The Sovereign Default Risk of Giant Oil Discoveries*

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Abstract

This paper studies the impact of natural resource discoveries on default risk. I use data of giant oil field discoveries to estimate their effect on the spreads of 37 emerging economies and find that spreads increase by 5.3 percentage points following a discovery of average size. I develop a quantitative sovereign default model with capital accumulation, production in three sectors, and oil discoveries. Following a discovery, investment and foreign borrowing increase. These choices have opposite effects on spreads: borrowing increases them and investment reduces them. There is also a reallocation of capital away from manufacturing and toward oil extraction and the non-traded sector, which increases the volatility of tradable income used to finance foreign debt payments. This increase in volatility explains half of the increase in spreads in the model. Despite the increase in default risk, oil discoveries generate welfare gains of 3.7 percent. However, there are foregone gains of 0.4 percent due to front-loading of consumption by an impatient government and higher default risk.

JEL Codes: E30, F34, F41

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1 Introduction

Between 1970 and 2012, sixty-four countries discovered at least one giant oil field, and fourteen of these countries had a default episode in the following ten years.[1] Considering all countries in the world, the unconditional probability of observing a country default in any given ten year period was 12 percent. Conditional on discovering a giant oil field, this probability was 18 percent.[2] This means that a country that just became richer also became more likely to default on its debt. This paper studies how the discovery and exploitation of natural resources impact default risk. Following the sovereign default literature, I focus on emerging economies as they are more prone to default episodes.

I use data of giant oil field discoveries to document the effect of a sudden increase in available natural resources on sovereign interest rate spreads. I build on the work by Arezki, Ramey and Sheng (2017), who work with data sets on giant oil discoveries in the world collected by Horn (2014) and the Global Energy Systems research group at Uppsala University. They use these data to calculate the net present value of potential future revenues from a discovery relative to the GDP of the country where it happened. I use this measure of size to estimate the effect of discoveries on the spreads of 37 emerging economies and find that the effect is large and positive: spreads increase by up to 5.3 percentage points following a discovery of average size (which is 18 percent of GDP). I also estimate the effect of discoveries on the current account, investment, GDP, and consumption. Following a discovery, these countries run a current account deficit and GDP, investment, and consumption increase, which is consistent with the findings of Arezki, Ramey and Sheng (2017) for a wider set of countries. In addition, I estimate the effects on sectoral investment and the real exchange rate and find evidence of the Dutch disease: the share of investment in the manufacturing sector decreases in favor of a higher share of investment in commodities and non-traded sectors.[3]

[1] A giant oil field contains at least 500 million barrels of ultimately recoverable oil. At 54 USD per barrel the value of this volume would be 27 billion USD (if the barrels were already out of the ground and ready for sale), which is around 1% of the GDP of France in 2018. "Ultimately recoverable reserves" is an estimate (at the time of the discovery) of the total amount of oil that could be recovered from a field.

[2] The data of default episodes are from Tomz and Wright (2007) for the years between 1970 and 2004. The default probability conditional on discovery is the probability that a country has a default episode in any of the ten years following a discovery.

[3] The Dutch disease refers to the way an increase in natural resource exports induces a reallocation of production factors away from manufacturing. Higher revenues from the natural resource boom increase the demand for all consumption goods. This income effect raises the price of non-traded goods, which causes an appreciation of the real exchange rate. This appreciation makes imports of manufactures relatively cheaper and thus induces the realloca-

This investment reallocation is accompanied by an appreciation of the real exchange rate. Arezki, Ramey and Sheng (2017) find weak evidence of real exchange rate appreciation following oil discoveries for all countries in the world. In contrast, I find that the evidence is stronger for the 37 emerging economies considered in this paper.

To reconcile these facts, I develop a small-open economy model of sovereign default with capital accumulation and production in three intermediate sectors: a non-traded sector, a traded "manufacturing" sector, and a traded "oil" sector. All sectors use capital for production and the oil sector additionally requires an oil field, which I model as a fixed factor of production. The economy starts with a small oil field and receives unexpected news about the discovery of a larger one, which will become productive at a given time in the near future. This lag between discovery and production is important because the actions in between, along with uncertainty about the price of oil, are what drive the increase in spreads. In the data, Arezki, Ramey and Sheng (2017) find that the average waiting period between discovery and production is 5.4 years.

After an oil discovery, investment increases so the economy can exploit the larger field when it becomes productive. The economy runs a current account deficit by issuing foreign debt to finance investment. Also, there is a reallocation of capital away from manufacturing and toward the non-traded sector, which is small at first but large once the exploitation of the larger oil field starts. In the model, as in the data, the price of oil is relatively more volatile than the price of the other traded goods.[4] Higher investment decreases spreads and higher foreign borrowing increases them. However, the effect of investment is weakened by the reallocation of production capital away from the manufacturing sector because this reallocation makes tradable income more dependent on oil revenue and thus more volatile.

I calibrate the model to the Mexican economy, which is a typical small-open economy widely studied in the sovereign debt and emerging markets literature. Mexico did not have any giant oil field discoveries between 1993 and 2012, which is the period analyzed in this paper.[5] This lack

tion of production factors away from this sector into the non-traded sector. The term was first used in 1977 by The Economist to describe this phenomenon in the Dutch economy after the discovery of natural gas reserves in 1959.

[4] Commodities have always shown a higher price volatility than manufactures. Jacks, O'Rourke and Williamson (2011) document this stylized fact using data that goes back to the 18th century.

[5] An interesting case of study would be the Mexican default in 1982, which was preceded by two giant oil field discoveries: one in 1977 and another in 1979, each with an estimated net present value of potential revenues of 50 percent of Mexico's GDP at the time. The main inconvenience is the lack of data on sovereign spreads, which are crucial to discipline the parameters in the model that control default incentives.

of discoveries allows me to discipline the parameters of the model with business cycle data that does not have any variation that could be driven by oil discoveries. I then validate the theory by contrasting the co-movement of model variables in response to unexpected oil discoveries with the responses estimated from the data.[6] Additionally, I use the oil discoveries data from Arezki, Ramey and Sheng (2017) to discipline the size of discoveries in the model.

Under the benchmark calibration, the model generates an increase in sovereign interest rate spreads of 1.3 percentage points following an oil discovery.[7] The probability of observing a default in any ten year window in the model is 14 percent. The probability is 19 percent conditional on being in the ten years after an oil discovery. These values in the data are 12 and 18 percent, respectively. Despite the higher frequency of default episodes, oil discoveries generate welfare gains equivalent to a permanent increase in consumption of 3.7 percent.

I use the model to perform two counterfactual exercises. For the first counterfactual I consider a model in which the price of oil is not volatile; I call this the *no-price-volatility* case. This exercise illustrates the counterfactual response of all variables if the economy was able to costlessly hedge against swings in the price of oil. For the second counterfactual I consider an economy in which the government discounts the future almost as much as the households (and international investors), which virtually eliminates default risk; I call this the *patient* case. After an oil discovery, spreads increase by 0.6 percentage points in the *no-price-volatility* case and by virtually nothing in the *patient* case. These results indicate that, in the presence of default risk, roughly half of the increase in spreads after an oil discovery is due to the increase in the volatility of tradable income due to the sectoral reallocation of capital.

In both counterfactual cases, as well as in the benchmark, the economy increases foreign borrowing to finance investment and all three feature capital reallocation. These are the co-movements that, together with the uncertainty about the price of oil, explain the increase in spreads in the

[6]The exercise of looking at model responses to unexpected news shocks is standard in the news-driven business cycle literature, see for example Jaimovich and Rebelo (2008), Jaimovich and Rebelo (2009), and Arezki, Ramey and Sheng (2017).

[7]There are other complementary forces that could also make spreads increase after an oil discovery that the model does not consider. For example, in the presence of growth externalities in the manufacturing sector, the reallocation of capital could hamper future growth and increase spreads in the present if these externalities are not internalized. See Hevia, Neumeyer and Nicolini (2013) and Alberola and Benigno (2017) for examples. Also, deterioration of institutions following giant oil discoveries could also cause spreads to increase. For example, Lei and Michaels (2014) find evidence that giant oil field discoveries increase the incidence of internal armed conflicts.

benchmark case. These results stress two important points. First, the frictions in this economy that explain high spreads are market incompleteness, the lack of commitment from the government, and its high relative impatience. Even in the absence of these frictions, the incentives to borrow to invest in the larger oil field and the incentives that drive the reallocation of capital are still present. Second, it is in the presence of these frictions that the volatility of the price of oil, the choice of borrowing to invest, and the reallocation of capital together generate an increase in spreads following an oil discovery.

I use the *patient* case to do a welfare decomposition in order to quantify the foregone welfare gains due to government impatience and default risk. If consumption after an oil discovery followed the path chosen by a benevolent planner these gains could be 4.1 percent and default risk (measured by the spreads) would not increase. Most of the foregone gains are due to the front-loading of consumption and higher default frequency during the transition years, both caused by the high relative impatience of the government. In a similar exercise, from the *no-price-volatility* case I find that, in the presence of default risk, the volatility of the price of oil increases the welfare gains of an oil discovery. This is because default acts as a form of insurance against very low realizations of the price of oil. On one hand, tradable income is high in high realizations of the price and, on the other, default reduces the debt burden in low realizations. Completely eliminating the volatility of the price of oil would reduce the welfare gains of oil discoveries to 3.4 percent, despite the fact that it would reduce the increase in spreads by half. These results suggest that policies aimed at limiting arbitrary spending of oil revenue (current and future) are much more valuable than hedging against swings in the price of oil because the option to default already provides a partial hedge against very low realizations of the price.

Related literature.—This paper contributes to the literature that studies the role of news as drivers of business cycles. For an extensive review of this literature see Beaudry and Portier (2014). This is closely related to the work by Jaimovich and Rebelo (2008) and Arezki, Ramey and Sheng (2017). Jaimovich and Rebelo (2008) propose a version of an open economy neoclassical growth model that generates co-movement in response to unexpected TFP news. They highlight weak wealth effects on labor supply and adjustment costs to labor and investment as key elements. Arezki, Ramey and Sheng (2017) propose a similar model with a resource sector to study the effects of news shocks in open economies and use data on giant oil discoveries to provide evidence in favor of the predictions of the model. The model in Section 3 builds on the work in these papers and contributes by connecting it with the sovereign default literature. To my knowledge, this is the first paper to study the effect of news on business cycles and default risk in a general equilibrium model with endogenous default.[8]

This paper also builds on the quantitative sovereign default literature following Aguiar and Gopinath (2006) and Arellano (2008), which extend the approach developed by Eaton and Gersovitz (1981). They introduce sovereign default models that feature counter-cyclicality of net exports and interest rates, which are consistent with the data from emerging markets. Hatchondo and Martinez (2009) and Chatterjee and Eyigungor (2012) extend the baseline framework of quantitative models of sovereign default to include long-term debt. Their extensions allow the models to jointly account for the debt level, the level and volatility of spreads around default episodes, and other cyclical factors.

Gordon and Guerron-Quintana (2018) analyze the quantitative properties of sovereign default models with capital accumulation and long-term debt. They show that the model can fit cyclical properties of investment and GDP while also remaining consistent with other business cycle properties of emerging economies. They also find that capital has non-trivial effects on sovereign risk but that increased capital almost always reduces risk premia in equilibrium. The model in Section 3 is based on their framework and extends it to have production in different sectors, with one of them also using natural resources. Arellano, Bai and Mihalache (2018) document how sovereign debt crises have disproportionately negative effects on non-traded sectors. They develop a model with capital, production in two sectors, and one period debt. In their model, default risk makes recessions more pronounced for non-traded sectors. This is because adverse productivity shocks limit capital inflows and induce a capital reallocation toward the traded sector to support debt payments. The model in Section 3 contrasts by featuring two traded sectors and long-term debt. The effect of sovereign risk on the non-traded sector during recessions also depends on shocks to the international price of oil and on the current capacity of the oil field. Additionally, news about future sovereign risk affect current variables due to the long-term nature of the debt.

This paper is closely related to Hamann, Mendoza and Restrepo-Echavarria (2018). They study

[8] In a related paper, Gunn and Johri (2013) explore how changes in expectations about future default on government debt can generate recessions in an environment where default is exogenous.

the relation between oil exports, oil reserves, and sovereign risk. They use an Institutional Investor Index as a measure of sovereign risk and document that, for the 30 largest emerging market oil exporters, country risk increases as unexploited oil reserves increase. Subsection 2.3 documents complementary evidence using a different measure of risk and a similar set of countries: sovereign risk, measured by interest rate spreads, increases following giant oil discoveries. They also document that an oil exporting country is perceived as less risky if its oil production is high, relative to their reserves, and that oil exports increase during default episodes. These observations motivate their hypothesis that idle oil reserves allow these countries to withstand the consequences of financial autarky and thus increase default risk by improving their outside option. My work contrasts with theirs in two ways. First, their work analyzes all changes in oil reserves, including those due to exploitation of existing oil fields. In contrast, I focus only on the effects of new giant oil discoveries on sovereign risk, which require investment in order to be exploited. Second, they develop a model in which the intensity of reserves exploitation interacts with sovereign risk by endogenously changing the government's outside option. In contrast, the model presented in Section 3 abstracts from this strategic motive for reserve exploitation. Instead, it focuses on the effects on sovereign risk of new oil discoveries through their implications for borrowing, investment, and the sectoral allocation of capital.

Finally, this paper relates to the literature that studies the macroeconomic effects of commodity-related shocks. Hevia and Nicolini (2015) analyze optimal monetary policy in a small-open economy that specializes in the production of commodities. They find that, due to price and wage nominal frictions, the Dutch disease generates inefficiencies and full price stability is not optimal. Ayres, Hevia and Nicolini (2019) argue that shocks to primary commodity prices account for a large fraction of the volatility of real exchange rates between developed economies and the US dollar. They suggest that considering trade in primary commodities could help models generate real exchange rate volatilities that are more in line with the data. The model in Section 3 can be used as a baseline to study the co-movement of sovereign risk and real exchange rates, which could point to questions regarding monetary policy in future work.

Layout.—Section 2 describes the data, documents the effect of giant oil discoveries on sovereign spreads and other macroeconomic aggregates, and discusses the evidence that motivates the theoretical framework. Section 3 presents the model and discusses the theoretical mechanism. Section

4 describes the calibration. Section 5 presents the quantitative results and the welfare analysis, and Section 6 concludes.

2 Giant oil discoveries in emerging economies

This section documents the effects of giant oil discoveries on thirty-seven emerging economies considered in JP Morgan's Emerging Markets Bonds Index (EMBI).[9] Due to data availability I restrict the analysis in this paper to these economies and the years between 1993 and 2012. I use a measure of the net present value (NPV) of oil discoveries as a percentage of GDP constructed by Arezki, Ramey and Sheng (2017). I follow their empirical strategy to estimate the effects of oil discoveries on investment, the current account, GDP, and consumption. As they do for a larger set of countries, I find evidence for the intertemporal approach to the current account (as developed by Obstfeld and Rogoff (1995)) and the permanent income hypothesis.

My contribution is to estimate the effect of giant oil discoveries on the sovereign spreads of these economies. I find that spreads increase by up to 530 basis points following a discovery of average size. In addition, I estimate the effect of discoveries on the real exchange rate and investment by sectors and find evidence of the Dutch disease. Subsection 2.1 describes the data and the empirical strategy. Subsections 2.2 through 2.4 present the main results and Appendix A discusses additional details and robustness checks.

2.1 Data and empirical strategy

Giant oil discoveries are a measure of changes in the future availability and potential exploitation of natural resources. As Arezki, Ramey and Sheng (2017) argue, giant oil discoveries have three unique features that allow the use of a quasi-natural experiment approach to identify their effect: they indicate significant increases in future production possibilities, the timing of discoveries is exogenous due to uncertainty around oil and gas exploration, and there is a time delay of 5.4 years

[9] The thirty-seven countries are: Argentina, Belize, Brazil, Bulgaria, Chile, China, Colombia, Dominican Republic, Ecuador, Egypt, El Salvador, Gabon, Ghana, Hungary, Indonesia, Iraq, Jamaica, Kazakhstan, Republic of Korea, Lebanon, Malaysia, Mexico, Pakistan, Panama, Peru, Philippines, Poland, Russian Federation, Serbia, South Africa, Sri Lanka, Tunisia, Turkey, Ukraine, Uruguay, Venezuela, and Vietnam.

on average between discovery and production.[10]

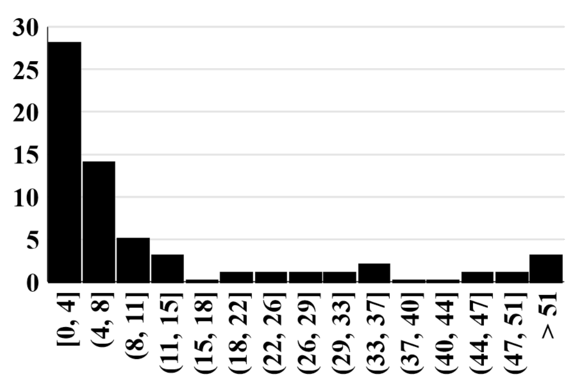
Arezki, Ramey and Sheng (2017) construct a measure of the net present value (NPV) of giant oil discoveries as a percentage of GDP at the time of discovery as follows:[11]

$$NPV_{i,t} = \frac{\sum_{j=5}^{J} \frac{q_{i,t+j}}{(1+r_i)^j}}{GDP_{i,t}} \times 100 \tag{1}$$

where $NPV_{i,t}$ is the discounted sum of gross revenue for country i at the year of discovery t, r_i is the annual discount rate in country i, and $GDP_{i,t}$ is annual GDP of country i at year t. The annual gross revenue $q_{i,t+j}$ is derived from an approximated production profile starting five years after the field discovery up to an exhaustion year J, which is greater than 50 years for a typical field of 500 million barrels of ultimately recoverable reserves.[12]

Considering the thirty-seven economies in the EMBI and the years 1993–2012, there are 61 giant oil discoveries in 15 of the 37 countries. The average NPV of a discovery was 18 percent of GDP and the largest was 467 for a discovery in Kazakhstan in 2000. Figure 1 depicts the distribution of the NPV of these discoveries.

Figure 1: Distribution of NPV of giant oil discoveries



Percent of GDP, EMBI countries, 1993 –2012.

[10] Arezki, Ramey and Sheng (2017) mention that experts' empirical estimates suggest that it takes between four and six years for a giant oil discovery to go from drilling to production. They also made their own calculation and found that the average delay between discovery and production is 5.4 years.

[11] They use the data on giant oil discoveries in the world collected by Horn (2014) and the Global Energy Systems research group at Uppsala University. For more details of the construction of the NPV see Section IV.B. in Arezki, Ramey and Sheng (2017).

[12] It is important to mention that the gross revenue $q_{i,t+j}$ considers the same price of oil for subsequent years. Since the price of oil closely resembles a random walk, the current price is the best forecast of future prices. See Appendix B of Arezki, Ramey and Sheng (2017) for a detailed explanation of the approximation of the production profile of giant oil discoveries.

I take investment, current account, GDP, and consumption data from the IMF (2013) and the World Bank (2013). GDP and consumption are measured in constant prices in local currency units. Investment and the current account are measured as a percentage of GDP. Spreads data are from JP Morgan's Emerging Markets Bonds Index (EMBI) Global. The index tracks a value weighted portfolio of US dollar denominated debt instruments, with fixed and floating-rates, issued by emerging market sovereign and quasi-sovereign entities. Spreads are measured against comparable US government bonds.[13] The real exchange rate is calculated as $RER_{i,t} = \frac{e_{i,t}P_t^{US}}{P_t^i}$ where P_t^{US} and P_t^i are the US and country i's GDP deflators, respectively, and $e_{i,t}$ is the nominal exchange rate between country i's currency and the US dollar. These data are also from the IMF (2013). Finally, the data on investment by sector is in terms of the share of total investment and is from the United Nations Statistics Division (2017).

Following Arezki, Ramey and Sheng (2017), I estimate the effect of giant oil discoveries on different macroeconomic variables using a dynamic panel model with a distributed lag of giant oil discoveries:

$$y_{i,t} = \rho y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s} + \alpha_i + \mu_t + \sum_{s=1}^{10} \xi_s p_{oil,t} \mathbb{I}_{disc,i,t-s} + \varepsilon_{i,t} \tag{2}$$

where $y_{i,t}$ is the dependent variable (the dependent variables I will consider are investment, the current account, log of real GDP, log of real consumption, sovereign spreads, log of the real exchange rate, and the share of investment by sector); $NPV_{i,t}$ is the NPV of a giant oil discovery in country i in year t; α_i controls for country fixed effects; μ_t are year fixed effects; $p_{oil,t}$ is the natural logarithm of the international price of oil at time t; $\mathbb{I}_{disc,i,t-s}$ is an indicator function of whether country i had an oil discovery in period $t-s$; and $\varepsilon_{i,t}$ is the error term.[14] Country fixed effects control for any unobservable and time-invariant characteristics, while year fixed effects control for common shocks like world business cycles and the international price of oil.[15]

[13]To be included, an instrument must have at least 2.5 years until maturity, a current face amount outstanding of at least 1 billion US dollars, and a sovereign credit rating of BB+ or lower. In addition, the issuing country's GNI per capita must be below a ceiling for three consecutive years. Currently, this is 19,708 US dollars.

[14]Also, as Arezki, Ramey and Sheng (2017) do, I include country-specific quadratic trends for the regressions of variables $y_{i,t}$ that are non-stationary in the sample. These are GDP, consumption, the real exchange rate, and the spreads. For these variables the augmented Dickey-Fuller test fails to reject a unit root in all countries.

[15]As noted by Nickell (1981), estimates of a dynamic panel with fixed effects are inconsistent when the time span is

The interactions of the natural logarithm of the international price of oil with indicator functions of recent discoveries control for the fact that the reaction of the dependent variable to this common shock may differ conditional on having a recent discovery. As discussed in Appendix A.2, these control variables are only relevant for the estimations of the effects of discoveries on spreads and the real exchange rate. For consistency, the results presented in this section include these controls in all regressions. Appendix A.2 shows the results for the specifications without these controls.

As in Arezki, Ramey and Sheng (2017)'s analysis, I exploit the dynamic feature of the panel regression and use impulse response functions to capture the dynamic effect of giant oil discoveries given by $\Delta y_{i,t} = \rho \Delta y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s}$.

2.2 Response of macroeconomic aggregates

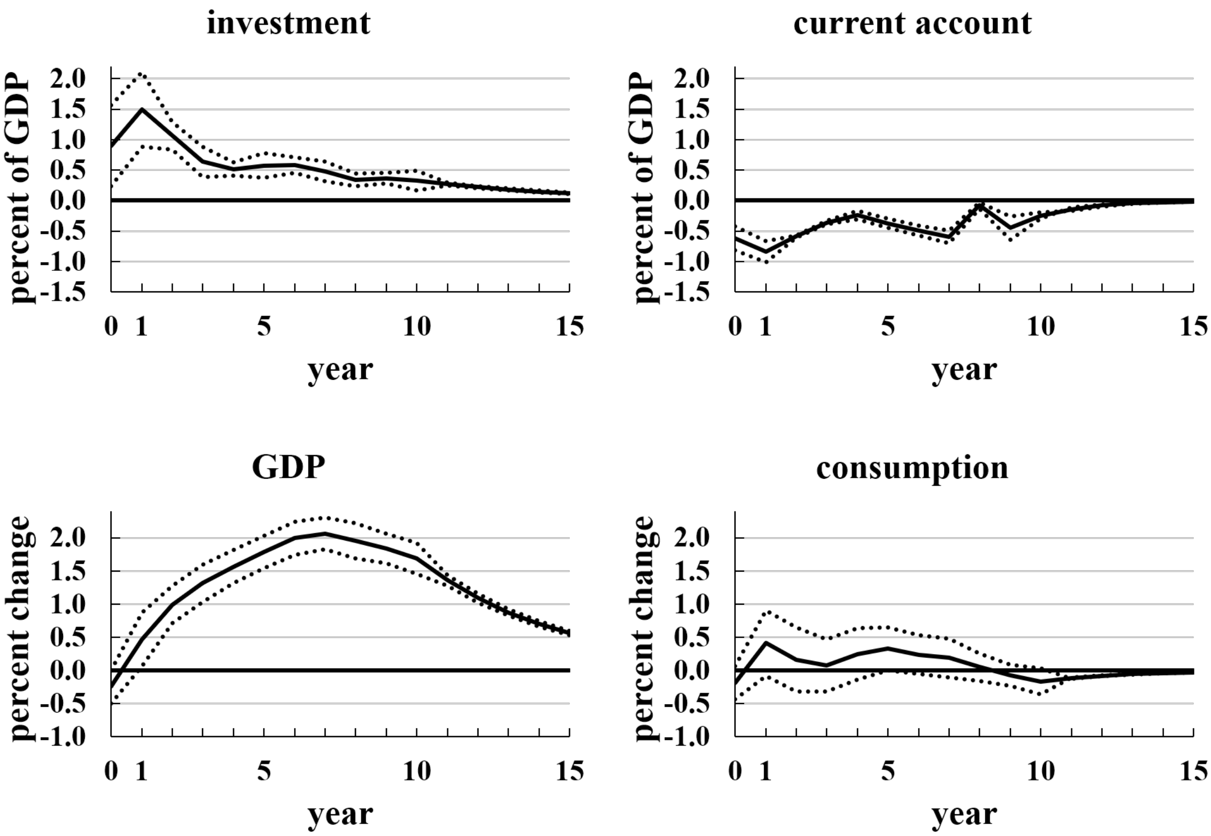
Figure 2 shows the dynamic response of investment, the current account, GDP, and consumption to an oil discovery of average size, based on the estimated coefficients of equation (2).

The dotted lines are 90% confidence intervals based on a Driscoll and Kraay (1998) estimation of standard errors, which yields standard error estimates that are robust to general forms of spatial and temporal clustering. Table 5 in Appendix A.1 reports point estimates and their standard errors for the coefficients in equation 2.

The top left panel shows that the investment-to-GDP ratio increases immediately after an oil discovery and continues to be higher in the subsequent years. The top right panel shows that oil discoveries have a negative effect on the current account-to-GDP ratio, which supports the hypothesis that these countries issue foreign debt to finance higher consumption and investment.

small. He shows that this asymptotic bias is of the order $1/T$, which, in the case of the sample considered in this paper, is 0.05. Arellano and Bond (1991) developed an efficient GMM estimator for dynamic panel data models with a small time span and large number of individuals. The results in this section are virtually unchanged using the Arellano-Bond estimator. Given the size of the Nickell bias and to keep the results comparable with those of Arezki, Ramey and Sheng (2017) I use the above approach.

Figure 2: Impact of giant oil discoveries on macroeconomic aggregates



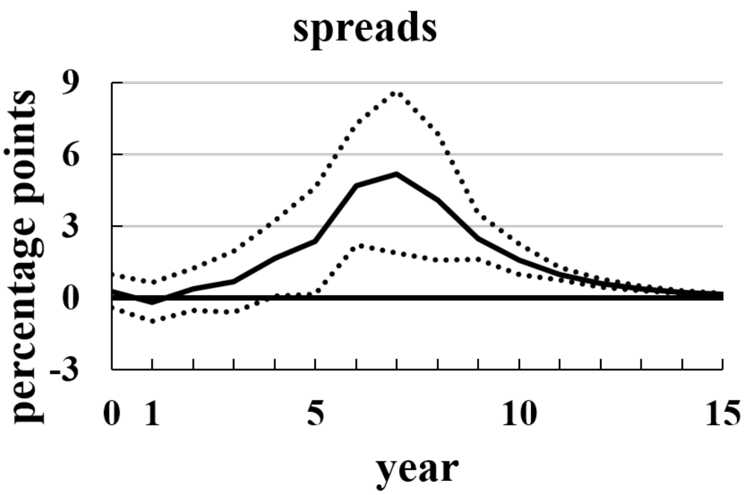
Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

The bottom-left panel shows that both GDP and consumption increase after an oil discovery. However, as Arezki, Ramey and Sheng (2017) found for a larger set of countries, the estimates for consumption are very imprecise. This could be a result of substantial measurement error and of the fact that the consumption variables includes both private and public consumption.

2.3 Effect on sovereign spreads

This subsection presents the main empirical finding of this paper. Figure 3 shows the dynamic response of the spreads. In the year of the discovery, this effect is small and not significantly different from zero. However, by the sixth year after the discovery is announced, spreads have increased by 5.3 percentage points on average.

Figure 3: Impact of giant oil discoveries on spreads



Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

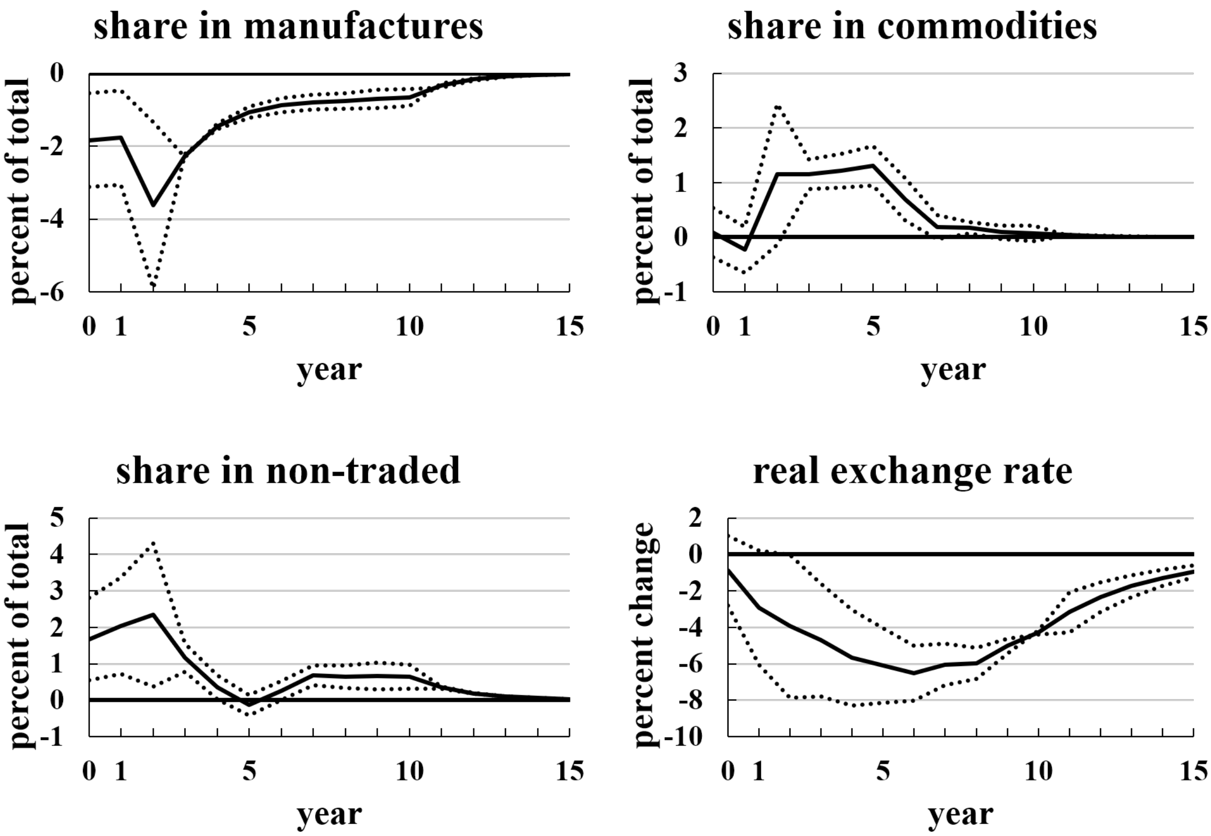
This result is striking since income increases during the years following the discovery as shown in the previous figure, which would indicate that the country has a higher ability to service its debt. The theoretical model in Section 3 shows how debt accumulation and the effects of the Dutch disease can reconcile these empirical observations.

2.4 Reallocation of capital

Figure 4 shows the dynamic response of the real exchange rate, as well as the share of total investment in manufactures, commodities, and non-traded sectors.[16] Commodities comprise agricultural, fishing, mining and querying activities. The non-traded sector includes construction and wholesale, retail, and logistics services.

[16]The estimations for the shares of total investment consider a wider set of countries due to limited data availability for the 37 countries considered in this paper. Their purpose is to support the evidence shown for the estimation of the effect of discoveries on the real exchange rate, which only considers the aforementioned 37 countries.

Figure 4: Impact of giant oil discoveries on sectoral investment and the RER



Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

Following a discovery, the share of investment in the manufacturing sector decreases and the shares in both the commodities and the non-traded sectors increase. The real exchange rate appreciates, which is in line with the theoretical predictions of the Dutch disease: higher income from the commodity sector increases the consumption of non-traded goods. This in turn increases the price of non-traded goods and production factors are moved out of manufacturing into non-traded sectors and resource extraction. Arezki, Ramey and Sheng (2017) also find (for a larger set of countries) that the real exchange rate appreciates during the five years following oil discoveries; however, their estimates are not significantly different from zero. Figure 4 shows that for the 37 countries studied in this paper, the evidence of appreciation is more conclusive than when all countries were considered in the same regression, as in Arezki, Ramey and Sheng (2017).

3 Model

This section presents a dynamic small-open economy model in the Eaton and Gersovitz (1981) tradition with long-term debt and capital accumulation. I augment the model in Gordon and Guerron-Quintana (2018) to include production in different sectors and discovery of natural resources. There is an impatient government that makes borrowing, investment, and production decisions on behalf of its constituent households and cannot commit to repay its debt.[17]

3.1 Environment

Goods and technology.—There is a final non-traded good used for consumption and capital accumulation. This good is produced with a constant elasticity of substitution (CES) technology using a bundle of an intermediate non-traded good $c_{N,t}$ and two intermediate traded goods: manufactures $c_{M,t}$ and oil, $c_{oil,t}$:

$$Y_t = A\left[\omega_N^{\frac{1}{\eta}}\left(c_{N,t}\right)^{\frac{\eta-1}{\eta}} + \omega_M^{\frac{1}{\eta}}\left(c_{M,t}\right)^{\frac{\eta-1}{\eta}} + \omega_{oil}^{\frac{1}{\eta}}\left(c_{oil,t}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{3}$$

where η is the elasticity of substitution, ω_i are the weights of each intermediate good i in the production of the final good, and A is a scaling parameter. Intermediate non-traded goods and manufactures are produced using capital k_N and k_M, and decreasing returns to scale technologies:

$$y_{N,t} = z_t k_{N,t}^{\alpha_N} \tag{4}$$

$$y_{M,t} = z_t k_{M,t}^{\alpha_M} \tag{5}$$

where z_t is a productivity shock that affects all sectors equally and $0 < \alpha_N < 1$, $0 < \alpha_M < 1$.[18] There is a general stock of capital k_t that can be freely allocated in these two sectors within the same period such that $k_{N,t} + k_{M,t} = k_t$.[19] Each period the economy has access to an oil field with

[17] In Appendix B I show how all the allocations and default decisions in this economy can be supported in a decentralized economy where households make consumption and investment decisions and firms demand capital in different sectors.

[18] Decreasing returns to scale captures the presence of a fixed factor, which in this case could be labor (immobile within sectors).

[19] The assumption about the free allocation of capital between the non-traded intermediate sector and manufacturing is made for simplicity. As it will become clear later, what is necessary for my results is that the capital to extract

capacity n_t. To produce oil the economy uses the field's capacity n_t, capital $k_{oil,t}$ that is specific to the oil sector, and technology:

$$y_{oil,t} = z_t k_{oil,t}^{\alpha_{oil}} n_t^{\zeta} \tag{6}$$

where $\zeta \in (0,1)$ is the share of oil revenue that corresponds to the oil rent and $0 < \alpha_{oil} + \zeta < 1$.

The resource constraint of the final non-traded good is:

$$c_t + i_{k,t} + i_{k_{oil},t} = Y_t + m_t, \tag{7}$$

where c_t is private consumption, $i_{k,t}$ is investment in general capital, $i_{k_{oil},t}$ is investment in capital for the oil sector, Y_t is production of the final non-traded good, and m_t is a small transitory income shock described below.[20] The laws of motion for the stocks of capital are:

$$k_{t+1} = (1-\delta)\, k_t + i_{k,t} - \Psi\,(k_{t+1}, k_t) \tag{8}$$

$$k_{oil,t+1} = (1-\delta)\, k_{oil,t} + i_{k_{oil},t} - \Psi\left(k_{oil,t+1}, k_{oil,t}\right) \tag{9}$$

where $i_{k,t}$ and $i_{k_{oil},t}$ are investment in general and oil capital, respectively; δ is the capital depreciation rate; and $\Psi\,(k_{t+1}, k_t) = \phi\,(k_{t+1} + k_t)^2$ is a capital adjustment cost function.[21] As discussed in Subsection 3.4, capital adjustment costs allow the model to reproduce the anticipation effect in investment observed in the data, that is, have the economy increase investment before production with the larger oil field starts.

Rest of the world and international prices of goods.—There is a rest of the world economy where international lenders are and with which the small-open economy trades manufactures and oil. All prices are expressed in terms of manufactures. I assume that the small-open economy is small enough so that neither its actions nor its oil discoveries have an effect on the relative price of

oil is sector specific. Having specific capital in all three sectors would add an additional endogenous state variable, which would significantly complicate the computation of equilibrium without adding much to the informativeness of the model.

[20]The presence of this m_t shock facilitates the numerical computation of equilibrium. See Chatterjee and Eyigungor (2012) and Gordon and Guerron-Quintana (2018).

[21]Including capital adjustment costs is important in business cycle models to avoid investment being overly volatile; see Mendoza (1991) for a discussion of the case of small-open economies. Additionally, as Gordon and Guerron-Quintana (2018) show, sovereign default models with capital accumulation require capital adjustment costs to sustain positive levels of debt in equilibrium. Without adjustment costs, the cheapest way for the sovereign to hedge against fluctuations would be to reduce investment rather than borrowing from the rest of the world.

oil. This price is pinned down in the rest of the world and for simplicity I assume it follows some exogenous stochastic process. As it will be discussed in Subsection 3.4, what is key for the results in this paper is that the price of oil is relatively more volatile than the price of other traded goods. For a richer model of the international oil industry see Bornstein, Krusell and Rebelo (2019).

Shocks and oil discoveries.—In each period the economy experiences one of finitely many events s_t that follow a Markov chain governed by transition matrix $\pi(s_{t+1}|s_t)$. The shock s_t determines aggregate productivity in the economy z_t and summarizes the shocks in the rest of the world that pin down the international price of oil $p_{oil,t}$. Additionally, in each period the economy receives a small transitory income shock $m_t \in [-\bar{m}, \bar{m}]$ drawn independently from a mean zero probability distribution with continuous CDF.[22]

The capacity of the oil field can take one of two values $n_t \in \{n_L, n_H\}$ with $0 \leq n_L < n_H$. The economy starts with $n_t = n_L$ and in some period τ receives *unexpected* news that its oil capacity will be larger six periods from then, that is $n_{\tau+6} = n_H$. The unexpected nature of the news is in line with the assumption made in Section 2 that, in the data, the timing of discoveries cannot be anticipated. Additionally, this is in line with the literature on news-driven business cycles, which models news shocks as one-time unexpected shifts (see, for example, Jaimovich and Rebelo (2008), Jaimovich and Rebelo (2009), and Arezki, Ramey and Sheng (2017)). For simplicity I assume that n_t remains high forever.[23]

Preferences.—The government has preferences over private consumption c_t represented by:

$$\mathbb{E}_0\left[\sum_{t=0}^{\infty} \beta_G^t u(c_t)\right]$$

where $u(c,l) = \frac{c^{1-\sigma}-1}{1-\sigma}$ and β_G is the government's discount factor. As is standard in the sovereign default literature, I model the government as an impatient agent. In particular, I assume that the

[22]This i.i.d. income shock is included to make computation of the model possible. In the calibration, the parameter $\bar{m}$ is chosen so that this shock is relatively small (i.e. the right-hand side of equation (7) is always positive). See Chatterjee and Eyigungor (2012) for a detailed theoretical discussion in an exchange economy and see Gordon and Guerron-Quintana (2018) for a discussion of the extension to production economies with capital accumulation.

[23]The average duration of a giant oil field is 50 years, much longer than the time-span in the data in section 2.1. Moreover, as Arezki, Ramey and Sheng (2017) document, the production rate is highest for the initial years after the field becomes productive and then decreases at a slow rate. A richer model of oil production would include details on the depletion of the reserves on the field through its exploitation. However, the focus of this paper is on the effect of oil discoveries and the transition between discovery and production, rather than on the long life-cycle of oil fields.

government's discount factor is smaller than the discount factor of the households $\beta_G < \beta_{HH}$.[24] In Section 5 I analyze the implications that this assumption has on spreads after an oil discovery and on the welfare gains of oil discoveries.

Debt structure.—As in Chatterjee and Eyigungor (2012) the government issues long-term bonds that mature probabilistically at a rate γ. Each period, the fraction $1-\gamma$ of bonds that did not mature pay a coupon κ. The law of motion of bonds is:

$$b_{t+1} = (1-\gamma)\, b_t + i_{b,t} \tag{10}$$

where b_t is the number of bonds due at the beginning of period t and $i_{b,t}$ is the amount of bonds issued in period t.[25] The bonds are denominated in terms of the numeraire good (manufactures).

Default, repayment, and the balance of payments.—At the beginning of every period the government has the option to default. If the government defaults it gets excluded from international financial markets—although it can still trade in goods—for a stochastic number of periods; the government gets re-admitted to financial markets with probability θ and zero debt. While in default the transitory income shock is $-\bar{m}$ and productivity is $z_t^d \leq z_t$.[26] More specifically, I assume an asymmetric penalty to productivity so that $z_t^d = z_t - \max\left\{0, d_0 z_t + d_1 z_t^2\right\}$, where $d_0 < 0 < d_1$. This implies that the productivity penalty is zero when $z_t \leq -\frac{d_0}{d_1}$ and rises more than proportionately when $z_t > -\frac{d_0}{d_1}$. This asymmetry in the default penalty is crucial in generating default dynamics that are in line with the data in this class of models (see the discussions in Arellano (2008) and Chatterjee and Eyigungor (2012)).

In default, the balance of payments is:

$$0 = x_{M,t} + p_{oil,t} x_{oil,t} \tag{11}$$

[24] There is a vast political economy literature that provides models that rationalize impatient policy makers. For examples with external sovereign debt see Cuadra and Sapriza (2008), Aguiar and Amador (2011), and Amador (2012, Working Paper.).

[25] Hatchondo and Martinez (2009) and Arellano and Ramanarayanan (2012) have an alternative formulation with no coupon payments ($\kappa = 0$). As Chatterjee and Eyigungor (2012) argue, including the parameter κ is advantageous because it allows the calibration to target data on maturity length and debt service separately.

[26] The transitory income shock is set to its minimal possible value to ease the computation of the equilibrium. All the results in this paper are unchanged if this assumption was relaxed to have the transitory component of income to vary also while in default. For a discussion of the computational advantages of this formulation see Chatterjee and Eyigungor (2012).

where $x_{M,t} = y_{M,t} - c_{M,t}$ and $x_{oil,t} = y_{oil,t} - c_{oil,t}$ are net exports of manufactures and oil, respectively. Equation (11) implies that in default trade in goods has to be balanced; imports to increase consumption of a traded good have to be financed by exports of the other traded good.

If the government decides to pay its debt obligations then it has access to international financial markets and can issue new debt $i_{b,t}$. In this case, the balance of payments is:

$$[\gamma + (1-\gamma)\kappa]\, b_t = x_{M,t} + p_{oil,t} x_{oil,t} + q_t i_{b,t} \tag{12}$$

where q_t is the price of newly issued debt. Equation (12) shows how payments of debt obligations (left-hand side) are supported by net exports of goods and by the issuance of new debt.

Lenders.—The bonds issued by the government are purchased by a large number of risk-neutral foreign lenders. I assume these lenders have deep pockets (in the sense that an individual lender is always able to purchase all of the government debt) and behave competitively. Also, lenders have access to a one-period risk-free bond that pays a fixed interest rate $r^{\star}$, which represents the lenders' opportunity cost of holding government debt for one period.

3.2 Recursive formulation and timing

The state of the economy is the underlying stochastic variable s, the i.i.d. income shock m, the stock of general capital k, the stock of capital for the oil sector k_{oil}, the outstanding government debt b, and an indicator of whether the government is in default or not.

The government.—Let $V(s,m,k,k_{oil},b)$ be the value of the government that starts the period not in default. I follow the Eaton and Gersovitz (1981) timing and assume that the government first chooses whether to repay its debt obligations, $d = 0$, or to default, $d = 1$:

$$V(s,m,k,k_{oil},b) = \max_{d \in \{0,1\}} \left\{ [1-d]\, V^P(s,m,k,k_{oil},b) + d V^D(s,k,k_{oil}) \right\}$$

where $V^P(s,m,k,k_{oil},b)$ is the value of repaying and $V^D(s,k,k_{oil})$ is the value of default.[27]

If the government decides to default then its debt obligations are erased and it gets excluded

[27] Alternative timing assumptions can give rise to multiplicity of equilibria like, for example, the one introduced by Cole and Kehoe (2000). For detailed discussions and literature surveys on this topic see Aguiar and Amador (2014) and Aguiar, Chatterjee, Cole and Stangebye (2016).

from financial markets. Then, the government simultaneously chooses the stocks of capital next period k' and k'_{oil}, static allocations of general capital in manufactures and the non-traded intermediate sector $K = \{k_N, k_M\}$, net exports of manufactures and oil $X = \{x_M, x_{oil}\}$, and consumption of final and intermediate goods $C = \{c, c_N, c_M, c_{oil}\}$ to solve:

$$V^D(s,k,k_{oil}) = \max_{\{k',k'_{oil},C,K,X\}} \left\{u(c) + \beta_G \mathbb{E}\left[\theta V\left(s',m',k',k'_{oil},0\right) + (1-\theta)V^D\left(s',k',k'_{oil}\right)\right]\right\}$$

subject to the resource constraint of the final good (7), the resource constraint of general capital $k_t = k_N + k_M$, the laws of motion of capital (8) and (9), the resource constraints of intermediate goods $c_N = y_N$, $c_M + x_M = y_M$ and $c_{oil} + x_{oil} = y_{oil}$, and the balance of payments under default (11). Note that the government can trade in goods, but trade has to be balanced since it cannot issue debt.

If the government decides to repay then it simultaneously chooses the stocks of capital k' and k'_{oil}, and debt b' in the next period, static allocations of general capital in manufactures and the non-traded intermediate sector $K = \{k_N, k_M\}$, net exports of manufactures and oil $X = \{x_M, x_{oil}\}$, and consumption of final and intermediate goods $C = \{c, c_N, c_M, c_{oil}\}$ to solve:

$$V^P(s,m,k,k_{oil},b) = \max_{\{k',k'_{oil},b',C,K,X\}} \left\{u(c) + \beta_G \mathbb{E}\left[V\left(s',m',k',k'_{oil},b'\right)\right]\right\}$$

subject to the resource constraint of the final good (7), the resource constraint of general capital $k_t = k_N + k_M$, the laws of motion of capital (8) and (9), the law of motion of bonds (10), the resource constraints of intermediate goods $c_N = y_N$, $c_M + x_M = y_M$ and $c_{oil} + x_{oil} = y_{oil}$, and the balance of payments under repayment (12).

Lenders.—In each period, if the government is in good financial standing it makes its borrowing and investment decisions simultaneously. Then, lenders observe these decisions and purchase the bonds. Since lenders behave competitively they make zero profits in expectation. Given that the lenders are risk-neutral they price the bonds issued by the government according to:

$$q\left(s,k',k'_{oil},b'\right) = \frac{\mathbb{E}_{m',s'|s}\left\{\left[1 - d\left(s',m',k',k'_{oil},b'\right)\right]\left[\gamma + (1-\gamma)\left(\kappa + q\left(s',k'',k''_{oil},b''\right)\right)\right]\right\}}{1+r^{\star}} \tag{13}$$

where k'', k''_{oil} and b'' are lenders' expectations about the government's investment and borrowing decisions in the following period. Note that, given the i.i.d. nature of the transitory income shock, the price schedule q does not depend on the current realization of m.

An important assumption in this environment is that all of the government's dynamic decisions are made simultaneously, in other words, both investment and indebtedness are contractible. This implies that next-period capital is an argument of the price function in (13). In a recent paper Galli (2019) studies an environment in which investment is not contractible. In that case the price function does not depend on next-period capital and multiple equilibria with high and low investment may arise.

3.3 Equilibrium

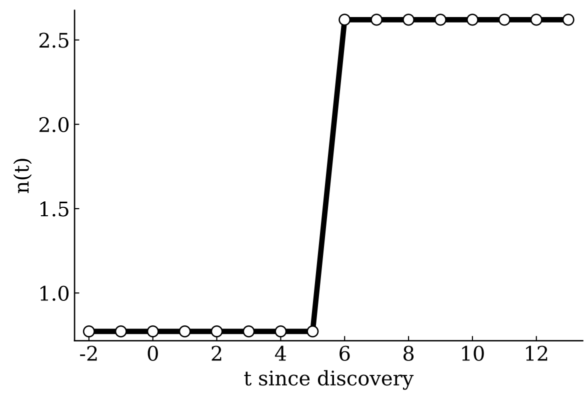
A Markov equilibrium is value functions $V\left(s,m,k,k'_{oil},b\right)$, $V^D\left(s,k,k'_{oil}\right)$, and $V^P\left(s,m,k,k'_{oil},b\right)$; policy functions for capital in default $k^D\left(s,k,k_{oil}\right)$ and $k^D_{oil}\left(s,k,k_{oil}\right)$; policy functions for capital $k'\left(s,m,k,k_{oil},b\right)$ and $k'_{oil}\left(s,m,k,k_{oil},b\right)$ and debt issuance $b'\left(s,m,k,k_{oil},b\right)$ in repayment; a default policy function $d\left(s,m,k,k_{oil},b\right)$; policy functions for static allocations in repayment and in default; and a price schedule of bonds $q\left(s,k',k'_{oil},b'\right)$ such that: (i) given the price schedule q, the value and policy functions solve the government's problem, (ii) the price schedule satisfies (13), and (iii) lenders have rational expectations about the government's future decisions, that is $k''=k'\left(s',m',k',k'_{oil},b'\right)$, $k''_{oil}=k'\left(s',m',k',k'_{oil},b'\right)$, and $b''=b'\left(s',m',k',k'_{oil},b'\right)$ in equation (13).

3.4 Discussion of assumptions and mechanism

There are four key assumptions in the model that allow it to produce similar responses to oil discoveries as we observe in the data: (i) capital adjustment costs, (ii) production of non-traded goods, (iii) high volatility of the international price of oil, and (iv) long-term debt. This Subsection discusses how these assumptions shape the mechanism through which spreads increase following an oil discovery, which can be summarized as follows. After an oil discovery, because of capital adjustment costs, the government borrows to invest in capital for the oil sector. Borrowing increases spreads and investment reduces them. However, the former effect dominates because, once the large oil field is being exploited, capital will be drawn away from the manufacturing sector. This reallocation will make tradable income—used to support debt payments—more dependent on oil revenue and thus more volatile. With long-term debt, this higher volatility of future income affects the spreads in all the preceding periods, starting with the period when the information of a discovery arrives.

Throughout this Subsection, I look at the path of different endogenous variables following an oil discovery in period $t = 0$. For illustrative purposes, all shocks are kept fixed at their mean values except for the size of the oil field in the economy, whose path is depicted in Figure 5.

Figure 5: Transition of size of oil field n_t

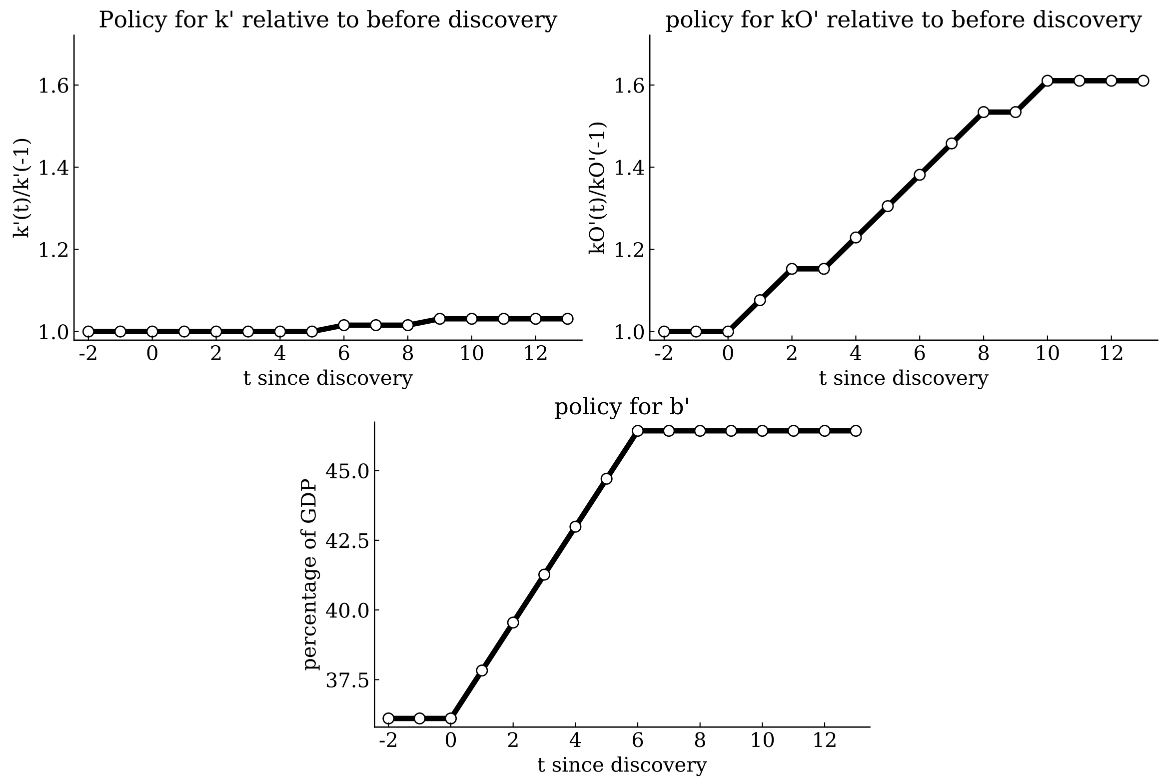


All shocks are kept fixed at their mean value. In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

The starting point of all endogenous states is their value after simulating a large number of periods keeping all shocks at their mean value. All the graphs in this Subsection are produced using the calibration described in Section 4.

Borrowing to invest.—An oil discovery in period $t = 0$ is news that the economy will have access to a larger oil field in period $t+6$. Thus, the government will want to have a higher level of capital for the oil sector k_{oil} by that period. Capital adjustment costs in both laws of motion for capital play a role in generating this anticipation effect in investment. First, recall that in the data investment increases much earlier than a year before production in the newly discovered field starts. In the model, all the additional capital in the oil sector would be installed in period $\tau + 5$ in the absence of adjustment costs. The quadratic capital adjustment costs incentivizes the government to smooth this investment through the preceding periods. Figure 6 shows the evolution of the stock of debt, as a percentage of GDP, chosen for the following period and the two stocks of capital relative to what they were before discovery.

Figure 6: Transition of borrowing and investment policies

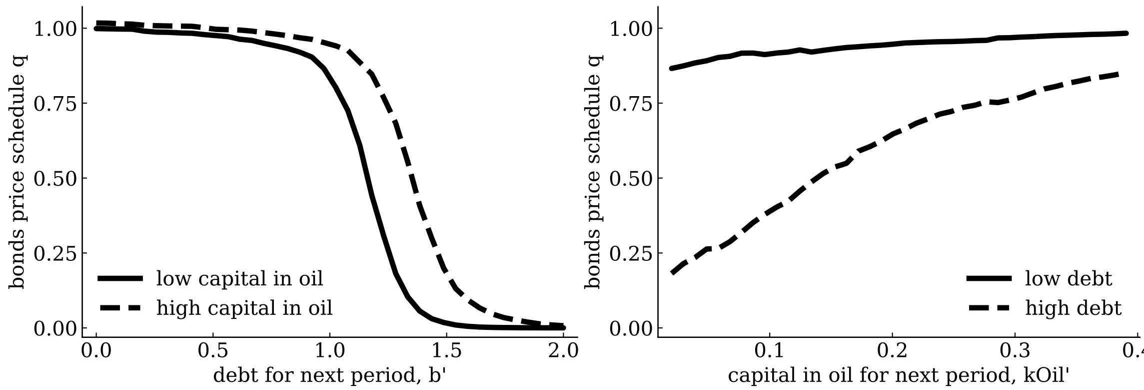


All shocks are kept fixed at their mean value. In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

Total investment increases after a discovery, but the stock of capital in the oil sector increases by a much higher proportion than the stock of capital used for manufacturing and non-traded production. Because of the adjustment costs for general capital, the government does not reallocate capital already installed for the other sectors into the oil sector. Instead, it borrows from the rest of the world in order to finance this investment. Borrowing increases spreads while investment, in general, reduces them.[28] Figure 7 illustrates this by showing the equilibrium price schedule of government bonds through two dimensions: bonds and capital in the oil sector chosen for the next period (using parameter values from the calibration in Section 4).

[28]For a detailed discussion of the effect of investment on spreads see Gordon and Guerron-Quintana (2018). They show that investment has non-trivial effects on the equilibrium level of the price of new bonds. On one hand, more capital gives the sovereign the ability to avoid default in bad times by disinvesting to repay debt, which makes spreads decrease with investment; on the other, higher levels of capital increase the value of default in the future, which in turn increases the default set and spreads in the current period. They show that, given a high enough level of indebtedness, the former effect dominates the latter and, everything else constant, sovereign spreads decrease with investment.

Figure 7: Bonds price schedule



These graphs show the price function of bonds 13 using the parameter values from Section 4 evaluated at the mean of the productivity and price of oil shocks and at the small oil field n_L. The left graph depicts the price of bonds as a function of debt in the next period b' for high and low values of capital in the oil sector k'_{oil} in the next period. The right graph shows the price of bonds as a function of capital in the oil sector k'_{oil} in the next period for high and low values of debt in the next period b'.

The left panel shows how higher indebtedness reduces the market price of bonds (which implies higher spreads), while the right panel shows how higher capital for the next period increases it (which implies lower spreads).[29] The government takes these effects into account when making borrowing and investment decisions.

Capital reallocation.—Within each period, general capital k can be freely allocated into the non-traded intermediate sector k_N and into the manufacturing sector k_M as long as $k_N + k_M = k$. Given the state of the economy, k_M is pinned down by:

$$\left(\frac{\alpha_M}{\alpha_N}\frac{(k-k_M)^{1-\alpha_N}}{(k_M)^{1-\alpha_M}}\right)^{\eta} z\,(k-k_M)^{\alpha_N} = \frac{\omega_N\left[z k_M{}^{\alpha_M} + p_{oil} z k_{oil}^{\alpha_{oil}} n^{\zeta} - X\right]}{\omega_M + \omega_{oil}\,(p_{oil})^{1-\eta}} \tag{14}$$

where $X = [\gamma + (1-\gamma)\,\kappa]\,b - q(\cdot)\,i_b$ is payments to foreigners of debt principal and interest net of new debt issuance. Note that the right-hand side of equation 14 is increasing in k_M and the left-hand side is decreasing. Thus, an increase in the size of the oil field n (while keeping k and k_{oil} fixed) lowers the equilibrium allocation of capital into the manufacturing sector. This is strengthened if k_{oil} also increases.

[29]As described in Section 4, spreads in the model are defined as the difference between the interest rate implied by the price of government bonds q_t and the risk free rate $r_t - r^{\star}$, where $r_t = \frac{\gamma+(1-\gamma)\kappa-\gamma q_t}{q_t}$

An intuitive interpretation of the economic forces driving this reallocation can be drawn from the version of equation (14) in a decentralized economy:[30]

$$p_N z k_N^{\alpha_N} = \frac{\omega_N (p_N)^{1-\eta} \left[z k_M^{\alpha_N} + p_{oil} z k_{oil}^{\alpha_{oil}} n^{\zeta} - X \right]}{\omega_M + \omega_{oil} (p_{oil})^{1-\eta}} \tag{15}$$

where p_N is the price of the non-traded intermediate good. Equation (15) shows that expenditure in the non-traded intermediate good (since $c_N = z k_N^{\alpha_N}$) is a fraction of tradable income net of debt payments. Higher n and higher k_{oil} both imply higher tradable income, so in order to increase consumption of the non-traded intermediate good the economy has to produce more of it—as opposed to consumption of manufactures, which can be increased by increasing imports. In the decentralized economy this higher production is supported by a higher price of non-traded goods p_N, which increases the marginal revenue of capital in that sector and appreciates the real exchange rate.

Higher volatility and spreads.—To highlight the role of volatility I borrow a simple example from Arellano (2008). Consider a small-open economy that each period receives a stochastic endowment of a tradable good $y \in Y = \left[\underline{y}, \bar{y}\right]$, which is iid across time and follows a cumulative distribution function F. There is an agent in the economy with preferences for lifetime consumption of the commodity $U\left(\{c_t\}_{t=0}^{\infty}\right) = \mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t u(c_t)\right]$ where u is strictly concave. The agent can issue one period non-contingent bonds b' and cannot commit to repay its debt. If the agent defaults on its debt it remains in autarky forever, which implies that the value of defaulting with income y is $V^D(y) = u(y) + \frac{\beta}{1-\beta}\mathbb{E}\left[u(y')\right]$. If the agent repays then she chooses consumption and debt issuance to maximize utility subject to the budget constraint $c + b \leq y + q(b')\, b'$. It can be shown that the sets of endowments $Y^D(b) \subseteq Y$ for which the agent decides to default given a debt level b can be characterized by an interval where only the upper bound is a function of assets $Y^D(b) = \left[\underline{y}, y^{\star}(b)\right)$. The cutoff $y^{\star}(b)$ is the income level at which the agent is indifferent between repaying and defaulting $V^P\left(y^{\star}(b), b\right) = V^D\left(y^{\star}(b)\right)$.[31] The debt of the agent is bought by a large number of risk-neutral competitive lenders with access to a risk free asset that pays interest rate r. Thus, the price of bonds

[30] Appendix B shows an equivalence result between the centralized economy presented in this paper and a decentralized economy with firms and a representative household.

[31] See Arellano (2008) for a proof of this result.

b' in equilibrium is characterized by:

$$q\left(b'\right)=\frac{1-F\left(y^{\star}\left(b'\right)\right)}{1+r}$$

which is the probability of repayment in the next period discounted by the risk free interest rate. Now, consider an unexpected and permanent increase in the variance of y. Since u is strictly concave both V^P and V^D decrease. To highlight the role of volatility I assume that preferences, the distribution F, and the change in volatility are such that the cutoffs $y^{\star}$ remain the same. With the same cutoffs the higher variance increases the probability of default, since the probability that $y<y^{\star}(b)$ is now higher. This decreases the price q at which lenders value the government debt and thus increases the spreads.

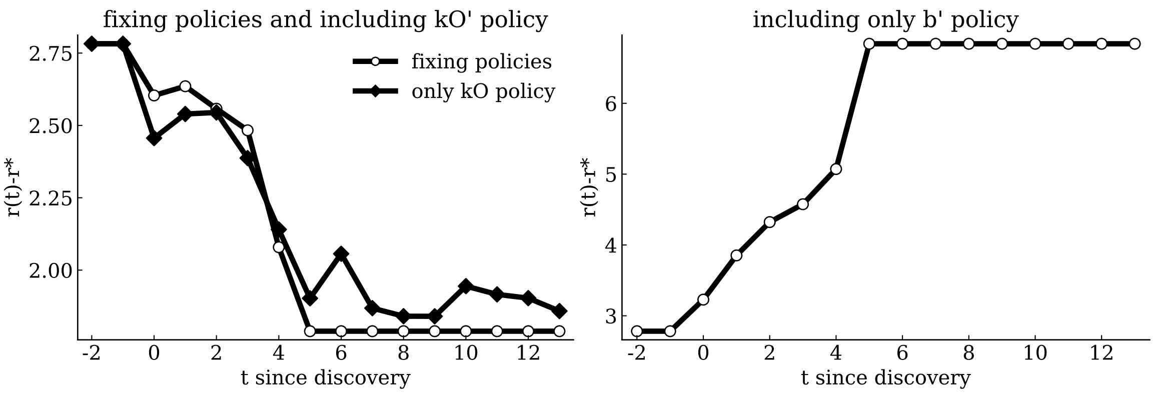
Going back to the model in this paper, the reallocation of production factors once the economy has access to the larger oil field increases the volatility of traded income, as can be seen in the balance of payments equation:

$$\underbrace{[\gamma+(1-\gamma)\kappa]b-q\left(s,k',k'_{oil},b'\right)\left[b'-(1-\gamma)b\right]}_{\text{net debt payments}}=\underbrace{\left[f^M\left(k_M\right)-c_M\right]+p_{oil}\left[f^{oil}\left(k_{oil},n\right)-c_{oil}\right]}_{\text{traded income}}$$

where the right-hand side is more dependent on oil revenue with high n, which, by assumption, is more volatile than manufacturing revenue.

Slow adjustment of spreads.—Note that the larger oil field only becomes available in period $t+6$. This directly affects the price function of bonds from the perspective of period $t+5$. However, if the debt is long-term (i.e. $\gamma<1$), a change in the price of bonds in $t+5$ affects the price of bonds in $t+4$, as can be seen in equation (13). Figure 8 depicts the change in spreads throughout the transition and the three main forces affecting it: the information about the oil discovery, investment in the oil sector, and foreign borrowing. Note that the state in period t can be summarized as $\left(n_t,k_t,k_{oil,t},b_t\right)$, since z and p_{oil} are kept fixed at their mean in this exercise. To ease exposition let $\hat{k}_{t+1}$, $\hat{k}_{oil,t+1}$ and $\hat{b}_{t+1}$ be the policy choices from Figure 6 at period t (recall that in this example $\hat{k}_{t+1}=k_{-1}\,\forall t$).

Figure 8: Decomposing transition of spreads

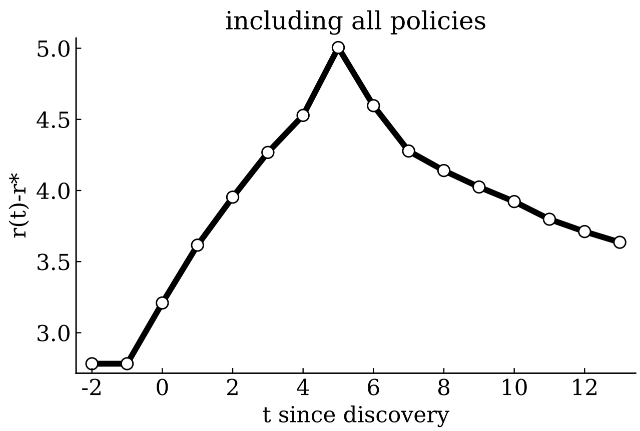


All shocks are kept fixed at their mean value. In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

The line with circled markers in the left panel shows the evolution of spreads after an oil discovery in $t = 0$ if all capital and debt stocks remained fixed but n_t evolves according to Figure 5, that is $r_t = r\left(n_t, k_{-1}, k_{oil,-1}, b_{-1}\right)$. Since there is certainty that in period $t = 6$ the size of the oil field will be larger, spreads fall in period 5. Spreads fall in periods 0 through 4 because debt is long-term and thus the price of debt in period t is affected by the price of debt in period $t+1$. The line with diamond markers shows the evolution of spreads considering the evolution of n_t and the policy of capital in the oil sector, that is $r_t = r\left(n_t, k_{-1}, \hat{k}_{oil,t+1}, b_{-1}\right)$. In periods $t = 0...3$ investment in the oil sector further decreases spreads because it increases traded income for the next period. However, this effect is dampened as $t \to 6$ because the reallocation of capital away from manufacturing (along with a larger oil sector) once $n_t = n_H$ increases the volatility of tradable income.

The right panel of Figure 6 shows the evolution of spreads considering the evolution of n_t and the borrowing policy, that is $r_t = r\left(n_t, k_{-1}, k_{oil,-1}, \hat{b}_{t+1}\right)$. The large increase in borrowing shown in Figure 6 more than compensates for the reduction in spreads due to the larger oil field in period $t = 6$ and, in this exercise, spreads would more than double if there was borrowing with no investment.

Figure 9: Transition of spreads



All shocks are kept fixed at their mean value. In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

Finally, Figure 9 shows the actual evolution of spreads, considering all policy functions $r_t = r\left(n_t, \hat{k}_{t+1}, \hat{k}_{oil,t+1}, \hat{b}_{t+1}\right)$. Spreads steadily increase during the transition (periods $t = 0 \ldots 5$) and start decreasing afterward. There are two reasons for the decrease in spreads after period 6: investment in the oil sector continues to increase and borrowing stops.

4 Calibration

I calibrate the model to the Mexican economy using the period 1993–2012.[32] There are two reasons that make Mexico an ideal example for the purposes of this paper: it is a typical small-open emerging economy that has been widely studied in the sovereign debt literature and it did not have any giant oil field discoveries during the period of study. This lack of giant oil discovery allows me to discipline the parameters of the model with business cycle data that does not include variation in endogenous variables induced by giant oil discoveries. I then validate the model by comparing the reaction of model variables to an oil field discovery with the estimates from Section 2.

A period in the model is one year.[33] There are two sets of parameters: the first (summarized in table 1) is calibrated directly and the second (summarized in table 2) is chosen so that moments

[32] Except for the spreads data, which starts in 1998 for this country.

[33] This is to be consistent with the empirical work from Section 2, which is limited to a yearly frequency since this is the scope of the oil discoveries data.

generated by the model match their data counterparts. I set the capital shares to $\alpha_N = 0.32$ and $\alpha_M = 0.37$ following Valentinyi and Herrendorf (2008), who calculate labor shares for the U.S. for different sectors and aggregate them into tradable and non-tradable. I find it reasonable to use estimates for the U.S. given the assumption that in the model there are no technological differences between the small-open economy and the rest of the world. I set the share of oil rent to $\zeta = 0.38$ and the capital share in the oil sector to $\alpha_{oil} = 0.49$ as in Arezki et al. (2017). I use data on sectoral GDP for Mexico between 1993 and 2012 to estimate the elasticity of substitution $\eta = 0.73$.[34] I set the weights $\omega_N = 0.79$, $\omega_M = 0.15$, and $\omega_{oil} = 0.06$ using aggregate consumption shares. I set the relative risk aversion parameter to $\sigma = 2$, the capital depreciation rate to $\delta = 0.05$, and the risk free interest rate to $r^\star = 0.04$, which are standard values in the international macroeconomics literature.

I assume the productivity shock follows an AR(1) process:

$$\log z_t = \rho_z \log z_{t-1} + \sigma_z \varepsilon_{z,t}$$

where $\varepsilon_{z,t}$ are iid with a standard normal distribution. I set the persistence to $\rho_z = 0.91$ and standard deviation $\sigma_z = 0.02$, which are standard values in the literature, and use these values to approximate the process with a finite state Markov-chain using the Rouwenhorst method.[35].

I assume that the price of oil in the model follows an AR(1) process:

$$\log p_{oil,t} = (1-\rho_{oil}) \log \bar{p}_{oil} + \rho_{oil} \log p_{oil,t-1} + \sigma_p \varepsilon_{oil,t} \tag{16}$$

where $\varepsilon_{oil,t}$ are iid with a standard normal distribution, v_p is the standard deviation, ρ_{oil} is the persistence parameter, and $\bar{p}_{oil}$ is the mean of the price of oil normalized in the model to $\bar{p}_{oil} = 1$. To estimate the persistence and standard deviation I use data of the average price of crude oil from the World Bank Commodity Price Data between 1993 and 2012. The source includes monthly data of the average of the Brent, Dubai, and West Texas Intermediate prices. I take the yearly average and divide by the US GDP deflator in each year to calculate a yearly series of the real price of oil.

[34] To estimate the elasticity of substitution I follow the methodology used by Stockman and Tesar (1995). As discussed by Mendoza (2005) and Bianchi (2011), the range of estimates for the elasticity of substitution between tradables and non-tradables is between 0.40 and 0.83.

[35] This method was first proposed by Rouwenhorst (1995) and it approximates the underlying AR(1) process better than that of Tauchen (1986) when the persistence ρ is close to 1. The method also requires a lower number of grid points to be robust. For a discussion of these properties see Kopecky and Suen (2010).

I rewrite equation 16 as

$$\bar{\Delta}\log p_{oil,t} = \rho_{oil}\bar{\Delta}\log p_{oil,t-1} + \sigma_p \varepsilon_{oil,t} \tag{17}$$

where $\bar{\Delta}\log p_{oil,t} = \log p_{oil,t} - \log \bar{p}_{oil}$ is the log deviation of the real price of oil from its long-term mean. I estimate that the persistence parameter in (17) is $\rho_{oil} = 0.92$ and the standard deviation of the iid shock is $\sigma_p = 0.24$. I use these estimates to approximate the process with a finite state Markov-chain using the Rouwenhorst method.

Table 1: Parameters calibrated directly from the data

Parameter		Value	Source
capital shares	α_N	0.32	Valentinyi and Herrendorf (2008)
	α_M	0.37	
	α_{oil}	0.49	Arezki et al. (2017)
oil rent	ζ	0.38	
elasticity of substitution	η	0.73	estimated for Mexico
intermediate	ω_N	0.79	shares in aggregate consumption
output	ω_M	0.15	
shares	ω_{oil}	0.06	
risk aversion	σ	2.00	standard values
capital depreciation rate	δ	0.05	
risk free rate	r^*	0.04	
bonds maturity rate	γ	0.14	7 year average duration
bonds coupon rate	κ	0.056	Chatterjee and Eyigungor (2012)
probability of reentry	θ	0.40	2.5 years exclusion
standard deviation and	σ_m	0.02	following Chatterjee and Eyigungor (2012)
support of i.i.d. shock	$\bar{m}$	0.04	bound is +/- 2 standard deviations
persistence of price of oil	ρ_{oil}	0.92	AR(1) estimation for
volatility of price of oil	σ_p	0.24	the real price of oil
persistence of productivity	ρ_z	0.91	standard
volatility of productivity	σ_z	0.02	values
size of small oil field	n_L	0.77	steady state oil net exports=1% of GDP
size of large oil field	n_H	2.62	steady state NPV of discovery=64% of GDP
normalization parameter	A	0.61	steady state final good production = 1

I set the probability of re-entry to financial markets to $\theta = 0.40$, so that the average duration of exclusion is 2.5 years, following Aguiar and Gopinath (2006). I set $\gamma = 0.14$ so that the average duration of bonds is 7 years, as documented for Mexico by Broner, Lorenzoni and Schmukler (2013).

To calibrate some parameters I need to compute nominal and real GDP. In the model, nominal GDP in period t is:

$$GDP_t = P_t\,(Y_t + m_t) + x_{M,t} + p_{oil,t}x_{oil,t}$$

where P_t is the standard CES price index for the production function in equation 3. To be consistent with national accounts for Mexico, I compute real GDP using base period prices:

$$RGDP_t = P_0\,(Y_t + m_t) + x_{M,t} + p_{oil,0}x_{oil,t}$$

where some period in the simulation $t = 0$ is the base period. I define the GDP deflator in the model to be $\tilde{p}_t = \frac{GDP_t}{RGDP_t}$.

I set the coupon payments $\kappa = 0.056$ so that debt service is 5.3% of GDP. Note that, given the average debt maturity γ and a target for the debt-to-GDP ratio $\frac{b}{GDP} = 0.27$ (see Table 2 below), κ is pinned down by $(\gamma + (1-\gamma)\,\kappa)\,\frac{100*b}{GDP} = 5.3$.

For the transitory income shock m I follow Chatterjee and Eyigungor (2012) and assume $m \sim \text{trunc}\,N\left(0, \sigma_m^2\right)$ with points of truncation $-\bar{m}$ and $\bar{m}$. As these authors did, based on experimentation I set $\sigma_m = 0.02$ so that convergence is achieved for a wide range of parameter values and I set the bounds for the support to $\bar{m} = 2\sigma_m$.

I calibrate the scaling parameter A and the size of the oil field before discovery n_L jointly using the steady state of the economy with no debt and all shocks set equal to their mean values. First, I set $A = 0.61$ and $n_L = 0.77$ so that in the steady state production of the final good is $Y_{ss} = 1$ and net exports of oil are 1% of GDP $\frac{x_{oil,ss}}{GDP_{ss}} = 0.01$ (which is the average for Mexico between 1993 and 2012). Then, I define the net present value of an oil discovery in the steady state as:

$$NPV_{ss} = \sum_{s=6}^{\infty}\left(\frac{1}{1+r_{ss}}\right)^{s} p_{oil,ss}\left[f^{oil}\left(z_{ss}, k_{oil,ss}, n_H\right) - f^{oil}\left(z_{ss}, k_{oil,ss}, n_L\right)\right]$$

where $p_{oil,ss} = z_{ss} = 1$ and $r_{ss} = 0.067$ is the interest rate consistent with a target for spreads of 2.7% (see Table 2 below). This calculation is akin to the calculation made by Arezki, Ramey and Sheng (2017) with actual data following equation (1). I set $n_H = 2.62$ so that the net present value of an oil discovery is 64% of nominal GDP in the steady state $\frac{NPV_{ss}}{GDP_{ss}} = 0.64$, which is the average

NPV of all oil discoveries in the world between 1970 and 2012.[36]

Table 2 summarizes the parameters calibrated by simulating the model. This calibration only considers simulated economies in their ergodic state with $n = n_L$. That is, economies in their ergodic state without oil discoveries.

Table 2: Parameters calibrated simulating the model

Parameter		Value	Parameter		Value
discount factor	β_G	0.85	default cost	d_0	-0.16
capital adjustment cost	ϕ	7.50	default cost	d_1	0.21
Moment			**Data**		**Model**
Average spread (percentage)			2.7		2.7
St. dev. of spreads (percentage)			1.3		1.2
Debt-to-GDP ratio			0.28		0.28
$\sigma_{inv}/\sigma_{GDP}$			3.4		3.4

There are four parameters chosen to match four moments from the data: the average and standard deviation of spreads, the debt-to-GDP ratio, and the volatility of investment relative to the volatility of GDP. The value of the discount factor β mainly determines the debt-to-GDP ratio; the average and standard deviation of spreads are mainly pinned down by the default cost parameters d_0 and d_1; and the relative volatility of investment is mostly determined by the capital adjustment cost parameter ϕ. Spreads data are from the EMBI (same as in Section 2).

Spreads in the model are computed as the difference between the interest rate implied by the price of government bonds q_t and the risk free rate $r_t - r^{\star}$, where $r_t = \frac{\gamma+(1-\gamma)\kappa-\gamma q_t}{q_t}$. Data of the debt-to-GDP ratio are from the updated version of the database collected by Lane and Milesi-Ferretti (2007). The debt-to-GDP ratio in the model is computed as the ratio of the stock of debt to nominal GDP $\frac{b_t}{GDP_t}$. For the relative volatility of investment I use HP-filtered data of the log of real investment and real GDP from Mexican national accounts and compute the standard deviation of their cyclical components. In the model, I compute real investment as total nominal investment divided by the GDP deflator $\frac{P_t\left(i_{k,t}+i_{k_{oil},t}\right)}{\tilde{p}_t}$. I apply the HP-filter to the log of both real investment and real GDP series and compute the standard deviation of the cyclical components.

The following section shows the model's predictions after an oil discovery, with special focus on the model's ability to reproduce the responses documented from the data in Section 2.

[36]This considers the entirety of discoveries considered in the data that Arezki, Ramey and Sheng (2017) analyze.

5 Quantitative Results

This section presents the main quantitative results. First, Subsection 5.2 compares the model predictions of the change in spreads and other macroeconomic variables to the estimates from the data laid out in Section 2. Subsection 5.3 explores two counterfactual cases: one in which the international price of oil is fixed, the *no-price-volatility* case, and one with a more patient government, the *patient* case. Finally, Subsection 5.4 computes the welfare gains for domestic households of an oil discovery and uses the two counterfactual cases to decompose the sources of these gains and potential welfare improvements.

5.1 Default events after oil discoveries

As mentioned in the introduction, the data of default episodes in Tomz and Wright (2007) show that the unconditional probability of observing a country default in any given ten-year period is 12 percent.[37] Conditioning on ten-year periods that follow a giant oil discovery, this probability is 18 percent. In the model, considering all simulated economies these probabilities are 14 and 19 percent, respectively.

5.2 Model vs data

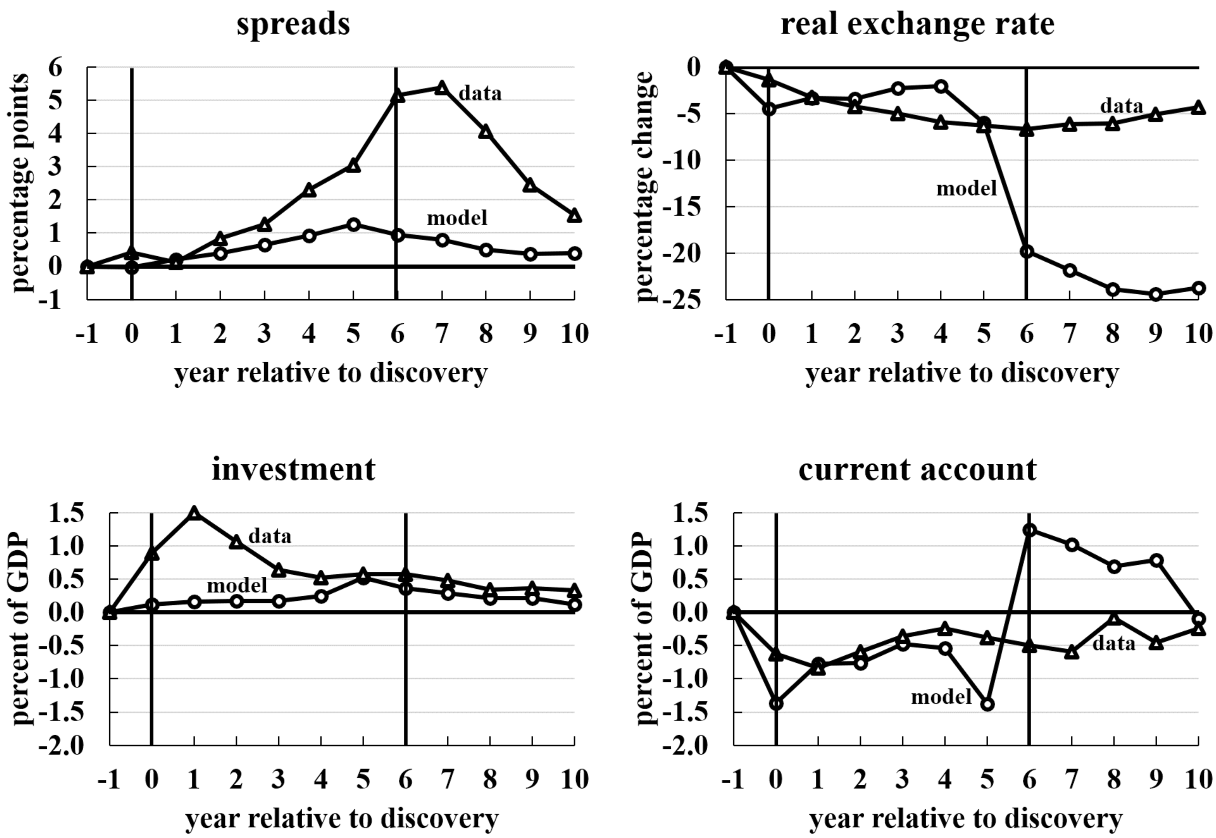
Figure 10 compares the impulse-responses of spreads, the real exchange rate, investment, and the current account in the model to the estimates from Section 2. All the impulse-response functions from the model are computed as follows: (i) simulate 300 economies for 2501 periods without any oil discoveries, (ii) drop the first 2500 to eliminate any effect of initial conditions and take period 2501 as the starting point, (iii) make the economy experience an unexpected oil discovery in period 2502 and simulate 10 more periods, (iv) center all economies such that $t = 0$ is the period when the discovery is announced and calculate the average of all paths, (v) calculate the impulse-response function of variable x as the change with respect to its value before the oil discovery in period $t = -1$, $IR(x_t) = x_t - x_{-1}$.

In the data, spreads start increasing when the news of the discovery is realized and continue

[37] I calculate this probability as $1 - Pr(\text{no default in 10 years})$, where $Pr(\text{no default in 10 years}) = [1 - Pr(\text{default in a year})]^{10}$.

to increase until they peak in year 7, when they reach a maximum increase of 5.3 percentage points. The top-left panel of Figure 10 shows that in the model spreads also increase when the news is realized and continue to do so until period 5, when they reach a maximum increase of 1.3 percentage points. The peak in the model happens exactly one period before the larger oil field is available.

Figure 10: Impulse-response to a discovery of average size



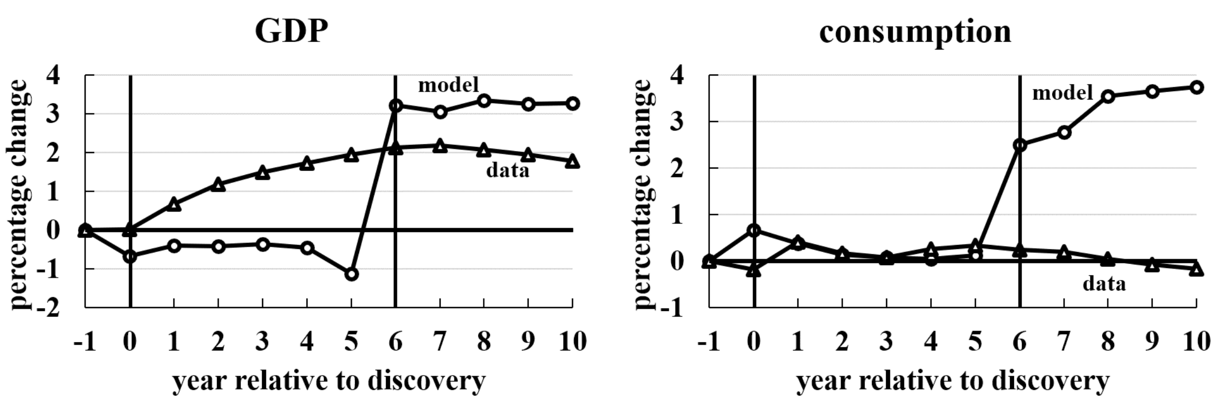
The model also explains the decrease in spreads after they reach their peak. In the data, however, spreads continue to increase until period 7, after which they decrease. One potential explanation is that the oil fields in the sample I consider took longer than average to start being productive. If I assumed the larger field in the model became available in year 8 rather than in year 6, the increase would continue until year 7, as in the data.

In the model, the real exchange rate is the reciprocal of the price index of the final good $1/P$. In both the model and the data the real exchange rate appreciates following an oil discovery, as the top-right panel of Figure 10 shows. This response is a result of the reallocation of production factors from manufacturing to non-traded sectors. In the data the appreciation is smother than in the model, where most of the appreciation happens once the larger oil field becomes available. This is a direct implication of the assumption that capital can be freely reallocated from the manufacturing sector to the non-traded sector.

The two bottom panel of Figure 10 show that in the model, as in the data, investment increases and the current account goes into deficit between the announcement of the discovery and the start of production. The orders of magnitude of these changes are of around 1 percentage point of GDP. The changes in the model happen closer to when production starts, while in the data they happen closer to the announcement. This may be due to the timing assumption. In the model, the economy has to wait 6 years to access the oil in the field, while in the real world this waiting period depends on the intensity, speed, and efficiency of investment in the sector.

Figure 11 compares the impulse-response of GDP and consumption in the model to the estimates from Figure 2. GDP increases both in the data and in the model. However, the increases in the model is more concentrated in the year when production starts.

Figure 11: Impulse-response to a discovery of average size



Regarding consumption, the data shows weak evidence of any movement at all. In the model, consumption increases once production in the oil field starts. The government in the model cannot smooth consumption more because the debt level is already too high in the ergodic state. In other words, borrowing to consume is already too expensive. Regarding GDP, Arezki, Ramey and Sheng (2017) find that, for a larger set of countries, GDP in the data also does not increase right away, which is consistent with standard models like the one they study and like the one laid out in Section 3. The fact that GDP increases right away for the sample of emerging economies considered in this paper is puzzling and a direction for future work.

5.3 Counterfactual cases

I now consider two counterfactual cases to analyze two sources of the increase in spreads following an oil discovery. For the first, I consider an economy in which the price of oil is fixed, the *no-price-volatility* case. I re-calibrate the parameters from Table 2 to match the same moments when the price of oil is not volatile and fixed at its mean.

Table 3: Parameters calibrated for *no-price-volatility* case

Parameter		Value	Parameter		Value
discount factor	β_G	0.85	default cost	d_0	-0.15
capital adjustment cost	ϕ	7.10	default cost	d_1	0.19

Moment	Data	Model
Average spread (percentage)	2.7	2.7
St. dev. of spreads (percentage)	1.3	1.1
Debt-to-GDP ratio	0.28	0.29
$\sigma_{inv}/\sigma_{GDP}$	3.4	3.3

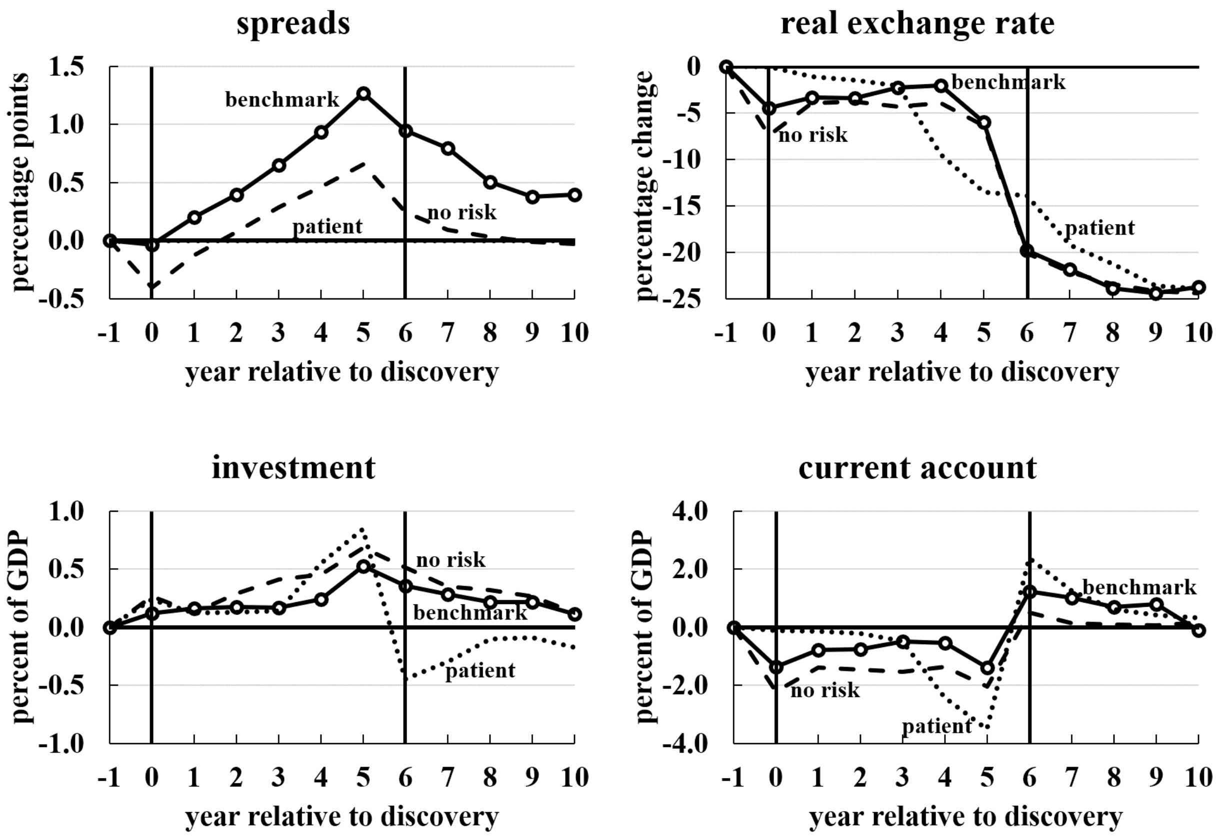
Table 3 presents these re-calibrated parameters. In this case, the reallocation of capital away from the manufacturing sector does not increase the volatility of total tradable income (since both tradable sectors are affected only by the same productivity shock).

For the second case, I consider an economy in which the government is almost as patient as the households ($\beta_G + \varepsilon = \beta_{HH}$ for a small $\varepsilon > 0$ where $\beta_{HH} = \frac{1}{1+r^\star}$), the *patient* case.[38] In this economy, default events are infrequent because the government does not accumulate much debt.

Figure 12 compares the impulse-response functions of spreads, the real exchange rate, investment, and the current account in each of these counterfactual cases with the benchmark from Subsection 5.2.

[38] I am implicitly assuming that the households are as patient as foreign lenders. The case of $\beta_G = \frac{1}{1+r^\star}$ could imply quantitative complications due to lack of stationarity as discussed by Schmitt-Grohe and Uribe (2003).

Figure 12: Impulse-response to a discovery of average size

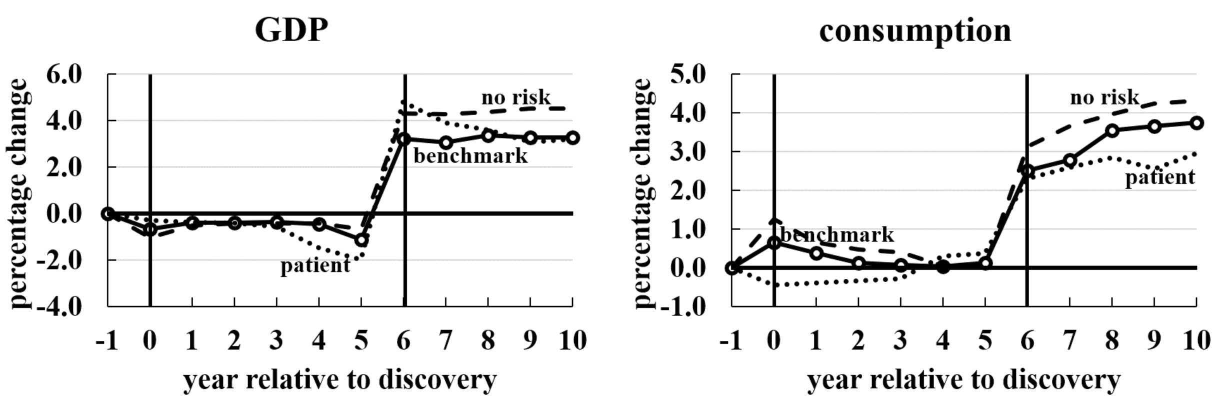


The top-left panel in Figure 12 shows that spreads still increase in the *no-price-volatility* case, but not as much as in the benchmark case. The increase peaks at 0.6 percentage points, which is around half of the size of the peak under the benchmark calibration. In the *patient* case, spreads do not change following an oil discovery. There are two reasons for this. First, the patient government accumulates lower levels of debt, so when news of an oil discovery arrives the increase in borrowing to invest does not increase spreads by much since the initial debt level is low. In fact, as can be seen in the bottom-right panel, the current account deficit following an oil discovery is larger in the *patient* case. Second, the higher valuation of the future in the *patient* case reduces default incentives for any state of the world and any level of borrowing *vis-a-vis* the economy with an impatient government, which also makes spreads smaller.

The bottom-left panel in Figure 12 shows that the response of investment in the three cases is very similar for the first five years after a discovery. However, investment drops much more in the *patient* case once production starts. This allows the government to finance a larger current account surplus starting in period six, as can be seen in the bottom-right panel. The top-right panel in Figure 12 shows that the depreciation of the real exchange rate reaches 25% in all three cases. The path of depreciation in the *patient* case is smoother since the adjustment in capital starts earlier.

Figure 13 compares the impulse-response functions of GDP and consumption in both counterfactual cases with the benchmark case from Subsection 5.2. The left panel shows that the response of GDP is virtually the same in all three cases: very close to zero for the first five years and then increasing once production in the oil field starts. The right panel shows that there is front-loading of consumption in both the benchmark and the *no-price-volatility* case, starting in period 0, when news of the discovery arrives. This contrasts with the response in the *patient* case, where consumption actually drops when the news arrives and increases in a smoother fashion during the subsequent periods.

Figure 13: Impulse-response to a discovery of average size



It is worth highlighting from Figures 12 and 13 that the response of spreads in the counterfactual cases differs much more from the benchmark than the responses of the other variables. This is because the two counterfactual cases address two frictions in the model that relate more directly to default risk. The frictions that make spreads high in the benchmark economy are market incompleteness, lack of commitment of the government, and impatience ($\beta_G < \beta_{HH}$). The *no-price-volatility* case can be interpreted as reducing the intensity of market incompleteness (since one source of risk is removed), while the counterfactual case of the patient government can be interpreted as eliminating the preference disagreement.

Figure 12 shows that eliminating the volatility of the price of oil cuts the increase in spreads after an oil discovery by half, while eliminating government impatience virtually eliminates this increase. The fact that the responses of the other variables do not differ as much indicates that the effect of the increase in permanent income (as studied by Arezki, Ramey and Sheng (2017)) affects these variables more after an oil discovery than the frictions that drive default risk do.

These results suggest that access to insurance against swings in the price of oil could eliminate half of the increase in spreads that follow giant oil discoveries.[39] In a recent paper, Rebelo, Wang and Yang (2019) study how financial development, defined as the extent to which countries can hedge against swings in the price of oil in international capital markets, interacts with sovereign risk and debt accumulation. They find that the inability to hedge against this risk reduces debt capacity and increases credit spreads, which is consistent with the findings in this Subsection. The exercise of eliminating the volatility in the price of oil is akin to giving the government the ability to hedge against swings in the price of oil without any cost. A more realistic model of this would include the availability of contracts contingent on the price of oil. As Rebelo, Wang and Yang (2019) argue, hedging against oil price risk is more cost effective than defaulting, so if these contracts were available the government would always take them.

5.4 Welfare gains of oil discoveries

This Subsection explores the question of whether giant oil discoveries are beneficial to the household. On one hand, an oil discovery increases permanent income, which allows for higher consumption; on the other hand, the frequency of default events increases in the periods that follow an oil discovery. In the model, this implies a productivity cost and financial autarky that may cause consumption to deviate from the path that the household would consider optimal. Additionally, the reallocation of capital away from the manufacturing sector increases the volatility of tradable income and, potentially, that of consumption. With a concave utility function, higher consumption volatility would generate welfare losses.

To calculate the welfare gains of an oil discovery in the model I proceed as follows. First,

[39] There are multiple ways for an economy to hedge against the volatility of the price of oil, from simple financial instruments like sell options to more complicated institutional arrangements like the sovereign wealth funds in Norway and Chile (in this case, to hedge against the volatility of the price of copper).

I take as a starting point a draw from the ergodic distribution of endogenous and exogenous states $S_0 = \left(z_0, p_{oil,0}, n_L, k_0, k_{oil,0}, b_0\right)$. Then, I simulate a series of shocks $\left\{\left(z_t, p_{oil,t}\right)\right\}_{t=1}^{T}$ for $T = 1000$ and I use the starting point, this time series, and the policy functions of the government to compute the consumption path of two economies: one with an oil discovery in $t = 1$ and one without it $\left\{\left(c_t^{Disc}, c_t^{NoDisc}\right)\right\}_{t=1}^{T}$. Then, I take $N = 1000$ draws of these consumption paths $C = \left\{\left\{\left(c_{t,n}^{Disc}, c_{t,n}^{NoDisc}\right)\right\}_{t=1}^{T}\right\}_{n=1}^{N}$ and define:

$$
\begin{aligned}
V_D(C) &= \mathbb{E}\left[\sum_{t=1}^{\infty} \beta_{hh}^{t-1} u\left(c_t^{Disc}\right)\right] \\
&\approx \sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta_{hh}^{t-1} u\left(c_{t,n}^{Disc}\right) \\
V_{ND}(C, \lambda) &= \mathbb{E}\left[\sum_{t=1}^{T} \beta_{hh}^{t-1} u\left((1+\lambda)\, c_{t,n}^{NoDisc}\right)\right] \\
&\approx \sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta_{hh}^{t-1} u\left((1+\lambda)\, c_{t,n}^{NoDisc}\right)
\end{aligned}
$$

where V_D is the value of discovering oil, V_{ND} is the value of not discovering oil, and λ is a compensation to the household in the economy that does not discover oil in terms of permanent consumption. I define welfare gains $\lambda^\star$ as the compensation such that the household is indifferent between discovering and not discovering oil $V_D = V_{ND}(C, \lambda^\star)$. With a CRRA utility function welfare gains are:

$$
\lambda^\star = \left(\frac{\sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta_{hh}^{t-1} \left(c_{t,n}^{Disc}\right)^{1-\sigma}}{\sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta_{hh}^{t-1} \left(c_{t,n}^{NoDisc}\right)^{1-\sigma}}\right)^{\frac{1}{1-\sigma}} - 1
$$

where $1/\sigma$ is the elasticity of intertemporal substitution. Let $C = \left\{\left\{\left(c_{t,n}^{Disc}, c_{t,n}^{NoDisc}\right)\right\}_{t=1}^{T}\right\}_{n=1}^{N}$ be the draws of consumption paths from the benchmark case, denote consumption paths from the *patient* case with "hats" $\hat{C} = \left\{\left\{\left(\hat{c}_{t,n}^{Disc}, \hat{c}_{t,n}^{NoDisc}\right)\right\}_{t=1}^{T}\right\}_{n=1}^{N}$, and consumption paths from the no-price-volatility case with "tildes" $\tilde{C} = \left\{\left\{\left(\tilde{c}_{t,n}^{Disc}, \tilde{c}_{t,n}^{NoDisc}\right)\right\}_{t=1}^{T}\right\}_{n=1}^{N}$. Column (1) in Table 4 reports the welfare gains of oil discoveries for the benchmark calibration using C as well as for the two counterfactual cases using $\hat{C}$ and $\tilde{C}$.

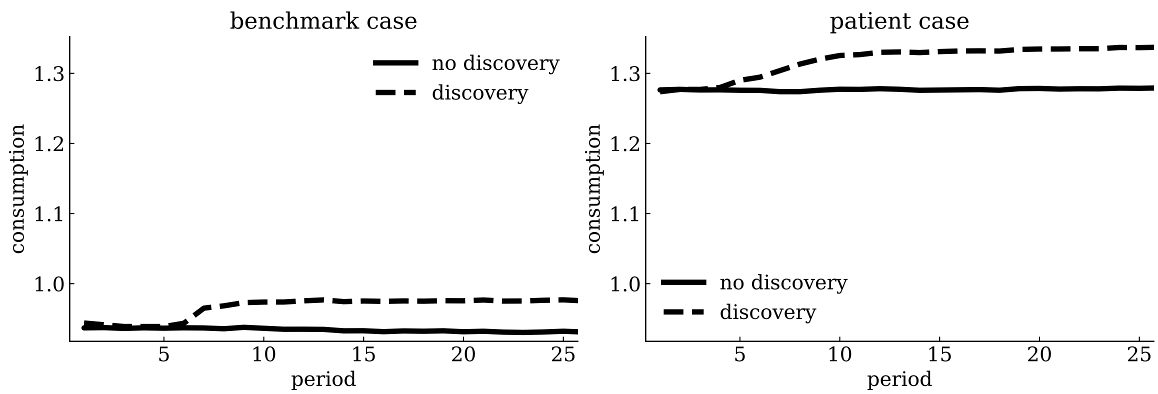
Table 4: Welfare gains of an oil discovery

case	welfare gains $\lambda^{\star}$	
	(1)	(2)[a]
benchmark	3.7%	3.7%
no-price-volatility	3.8%	3.8%
patient	3.5%	4.7%

a. The average consumption paths are adjusted to have a comparable average level to the benchmark.

Welfare gains of an oil discovery are 3.7 percent in the benchmark case and 3.8 percent in the *no-price-volatility* case. For the *patient* case welfare gains are 3.5 percent. However, it is important to note that the patient government accumulates larger stocks of capital, which yields, in general, higher levels of consumption. To illustrate this, Figure 14 shows the average paths of consumption, with and without an oil discovery in period $t = 1$, for both the benchmark and the patient case.

Figure 14: Average consumption paths

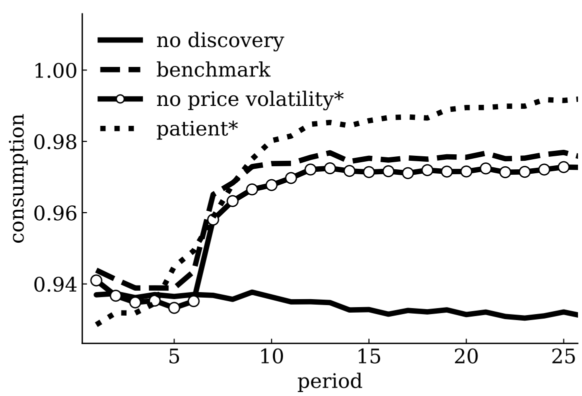


Since the utility function is concave, the household in the patient case values absolute changes in consumption differently due to the higher level. In order to make welfare gains comparable, I adjust consumption paths in the counterfactual cases using differences in average consumption without discovery. Denote $\bar{c}^{ND}_{\text{bench}}$ as the average, across t and n, of consumption without discovery in the benchmark case. Similarly, let $\bar{c}^{ND}_{\text{patient}}$ and $\bar{c}^{ND}_{\text{no-pr-vol}}$ be the corresponding averages for the *patient* and the *no-price-volatility* cases, respectively. Given an observation of consumption from the patient case $\hat{c}^{Disc}_{t,n}$ I define its adjusted counterpart as $\hat{\mathbf{c}}^{Disc}_{t,n} = \hat{c}^{Disc}_{t,n} + \left(\bar{c}^{ND}_{\text{bench}} - \bar{c}^{ND}_{\text{patient}}\right)$ (for notation purposes, bold indicates adjusted consumption). I perform the same calculation with all consumption series in $\hat{C}$ and $\tilde{C}$ to get the adjusted series $\hat{\mathbf{C}}$ and $\tilde{\mathbf{C}}$.

Column (2) in Table 4 reports the welfare gains of oil discoveries considering the adjusted consumption paths for the *patient* $\hat{\mathbf{C}}$ and the *no-price-volatility* $\tilde{\mathbf{C}}$ cases, which are 4.7 and 3.8 percent , respectively. Recall that the government in the *patient* case is arbitrarily close to being benevolent ($\beta_G + \varepsilon = \beta_{HH}$ for a small $\varepsilon > 0$), so it is expected that the household will value the expected consumption path in this case the most.

The larger gains in the *patient* case contrast with those from the *no-price-volatility* case, which are almost the same as in the benchmark. In order to understand why this is the case, it is useful to compare the average paths of consumption in the three cases. Figure 15 shows the consumption path with no discovery from the benchmark case, the path with discovery for the benchmark case, and the alternative consumption paths with discovery for the *no-price-volatility* and the *patient* cases.

Figure 15: Average comparable consumption paths



*The average consumption paths are adjusted to have a comparable level to the benchmark.

In the benchmark case, the government, on average, increases consumption in the period when news of the discovery arrives. This front-loading of consumption is a result of the disagreement in discount factors between the government and the household. Average consumption then decreases during years 1 through 5, due to the higher frequency of default events, and starts increasing in year 6, once the larger field becomes available. In contrast, consumption in the *patient* case decreases when the news arrives in order to finance investment and steadily increases afterward, reaching a higher average level than in the benchmark case and through a smoother path. The path of average consumption in the *no-price-volatility* case closely resembles that of the benchmark case.

In order to quantify the foregone welfare gains due to government impatience I do a welfare decomposition similar to the one presented in Aguiar, Amador and Fourakis (2020). Let

$$W_D^B = \sum_{t=1}^{T}\sum_{n=1}^{N} \beta_{hh}^{t-1}\left(c_{t,n}^{Disc}\right)^{1-\sigma}$$
$$W_{ND}^B = \sum_{t=1}^{T}\sum_{n=1}^{N} \beta_{hh}^{t-1}\left(c_{t,n}^{NoDisc}\right)^{1-\sigma}$$

where $c_{t,n}^{Disc}$ and $c_{t,n}^{NoDisc}$ are the consumption values in the benchmark case with and without discovery, respectively. Similarly, let

$$W_D^P = \sum_{t=1}^{T}\sum_{n=1}^{N} \beta_{hh}^{t-1}\left(\hat{\mathbf{c}}_{t,n}^{Disc}\right)^{1-\sigma}$$
$$W_{ND}^P = \sum_{t=1}^{T}\sum_{n=1}^{N} \beta_{hh}^{t-1}\left(\hat{\mathbf{c}}_{t,n}^{NoDisc}\right)^{1-\sigma}$$

where $\hat{\mathbf{c}}_{t,n}^{Disc}$ and $\hat{\mathbf{c}}_{t,n}^{NoDisc}$ are the adjusted consumption values in the *patient* case with and without discovery. Note that welfare gains in the benchmark case can be decomposed as follows:

$$\begin{aligned}(1+\lambda^B) &= \left(\frac{W_D^P}{W_{ND}^B}\right)^{\frac{1}{1-\sigma}}\left(\frac{W_D^B}{W_D^P}\right)^{\frac{1}{1-\sigma}} \\ &= \underbrace{\left(1+\lambda^{\text{discovery}}\right)}_{\text{gains from discovery}}\underbrace{\left(1+\lambda^{\text{impatience}}\right)}_{\text{loses from impatience}}\end{aligned}$$

where $\lambda^{\text{discovery}} = 4.1\%$ are the welfare gains of a discovery in the benchmark economy if consumption followed the path from the adjusted *patient* case and $\lambda^{\text{impatience}} = -0.4\%$ are the foregone welfare gains of consumption actually following the path from the benchmark case instead. Similarly, the effect on welfare from the higher volatility induced by the capital reallocation can be quantified as follows:

$$\begin{aligned}(1+\lambda^B) &= \left(\frac{W_D^{NV}}{W_{ND}^B}\right)^{\frac{1}{1-\sigma}}\left(\frac{W_D^B}{W_D^{NV}}\right)^{\frac{1}{1-\sigma}} \\ &= \underbrace{\left(1+\lambda^{\text{insurance}}\right)}_{\text{gains from discovery with fixed price of oil}}\underbrace{\left(1+\lambda^{\text{volatility}}\right)}_{\text{gains from higher volatility}}\end{aligned}$$

where $W_D^{NV} = \sum_{t=1}^{T} \sum_{n=1}^{N} \beta_{hh}^{t-1} \left(\tilde{\mathbf{c}}_{t,n}^{Disc}\right)^{1-\sigma}$ and $W_{ND}^{NV} = \sum_{t=1}^{T} \sum_{n=1}^{N} \beta_{hh}^{t-1} \left(\tilde{\mathbf{c}}_{t,n}^{NoDisc}\right)^{1-\sigma}$ are calculated using the adjusted consumption paths from the *no-price-volatility* case. From this decomposition, the welfare gains of an oil discovery combined with eliminating the volatility of the price of oil are $\lambda^{\text{insurance}} = 3.4\%$. In this case, the volatility of the price of oil actually increases the welfare gains of an oil discovery by $\lambda^{\text{volatility}} = 0.3\%$. To understand this last result it is important to note that default in the benchmark case acts as a form of insurance against very low realizations of the price of oil. On one hand, tradable income is high in high realizations of the price of oil and, on the other, default reduces the debt burden in low realizations. Default allows the economy to allocate more capital to the non-traded sector in order to increase consumption instead of allocating it to the manufacturing sector to service the debt. This higher consumption compensates for the drop in productivity caused by the default cost. Overall, in this particular numerical exercise, the gains from higher potential consumption in high price realizations more than compensate for the default cost in low realizations.

6 Conclusion

In this paper, I documented the effect of giant oil field discoveries on sovereign spreads, the sectoral allocation of capital, and macroeconomic aggregates of emerging economies. Following a giant oil discovery of average size, sovereign spreads increase by up to 5.3 percentage points and the share of investment in manufacturing decreases in favor of investment in commodities and non-traded sectors. Countries run a current account deficit and GDP and investment increase.

I developed a sovereign default model with production in three sectors, capital accumulation, and discovery of oil fields. The model generates an increase in spreads after oil discoveries caused by an increase in borrowing and an increase in the volatility of tradable income due to a reallocation of capital. According to the counterfactual exercises, the higher volatility of tradable income explains roughly half of the increase in spreads in the presence of default risk.

Oil discoveries generate welfare gains equivalent to a permanent increase in consumption of 3.7 percent, despite the higher frequency of default episodes. However, these gains could be 4.1 percent if consumption followed the path chosen by a benevolent planner. Most of the foregone welfare gains are due to the front-loading of consumption and higher default frequency during the transition years, both caused by the high relative impatience of the government. In the presence of default risk, the high volatility of the price of oil increases the welfare gains of an oil discovery. On one hand, tradable income is high in high realizations of the price of oil and, on the other, default reduces the debt burden in low realizations. Completely eliminating the volatility of the price of oil would reduce the welfare gains of oil discoveries, despite the fact that it would reduce the increase in default risk by half (as measured by the increase in spreads).

These results suggest that policies aimed at limiting arbitrary spending of oil revenue (current and future) are much more valuable than hedging against swings in the price of oil. Sovereign wealth funds, such as the ones in Norway (for oil) and in Chile (for copper), are examples of successful implementations of such policies.

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A Data appendix

This Appendix supports the empirical work in Section 2.

A.1 Benchmark estimations

Tables 5 and 6 show the estimation results for equation (2).

Table 5: Estimation results of main variables, benchmark specification

	(1) spreads	(2) inv/GDP	(3) CA/GDP	(4) ln(GDP)	(5) ln(cons)	(6) ln(RER)
y_{t-1}	0.622***	0.818***	0.577***	0.807***	0.703***	0.741***
	(0.114)	(0.059)	(0.083)	(0.037)	(0.049)	(0.200)
NPV_t	1.616	4.009	-3.469***	0.029	-1.040	-7.596
	(2.879)	(2.534)	(0.640)	(0.535)	(1.072)	(7.769)
NPV_{t-1}	-1.934	4.208*	-2.675**	3.698*	3.007	-12.454
	(3.226)	(2.407)	(1.002)	(1.823)	(2.193)	(14.576)
NPV_{t-2}	2.608	-0.949*	-0.594	3.576***	-0.700	-10.191
	(4.043)	(0.520)	(0.440)	(1.079)	(1.985)	(20.275)
NPV_{t-3}	2.471	-1.318*	-0.112	3.007**	-0.229	-10.214
	(5.136)	(0.749)	(0.408)	(0.971)	(1.673)	(17.806)
NPV_{t-4}	6.884	0.021	-0.193	2.904***	1.097	-12.294
	(6.305)	(0.274)	(0.478)	(0.792)	(1.659)	(16.665)
NPV_{t-5}	7.347	0.849	-1.298***	3.005***	0.833	-10.611
	(8.270)	(0.697)	(0.432)	(0.699)	(1.337)	(15.277)
NPV_{t-6}	18.011*	0.607	-1.537***	3.163***	0.039	-11.280
	(9.214)	(0.364)	(0.530)	(0.677)	(1.172)	(13.272)
NPV_{t-7}	12.428	0.028	-1.726**	2.604***	0.120	-6.809
	(11.364)	(0.519)	(0.674)	(0.618)	(1.189)	(12.179)
NPV_{t-8}	4.954	-0.298	1.455***	1.658**	-0.458	-8.367
	(7.577)	(0.274)	(0.498)	(0.716)	(0.859)	(10.377)
NPV_{t-9}	-0.435	0.498*	-2.242**	1.510**	-0.618	-3.344
	(1.080)	(0.255)	(0.851)	(0.563)	(0.682)	(8.435)
NPV_{t-10}	0.107	0.155	0.077	1.165*	-0.624	-3.108
	(0.852)	(0.579)	(0.442)	(0.648)	(0.873)	(5.120)
N	430	622	660	676	672	653
within R-squared	0.557	0.735	0.426	0.989	0.980	0.787

All regressions include country and year fixed effects as well as a constant. All regressions control for the interaction of the price of oil with an indicator for recent discoveries. Country specific quadratic trends are included for spreads, log real exchange rate, log GDP, and log consumption. Robust standard errors for panel regressions with cross-sectional dependence are in parenthesis. ***p<0.01, **p<0.05, *p<0.1.

The estimated coefficients in Table 5 are used to construct the impulse-response functions for spreads, investment, the current account, GDP, consumption, and the real exchange rate reported in Figures 2, 3, and 4.[40] Table 6 presents the point estimates of the coefficients ξ_s related to the interaction between the natural logarithm of the price of oil $p_{oil,t}$ and the indicator of an oil discovery in $t-s$ for $s=1...10$.

Table 6: Point estimates of interaction between price of oil and indicators of recent discoveries

	(1) spreads	(2) inv/GDP	(3) CA/GDP	(4) ln(GDP)	(5) ln(cons)	(6) ln(RER)
$p_{oil,t}\mathbb{I}_{disc,i,t-1}$	-0.253*	0.000	0.001	0.001	0.003**	0.009
	(0.129)	(0.001)	(0.002)	(0.002)	(0.002)	(0.008)
$p_{oil,t}\mathbb{I}_{disc,i,t-2}$	-0.240	0.002	0.000	0.001	0.002**	0.018
	(0.169)	(0.001)	(0.001)	(0.001)	(0.001)	(0.011)
$p_{oil,t}\mathbb{I}_{disc,i,t-3}$	-0.143	0.001	0.000	-0.001	0.000	0.008
	(0.250)	(0.001)	(0.001)	(0.001)	(0.001)	(0.006)
$p_{oil,t}\mathbb{I}_{disc,i,t-4}$	-0.376*	-0.001	0.001	-0.002	0.002	0.010
	(0.207)	(0.001)	(0.001)	(0.001)	(0.001)	(0.008)
$p_{oil,t}\mathbb{I}_{disc,i,t-5}$	-0.142	0.001	0.001	-0.002	0.000	0.010
	(0.238)	(0.001)	(0.001)	(0.001)	(0.001)	(0.006)
$p_{oil,t}\mathbb{I}_{disc,i,t-6}$	0.245	-0.002*	0.004***	-0.002	-0.002	0.018
	(0.600)	(0.001)	(0.001)	(0.002)	(0.002)	(0.011)
$p_{oil,t}\mathbb{I}_{disc,i,t-7}$	0.043	-0.001	0.001	-0.001	0.000	0.008
	(0.190)	(0.001)	(0.001)	(0.001)	(0.001)	(0.009)
$p_{oil,t}\mathbb{I}_{disc,i,t-8}$	0.116	0.000	0.000	0.001	0.000	0.006
	(0.162)	(0.001)	(0.001)	(0.001)	(0.001)	(0.012)
$p_{oil,t}\mathbb{I}_{disc,i,t-9}$	0.120	0.000	0.001	0.001	0.000	0.004
	(0.157)	(0.001)	(0.001)	(0.001)	(0.001)	(0.006)
$p_{oil,t}\mathbb{I}_{disc,i,t-10}$	-0.430	0.001	-0.004***	0.002	0.000	0.003
	(0.322)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)

***p<0.01, **p<0.05, *p<0.1.

Note that the coefficients in column (1) are three orders of magnitude larger than those in columns (2) through (5). Similarly, the coefficients in column (6) are also much larger than those in columns (2) through (5). As discussed in the following section, this difference shows how the inclusion of these control variables is relevant for the estimation of the effect of oil discoveries on spreads and the real exchange rate but not for their effect on the rest of the variables.

[40] Appendix A.3 shows the details about the estimation of the shares of investment in different sectors.

A.2 Estimations without interaction control variables

Table 7 shows the estimation results for the following regression:

$$y_{i,t} = \rho y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s} + \alpha_i + \mu_t + \varepsilon_{i,t}$$

Table 7: Estimation results of main variables, no interaction term

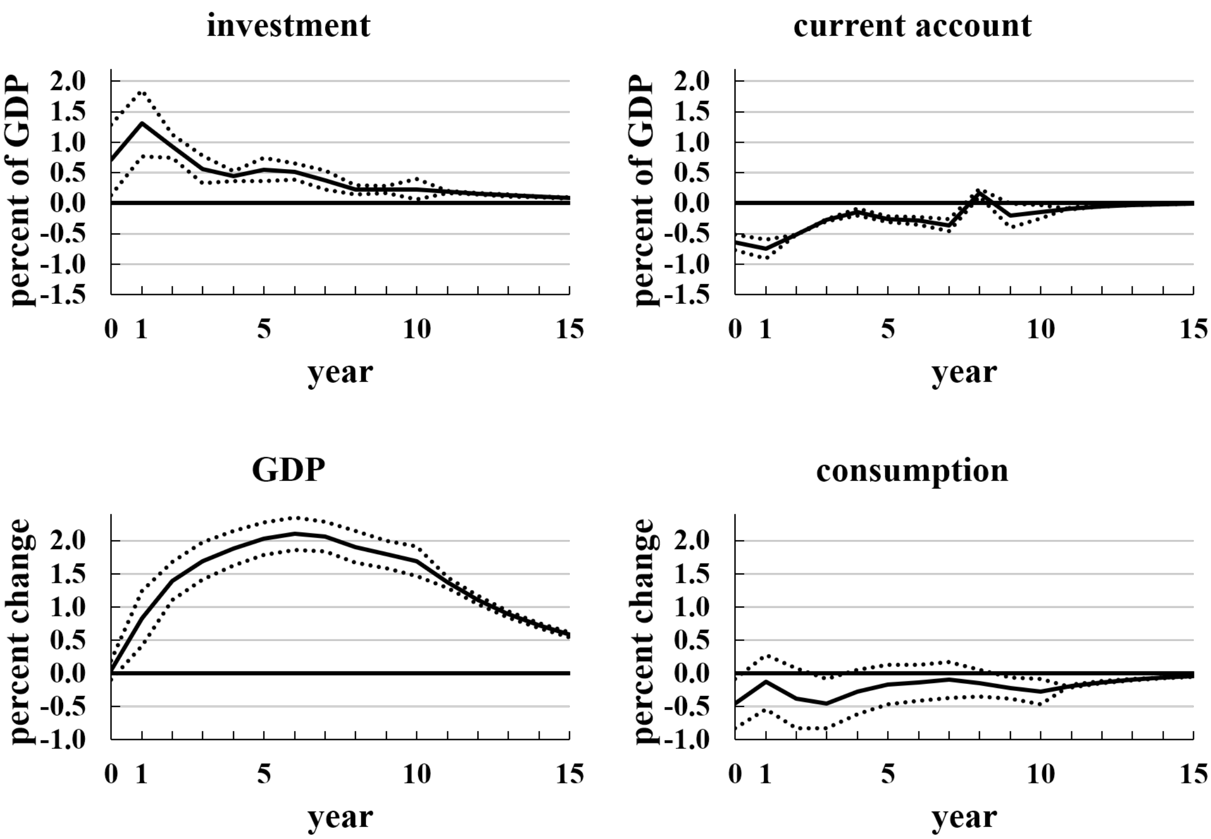
	(1) spreads	(2) inv/GDP	(3) CA/GDP	(4) ln(GDP)	(5) ln(cons)	(6) ln(RER)
y_{t-1}	0.621***	0.820***	0.582***	0.807***	0.701***	0.744***
	(0.118)	(0.060)	(0.084)	(0.036)	(0.050)	(0.197)
NPV_t	-1.491	3.937	-3.600***	0.262	-1.078	-8.304
	(2.799)	(2.479)	(0.551)	(0.620)	(1.030)	(7.972)
NPV_{t-1}	-7.769*	4.050*	-2.082**	4.394**	0.996	-6.185
	(4.155)	(2.110)	(0.962)	(1.780)	(1.921)	(10.852)
NPV_{t-2}	-6.075	-0.776*	-0.437	3.995***	-1.465	-2.295
	(4.680)	(0.410)	(0.357)	(1.066)	(2.013)	(15.110)
NPV_{t-3}	-5.349	-1.176*	0.135	3.183***	-0.900	-3.170
	(4.502)	(0.646)	(0.311)	(0.947)	(1.733)	(13.035)
NPV_{t-4}	-3.212	-0.044	0.066	2.878***	0.264	-5.286
	(5.341)	(0.157)	(0.374)	(0.781)	(1.597)	(12.029)
NPV_{t-5}	-1.386	1.022	-0.992***	2.833***	0.228	-3.368
	(6.427)	(0.682)	(0.267)	(0.671)	(1.382)	(10.805)
NPV_{t-6}	25.514*	0.363	-0.756*	2.574***	-0.079	-4.525
	(13.036)	(0.398)	(0.390)	(0.657)	(1.219)	(9.186)
NPV_{t-7}	15.521**	-0.243	-1.071*	2.045***	0.038	-0.994
	(7.267)	(0.491)	(0.569)	(0.546)	(1.223)	(8.519)
NPV_{t-8}	4.411	-0.498**	2.107***	1.330**	-0.469	-3.264
	(6.384)	(0.190)	(0.434)	(0.629)	(0.913)	(6.231)
NPV_{t-9}	-0.975	0.245	-1.665**	1.421**	-0.616	0.151
	(1.131)	(0.171)	(0.763)	(0.519)	(0.743)	(5.719)
NPV_{t-10}	-0.457	0.237	-0.147	1.353*	-0.652	-1.228
	(0.522)	(0.634)	(0.567)	(0.617)	(0.866)	(3.235)
N	430	622	660	676	672	653
within R-squared	0.545	0.731	0.414	0.989	0.980	0.786

All regressions include country and year fixed effects as well as a constant. Country specific quadratic trends are included for spreads, log real exchange rate, log GDP, and log consumption. Robust standard errors for panel regressions with cross-sectional dependence are in parenthesis. ***p<0.01, **p<0.05, *p<0.1.

That is, equation (2) without controlling for the interaction between the price of oil and indicators for recent discoveries. Comparing the results shown in Table 7 with those from Table 5 it is clear that the interaction controls are of very little consequence for all regressions except for those regarding spreads and the real exchange rate.

To illustrate this point even further, Figures 16, 17, and 18 show the impulse-response functions constructed with the point estimates from Table 7.

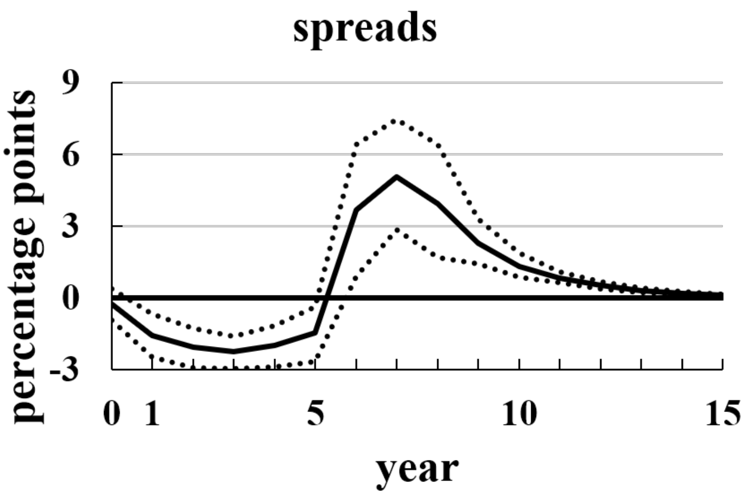
Figure 16: Impact of giant oil discoveries on macroeconomic aggregates



Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

As is clear from comparing Figure 16 with Figure 2, the impulse-response functions of investment, the current account, GDP, and consumption remain virtually unchanged if we exclude the interaction controls. By comparing Figure 17 with Figure 3, we can observe that the impact of oil discoveries on the dynamics of spreads is sensitive to the inclusion of these interaction controls.

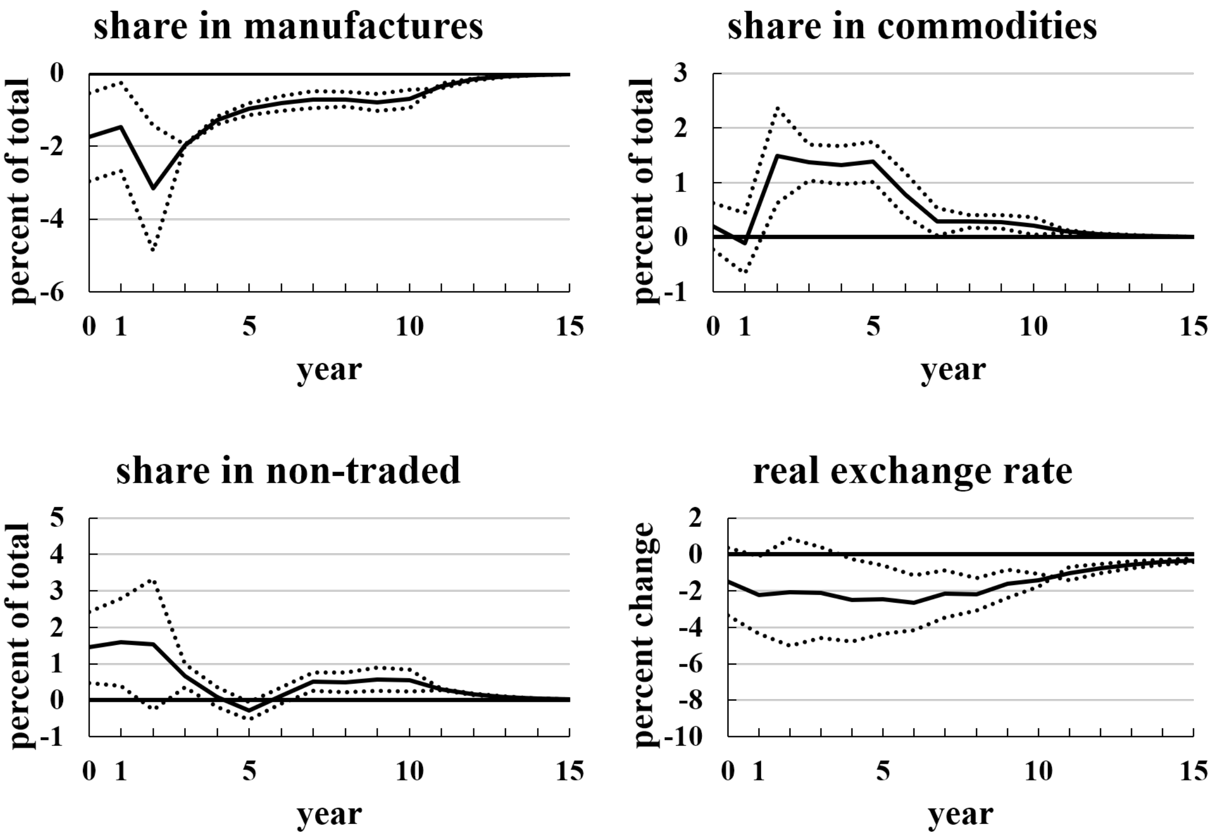
Figure 17: Impact of giant oil discoveries on spreads



Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

In both cases, with and without the interaction controls, the change in spreads peaks in the seventh year after a discovery at around 5 percentage points. However, in the benchmark specification spreads steadily increase in the years following a discovery, while in the specification that excludes the interaction controls spreads first decrease during the first five years and then increase. These differences are expected considering the sign of the coefficients reported in column (1) of Table 6. These coefficients are negative for $p_{oil,t}\mathbb{I}_{disc,i,t-s}$ for $s = 1 \ldots 5$, which implies that the coefficients of $NPV_{i,t-s}$ for $s = 1 \ldots 5$ are biased downward when the interaction terms are omitted.

Figure 18: Impact of giant oil discoveries on sectoral investment and the RER



Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

Figure 18 presents the impulse-response functions of the real exchange rate and the shares of total investment that go into manufacturing, commodities, and non-traded sectors for the estimations that do not consider the interaction controls. As is clear by comparing Figure 18 with Figure 4, only the response of the real exchange rate is affected by the omission.[41] Given the sign of the coefficients reported in column (6) of Table 6, the coefficients of $NPV_{i,t-s}$ for $s = 1...10$ are biased upward when the interaction terms are omitted.

[41] Note how the coefficients in column (6) of Table 6 are much larger than the coefficients reported in Table 10.

A.3 The effect of oil discoveries on investment shares by sector

This Section provides details on the estimation of the effect of oil discoveries on the share of total investment in manufactures, commodities, and non-traded sectors. These estimates consider 47 countries for which sectoral investment data for the period 1993–2012 are available.[42]

The data of investment by sector are from Division (2017) following the International Standard Industrial Clasification, Revision 3 (ISIC Rev. 3). It considers investment per country for 11 sub-items. Table 8 summarizes the sub-items and how I classify them into non-traded, manufacturing, and commodities.

Table 8: Industry classification

sub-item	clasification
Agriculture, hunting, forestry; fishing (A+B)	commodities
Mining and quarrying (C)	commodities
Manufacturing (D)	manufacturing
Electricity, gas and water supply (E)	non-traded
Construction (F)	non-traded
Wholesale retail; hotels and restaurants (G+H)	non-traded
Transport, storage and communications (I)	non-traded
Financial intermediation; real estate (J+K)	non-traded
Public administration; compulsory social security (L)	non-traded
Education; health and social work; other (M+N+O)	non-traded
Private households with employed persons (P)	non-traded

Tables 9 and 10 show the estimation results for equation (2). The estimated coefficients in Table 9 are used to construct the impulse-response functions for the shares of total investment that go into manufacturing, commodities, and non-traded sectors reported in Figure 4.

[42] These countries are Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Botswana, Canada, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kuwait, Latvia, Lithuania, Luxembourg, Malta, Mauritius, Mexico, Namibia, Netherlands, New Zealand, Norway, Oman, Pakistan, Poland, Portugal, Qatar, Saudi Arabia, Slovenia, South Africa, Spain, Sweden, Syrian Arab Republic, Tunisia, Ukraine, United Arab Emirates, United Kingdom, United States, and Uruguay.

Table 9: Estimation results of investment shares, benchmark specification

	(1) non-traded	(2) manufacturing	(3) commodities
y_{t-1}	0.545***	0.499***	0.520***
	(0.037)	(0.071)	(0.113)
NPV_t	9.306*	-10.222	0.475
	(4.895)	(5.570)	(1.949)
NPV_{t-1}	6.289	-4.746	-1.529
	(5.362)	(6.327)	(1.772)
NPV_{t-2}	6.789	-15.227	7.059
	(8.062)	(10.547)	(5.725)
NPV_{t-3}	-0.594	-2.491**	3.065***
	(1.214)	(1.212)	(0.435)
NPV_{t-4}	-1.577	-1.854	3.431***
	(1.180)	(1.248)	(0.604)
NPV_{t-5}	-1.822	-1.883	3.758***
	(1.153)	(1.247)	(0.788)
NPV_{t-6}	1.887	-1.884	0.072
	(1.128)	(1.250)	(0.850)
NPV_{t-7}	2.983**	-2.014	-0.967*
	(1.151)	(1.214)	(0.534)
NPV_{t-8}	1.511	-1.984	0.407
	(1.232)	(1.235)	(0.319)
NPV_{t-9}	1.763	-1.827	0.014
	(1.445)	(1.394)	(0.407)
NPV_{t-10}	1.528	-1.750	0.152
	(1.272)	(1.261)	(0.564)
N	569	569	569
within R-squared	0.522	0.414	0.461

All regressions include country and year fixed effects as well as a constant. All regressions control for the interaction of the price of oil with an indicator for recent discoveries. Robust standard errors for panel regressions with cross-sectional dependence are in parenthesis. ***p<0.01, **p<0.05, *p<0.1.

Table 10 presents the point estimates of the coefficients ξ_s of the interaction between the natural logarithm of the price of oil $p_{oil,t}$ and the indicator of an oil discovery in $t-s$ for $s = 1 \ldots 10$.

Table 10: Point estimates of interaction between price of oil and indicators of recent discoveries

	(1) non-traded	(2) manufacturing	(3) commodities
$p_{oil,t}\mathbb{I}_{disc,i,t-1}$	-0.002*	0.002	0.000
	(0.003)	(0.002)	(0.002)
$p_{oil,t}\mathbb{I}_{disc,i,t-2}$	-0.001	0.001	0.000
	(0.001)	(0.002)	(0.002)
$p_{oil,t}\mathbb{I}_{disc,i,t-3}$	-0.002	0.003**	-0.001
	(0.003)	(0.001)	(0.003)
$p_{oil,t}\mathbb{I}_{disc,i,t-4}$	0.002	0.001	-0.003**
	(0.002)	(0.001)	(0.001)
$p_{oil,t}\mathbb{I}_{disc,i,t-5}$	0.002	0.000	-0.001
	(0.002)	(0.002)	(0.002)
$p_{oil,t}\mathbb{I}_{disc,i,t-6}$	-0.001	0.000	0.001
	(0.001)	(0.001)	(0.001)
$p_{oil,t}\mathbb{I}_{disc,i,t-7}$	-0.003**	0.003	0.001
	(0.002)	(0.004)	(0.002)
$p_{oil,t}\mathbb{I}_{disc,i,t-8}$	-0.001	0.000	0.002*
	(0.002)	(0.002)	(0.001)
$p_{oil,t}\mathbb{I}_{disc,i,t-9}$	0.001	-0.005***	0.004***
	(0.002)	(0.001)	(0.001)
$p_{oil,t}\mathbb{I}_{disc,i,t-10}$	-0.001	0.001	0.000
	(0.001)	(0.001)	(0.002)

***p<0.01, **p<0.05, *p<0.1.

Finally, Table 11 shows the estimation results for the following regression:

$$y_{i,t} = \rho y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s} + \alpha_i + \mu_t + \varepsilon_{i,t}$$

that is the same as equation (2) but without controlling for the interaction between the price of oil and indicators for recent discoveries.

Table 11: Estimation results of investment shares, no interaction term

	(1) non-traded	(2) manufacturing	(3) commodities
y_{t-1}	0.551***	0.496***	0.533***
	(0.036)	(0.069)	(0.112)
NPV_t	8.047*	-9.735*	1.098
	(4.220)	(5.216)	(1.844)
NPV_{t-1}	4.418	-3.351	-1.191
	(4.909)	(5.912)	(2.252)
NPV_{t-2}	3.654	-13.469	8.607**
	(7.419)	(7.988)	(3.840)
NPV_{t-3}	-0.958	-2.228*	3.184***
	(1.087)	(1.254)	(0.483)
NPV_{t-4}	-1.598	-1.734	3.280***
	(1.052)	(1.233)	(0.638)
NPV_{t-5}	-1.868	-1.909	3.765***
	(1.024)	(1.234)	(0.763)
NPV_{t-6}	1.614	-1.871	0.264
	(1.009)	(1.247)	(0.874)
NPV_{t-7}	2.437**	-1.734	-0.744
	(1.057)	(1.302)	(0.618)
NPV_{t-8}	1.175	-2.000	0.757**
	(1.055)	(1.166)	(0.326)
NPV_{t-9}	1.683	-2.453*	0.720*
	(1.251)	(1.298)	(0.367)
NPV_{t-10}	1.268	-1.705	0.318
	(1.178)	(1.396)	(0.526)
N	569	569	569
within R-squared	0.514	0.398	0.449

All regressions include country and year fixed effects as well as a constant. Robust standard errors for panel regressions with cross-sectional dependence are in parenthesis. ***p<0.01, **p<0.05, *p<0.1.

B Decentralized economy

This Appendix shows how the allocations from the economy in Section 3 can be decentralized by an economy with a representative household, a government, and competitive firms. First I lay out the environment and then I prove an equivalence result that is akin to a first welfare theorem.

B.1 Environment

Final Good.—There is a competitive firm that assembles the final non-traded good Y_t from the intermediate non-traded good $c_{N,t}$, manufactures $c_{M,t}$, and oil $c_{oil,t}$ and sells it to the representative household at price P_t. The firm has access to the technology:

$$Y_t = f^Y\left(c_{N,t}, c_{M,t}, c_{oil,t}\right) = \left[\omega_N^{\frac{1}{\eta}}\left(c_{N,t}\right)^{\frac{\eta-1}{\eta}} + \omega_M^{\frac{1}{\eta}}\left(c_{M,t}\right)^{\frac{\eta-1}{\eta}} + \omega_{oil}^{\frac{1}{\eta}}\left(c_{oil,t}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

where η is the elasticity of substitution and ω_i are the weights of each intermediate good i in the production of the final good. The firm purchases manufactures and oil in international markets at prices p_M and $p_{oil,t}$ and purchases the intermediate non-traded good at price $p_{N,t}$ from a domestic producer. Cost minimization implies the demands for intermediate goods are:

$$c_{N,t} = \left(\frac{P_t}{p_{N,t}}\right)^{\eta} Y_t \omega_N$$
$$c_{M,t} = \left(\frac{P_t}{p_{M,t}}\right)^{\eta} Y_t \omega_M$$
$$c_{oil,t} = \left(\frac{P_t}{p_{oil,t}}\right)^{\eta} Y_t \omega_{oil}$$

and since the firm is competitive the price of the final good equals its marginal cost:

$$P_t = \left[\omega_N\left(p_{N,t}\right)^{1-\eta} + \omega_M\left(p_{M,t}\right)^{1-\eta} + \omega_{oil}\left(p_{oil_t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

Intermediate Goods.—Manufactures $y_{M,t}$, oil $y_{oil,t}$, and the intermediate non-traded good $y_{N,t}$

are produced by competitive firms with access to technologies:

$$y_{N,t} = f^N(z_t, k_{N,t}) = z_t k_{N,t}^{\alpha_N}$$
$$y_{M,t} = f^M(z_t, k_{M,t}) = z_t k_{M,t}^{\alpha_M}$$
$$y_{oil,t} = f^{oil}(z_t, k_{oil,t}, n_t) = z_t k_{oil,t}^{\alpha_{oil}} n_t^{\zeta}$$

. Each period, these firms rent general capital $k_{N,t}$ and $k_{M,t}$ and capital for oil extraction $k_{oil,t}$ from the household in exchange for rental rates r_t and $r_{oil,t}$. The manufacturing and oil firms sell their product in international markets at prices $p_{M,t}$ and $p_{oil,t}$ and the non-traded firm sells its product to the domestic final good firm at price $p_{N,t}$. The representative household owns all the firms and gets the profits from the firms.

Households.—There is a representative household with preferences over consumption c_t represented by:

$$\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t u(c_t)\right]$$

where $u(c) = \frac{c^{1-\sigma}-1}{1-\sigma}$ and β is the discount factor. The household owns all the firms and faces a budget constraint and laws of motion for capital:

$$c_t + (1+\tau_{i,t})\, i_{k,t} + (1+\tau_{i_{oil},t})\, i_{k_{oil},t} \leq \frac{r_t}{P_t}k_t + \frac{r_{oil,t}}{P_t}k_{oil,t} + \frac{\pi_t^N + \pi_t^M + \pi_t^{oil}}{P_t} + m_t + T_t$$
$$k_{t+1} = (1-\delta)\, k_t + i_{k,t} - \Psi(k_{t+1}, k_t)$$
$$k_{oil,t+1} = (1-\delta)\, k_{oil,t} + i_{k_{oil},t} - \Psi_{oil}\left(k_{oil,t+1}, k_{oil,t}\right)$$

where $\tau_{i,t}$ and $\tau_{i_{oil},t}$ are distortionary taxes, T_t are transfers from the government, m_t is a small transitory income shock, and π_t^N, π_t^M and π_t^{oil} are profits from the intermediate goods firms. The household takes taxes and prices as given and maximizes its lifetime utility subject to its budget constraint and the laws of motion of capital.

Government.—There is a benevolent government that can issue long term debt in international financial markets and lacks commitment to repay. The law of motion for debt is:

$$b_{t+1} = (1-\gamma)\, b_t + i_{b,t}$$

where γ is the fraction of debt that matures each period, b_t is the stock of debt in period t and $i_{b,t}$ is new debt issuances. At the beginning of each period the government chooses whether to default or not. If the government defaults then productivity in the economy is $\tilde{z}_t = z_t - \max\left\{d_0 z_t + d_1 z_t^2\right\}$. After default, the government is excluded from financial markets and is readmitted with probability θ. If the government repays then it can issue new debt. Regardless of default or repayment, the government has access to distortionary taxes $\tau_{i,t}$ and $\tau_{i_{oil},t}$ and lump-sum transfers T_t to influence the decisions of the households. The government maximizes the representative household's utility subject to its budget constraint and to an implementability constraint that restricts the allocations that the government chooses for the household to be a solution to the household's problem given the taxes. If the government is in good financial standing then its budget constraint is:

$$P_t \tau_{i,t} i_{k,t} + P_t \tau_{i_{oil},t} i_{k_{oil},t} + q_t\left(s_t, k_{t+1}, k_{oil,t+1}, b_{t+1}\right)\left[b_{t+1} - (1-\gamma) b_t\right] = P_t T_t + \left[\gamma + (1-\gamma)\kappa\right] b_t$$

where $(1-\gamma)\kappa b_t$ are the coupon payments for the outstanding debt. If the government decides to default then its budget constraint is:

$$P_t \tau_{i,t} i_{k,t} + P_t \tau_{i_{oil},t} i_{k_{oil},t} = P_t T_t$$

and gets readmitted to financial markets with probability θ and zero debt.

B.2 Equivalence result

In this subsection I prove that the allocations that characterize the equilibrium of the economy in Section 3 can be decentralized by the market economy described above. I do this in two steps: first, I show that, given the state and the dynamic decisions, the static allocations in each period are the same. Then I show that the dynamic problems are the same.

B.2.1 Recursive problems

The recursive formulation of the problem of the government in Section 3 is:

$$V\left(s, m, k, k_{oil}, b\right) = \max_{d \in \{0,1\}} \left\{[1-d] V^P\left(s, m, k, k_{oil}, b\right) + d V^D\left(s, k, k_{oil}\right)\right\}$$

where the value in repayment can be written as:

$$
\begin{aligned}
V^P(s,m,k,b) = & \max_{\left\{k',b',l,\vec{C},\vec{L},\vec{K},\vec{X}\right\}} \left\{u(c)+\beta\mathbb{E}\left[V\left(s',m',k',b'\right)\right]\right\} \\
s.t. \qquad c+i_k+i_{k_{oil}} & \leq F(s,k,k_{oil},X)+(1-\delta)k+m \\
k' & = (1-\delta)k+i_k-\Psi\left(k',k\right) \\
k'_{oil} & = (1-\delta)k_{oil}+i_{k_{oil}}-\Psi_{oil}\left(k'_{oil},k_{oil}\right) \\
X & = q\left(s,k',b'\right)\left[b'-(1-\gamma)b\right]-\left[\gamma+\kappa(1-\gamma)\right]b
\end{aligned}
$$

and the value in default can be written as:

$$
\begin{aligned}
V^D(s,k) = & \max_{\left\{k',l,\vec{C},\vec{L},\vec{K},\vec{X}\right\}} \left\{u(c,l)+\beta\mathbb{E}\left[\theta V\left(s',m',k',0\right)+(1-\theta)V^D\left(s',k'\right)\right]\right\} \\
s.t. \qquad c+i_k+i_{k_{oil}} & \leq F^D(s,k,k_{oil})+(1-\delta)k-\bar{m} \\
k' & = (1-\delta)k+i_k-\Psi\left(k',k\right) \\
k'_{oil} & = (1-\delta)k_{oil}+i_{k_{oil}}-\Psi_{oil}\left(k'_{oil},k_{oil}\right)
\end{aligned}
$$

where $F(s,k,k_{oil},X)$ and $F^D(s,k,k_{oil})$ summarize all the static allocations given the state and the choices of $\left(k',k'_{oil},b'\right)$. In repayment F is defined as:

$$
\begin{aligned}
F(s,k,k_{oil},X) = & \max_{c_N,c_M,c_{oil},k_N,k_M,k_{oil},x_{oil},x_M} f^Y(c_N,c_M,c_{oil}) \\
s.t. \qquad c_N & = f^N(z,k_N) \\
c_M & = f^M(z,k_M)-x_M \\
c_{oil} & = f^{oil}(z,k_{oil},n)-x_{oil} \\
X & = p_M x_M + p_{oil} x_{oil} \\
k & = k_N + k_M
\end{aligned}
$$

and in default F^D is defined as:

$$
\begin{aligned}
F^D(s,k,k_{oil}) = & \max_{c_N,c_M,c_{oil},k_N,k_M,k_{oil},x_{oil},x_M} f^Y(c_N,c_M,c_{oil}) \\
s.t. \qquad & c_N = f^N(\tilde{z},k_N) \\
& c_M = f^M(\tilde{z},k_M) - x_M \\
& c_{oil} = f^{oil}(\tilde{z},k_{oil},n) - x_{oil} \\
& 0 = p_M x_M + p_{oil} x_{oil} \\
& k = k_N + k_M
\end{aligned}
$$

B.2.2 Equivalence for static allocations

In repayment, the first-order conditions that characterize the static allocations in the government problem are:

$$f^Y_{c_N}(c_N,c_M,c_{oil}) = \lambda_{C_N} \tag{18}$$

$$f^Y_{c_M}(c_N,c_M,c_{oil}) = \lambda_{C_M} \tag{19}$$

$$f^Y_{c_{oil}}(c_N,c_M,c_{oil}) = \lambda_{C_{oil}} \tag{20}$$

$$f^N_k(z,k_N) = \frac{\lambda_k}{\lambda_{C_N}} \tag{21}$$

$$f^M_k(z,k_M) = \frac{\lambda_k}{\lambda_{C_M}} \tag{22}$$

$$\lambda_{C_{oil}} = \frac{p_{oil}}{p_M}\lambda_{C_M} \tag{23}$$

$$\lambda_{BoP} = \frac{\lambda_{C_M}}{p_M} \tag{24}$$

where λ_{C_N}, λ_{C_M}, $\lambda_{C_{oil}}$, λ_k, and λ_{BoP} are the multipliers of the market clearing constraints for intermediate goods, for general capital, and for the balance of payments, respectively. Note that equations (23) and (24) already pin down $\lambda_{C_{oil}}$ and λ_{BoP} in terms of λ_{C_M} and the international prices p_M and p_{oil}. Thus, we are left with a system of 5 first-order conditions plus 5 constraints to solve for 7 static allocations c_N, c_M, c_{oil}, k_N, k_M, x_{oil}, and x_M and 3 multipliers λ_{C_N}, λ_{C_M}, and λ_k.

Now, in the market economy the final good firm solves:

$$\min_{c_N, c_M, c_{oil}} p_N c_N + p_M c_M + p_{oil} c_{oil}$$
$$s.t. \quad Y \leq f^Y (c_N, c_M, c_{oil})$$

and the intermediate goods firms solve:

$$\max_{k_N} f^N (z, k_N) - r k_N$$
$$\max_{k_M} f^M (z, k_M) - r k_M$$
$$\max_{k_{oil}} f^{oil} (z, k_{oil}, n) - r_{oil} k_{oil}$$

The 8 static allocations c_N, c_M, c_{oil}, k_N, k_M, k_{oil}, x_{oil} and x_M, 3 endogenous prices p_N, r, and r_{oil}, and the multiplier μ^Y of the constraint in the minimization problem of the final good firm are pinned down by the 6 F.O.C.s of these problems:

$$f^Y_{c_N} (c_N, c_M, c_{oil}) = \frac{p_N}{\mu^Y} \tag{25}$$
$$f^Y_{c_M} (c_N, c_M, c_{oil}) = \frac{p_M}{\mu^Y} \tag{26}$$
$$f^Y_{c_{oil}} (c_N, c_M, c_{oil}) = \frac{p_{oil}}{\mu^Y} \tag{27}$$
$$f^N_k (z, k_N) = r \tag{28}$$
$$f^M_k (z, k_M) = r \tag{29}$$
$$f^{oil}_k (z, k_{oil}) = r_{oil} \tag{30}$$

the balance of payments, the market clearing conditions and the constraint:

$$c_N = f^N(z, k_N)$$
$$c_M = f^M(z, k_M) - x_M$$
$$c_{oil} = f^{oil}(z, k_{oil}, n) - x_{oil}$$
$$X = p_M x_M + p_{oil} x_{oil}$$
$$k_N + k_M = k$$

where, recall, $X = q(s, k', b')[b' - (1-\gamma)b] - [\gamma + \kappa(1-\gamma)]b$, k', and $b'$are given.

Note that r_{oil} is already pinned down by k_{oil}, n, and z in equation (30). Also note that if $\mu^Y = \frac{p_M}{\lambda_{C_M}}$, $p_N = \mu^Y \frac{\lambda_{C_N}}{p_M}$, and $r = \mu^Y \frac{\lambda_k}{p_M}$ then the two systems of equations are the same and, thus, the allocations that satisfy them are the same.

B.2.3 Equivalence for dynamic allocations

Finally, for the dynamic allocations note that the government in the market economy has three instruments τ_k, $\tau_{k_{oil}}$, and T to pin down the households decisions for k, k_{oil}, and c. Thus, with the correct choices of taxes on capital and transfers the two problems are equivalent.