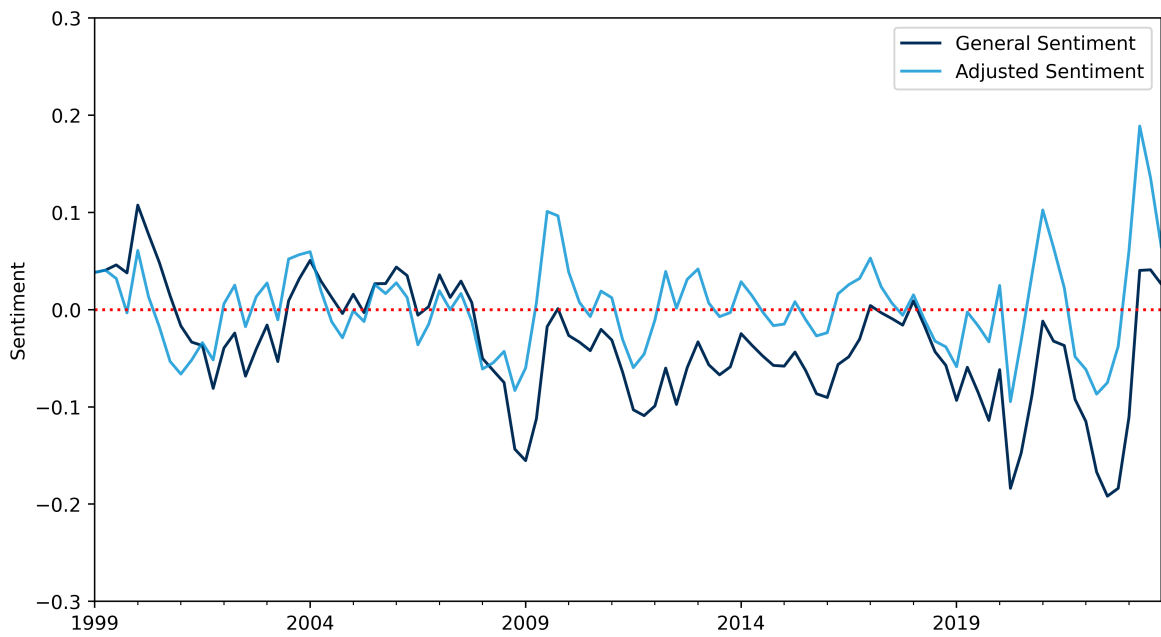


Figure 5.D: Raw and Adjusted Financial Sentiment

Note: The figure shows the monthly average levels of both raw and adjusted sentiments for all entities. The adjusted sentiment is calculated by subtracting the entity-specific sentiment measure from the overall average sentiment.

Appendix 5.C. Embedding-based LLM and Theme Clustering

Language models such as BERT (Bidirectional Encoder Representations from Transformers) serve as prime examples of embedding-based Large Language Models (LLMs). Unlike models designed for text generation, these models excel in understanding and representing text within a high-dimensional space. Their effectiveness is particularly noted in Natural Language Understanding (NLU) tasks, including text classification, sentiment analysis, and entity recognition.

Given a text sequence $X = x_1, x_2, \dots, x_N$, the goal of an embedding-based LLM, like BERT, is to produce a set of embeddings $Z = z_1, z_2, \dots, z_N$ that encapsulate the contextual details of the sequence. This process is mathematically represented as:

$$Z = f_{\text{embLLM}}(X; \theta_{\text{embLLM}})$$

where f_{embLLM} denotes the BERT-style model function, and θ_{embLLM} represents the parameters of the model.

These embedding-based LLMs are particularly valuable for tasks such as entity disambiguation. By leveraging the semantic similarities within the high-dimensional embeddings, these models can distinguish between entities that appear identical in different textual contexts, thereby resolving ambiguities efficiently.

The advent of embedding-based LLMs has introduced new topic modeling method by using the embeddings. Such topic model leverages the power of LLMs to generate vectorized topic representations through a structured process consisting of several key steps:

1. **Document Embedding:** Initially, documents are converted into embeddings using LLM, capturing their semantic essence in high-dimensional vector space.
2. **Dimensionality Reduction:** To manage the curse of dimensionality, these embeddings undergo dimensionality reduction, often via UMAP, to a more tractable space that preserves both local and global structures.
3. **Clustering:** The reduced embeddings are then clustered, typically using HDBSCAN, to identify groups of documents sharing similar topics.
4. **Topic Creation:** For each cluster, a representative topic is generated by taking the average of the top clustered documents' embeddings (e.g., top 10 or top 15 documents or topic keywords), encapsulating the cluster's thematic focus.

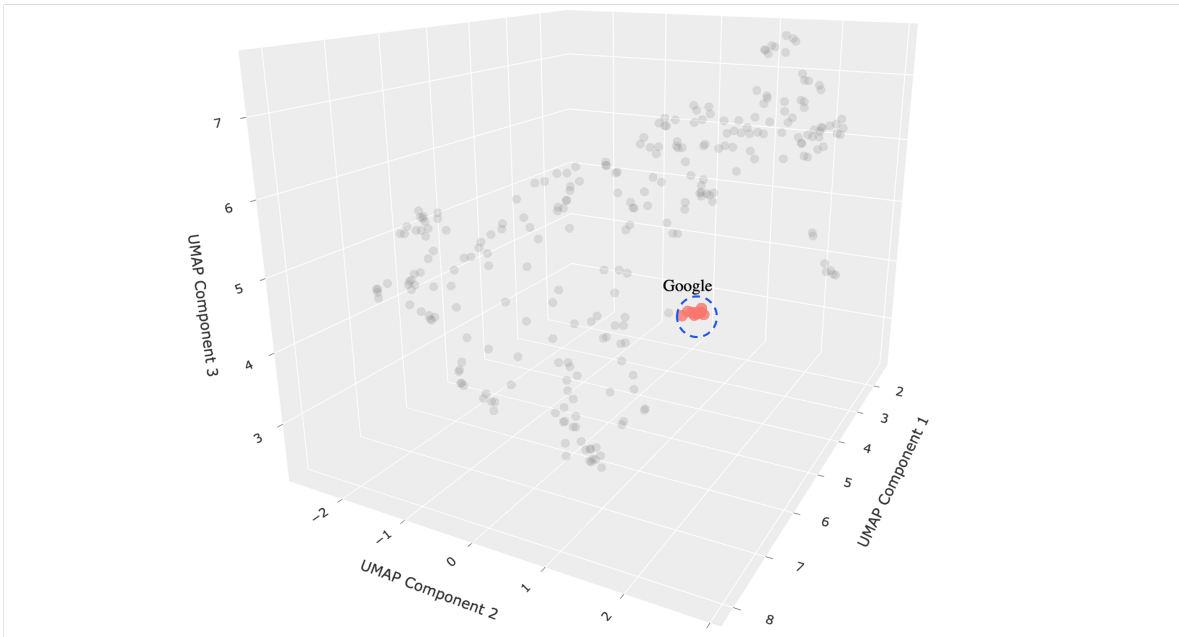


Figure 5.E: 3D UMAP Embeddings of Google Inc.'s Entity Cluster

5. **Refinement:** Finally, the topics are refined and presented, ensuring they accurately reflect the underlying documents.

This process, while standardized, offers flexibility, allowing each step to be independently adjusted or replaced to suit different needs or explore new approaches. For instance, the choice of tokenization can be varied without affecting the embedding model used, and the dimensionality reduction technique can be swapped from UMAP to PCA or others, depending on the specific requirements of the clustering algorithm or the desired outcome.

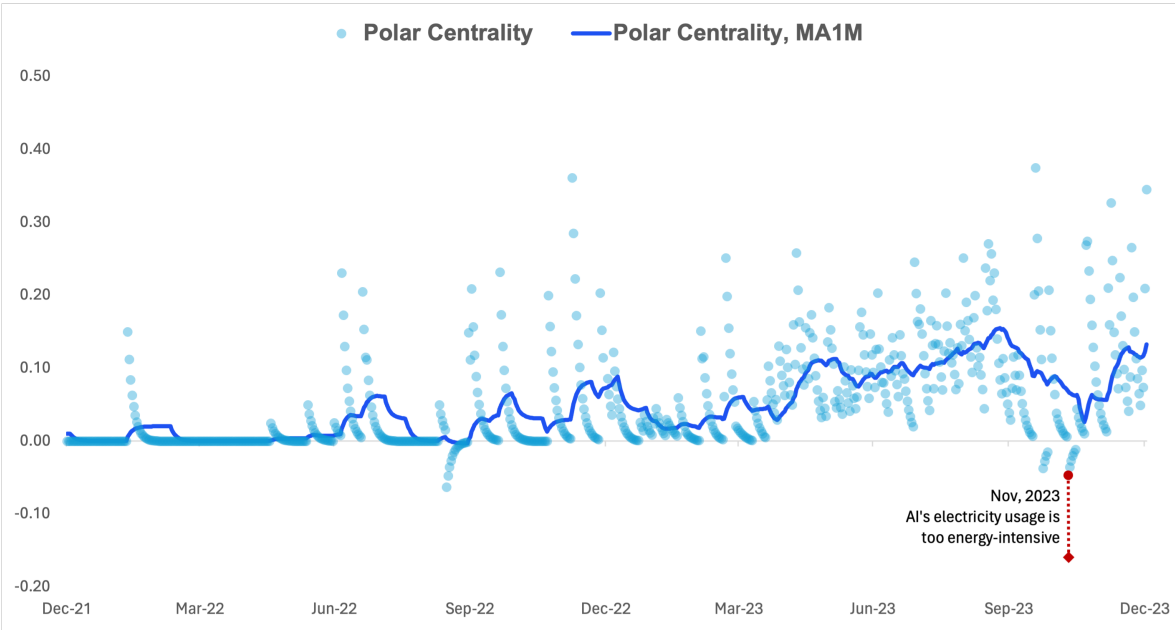


Figure 5.F: AI Theme Polar Centrality Index

Appendix 5.D: Predictive Regression results.

Table 5.D: Descriptive Statistics for Theme State Variables

Theme State Variable	Mean	Standard Deviation	AC(1)
Oil	0.039	0.162	0.674
China	0.057	0.151	0.784
Financial Regulation	0.049	0.045	0.572
Recession	-0.143	0.146	0.817
Economic Recovery	0.072	0.103	0.763
Manufacturing	0.017	0.120	0.689
Economy Growth	0.046	0.149	0.751
Financial Conditions	-0.031	0.080	0.534
Consumer Spending	0.014	0.071	0.549

Table 5.E: Correlation Matrix for Theme State Variables

	OI	CH	FR	RE	ER	MF	EG	FC	CS
Oil (OI)		0.12	0.10	0.11	0.10	0.10	0.12	0.12	-0.03
China (CH)	0.22		0.15	-0.07	0.08	0.18	0.17	0.13	-0.05
Fin. Regulation (FR)	0.03	0.21		-0.13	-0.02	0.03	0.02	-0.04	-0.02
Recession (RE)	0.12	0.02	-0.10		0.00	-0.01	0.08	0.08	-0.02
Econ. Recovery (ER)	0.12	0.09	0.26	0.06		0.19	0.28	0.10	0.15
Manufacturing (MF)	0.29	0.28	0.13	0.24	0.39		0.16	0.13	0.10
Econ. Growth (EG)	0.28	0.28	0.11	0.37	0.45	0.59		0.17	0.16
Fin. Conditions (FC)	0.21	0.24	0.13	0.24	0.24	0.30	0.30		-0.13
Cons. Spending (CS)	-0.05	-0.13	0.06	0.21	0.27	0.10	0.18	0.17	

Note: This table reports the correlation of the theme state variables. The correlation consists of two parts. The upper triangular values correspond to the AR(1) innovations in the state variables. The lower triangular values correspond to the levels of the state variables.

Link Oil Index to Stochastic Discount Factor

Formally, let $\varepsilon_{O,t}$ denote the polar-centrality innovation of the Oil Index. In a representative-agent economy with CRRA utility $u(C) = C^{1-\gamma}/(1-\gamma)$ the log-linearised SDF can be written as

$$m_{t+1} = -\gamma \Delta c_{t+1},$$

where lower-case variables are log quantities. If oil-supply disturbances shift expected consumption growth one period ahead,

$$E_t[\Delta c_{t+1}] = \kappa_0 + \kappa_O \varepsilon_{O,t}, \quad \kappa_O < 0,$$

then substituting into the Euler equation yields a linear factor representation of the SDF,

$$m_{t+1} = -\gamma \kappa_O \varepsilon_{O,t} - \gamma (\Delta c_{t+1} - E_t[\Delta c_{t+1}]).$$

Hence the Oil Index enters the discount factor with price of risk $\lambda_O = -\gamma \kappa_O > 0$. Assets that covary negatively with the index—i.e. that lose value when an energy-supply contraction raises marginal utility—must therefore earn a positive risk premium. This sign implication coincides with the restriction proposed by [Maio and Santa-Clara \(2012\)](#) and [Boons \(2016\)](#), providing an a-priori criterion for the index to qualify as an ICAPM state variable. The empirical sections estimate κ_O and λ_O and test whether the predicted premium materialises in the data.

Appendix 5.D.I: Single Polar Centrality Index Regression results.

Table 5.F1: Predicting One-month Future Macroeconomic Activity Using Single Polar Centrality Index

Note: This table presents the results of single-variable predictive regressions. The 59 selected thematic indexes are used to predict the one-month future growth of two macroeconomic indicators: industrial production log growth and real personal consumption expenditure per capita log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of the COVID-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized, such that for the single-variable regression, the R^2 is equal to the square of the regression slopes. The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
E-Commerce	0.25***	3.45	0.063	Oil	0.26*	1.83	0.070
Economic Recovery	0.24***	3.28	0.056	Global Economy	0.25	1.62	0.063
Credit	0.22***	3.45	0.048	Economy Growth	0.25**	2.25	0.062
Financial Sector	0.22***	3.45	0.046	Financial Conditions	0.23**	2.38	0.054
Financial Crisis	0.20***	3.25	0.039	Stock Market	0.22***	2.82	0.050
Industrial Production	0.20***	3.52	0.039	Economy Contraction	0.19***	3.35	0.038
Europe	0.19***	2.64	0.037	Financial Sector	0.19***	3.09	0.035
Economy Contraction	0.18**	2.46	0.034	China Economy	0.19*	1.71	0.034
Manufacturing	0.18***	2.89	0.032	Credit	0.17***	2.91	0.030
Financial Conditions	0.18***	3.33	0.032	China	0.17	1.32	0.030
Stock Market	0.18**	2.34	0.032	Manufacturing	0.17**	2.56	0.029
Economy Growth	0.18***	2.66	0.031	Economic Recovery	0.16***	2.97	0.025
Banking	0.17***	3.33	0.028	Japan	0.15***	3.20	0.023
Recession	0.16**	2.01	0.026	Automobile	0.15**	2.45	0.022
Investment	0.16**	2.50	0.025	Earnings Results	0.14***	2.58	0.018
IPOs	0.14***	2.65	0.020	IPOs	0.13***	3.11	0.018
Corporate Earnings	0.12**	2.04	0.015	Financial Crisis	0.13**	2.40	0.018
Global Economy	0.12	1.62	0.015	Corporate Earnings	0.13	1.44	0.018
Economy Outlook	0.12	1.49	0.015	Elections	-0.13	-1.39	0.018
Currency FX	-0.12**	-2.51	0.014	Technology	0.13***	3.81	0.018
Interest Rates	-0.12**	-2.04	0.014	Market Risk	0.13*	1.67	0.018
US Economy	0.11	1.31	0.012	Investment	0.12	1.21	0.016
Layoffs	0.11	1.59	0.011	Japan Economy	0.12***	3.25	0.013

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Table 5.F1 (continued)

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Mortgage	0.10*	1.70	0.011	Industrial Production	0.12*	1.81	0.013
Earnings Results	0.10**	1.96	0.010	Economy Outlook	0.11*	1.79	0.011
Technology	0.09*	1.76	0.009	Layoffs	0.10**	1.96	0.010
Great Britain	0.09	1.26	0.008	Middle East	0.09	0.73	0.009
Consumer Spending	0.09	1.11	0.008	US Economy	0.09	1.40	0.009
Gold	-0.09	-1.62	0.008	Recession	0.09	1.31	0.007
Inflation	0.09	1.35	0.008	Natural Gas	0.08	1.47	0.007
Automobile	0.09	1.14	0.008	Europe	0.08	1.47	0.007
Real Estate	0.08	1.03	0.007	Real Estate	0.08	1.27	0.006
Global Trade	-0.08	-1.36	0.006	Sanctions	0.07	1.36	0.006
Middle East	0.08	1.16	0.006	E-Commerce	0.07	1.14	0.006
Consumer Confidence	0.08	1.04	0.006	Banking	0.07	1.41	0.005
Elections	-0.07	-1.11	0.005	Consumer Spending	0.07	0.98	0.005
Financial Regulation	0.07	1.23	0.004	U.S. Dollar	-0.07*	-1.92	0.004
Oil	0.07	1.11	0.004	Consumer Confidence	0.06**	1.98	0.004
Russia	-0.06*	-1.73	0.004	Bonds Market	-0.06	-1.45	0.003
U.S. Dollar	-0.06	-1.26	0.004	European Economy	0.06	1.47	0.003
Japan	0.06	1.06	0.003	Russia	0.06*	1.88	0.003
Labor Market	0.05	0.41	0.002	Labor Market	-0.05	-0.60	0.003
Sanctions	-0.04	-0.71	0.002	US Fed Policy	-0.05	-0.47	0.002
European Economy	0.04	0.73	0.002	Monetary Policy	-0.04	-0.94	0.002
Monetary Policy	-0.04	-0.74	0.002	Great Britain	0.04	1.01	0.002
United States	0.03	0.39	0.001	Geopolitics Risks	0.04	1.05	0.002
Network	0.03	0.56	0.001	Tax	0.04	0.60	0.001
War	-0.03	-0.55	0.001	Global Trade	-0.04	-0.84	0.001
Terrorism	-0.03	-0.59	0.001	Interest Rates	-0.04	-0.79	0.001
Infrastructure	0.03	0.35	0.001	Infrastructure	-0.03	-0.61	0.001
Natural Gas	0.03	0.50	0.001	United States	0.03	0.48	0.001
Japan Economy	-0.02	-0.48	0.001	Network	0.03	0.95	0.001
US Fed Policy	-0.02	-0.24	0.001	Currency FX	-0.02	-0.64	0.001
Tax	0.02	0.38	0.001	Inflation	0.02	0.28	0.000
China Economy	0.02	0.37	0.000	War	0.02	0.42	0.000
China	-0.01	-0.23	0.000	Mortgage	0.01	0.21	0.000
Bonds Market	0.01	0.12	0.000	Financial Regulation	0.01	0.18	0.000
Market Risk	0.01	0.12	0.000	Terrorism	-0.01	-0.12	0.000
Geopolitics Risks	0.00	0.05	0.000	Gold	0.00	-0.01	0.000

Table 5.F2: Predicting Three-month Future Macroeconomic Activity Using Single Polar Centrality index

Note: This table presents the results of single-variable predictive regressions. The 59 selected thematic indexes are used to predict the three-month future growth of two macroeconomic indicators: industrial production log growth and real personal consumption expenditure per capita log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized, such that for the single-variable regression, the R^2 is equal to the square of the regression slopes. The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.42***	4.23	0.174	Economy Contraction	0.28***	3.46	0.085
Financial Sector	0.36***	3.65	0.132	Economy Growth	0.28***	3.16	0.080
Credit	0.35***	3.65	0.124	Manufacturing	0.25***	3.40	0.075
Economy Growth	0.31***	3.21	0.096	Credit	0.25**	2.55	0.067
Financial Crisis	0.30***	3.42	0.092	Financial Sector	0.24**	2.14	0.066
Europe	0.29***	3.15	0.085	Automobile	0.22***	2.59	0.056
E-Commerce	0.29**	2.47	0.083	Economic Recovery	0.22***	3.60	0.054
Economy Contraction	0.28***	2.81	0.081	China Economy	0.21**	2.03	0.053
Financial Conditions	0.28***	2.76	0.079	Stock Market	0.20**	2.10	0.049
Manufacturing	0.27***	3.08	0.075	Elections	-0.20	-1.46	0.048
Recession	0.25**	2.39	0.063	Oil	0.19*	1.84	0.047
Banking	0.24***	3.01	0.058	Earnings Results	0.18***	3.05	0.039
Industrial Production	0.23***	3.02	0.053	Japan	0.18***	2.70	0.038
Investment	0.23**	2.39	0.051	IPOs	0.17**	2.53	0.034
Stock Market	0.22**	1.97	0.048	China	0.17*	1.76	0.031
US Economy	0.22*	1.85	0.047	Global Economy	0.17	1.58	0.029
IPOs	0.22***	2.87	0.047	Japan Economy	0.16***	3.20	0.028
Economy Outlook	0.21**	2.02	0.046	Financial Regulation	0.16**	2.45	0.026
Corporate Earnings	0.20**	2.38	0.040	Technology	0.14***	3.82	0.024
Financial Regulation	0.19***	2.73	0.037	Industrial Production	0.14**	2.27	0.024
Great Britain	0.18*	1.78	0.034	Financial Conditions	0.14	1.03	0.022
Global Economy	0.18*	1.68	0.033	Corporate Earnings	0.13*	1.69	0.020
Interest Rates	-0.18**	-2.19	0.032	Financial Crisis	0.13	1.16	0.020
Earnings Results	0.17***	2.64	0.030	Natural Gas	0.12*	1.67	0.020
Automobile	0.17	1.50	0.029	Global Trade	-0.12	-1.10	0.020
Real Estate	0.17	1.61	0.029	Investment	0.12	1.56	0.018

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Table 5.F2 – continued from previous page

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Technology	0.17**	2.34	0.028	Europe	0.12*	1.72	0.018
Consumer Confidence	0.17*	1.78	0.028	Consumer Confidence	0.11*	1.73	0.015
Consumer Spending	0.16	1.44	0.025	Labor Market	-0.11	-0.79	0.014
Layoffs	0.15	1.52	0.022	Real Estate	0.10	1.01	0.013
European Economy	0.15**	2.09	0.021	Layoffs	0.10	1.17	0.012
Japan	0.15*	1.87	0.021	Sanctions	0.09	1.15	0.011
War	-0.14	-1.62	0.020	U.S. Dollar	-0.09	-1.33	0.011
Middle East	0.14	1.45	0.019	Bonds Market	-0.08	-1.42	0.011
Currency FX	-0.13**	-1.96	0.016	Middle East	0.08	0.55	0.011
Inflation	0.13	1.22	0.016	US Economy	0.08	0.67	0.011
Labor Market	0.12	0.85	0.015	Interest Rates	-0.07	-0.83	0.009
Mortgage	0.12	1.46	0.015	Network	0.07*	1.65	0.009
U.S. Dollar	-0.11	-1.44	0.013	Russia	0.07	1.39	0.007
Sanctions	-0.11	-1.19	0.011	Geopolitics Risks	0.07	1.03	0.006
United States	0.09	0.73	0.009	Recession	0.07	0.60	0.004
Network	0.09	1.39	0.008	Gold	0.06*	1.69	0.004
Terrorism	-0.08	-1.13	0.007	European Economy	0.06	1.22	0.004
US Fed Policy	-0.08	-0.65	0.007	Inflation	0.06	0.62	0.003
Oil	0.08	0.97	0.006	United States	-0.05	-0.48	0.003
Geopolitics Risks	-0.07	-0.75	0.005	Monetary Policy	-0.05	-0.68	0.003
Gold	-0.07	-1.02	0.005	E-Commerce	0.04	0.52	0.003
Russia	-0.06	-1.04	0.004	Market Risk	0.03	0.60	0.003
China Economy	0.06	1.01	0.004	Economy Outlook	0.03	0.22	0.002
Elections	-0.06	-0.55	0.003	Banking	0.02	0.25	0.002
Monetary Policy	-0.06	-0.69	0.003	Terrorism	-0.02	-0.33	0.002
Natural Gas	0.06	0.83	0.003	Great Britain	0.02	0.22	0.000
Infrastructure	0.04	0.32	0.001	Infrastructure	0.02	0.26	0.000
Japan Economy	0.03	0.46	0.001	US Fed Policy	-0.02	-0.12	0.000
Global Trade	-0.03	-0.33	0.001	Tax	-0.01	-0.16	0.000
Tax	-0.02	-0.21	0.000	Consumer Spending	0.01	0.06	0.000
China	0.01	0.11	0.000	Mortgage	0.00	-0.01	0.000
Market Risk	0.00	0.07	0.000	Currency FX	0.00	-0.02	0.000
Bonds Market	0.00	0.00	0.000	War	0.00	0.00	0.000

Table 5.F3: Predicting Six-month Future Macroeconomic Activity Using Single Polar Centrality index

Note: This table presents the results of single-variable predictive regressions. The 59 selected thematic indexes are used to predict the six-month future growth of two macroeconomic indicators: industrial production log growth and real personal consumption expenditure per capita log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized, such that for the single-variable regression, the R^2 is equal to the square of the regression slopes. The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.43***	3.92	0.182	Financial Sector	0.37**	2.32	0.135
Credit	0.42***	3.90	0.175	Manufacturing	0.34***	3.08	0.112
Financial Sector	0.41***	3.42	0.169	Economy Contraction	0.33***	3.02	0.112
E-Commerce	0.35***	2.61	0.124	Credit	0.33**	2.15	0.110
Economy Contraction	0.34***	2.99	0.116	Economy Growth	0.31***	2.96	0.098
Recession	0.33***	3.38	0.106	Economic Recovery	0.28***	3.12	0.078
Europe	0.31***	3.79	0.096	Automobile	0.27**	2.53	0.072
Economy Growth	0.31***	2.87	0.095	Stock Market	0.26*	1.90	0.066
Financial Crisis	0.30***	3.18	0.090	China Economy	0.25***	2.68	0.064
Investment	0.29***	2.75	0.084	Global Economy	0.23*	1.75	0.054
Manufacturing	0.29***	2.86	0.084	Earnings Results	0.23***	3.07	0.052
IPOs	0.28***	2.92	0.078	Japan Economy	0.22***	3.12	0.047
US Economy	0.26**	2.02	0.070	Japan	0.22**	2.39	0.046
Financial Conditions	0.24	1.52	0.055	China	0.21**	2.33	0.043
Industrial Production	0.23***	2.80	0.051	Financial Conditions	0.20	1.01	0.039
Japan	0.22***	2.59	0.048	Financial Regulation	0.19***	2.89	0.035
Consumer Confidence	0.22**	2.42	0.047	IPOs	0.19*	1.72	0.034
Financial Regulation	0.21***	2.70	0.045	Consumer Confidence	0.17	1.64	0.028
Inflation	0.21	1.54	0.043	Investment	0.16	1.54	0.027
Great Britain	0.20*	1.88	0.041	Technology	0.16***	2.97	0.026
Banking	0.20*	1.70	0.040	Real Estate	0.16	1.19	0.025
Economy Outlook	0.20*	1.74	0.040	US Economy	0.15	1.00	0.024
Real Estate	0.20*	1.65	0.039	Inflation	0.15	1.13	0.023
Automobile	0.20*	1.69	0.039	Corporate Earnings	0.14	1.60	0.020
Stock Market	0.19	1.37	0.037	Industrial Production	0.14*	1.90	0.019
European Economy	0.19***	3.10	0.037	Sanctions	0.12	1.44	0.015

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Table 5.F3 – continued from previous page

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Corporate Earnings	0.19*	1.85	0.037	Oil	0.12	1.15	0.015
Earnings Results	0.18**	2.44	0.034	Gold	0.12**	2.19	0.015
Interest Rates	-0.18*	-1.91	0.034	Russia	0.12*	1.89	0.014
Middle East	0.18*	1.76	0.032	Labor Market	-0.12	-0.84	0.014
Global Economy	0.18	1.33	0.031	Europe	0.12	1.26	0.014
Technology	0.18**	2.19	0.031	Geopolitics Risks	0.11	1.00	0.012
Consumer Spending	0.17	1.20	0.027	Network	0.10*	1.82	0.010
War	-0.15	-1.46	0.022	Natural Gas	0.10**	2.02	0.010
Mortgage	0.14	1.15	0.021	Elections	-0.10	-1.05	0.010
Natural Gas	0.14**	2.41	0.019	Great Britain	0.09	0.96	0.008
Labor Market	0.13	0.93	0.017	European Economy	0.09	1.13	0.007
U.S. Dollar	-0.13	-1.47	0.017	Financial Crisis	0.08	0.70	0.007
Terrorism	-0.13	-1.60	0.016	Infrastructure	0.08	1.21	0.006
Currency FX	-0.12*	-1.73	0.015	Layoffs	0.07	0.80	0.005
Japan Economy	0.12	1.49	0.014	Terrorism	-0.07	-0.99	0.005
Sanctions	-0.11	-1.19	0.013	U.S. Dollar	-0.07	-0.76	0.005
Network	0.10	1.56	0.010	Recession	0.07	0.62	0.005
United States	0.10	0.74	0.010	Mortgage	0.07	0.37	0.005
Layoffs	0.09	0.91	0.009	Economy Outlook	0.07	0.63	0.004
Russia	-0.07	-0.96	0.006	Interest Rates	-0.06	-0.52	0.003
Gold	-0.07	-1.01	0.005	Banking	0.05	0.34	0.003
China Economy	0.07	0.82	0.004	Middle East	0.05	0.35	0.002
Infrastructure	0.06	0.57	0.004	Currency FX	0.05	0.63	0.002
Bonds Market	0.06	0.76	0.003	Bonds Market	-0.05	-0.66	0.002
Geopolitics Risks	-0.06	-0.49	0.003	Market Risk	0.04	0.67	0.002
Market Risk	-0.05	-0.64	0.002	Tax	-0.03	-0.64	0.001
US Fed Policy	-0.05	-0.28	0.002	E-Commerce	0.02	0.22	0.001
Tax	-0.02	-0.24	0.000	US Fed Policy	-0.02	-0.14	0.000
Global Trade	-0.01	-0.11	0.000	Monetary Policy	0.02	0.18	0.000
Monetary Policy	-0.01	-0.07	0.000	Global Trade	-0.02	-0.19	0.000
China	0.00	-0.04	0.000	War	0.01	0.17	0.000
Oil	0.00	-0.02	0.000	Consumer Spending	0.01	0.07	0.000
Elections	0.00	0.00	0.000	United States	-0.01	-0.05	0.000

Table 5.F4: Predicting Twelve-month Future Macroeconomic Activity Using Single Polar Centrality index

Note: This table presents the results of single-variable predictive regressions. The 59 selected thematic indexes are used to predict the twelve-month future growth of two macroeconomic indicators: industrial production log growth and real personal consumption expenditure per capita log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of the Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized, such that for the single-variable regression, the R^2 is equal to the square of the regression slopes. The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.49***	4.88	0.238	Financial Sector	0.48***	3.12	0.234
Credit	0.47***	5.04	0.222	Credit	0.38*	1.84	0.142
Financial Sector	0.46***	4.15	0.211	Financial Conditions	0.33*	1.86	0.110
Europe	0.37***	5.06	0.135	Stock Market	0.33***	2.60	0.109
Economy Growth	0.35***	3.11	0.123	Economic Recovery	0.32***	2.83	0.103
Manufacturing	0.34***	3.12	0.113	Manufacturing	0.28***	3.03	0.080
Economy Contraction	0.33***	3.16	0.107	Economy Growth	0.28**	2.51	0.077
Financial Regulation	0.32***	3.94	0.102	Global Economy	0.27**	2.20	0.071
Investment	0.31***	3.04	0.096	Financial Regulation	0.26***	2.64	0.066
US Economy	0.29**	2.21	0.084	Japan Economy	0.26***	2.88	0.066
Real Estate	0.29***	2.70	0.084	Inflation	0.25	1.44	0.063
Great Britain	0.28***	2.67	0.081	Economy Contraction	0.24**	2.26	0.058
Japan	0.28***	3.38	0.076	Labor Market	-0.23	-1.64	0.055
E-Commerce	0.27*	1.90	0.072	China Economy	0.23***	2.79	0.054
Recession	0.26***	2.94	0.068	Mortgage	0.23	1.01	0.054
IPOs	0.26***	2.72	0.067	China	0.23**	2.29	0.054
Global Economy	0.26*	1.88	0.066	Japan	0.21**	2.05	0.043
European Economy	0.25***	4.44	0.063	Automobile	0.21**	2.45	0.042
Economy Outlook	0.24**	2.14	0.056	Real Estate	0.20	1.17	0.041
Financial Conditions	0.24	1.44	0.056	Earnings Results	0.20***	2.59	0.039
Industrial Production	0.23***	2.80	0.054	Sanctions	0.20*	1.66	0.038
Banking	0.22*	1.86	0.050	US Economy	0.18	0.84	0.033
Consumer Confidence	0.22**	2.29	0.046	Russia	0.17**	2.00	0.030
Corporate Earnings	0.21**	2.03	0.045	Consumer Confidence	0.17	1.21	0.030
Middle East	0.21*	1.78	0.043	Infrastructure	0.16*	1.67	0.027
Financial Crisis	0.20*	1.89	0.040	Corporate Earnings	0.15	1.51	0.023

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Table 5.F4 – continued from previous page

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Inflation	0.20	1.36	0.040	Banking	0.15	0.88	0.023
Automobile	0.19*	1.84	0.037	Technology	0.14**	2.23	0.019
Stock Market	0.19	1.38	0.037	Monetary Policy	0.13	0.92	0.017
War	-0.19**	-2.00	0.036	United States	0.12	0.67	0.014
Terrorism	-0.18**	-2.34	0.032	Great Britain	0.12	0.87	0.014
Consumer Spending	0.17	1.25	0.031	Geopolitics Risks	0.11	0.82	0.012
Earnings Results	0.17**	2.33	0.030	Gold	0.11	1.54	0.012
Technology	0.17**	2.26	0.027	Currency FX	0.11	1.19	0.012
Gold	-0.15**	-2.25	0.024	Terrorism	-0.10	-1.11	0.011
Interest Rates	-0.15*	-1.71	0.023	Europe	0.10	1.01	0.010
Japan Economy	0.15**	2.36	0.022	Industrial Production	0.10	1.13	0.010
Natural Gas	0.13**	2.28	0.017	Market Risk	0.09	1.15	0.008
Mortgage	0.12	0.74	0.014	Economy Outlook	0.09	0.92	0.008
Infrastructure	0.12	1.32	0.014	Investment	0.09	0.91	0.007
China Economy	0.11	0.94	0.012	US Fed Policy	0.08	0.70	0.007
Elections	0.11	0.93	0.011	Consumer Spending	0.08	0.44	0.007
United States	0.10	0.69	0.011	Interest Rates	0.08	0.97	0.006
U.S. Dollar	-0.09	-0.83	0.008	European Economy	0.08	0.81	0.006
Sanctions	-0.09	-0.93	0.007	Network	0.07	0.84	0.004
Russia	-0.08	-1.13	0.007	Natural Gas	0.07	1.34	0.004
Oil	-0.08	-0.84	0.006	IPOs	0.06	0.50	0.003
Geopolitics Risks	-0.07	-0.64	0.006	Global Trade	0.06	0.59	0.003
Bonds Market	0.07	0.91	0.005	Tax	-0.06	-0.84	0.003
China	0.07	0.60	0.004	Financial Crisis	-0.05	-0.57	0.003
US Fed Policy	-0.04	-0.26	0.002	Layoffs	-0.05	-0.66	0.003
Network	0.04	0.55	0.002	Elections	0.04	0.46	0.002
Labor Market	0.04	0.25	0.001	E-Commerce	0.03	0.24	0.001
Monetary Policy	0.03	0.35	0.001	U.S. Dollar	-0.03	-0.21	0.001
Layoffs	-0.03	-0.27	0.001	War	0.02	0.20	0.001
Tax	-0.02	-0.36	0.001	Oil	0.01	0.07	0.000
Currency FX	-0.02	-0.35	0.001	Middle East	0.01	0.06	0.000
Market Risk	-0.02	-0.33	0.001	Recession	0.00	0.01	0.000
Global Trade	-0.01	-0.08	0.000	Bonds Market	0.00	0.02	0.000

Appendix 5.D.II: Multiple Predictors Regression results.

Table 5.G: Predicting One-month Future Macroeconomic Activity with Baseline Model

Panel A: Consumption Expenditure Growth				
Horizon	Dividend Yield	Default Spread	Term Spread	Adjusted R^2
1	-0.18** (-2.29)	-0.13* (-1.81)	-0.03 (-0.63)	0.077
3	-0.21** (-1.79)	-0.25*** (-2.60)	-0.01 (-0.13)	0.171
6	-0.16 (-1.25)	-0.29** (-2.45)	0.02 (0.18)	0.168
12	-0.18 (-1.25)	-0.23 (-1.61)	0.18 (1.36)	0.140
Panel B: Industrial Production Growth				
Horizon	Dividend Yield	Default Spread	Term Spread	Adjusted R^2
1	-0.15 (-1.28)	-0.11 (-1.29)	0.11* (1.78)	0.044
3	-0.15 (-1.35)	-0.11 (-0.70)	0.16** (2.13)	0.060
6	-0.09 (-0.79)	-0.16 (-0.97)	0.22** (2.27)	0.070
12	-0.05 (-0.40)	-0.08 (-0.52)	0.31*** (2.62)	0.083

Note: This table presents the results of baseline predictive regressions. The three baseline state variables: Dividend Yield, Default Spread, and Term Spread are used to predict the future growth of two macroeconomic indicators (cumulated over horizons of 1, 3, 6, and 12 months): industrial production log growth and real personal consumption expenditure per capita log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized. The t-statistics are represented in parentheses under the coefficients. The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Table 5.H1: Results of One-Month Multiple Predictors Regressions with Index Inclusion

Note: This table presents the results of Multiple-variable predictive regressions. The 59 selected thematic indexes are added to the baseline three-predictor model one at a time to run a four-predictor regression to predict the one-month future growth of two macroeconomic indicators: real personal consumption expenditure per capita log growth and industrial production log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized. The R^2 equals the adjusted R^2 of the corresponding predictive regressions. Only the top 10 predictors, sorted by adjusted R^2 , are presented in this table. For the full results, please refer to [Appendix D](#). The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
E-Commerce	0.25***	3.51	0.131	Oil	0.22	1.62	0.089
Economic Recovery	0.23***	3.60	0.121	Stock Market	0.22**	2.42	0.087
Stock Market	0.18***	2.58	0.103	Financial Conditions	0.20**	2.11	0.079
Inflation	0.14**	2.27	0.094	Economy Growth	0.19*	1.74	0.073
Global Trade	-0.14**	-2.46	0.091	China	0.18	1.44	0.072
IPOs	0.14***	2.67	0.091	Global Economy	0.19	1.20	0.071
Technology	0.14**	2.22	0.091	China Economy	0.16*	1.67	0.067
Industrial Production	0.14**	2.36	0.091	Japan	0.17**	2.56	0.066
Financial Sector	0.13**	2.25	0.090	Technology	0.16***	3.04	0.064
Manufacturing	0.13**	2.25	0.089	Japan Economy	0.16***	2.73	0.062
US Fed Policy	0.14*	1.66	0.089	Financial Sector	0.15***	2.61	0.060
Europe	0.12*	1.88	0.088	Economy Contraction	0.14**	2.28	0.059
Financial Conditions	0.12**	2.34	0.087	Market Risk	0.12*	1.81	0.054
Credit	0.12**	2.23	0.087	Earnings Results	0.11**	2.31	0.054
Investment	0.10	1.49	0.083	IPOs	0.12**	2.34	0.052
Economy Contraction	0.10	1.55	0.082	Global Trade	-0.11**	-2.10	0.052
Network	0.09	1.47	0.082	Layoffs	0.12**	2.52	0.052
Earnings Results	0.08	1.59	0.081	Manufacturing	0.11*	1.85	0.052
Economy Growth	0.09	1.40	0.081	Credit	0.11*	1.84	0.052
Banking	0.09*	1.87	0.081	Economic Recovery	0.11**	2.05	0.051
Infrastructure	0.08	1.21	0.080	Labor Market	-0.12	-0.98	0.051
Layoffs	0.08	1.30	0.079	Elections	-0.09	-1.00	0.048
Russia	-0.07	-1.52	0.079	Sanctions	0.09**	2.24	0.048
Monetary Policy	0.08	1.55	0.079	E-Commerce	0.08	1.10	0.047

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Table 5.H1 – continued from previous page

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Japan	0.07	1.28	0.078	Automobile	0.08*	1.94	0.047
Mortgage	0.06	1.15	0.078	Network	0.08*	1.75	0.046
Labor Market	-0.07	-0.69	0.078	Investment	0.07	0.67	0.046
Terrorism	-0.06	-1.19	0.078	Natural Gas	0.06	1.08	0.045
Financial Regulation	0.06	1.01	0.077	Bonds Market	-0.06	-1.41	0.045
Great Britain	0.05	0.96	0.077	Middle East	0.07	0.57	0.044
Interest Rates	-0.05	-0.94	0.077	US Fed Policy	0.06	0.63	0.044
Consumer Confidence	0.04	0.77	0.076	Industrial Production	0.05	1.09	0.044
Middle East	0.05	0.77	0.076	Currency FX	0.06	1.41	0.044
US Economy	0.04	0.69	0.076	Inflation	0.05	0.70	0.044
Gold	-0.04	-0.67	0.075	Russia	0.05*	1.70	0.044
Corporate Earnings	0.04	0.60	0.075	Tax	0.05	0.75	0.044
Real Estate	0.04	0.58	0.075	Europe	0.05	0.91	0.043
Consumer Spending	0.03	0.55	0.075	Corporate Earnings	0.05	0.62	0.043
Tax	0.03	0.48	0.075	Financial Regulation	-0.05	-0.85	0.043
Geopolitics Risks	0.03	0.54	0.075	United States	0.04	0.61	0.043
Recession	-0.03	-0.45	0.075	Consumer Confidence	0.04	1.30	0.042
United States	0.02	0.32	0.075	Real Estate	0.04	0.68	0.042
War	-0.02	-0.45	0.075	Consumer Spending	0.03	0.55	0.042
Japan Economy	0.02	0.39	0.075	European Economy	0.03	0.82	0.042
Market Risk	-0.02	-0.46	0.075	Banking	0.03	0.73	0.042
Currency FX	-0.02	-0.48	0.075	Geopolitics Risks	0.03	0.65	0.042
Global Economy	0.02	0.29	0.075	US Economy	0.03	0.59	0.042
Sanctions	-0.02	-0.35	0.074	Recession	-0.04	-0.51	0.042
Financial Crisis	-0.01	-0.18	0.074	Mortgage	-0.03	-0.48	0.042
U.S. Dollar	0.01	0.19	0.074	Financial Crisis	0.04	0.49	0.042
China	0.01	0.12	0.074	Economy Outlook	0.03	0.47	0.042
Elections	0.00	-0.06	0.074	Gold	0.02	0.75	0.041
Economy Outlook	0.00	0.07	0.074	Great Britain	-0.02	-0.48	0.041
Automobile	0.00	-0.06	0.074	Monetary Policy	0.02	0.56	0.041
China Economy	0.00	-0.05	0.074	Terrorism	0.02	0.28	0.041
Oil	0.00	-0.04	0.074	Infrastructure	-0.01	-0.28	0.041
Natural Gas	0.00	0.04	0.074	Interest Rates	0.01	0.22	0.041
Bonds Market	0.00	0.02	0.074	U.S. Dollar	-0.01	-0.18	0.041
European Economy	0.00	0.00	0.074	War	0.01	0.12	0.041
Baseline			0.077	Baseline			0.044

Table 5.H2: Results of Three-Month Multiple Predictors Regressions with Index Inclusion

Note: This table presents the results of Multiple-variable predictive regressions. The 59 selected thematic indexes are added to the baseline three-predictor model one at a time to run a four-predictor regression to predict the three-month future growth of two macroeconomic indicators: real personal consumption expenditure per capita log growth and industrial production log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized. The R^2 equals the adjusted R^2 of the corresponding predictive regressions. Only the top 10 predictors, sorted by adjusted R^2 , are presented in this table. For the full results, please refer to [Appendix D](#). The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.41***	5.62	0.318	Economy Contraction	0.24***	3.61	0.108
E-Commerce	0.27***	2.93	0.236	Global Trade	-0.23	-1.57	0.102
Financial Sector	0.25***	3.20	0.224	Financial Sector	0.22**	2.33	0.099
Inflation	0.20**	2.33	0.209	Economy Growth	0.22**	2.36	0.098
Technology	0.21***	2.77	0.209	Stock Market	0.20**	2.36	0.093
Credit	0.22***	3.18	0.208	Japan Economy	0.21***	3.03	0.093
Europe	0.20**	2.52	0.204	Japan	0.20**	2.41	0.092
Stock Market	0.20**	2.03	0.204	Credit	0.20**	2.40	0.091
Financial Conditions	0.19**	2.25	0.202	Manufacturing	0.20**	2.36	0.090
Manufacturing	0.19**	2.43	0.200	China Economy	0.18*	1.93	0.089
IPOs	0.19***	2.73	0.198	China	0.17*	1.95	0.086
Financial Regulation	0.18***	2.75	0.198	Technology	0.17***	4.10	0.082
Economy Growth	0.18**	2.22	0.197	Earnings Results	0.16***	2.90	0.081
Network	0.17**	2.34	0.191	Elections	-0.15	-1.11	0.079
Economy Contraction	0.16*	1.94	0.190	Automobile	0.16***	2.70	0.078
Japan	0.15**	2.33	0.187	Labor Market	-0.18	-1.15	0.077
Earnings Results	0.14**	2.01	0.187	Economic Recovery	0.15***	2.78	0.077
Industrial Production	0.14**	2.06	0.186	IPOs	0.16**	2.05	0.076
Banking	0.14**	2.27	0.185	Oil	0.14	1.51	0.075
War	-0.13*	-1.90	0.185	Network	0.14***	2.73	0.072
US Fed Policy	0.13	1.15	0.183	Layoffs	0.13*	1.71	0.069
Investment	0.13	1.57	0.182	Natural Gas	0.11	1.27	0.067
Great Britain	0.12	1.58	0.182	US Fed Policy	0.12	0.82	0.067
Consumer Confidence	0.11	1.59	0.181	Financial Regulation	0.10	1.39	0.066

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Table 5.H2 – continued from previous page

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Middle East	0.12	1.63	0.180	Financial Conditions	0.10	0.87	0.066
US Economy	0.12	1.35	0.180	Consumer Confidence	0.09*	1.76	0.064
Terrorism	-0.11*	-1.68	0.179	Inflation	0.09	0.87	0.064
Global Trade	-0.10	-1.14	0.178	Sanctions	0.10*	1.88	0.064
Infrastructure	0.09	0.93	0.176	Europe	0.09	1.47	0.064
European Economy	0.09	1.40	0.176	Bonds Market	-0.09	-1.39	0.064
Interest Rates	-0.09	-1.26	0.176	Gold	0.08**	1.99	0.062
Japan Economy	0.09	1.27	0.175	Currency FX	0.08*	1.93	0.062
Real Estate	0.09	1.35	0.175	Global Economy	0.08	0.84	0.061
Monetary Policy	0.09	1.16	0.175	Industrial Production	0.07	1.25	0.061
United States	0.08	0.78	0.175	Economy Outlook	-0.07	-0.62	0.061
Layoffs	0.09	1.03	0.174	Investment	0.06	0.80	0.060
Consumer Spending	0.07	1.04	0.174	Great Britain	-0.06	-0.73	0.060
Mortgage	0.06	0.97	0.173	Russia	0.06	0.96	0.060
Sanctions	-0.06	-0.97	0.172	Real Estate	0.06	1.04	0.059
Corporate Earnings	0.06	0.85	0.172	Mortgage	-0.05	-0.46	0.059
Russia	-0.06	-1.17	0.172	E-Commerce	0.05	0.74	0.059
Economy Outlook	0.05	0.56	0.171	Recession	-0.07	-0.73	0.059
Elections	0.05	0.47	0.171	Geopolitics Risks	0.05	1.07	0.059
Geopolitics Risks	-0.04	-0.55	0.170	European Economy	0.04	0.86	0.058
China	0.04	0.54	0.170	Interest Rates	-0.04	-0.39	0.058
Financial Crisis	0.05	0.49	0.170	Infrastructure	0.04	0.79	0.058
China Economy	0.03	0.51	0.170	Middle East	0.04	0.29	0.058
Oil	-0.03	-0.48	0.169	Financial Crisis	0.05	0.40	0.057
Automobile	0.03	0.42	0.169	Consumer Spending	-0.03	-0.46	0.057
Market Risk	-0.02	-0.50	0.169	United States	-0.03	-0.31	0.057
Labor Market	-0.03	-0.19	0.169	Corporate Earnings	0.03	0.49	0.057
Global Economy	0.02	0.27	0.169	U.S. Dollar	-0.02	-0.44	0.057
Recession	-0.02	-0.28	0.169	War	-0.02	-0.34	0.057
Currency FX	0.02	0.31	0.169	Terrorism	0.02	0.28	0.057
Tax	-0.01	-0.23	0.169	Monetary Policy	0.02	0.23	0.057
U.S. Dollar	-0.01	-0.19	0.169	US Economy	0.01	0.13	0.056
Natural Gas	0.01	0.17	0.169	Tax	0.01	0.19	0.056
Bonds Market	-0.01	-0.07	0.169	Banking	-0.01	-0.07	0.056
Gold	0.00	-0.01	0.169	Market Risk	0.00	0.05	0.056
Baseline			0.171	Baseline			0.060

Table 5.H3: Results of Six-Month Multiple Predictors Regressions with Index Inclusion

Note: This table presents the results of Multiple-variable predictive regressions. The 59 selected thematic indexes are added to the baseline three-predictor model one at a time to run a four-predictor regression to predict the six-month future growth of two macroeconomic indicators: real personal consumption expenditure per capita log growth and industrial production log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized. The R^2 equals the adjusted R^2 of the corresponding predictive regressions. Only the top 10 predictors, sorted by adjusted R^2 , are presented in this table. For the full results, please refer to [Appendix D](#). The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.42***	4.01	0.319	Financial Sector	0.37***	2.73	0.186
E-Commerce	0.34***	2.76	0.271	Credit	0.31**	2.24	0.150
Financial Sector	0.31***	2.98	0.249	Economy Contraction	0.30***	3.17	0.147
Inflation	0.29**	2.13	0.245	Manufacturing	0.28**	2.44	0.133
Credit	0.30***	3.20	0.241	Economy Growth	0.26***	2.90	0.122
IPOs	0.25***	2.60	0.215	Stock Market	0.24**	2.07	0.120
Europe	0.22***	3.54	0.210	China Economy	0.22***	2.58	0.116
Economy Contraction	0.22**	2.42	0.208	Japan Economy	0.24***	3.22	0.114
Japan	0.22***	3.01	0.206	Japan	0.22***	2.70	0.109
Technology	0.21**	2.28	0.204	Economic Recovery	0.22***	2.62	0.108
Financial Regulation	0.19**	2.51	0.199	China	0.19**	2.39	0.104
Manufacturing	0.20**	2.05	0.199	Earnings Results	0.19***	3.24	0.103
Investment	0.19**	2.02	0.197	Automobile	0.21***	2.72	0.101
Middle East	0.20**	2.30	0.194	Inflation	0.17	1.16	0.094
Economy Growth	0.18**	2.07	0.191	Financial Conditions	0.16	0.95	0.092
Consumer Confidence	0.16**	2.18	0.190	Technology	0.16***	3.12	0.091
US Fed Policy	0.18	1.08	0.190	Consumer Confidence	0.14*	1.75	0.087
Japan Economy	0.17**	2.35	0.190	Labor Market	-0.17	-1.12	0.086
Stock Market	0.16	1.15	0.188	Network	0.15**	2.49	0.085
Telecommunication	0.17**	2.23	0.188	Sanctions	0.14**	2.27	0.085
US Economy	0.16	1.44	0.187	Global Economy	0.15	1.22	0.084
Earnings Results	0.14*	1.77	0.184	IPOs	0.14	1.43	0.084
Financial Conditions	0.14	0.99	0.183	Gold	0.12**	2.08	0.081
European Economy	0.13***	2.68	0.183	Financial Regulation	0.12	1.58	0.081

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Table 5.H3 – continued from previous page

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Industrial Production	0.14**	2.11	0.183	Currency FX	0.12**	2.44	0.080
War	-0.13	-1.59	0.181	Russia	0.11	1.42	0.079
Terrorism	-0.14**	-2.18	0.181	Geopolitics Risks	0.11	1.27	0.077
Great Britain	0.13	1.57	0.181	Global Trade	-0.11	-1.18	0.077
Monetary Policy	0.13	1.21	0.179	Investment	0.11	1.00	0.077
Oil	-0.11	-1.53	0.177	Europe	0.10	1.32	0.076
Elections	0.11	0.98	0.176	Real Estate	0.11	1.03	0.076
Infrastructure	0.10	1.14	0.175	Infrastructure	0.09	1.38	0.074
Banking	0.10	0.95	0.174	US Fed Policy	0.09	0.60	0.074
Real Estate	0.11	1.32	0.174	Industrial Production	0.08	1.21	0.073
Interest Rates	-0.10	-0.99	0.174	US Economy	0.08	0.66	0.073
Natural Gas	0.09*	1.71	0.173	Natural Gas	0.07	1.33	0.072
United States	0.09	0.71	0.173	Layoffs	0.08	0.87	0.072
Mortgage	0.09	0.77	0.173	Oil	0.07	0.65	0.072
Recession	0.11	1.59	0.173	European Economy	0.07	0.89	0.071
Consumer Spending	0.08	0.72	0.171	Monetary Policy	0.06	0.48	0.070
Global Trade	-0.08	-0.89	0.171	Elections	-0.05	-0.67	0.070
Market Risk	-0.07	-1.01	0.170	Banking	0.04	0.32	0.069
Russia	-0.06	-0.95	0.169	Corporate Earnings	0.04	0.64	0.069
Sanctions	-0.07	-0.88	0.169	Interest Rates	-0.04	-0.35	0.069
Bonds Market	0.06	0.76	0.169	Bonds Market	-0.04	-0.59	0.069
Financial Crisis	0.07	0.53	0.168	E-Commerce	0.04	0.36	0.068
Automobile	0.05	0.69	0.167	Recession	-0.04	-0.45	0.068
Corporate Earnings	0.05	0.58	0.167	Consumer Spending	-0.03	-0.24	0.068
China Economy	0.04	0.43	0.167	Mortgage	0.02	0.13	0.068
U.S. Dollar	-0.03	-0.47	0.166	Market Risk	0.02	0.29	0.068
Economy Outlook	0.03	0.30	0.166	Economy Outlook	-0.02	-0.19	0.067
China	0.03	0.35	0.166	Financial Crisis	0.03	0.18	0.067
Currency FX	0.02	0.30	0.166	Tax	-0.02	-0.32	0.067
Tax	-0.01	-0.23	0.166	Terrorism	-0.01	-0.23	0.067
Geopolitics Risks	-0.02	-0.16	0.166	Middle East	0.01	0.11	0.067
Labor Market	-0.02	-0.09	0.166	United States	0.01	0.10	0.067
Gold	-0.01	-0.16	0.165	U.S. Dollar	-0.01	-0.11	0.067
Global Economy	0.01	0.09	0.165	War	0.00	0.05	0.067
Layoffs	0.00	0.00	0.165	Great Britain	0.00	-0.04	0.067
Baseline			0.168	Baseline			0.070

Table 5.H4: Results of Twelve-Month Multiple Predictors Regressions with Index Inclusion

Note: This table presents the results of Multiple-variable predictive regressions. The 59 selected thematic indexes are added to the baseline three-predictor model one at a time to run a four-predictor regression to predict the twelve-month future growth of two macroeconomic indicators: real personal consumption expenditure per capita log growth and industrial production log growth. The sample period for both macroeconomic indicators begins in the first month of 2000 and ends in the last month of 2023. The outliers in log consumption expenditure data during the outbreak period of Covid-19 are identified and trimmed using the Interquartile Range (IQR) methodology with a 1.5 multiplier. The values for all variables are standardized. The R^2 equals the adjusted R^2 of the corresponding predictive regressions. Only the top 10 predictors, sorted by adjusted R^2 , are presented in this table. For the full results, please refer to [Appendix D](#). The t-statistics reported are calculated using [Newey and West \(1986\)](#) (NW) standard errors with 6 lags. The NW standard errors are presented in parentheses underneath each regression coefficient. Note: * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW t-statistics.

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Economic Recovery	0.44***	3.79	0.306	Financial Sector	0.54***	3.59	0.338
Financial Sector	0.40***	3.44	0.275	Credit	0.43**	2.04	0.234
Credit	0.40***	3.67	0.272	Financial Conditions	0.32*	1.94	0.177
E-Commerce	0.29*	1.95	0.215	Stock Market	0.32***	2.74	0.176
Europe	0.29***	4.32	0.214	Economic Recovery	0.25**	2.35	0.136
Japan	0.29***	4.43	0.209	Japan Economy	0.27***	2.81	0.136
Financial Regulation	0.27***	2.79	0.200	Economy Growth	0.25***	2.79	0.131
Inflation	0.24	1.33	0.193	Inflation	0.22	1.17	0.127
Manufacturing	0.24**	1.99	0.185	Economy Contraction	0.23**	2.04	0.126
Investment	0.23***	2.99	0.183	Manufacturing	0.23**	2.55	0.126
Economy Growth	0.23***	2.84	0.181	Japan	0.22**	2.41	0.120
Economy Contraction	0.23**	2.48	0.181	Mortgage	0.20	0.89	0.119
Real Estate	0.25**	2.43	0.180	Global Economy	0.22*	1.90	0.117
European Economy	0.21***	3.69	0.178	Labor Market	-0.23	-1.56	0.116
IPOs	0.22**	2.24	0.177	Banking	0.20	1.20	0.115
Elections	0.20**	1.96	0.175	Sanctions	0.20*	1.73	0.113
Oil	-0.20**	-2.34	0.173	China Economy	0.18**	2.41	0.111
War	-0.20**	-2.13	0.172	Financial Regulation	0.18*	1.79	0.107
US Economy	0.20	1.50	0.170	Earnings Results	0.17**	2.57	0.107
Great Britain	0.19**	1.97	0.167	Real Estate	0.19	1.01	0.106
Technology	0.18**	2.07	0.165	Consumer Confidence	0.16	1.28	0.105
Consumer Confidence	0.17*	1.95	0.165	Infrastructure	0.16	1.55	0.104
Japan Economy	0.19***	2.87	0.164	China	0.16*	1.70	0.103
Middle East	0.19	1.52	0.163	US Economy	0.15	0.67	0.098

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Table 5.H4 – continued from previous page

Panel A: Consumption Expenditure Growth				Panel B: Industrial Production Growth			
Theme	Coeff.	T-Stats	R^2	Theme	Coeff.	T-Stats	R^2
Banking	0.17	1.47	0.161	Automobile	0.15**	2.04	0.097
Infrastructure	0.16*	1.83	0.159	Currency FX	0.14**	2.13	0.097
Stock Market	0.16	1.06	0.159	Monetary Policy	0.14	0.77	0.095
Terrorism	-0.16**	-2.27	0.158	Russia	0.12	1.04	0.093
Financial Conditions	0.15	0.94	0.157	US Fed Policy	0.13	0.79	0.092
Industrial Production	0.14**	2.41	0.156	Technology	0.11**	2.16	0.090
Gold	-0.13	-1.64	0.154	United States	0.11	0.64	0.090
Interest Rates	-0.14	-1.08	0.153	Corporate Earnings	0.10	1.17	0.088
Monetary Policy	0.15	1.06	0.153	Network	0.09	1.59	0.086
Global Trade	-0.14	-1.61	0.153	E-Commerce	0.09	0.59	0.086
US Fed Policy	0.14	0.69	0.152	Europe	0.09	0.97	0.086
Earnings Results	0.12**	2.06	0.151	Geopolitics Risks	0.09	0.66	0.086
Russia	-0.12*	-1.71	0.151	Gold	0.08	1.14	0.085
Consumer Spending	0.11	0.83	0.148	Consumer Spending	0.07	0.45	0.085
Currency FX	0.10	1.51	0.145	European Economy	0.07	0.75	0.084
Economy Outlook	0.10	0.99	0.145	Industrial Production	0.07	1.18	0.084
Global Economy	0.10	1.01	0.144	Middle East	-0.07	-0.59	0.083
Network	0.10	1.23	0.144	Elections	0.06	0.66	0.083
Recession	0.11	1.48	0.144	Market Risk	0.05	0.59	0.082
United States	0.09	0.59	0.144	Investment	0.06	0.78	0.082
Natural Gas	0.08	1.53	0.143	Economy Outlook	0.06	0.65	0.082
Geopolitics Risks	-0.09	-0.73	0.143	Global Trade	-0.05	-0.58	0.082
Bonds Market	0.07	0.96	0.142	Oil	-0.04	-0.26	0.081
Sanctions	-0.08	-1.01	0.142	Natural Gas	0.04	0.69	0.081
Market Risk	-0.07	-0.83	0.141	Tax	-0.03	-0.53	0.081
Layoffs	-0.08	-0.64	0.141	Financial Crisis	-0.05	-0.22	0.081
Corporate Earnings	0.07	0.76	0.141	Terrorism	-0.04	-0.45	0.081
Mortgage	0.05	0.29	0.139	War	0.02	0.18	0.080
China Economy	0.05	0.49	0.139	U.S. Dollar	0.02	0.11	0.080
China	0.04	0.52	0.138	Bonds Market	0.01	0.25	0.080
Automobile	0.04	0.45	0.137	Layoffs	0.01	0.11	0.080
Labor Market	-0.03	-0.17	0.137	IPOs	0.01	0.06	0.080
Financial Crisis	0.02	0.15	0.137	Interest Rates	-0.01	-0.07	0.080
U.S. Dollar	0.01	0.11	0.137	Recession	-0.01	-0.08	0.079
Tax	-0.01	-0.14	0.136	Great Britain	0.00	0.01	0.079
Baseline			0.140	Baseline			0.083

Appendix 5.E: Risk Premium Test results

Table 5.I: GX Risk Premium and T-Statistics Estimation: Test for the Factors Risk Premium

Note: This table presents the risk premium test using the GX methodology for each index using the 1272 portfolio as test assets. The risk premium column indicates the scaled factor risk premium of the candidate factor index, reflecting a unit beta exposure. They are normalized as bps return per month. The t-statistics reported are calculated using Newey-West standard errors with 12 lags. Note * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$, signifying levels of statistical significance for the NW T-Statistics.

Topic Index	Risk Premium	NW T-Statistics
Oil	116.36**	2.15
Stock Market	108.53**	2.06
US Economy	106.95**	2.52
Global Economy	76.49**	2.03
Recession	66.13**	2.20
Economy Growth	58.96*	1.83
Consumer Spending	56.13***	3.57
Financial Conditions	53.39**	2.40
Financial Crisis	52.01*	1.80
Economy Outlook	51.02***	3.11
Labor Market	50.76*	1.73
Economic Recovery	50.28*	1.87
China	39.22	1.64
IPOs	38.57**	2.10
Manufacturing	36.69	1.39
Financial Sector	35.38*	1.84
Consumer Confidence	34.55**	2.03
Japan	29.97	1.33
Terrorism	29.09	1.07
European Economy	28.84	0.93
Economy Contraction	25.86	1.65
Technology	25.43	1.10
Sanctions	24.48**	2.42
Market Risk	23.95*	1.94
Europe	23.91	1.15
Investment	20.52	1.56
Real Estate	19.94*	1.91
Mortgage	16.34	0.96
United States	15.25	0.98
Tax	14.68	1.40

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Table 5.I – continued from previous page

Topic Index	Risk Premium	NW T-Statistics
Middle East	14.67	0.59
War	13.26	0.86
E-Commerce	12.91	1.52
China Economy	12.85	0.67
Great Britain	12.71	0.94
Interest Rates	12.33	0.65
Russia	11.46	0.81
Automobile	11.37	0.93
Credit	10.98*	1.74
Japan Economy	10.68	0.65
US Fed Policy	9.30	0.57
Banking	9.07	0.78
Global Trade	7.04	0.60
Industrial Production	5.63	0.36
Elections	2.97	0.24
Layoffs	2.38	0.11
Natural Gas	1.28	0.15
Corporate Earnings	0.53	0.03
Network	0.11	0.01
Geopolitics Risks	-1.36	-0.06
Earnings Results	-2.99	-0.17
Monetary Policy	-4.71	-0.47
Infrastructure	-4.81	-0.75
Inflation	-7.50	-0.35
Bonds Market	-7.63	-0.69
Currency FX	-9.54	-0.66
Financial Regulation	-16.44**	-2.12
Gold	-19.26	-1.02
U.S. Dollar	-27.28	-0.79

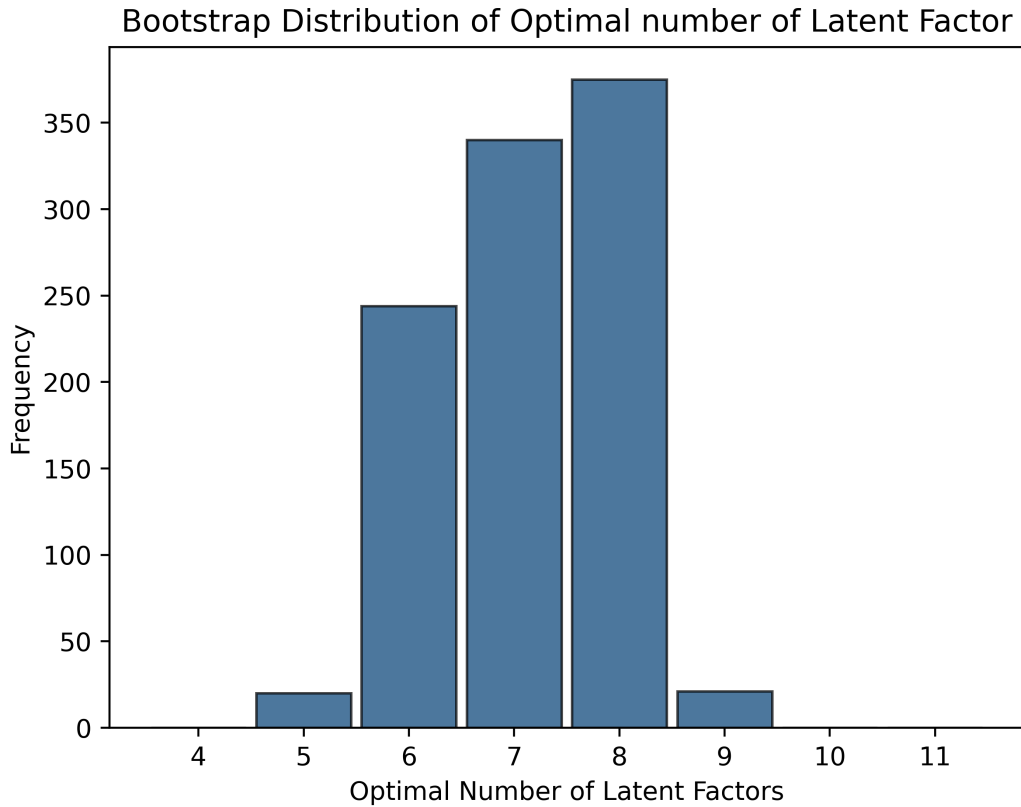


Figure 5.G: The Bootstrap Distribution of the Optimal Number of Latent Factors

Note: This figure plots the bootstrap distribution of the optimal number of latent factors. We resampled the test portfolio return data 1000 times and calculated the optimal number of latent factors that minimize the objective function. The histogram shows that the most frequently selected optimal numbers of latent factors are 7 and 8, followed by 6. The most frequent optimal numbers of latent factors are 7 and 8, followed by 6 and 9.

Appendix 5.F: Two-pass Regression with Double-sorted Lasso

The “two-pass regression with double-sorted Lasso” methodology proposed by [Feng et al. \(2020\)](#) is designed to estimate and test the factor loading on the SDF function. The methodology is summarized as follows:

Two-pass Variable Selection

Assume we have a monthly return matrix R containing n test portfolios, each with a length of T . Additionally, we have a matrix G that represents all q control factors in the factor zoo with a length of T . The test factors, which constitute our centrality index, are represented by a $d \times T$ matrix Z .

Step 1: First Lasso Regression

Conduct a cross-sectional LASSO regression using the average returns and the sample covariances between the control factors in G and the returns in R :

$$\min_{r, \lambda} \left\{ n^{-1} \left\| r - \iota_n \gamma - \hat{\Sigma}_g \lambda \right\|^2 + \phi_0 n^{-1} \|\lambda\|_1 \right\}, \quad (5.15)$$

where $\hat{\Sigma}_g = \widehat{\text{Cov}}(r_t, g_t) = T^{-1} \hat{R} \hat{G}$. The Lasso default parameter is ϕ_0 . This Lasso regression is a dimension-reduction technique designed to apply regularization to filter out control factors that have low loadings λ in the SDF functions. The selected control factors are shared among all test factors. We use $\hat{\mathcal{B}}_1$ to represent the factors selected by this first-step Lasso regression, defined as the factors with non-zero loadings.

Step 2: Second Lasso Regression

For each test factor z in Z (with $z = 1, \dots, d$), a second cross-sectional Lasso regression with penalty $\phi_{1,z}$ is conducted to select the control factors whose exposures in the SDF equations are highly correlated with the exposures of test factor z .

$$\min_{\kappa_z, \chi_z} \left\{ n^{-1} \left\| \left(\hat{\Sigma}_{r,z} - \iota_n \kappa_j \right) - \hat{\Sigma}_g \chi_z^T \right\|^2 + \phi_{1,z} n^{-1} \|\chi_z^T\|_1 \right\}. \quad (5.16)$$

Where $\hat{\Sigma}_{r,z}$ denotes the covariance of a test factor j with all the test portfolios. The κ_j and χ_z^T are the coefficients for the lasso regression. We collect all the control factors with non-zero coefficients for test factor z into the subset $\hat{\mathcal{B}}_{2,z}$. $\hat{\mathcal{B}}_{2,z}$ contains all the selected factors in the second Lasso regression.

Step 3: Post-selection Estimation

For each test factor z in Z (with $z = 1, \dots, d$), run an OLS cross-sectional regression using covariances between the selected factors from the first two steps and returns:

$$(\hat{\alpha}, \hat{\lambda}_z, \hat{\lambda}_g) = \arg \min_{\alpha, \lambda_z, \lambda_g} \left\{ n^{-1} \left\| \bar{r} - \iota_n \alpha - \hat{\Sigma}_z \lambda_z - \hat{\Sigma}_g \lambda_g \right\|^2 \right\} : \quad (5.17)$$

$$s.t. \quad \lambda_{z,g} = 0, \quad \forall g \notin \hat{\mathcal{B}}_1 \cup \hat{\mathcal{B}}_{2,z}.$$

The constraint condition guarantees a coefficient of 0 for control factors not selected in Steps 1 or 2. We use the union of the control factors from Steps 1 and 2 so that we consider both factors with good cross-sectional explanations for the portfolio returns and those that have strong correlations with the test factors. This approach minimizes the omitted variables bias issue.

Step 4: Select Optimal Penalty Parameters

The penalty parameters in the two-step Lasso regressions are selected through a grid search using 10-fold cross-validation (CV). Since the 10-fold CV splits are not fixed, we follow the methodology of the [Feng et al. \(2020\)](#) to increase robustness. Specifically, we employ 200 different random seeds to perform the grid search, ensuring that our selection of penalty parameters is robust. For each random seed i , we first run the first regression using a 10-fold CV method and document the optimal $\hat{\phi}_{1,i}$ that minimizes the average square error. We then run the second-step Lasso regression using a 10-fold CV to find the optimal and $\hat{\phi}_{2,j,i}$ for each factor j that minimizes the average square error of the second step Lasso. For each test factor j , the penalty parameters $\hat{\phi}_1$ and $\hat{\phi}_{2,j}$ using for the key results are the averages obtained from these 200 random seeds:

$$\hat{\phi}_1 = \frac{1}{200} \sum_{i=1}^{200} \hat{\phi}_{1,i}$$

$$\hat{\phi}_{2,j} = \frac{1}{200} \sum_{i=1}^{200} \hat{\phi}_{2,j,i}$$

Chapter 6

Conclusion

The first two papers of this thesis shed light on topics related to external debt risk in emerging market economies (EMEs). The first paper proposes a general equilibrium model to estimate the trade-offs between sovereign restructuring and raising domestic interest rates in response to U.S. monetary tightening, in terms of their impact on domestic social welfare. The welfare analysis through a decomposition methodology identifies the effect of equilibrium default at a bad state in absorbing US monetary policy shock and maintaining economic stability.

The second paper extends this analysis by incorporating exchange rate externalities and imported capital goods. EMEs with higher dependence on imported capital goods have weaker incentives to default, as currency depreciation entails higher externality costs due to the inelasticity of external demand to currency depreciation. I further show that when the capital share in the economy is small, the default incentive decreases rather than increases with the external debt level. This result is attributable to the increasing default cost associated with the exchange rate externality in an environment characterized by a high external debt-to-GDP ratio.

Chapter 3 examines the impact of climate change, carbon taxes, and green credit policies on the inflation dynamic. The analytical solution of our stylized model links transition risk to inflation. We claim that climate damage and carbon taxes have a

substantial effect on inflation and price stability. Green credit policies implemented by the central bank can serve as a complementary policy to the carbon tax to increase social welfare and reduce carbon emissions. However, such policies must be evaluated with care to balance the trade-off between reducing carbon emissions and lowering the effective interest rate to avoid unexpected inflationary pressure.

Chapter 4 introduces a dynamic knowledge graph methodology that captures the evolving relationships between different aspects of macroeconomic entities. The LLM-driven methodology has been shown to enhance the predictability of future economic activities. The asset pricing test demonstrates the effectiveness of our index as a risk factor in pricing assets. The nature of the knowledge graph allows our thematic factors to serve as unconditional risk factors in asset pricing, contributing to the literature discussing conditional and unconditional asset pricing models.

In summary, this thesis contributes to the literature by providing new theoretical, empirical, and methodological insights into various topics within macro-finance. However, further research using the framework provided in this thesis is necessary to deepen our understanding of the intricate relationships between different aspects of the macro-finance network.

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