The Sovereign Default Risk of Giant Oil Discoveries

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Abstract

This paper studies the impact of giant oil field discoveries on default risk. I document that interest rate spreads of emerging economies increase by 1.3 percentage points following a discovery of median size. I develop a sovereign default model with investment, production in three sectors, and oil discoveries. Following a discovery, borrowing increases to finance investment for oil extraction. Also, capital is reallocated from manufacturing toward the non-traded sector, which appreciates the real exchange rate and increases the volatility of tradable income. Higher oil income improves borrowing terms, but higher volatility and borrowing deteriorate them. With an impatient government, the latter effects dominate. Despite higher default risk, discoveries generate welfare gains of 2.1 percent. Foregone gains due to government impatience are 0.8 percent. Eliminating the volatility of the price of oil has virtually no effect, but "put" options that insure against low oil prices yield additional gains of 0.5 percent. (JEL Codes: F34, F41, Q33)

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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 0.12. Conditional on discovering a giant oil field, this probability was 0.18.[2] Hence, 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 an unexpected large 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 1.3 percentage points following a discovery of median size (which is 4.5 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] This investment reallocation is accompanied by an appreciation of the real

[1] A giant oil field contains at least 500 million barrels of ultimately recoverable oil. "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 how an increase in natural resource exports induces a reallocation of production factors away from manufacturing. Higher revenues from the 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 reallocation 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.

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 capital and debt accumulation that follow a discovery, 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 of discoveries allows me to discipline the parameters of the model with business cycle data that does

[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.

not have any variation that could be driven by oil discoveries. Additionally, I use the oil discoveries data from Arezki, Ramey, and Sheng (2017) to discipline the size and probability of discoveries in the model. To validate the theory, I generate a panel of model economies and estimate the responses of macroeconomic variables using the same specification as with actual data.

Under the benchmark calibration, the model generates an increase in sovereign interest rate spreads of up to 0.5 percentage points following an oil discovery.[6] The probability of observing a default in any ten year window in the model is 0.11. The probability is 0.14 conditional on being in the ten years after an oil discovery. These values in the data are 0.12 and 0.18, respectively. Despite the higher frequency of default episodes, oil discoveries generate welfare gains equivalent to a permanent increase in consumption of 2.1 percent due to the increase in permanent income.

I use the model to perform three 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 what would happen if the economy was able to costlessly hedge against all swings in the price of oil. For the second counterfactual I consider an economy with a more patient government, which virtually eliminates default risk; I call this the *patient* case. Finally, I consider an economy in which the government has access to "put" options that allow it to sell its oil production at a predetermined price, if the realized price of oil is too low, or at the market price for high realizations; I call this the *options* case. Oil hedges like these are common practice in private industries (private oil producers and airlines are usually involved) and the Mexican government has been a regular participant in these markets since 1990.

In all 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 benchmark case. Default events become more frequent in all but the *patient* case, in which defaults are virtually inexistent. These results stress two important points. First, the frictions in this economy that explain default events and high spreads are market incompleteness, the lack of com-

[6]The model abstracts from other complementary forces that could also make spreads increase after an oil discovery. 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. See Hevia, Neumeyer, and Nicolini (2013) and Alberola and Benigno (2017) for examples. Also, deterioration of institutions following giant oil discoveries could cause spreads to increase. Lei and Michaels (2014) find evidence that giant oil field discoveries increase the incidence of internal armed conflicts.

mitment from the government, and high borrowing driven by 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 also compare the welfare gains of oil discoveries in all counterfactual cases with those in the benchmark. I find that welfare gains remain virtually unchanged in the *no-price-volatility* case because losses from higher volatility of consumption are offset by gains from high consumption in states with high oil prices and not-so-low consumption in states with low oil prices (since default provides a partial hedge for these low realizations with high debt). I use the *patient* case to do a decomposition of welfare gains from oil discoveries and find that there are foregone gains of 0.8 percent due to default risk and high indebtedness driven by government impatience in the benchmark case. This results favor policies aimed at limiting arbitrary spending of oil revenue (current and future), like the sovereign wealth funds in Norway (for oil) and in Chile (for copper). However, implementing such policies may require costly and lengthy institutional reforms, which may not be feasible when an unexpected giant oil discovery happens. An easier to implement alternative would be to give the government access to "put" options after an oil discovery. From the *options* case I find that this access yields additional gains of 0.5 percent, which are almost as large as the foregone gains from impatience.

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.[7]

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 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 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 (2020). They study the relation between oil exports, proved oil reserves, and sovereign risk. They use the Institutional Investor Index (III) as a measure of sovereign risk and document how variations in proved oil reserves impact the dynamics of the III in oil exporting countries. The shocks these authors identify are driven by international economic conditions (like oil prices) and by endogenous ex-

[7] 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.

traction decisions, both of which are the main source of variation in proved oil reserves. There are three key differences between Hamann, Mendoza, and Restrepo-Echavarria (2020) and the empirical work presented in this paper. The first has to do with the magnitude of the shocks at hand. By definition, proved reserves do not immediately incorporate giant oil discoveries and the size of their year-to-year changes is much smaller (see the detailed discussion in Subsection (2.1)). The second has to do with the fact that, unlike with an increase in proved reserves, newly discovered giant oil fields cannot be immediately exploited; instead, they require a substantial amount of investment in subsequent years. Both the size and required investment of discoveries have important implications on expectations and economic activity. The implied increases in aggregate investment and foreign borrowing to finance it impact sovereign interest rate spreads in a way that marginal changes in proved reserves do not. The third is that the nature of the data on oil discoveries allows for a quasi-natural experiment approach to identify their effect, in contrast to vector autoregressions (VARs) which require untested identification assumptions and a long time series. The different nature of the shocks at hand and their economic implications motivate a different theoretical approach as well. Hamann, Mendoza, and Restrepo-Echavarria (2020) develop a model in which the dynamics of existing reserves interact with sovereign risk for an implicit fixed stock of capital (i.e., they abstract from capital accumulation). Reserves increase by random frequent discoveries, which can be interpreted as additional resources found in existing fields or improvements in extraction technology that allows to access formerly inaccessible resources (like the introduction of fracking). In contrast, the model presented in Section 3 allows for capital accumulation and models infrequent and much larger oil discoveries to mimic the discovery of new fields that require investment. This allows the model to study the interaction of sovereign risk with the accumulation of debt and capital that follow the discovery of giant oil fields.

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. Section 4 describes the calibration, discusses the main mechanisms in the model, and performs all quantitative analyses. Section 5 concludes.

2 Giant oil discoveries in emerging economies

This section documents the effects of giant oil discoveries on 37 emerging economies considered in JP Morgan's Emerging Markets Bonds Index (EMBI).[8] Due to data availability, I restrict the analysis in this paper to these economies and the years between 1993 and 2012. I work with annual data since the date of oil field discoveries only reports the year of discovery. I use a measure of the net present value (NPV) of oil discoveries as a percentage of the GDP of the country at the time of discovery, which was 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 interest rate spreads of these economies. I find that spreads increase by up to 1.3 percentage points in the years following a discovery of median size. This result is robust to controlling for existing proved oil reserves, which, as discussed in the following subsection, is a consequence of conceptual differences between proved reserves and discoveries and also a consequence of the different economic forces through which these affect default risk. 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

[8] The 37 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.

describes the data and the empirical strategy. Subsections 2.3 through 2.5 present the main results and the Appendix discusses additional details and robustness checks.

2.1 Oil field discoveries and oil reserves

Giant oil discoveries are a measure of changes in the future availability and potential exploitation of natural resources. Their size is large relative to the GDP of the countries where discoveries happen, which indicates significant increases in future production possibilities. In order to make this comparison, 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:[9]

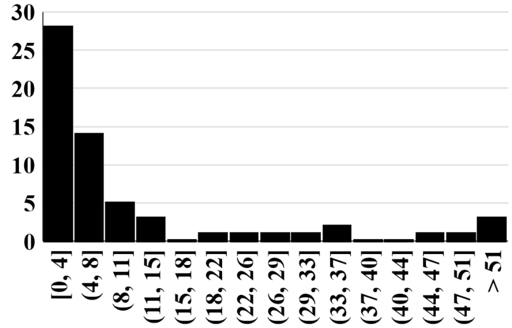
$$NPV_{i,t} = \frac{\sum_{j=5}^{J} \frac{q_{i,t+j}}{(1+r_i)^j}}{GDP_{i,t}} \times 100 \tag{1}$$

where $q_{i,t+j}$ is the annual gross revenue in year $t+j$ from the field discovered in country i in period t, r_i is the annual discount rate in country i, and $GDP_{i,t}$ is annual GDP of country i at year t. In the data, there is a time delay of 5.4 years on average between when an oil field is discovered and when production starts. The annual gross revenue $q_{i,t+j}$ is derived from an approximated production profile starting five years after the announcement of the discovery and up to an exhaustion year J, which is greater than 50 years for a typical giant oil field.[10] The data used to estimate the path of $q_{i,t+j}$ uses data of "ultimately recoverable reserves" (URR), which is an estimate (at the time of the discovery) of the total amount of oil that could be eventually recovered from a field given existing technology.

[9] 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).

[10] 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.

Figure 1: Distribution of NPV of giant oil discoveries

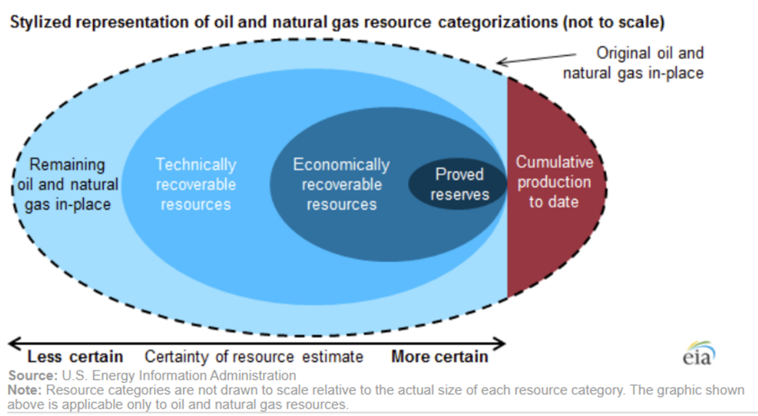


Percent of GDP, EMBI countries, 1993 –2012.

Considering the 37 economies and the years 1993–2012, there are 61 giant oil field discoveries in 15 of the 37 countries. The average and median NPV were 18 and 4.5 percent of GDP, respectively. The largest discovery in the sample was in Kazakhstan in 2000 with a NPV of 467. Figure 1 depicts the distribution of the NPV of these discoveries.

As documented by Hamann, Mendoza, and Restrepo-Echavarria (2020), the dynamics of proved oil reserves have a significant impact on the evolution of credit worthiness of emerging economies who are oil exporters. In order to understand my findings in light of their results it is important to note a conceptual distinction between proved oil reserves and URR. There is a range of categories to measure oil reserves. Figure 2 shows a conceptual diagram from the U.S. Energy Information Administration that illustrates the differences between these categories.

Figure 2: Oil and natural gas resource categories



Each category implies a different level of uncertainty, where the most certain measure is proved reserves and the most uncertain is remaining oil and natural gas in-place. Oil and gas in-place refers to the total amount of resources within a geological formation. Technically recoverable resources includes oil and gas that can be produced based on current technology.[11] This is the estimate of URR that Arezki, Ramey, and Sheng (2017) use to construct the NPV of oil fields, which can be interpreted as the amount of oil in a field that is physically feasible to extract. Economically recoverable resources (ERR) are all URR that can be profitably produced given economic conditions (like the price of oil and variable costs of production) at the time of measurement. Finally, proved oil reserves require a higher standard of certainty to be considered profitably and physically recoverable. As ERR, proved reserves shrink and grow as the prices of oil and extraction inputs vary, URR do not.

It is crucial to note that, by definition, the resources contained in giant oil field discoveries are not included in the measure of proved oil reserves at the time of the discovery. Instead, the oil in a field is gradually added to proved reserves once drilling starts and new information is collected about its feasibility and profitability.

Hamann, Mendoza, and Restrepo-Echavarria (2020) document how marginal changes in proved oil reserves impact the credit worthiness of oil exporting countries, identifying both long and short-run effects. The shocks these authors identify are driven by international economic conditions (like oil prices) and by endogenous extraction decisions, both of which are the main source of variation in proved oil reserves. There are three important differences between Hamann, Mendoza, and Restrepo-Echavarria (2020) and the work presented in the remainder of this section. The first has to do with the magnitude of the shocks at hand. By definition, the size of year-to-year changes in proved reserves is dwarfed by the size of giant oil discoveries. The second has to do with the fact that newly discovered giant oil fields cannot be immediately exploited; instead, they require a substantial amount of investment through several years in order to become productive. In contrast, proven reserves can be more easily exploited within shorter periods of time. Both the size of discoveries, and the investment and time they require to become productive have important implications for expectations and actual economic activity in other sectors, aggregate investment, and foreign borrowing. These implications impact sovereign interest rate spreads in a way that marginal changes in proved reserves do not. Finally, as discussed in the next subsection, the nature of the data on oil discoveries allows for a quasi-natural experiment approach to identify their effect,

[11] Geophysical characteristics of rocks, as well as physical properties of hydrocarbons (such as viscosity) prevent technology from producing the entirety of the ultimately recoverable reserves.

in contrast to vector autoregressions (VARs) which require untested identification assumptions and long time series.[12]

2.2 Empirical strategy and macroeconomic data

As Arezki, Ramey, and Sheng (2017) argue, giant oil discoveries have two unique features that allow for the use of a quasi-natural experiment approach to identify their effect. First, while policy and oil prices may drive exploration decisions, the actual timing of discoveries is exogenous due to uncertainty around oil and gas exploration. Second, there is a time delay of 5.4 years on average between discovery and production.[13] This significant delay allows me to treat giant oil discoveries as news shocks about future economic conditions.

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:

$$y_{i,t} = \rho y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s} + \alpha_i + \mu_t + \xi' X + \varepsilon_{i,t} \tag{2}$$

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; X is a vector of additional control variables; 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]

[12] Additionally, while proved reserves are measured (and vary) periodically, giant oil field discoveries are only measured when they happen, which makes it impossible to identify their effect under the VAR assumptions.

[13] 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.

[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 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.

In my benchmark regressions, the vector X contains contemporaneous and up to ten lags of the constructed variable $\mathbb{I}_{\text{disc},i,t-s} p_{oil,t}$, where $p_{oil,t}$ is the natural logarithm of the international price of oil at time t and $\mathbb{I}_{disc,i,t-s}$ is an indicator function of whether country i had an oil discovery in period $t-s$. The international price of oil is a common shock to all countries; however, the dependent variables may react differently to this common shock conditional on having had a recent discovery. These interaction terms control for this. As discussed in the Appendix, 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. The Appendix shows the results for the specifications without these controls.

As a robustness check in the regression of spreads, I also control for contemporaneous and up to ten lags of the natural log of proved oil reserves $res_{i,t}$ at year t in country i. Data of proved oil reserves are from the U.S. Energy Information Administration (EIA) and are measured in billions of barrels. As can be seen in Subsection 2.4, the results are robust to these controls.

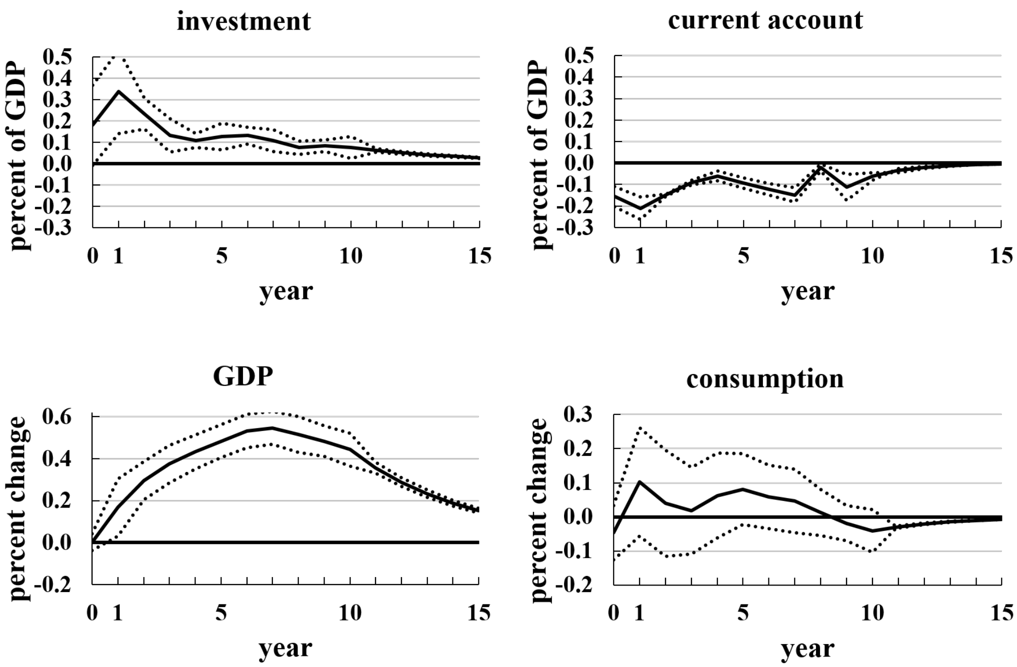
As in Arezki, Ramey, and Sheng (2017)'s analysis, I exploit the dynamic feature of the panel regression and use impulse response functions to capture the dynamic effect of giant oil discoveries given by $\Delta y_{i,t} = \rho \Delta y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s}$.

My investment, current account, GDP, and consumption data come 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. 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).

2.3 Response of macroeconomic aggregates

Figure 3 shows the dynamic response of investment, the current account, GDP, and consumption to an oil discovery of median size, based on the estimated coefficients of equation (2).[16]

Figure 3: Impact of giant oil discoveries on macroeconomic aggregates



Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The dotted lines indicate 90 percent 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.

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. In contrast with the findings in Arezki, Ramey, and Sheng (2017), I find that the current account does not turn positive even after oil production starts in this subset of emerging economies. As Aguiar and Amador (2011) argue, governments in highly distorted political environments are unwilling to reduce their sovereign debt quickly because the value of high immediate consumption outweighs the cost of debt overhang. The path of the current account in Figure 3 is consistent with these governments being more impatient and less politically stable than the average governments in the

[16]The Appendix reports point estimates and their standard errors for the coefficients in equation 2.

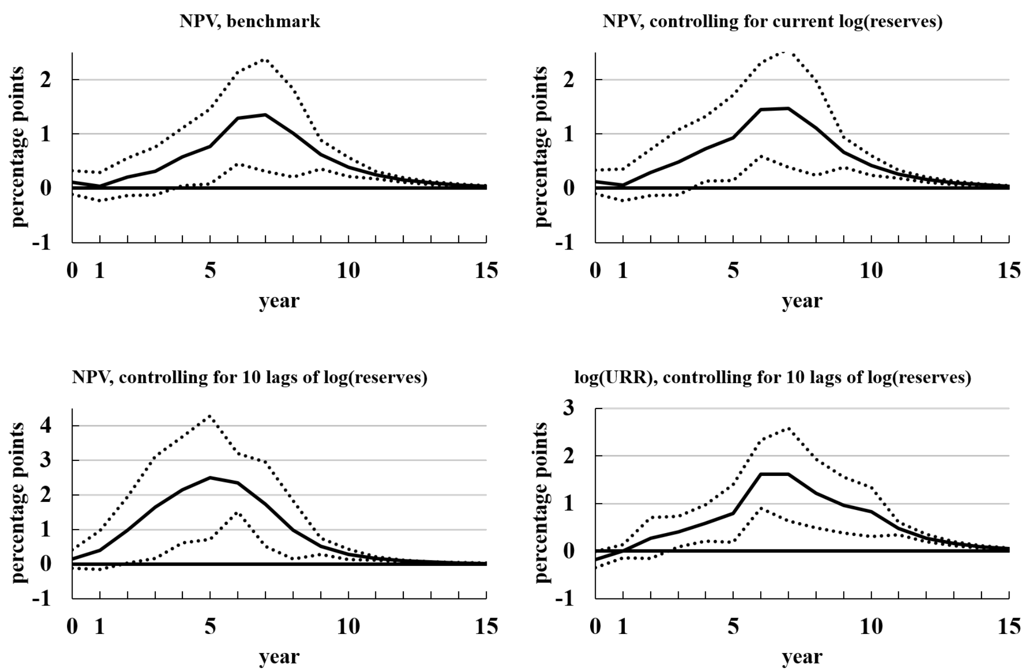
countries studied in Arezki, Ramey, and Sheng (2017).

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 variable includes both private and public consumption.

2.4 Effect on sovereign spreads

Figure 4 shows the dynamic response of the spreads following a discovery of median size. The top left panel shows the response constructed using the estimates from the benchmark regression. In the year of the discovery, the effect is small and not significantly different from zero. However, spreads steadily increase in the subsequent years and, by the sixth year after the discovery was announced, spreads have increased by 1.3 percentage points.

Figure 4: Impact of giant oil discoveries on spreads



Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The median URR is 1 billion barrels. The dotted lines indicate 90 percent 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.

This result is robust to controlling for proved oil reserves. The top right panel controls for the natural logarithm of contemporaneous proved reserves and the bottom left panel controls for this and ten lags. Finally, the bottom right panel uses the natural logarithm of the URR in oil discoveries as the dependent variable. The evident similarities between these impulse-response functions suggest that the benchmark result is not sensitive to the particular way of computing the NPV of discoveries and that it is robust to controlling for proved oil reserves. The Appendix reports the estimated coefficients for each of these equations. As can be seen there, the coefficients for proved reserves are positive, which indicates that higher proved reserves are associated with a deterioration in a country's credit worthiness, as Hamann, Mendoza, and Restrepo-Echavarria (2020) document.

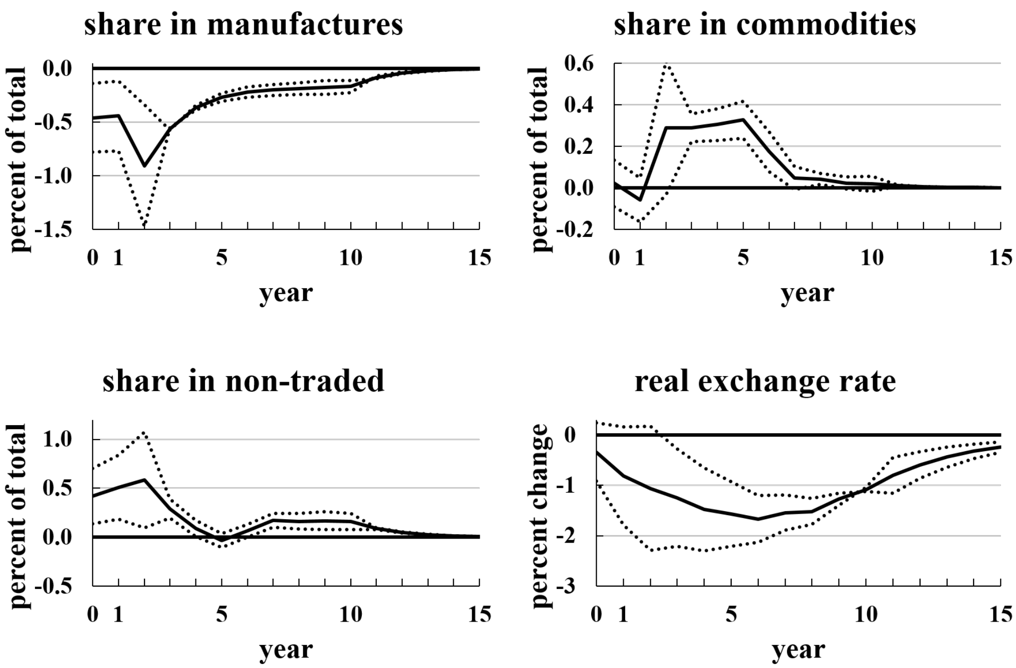
These results are striking in the light of the evidence from the previous Subsection and also in Arezki, Ramey, and Sheng (2017). Income increases during the years following the discovery, which would indicate that the country has a higher ability to service its debt. However, both investment and foreign borrowing increase. This suggests that countries still find it preferable to borrow at higher rates in order to finance the investment that is necessary to exploit the recently discovered oil field. The theoretical model in Section 3 provides a framework to study how debt accumulation to finance investment, along with the effects of the Dutch disease, reconcile these observations.

2.5 Reallocation of capital

Figure 5 shows the dynamic response of the real exchange rate, as well as the share of total investment in manufactures, commodities, and non-traded sectors.[17] Commodities comprise agricultural, fishing, mining and querying activities. The non-traded sector includes construction and wholesale, retail, and logistics services.

[17]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 5: Impact of giant oil discoveries on sectoral investment and the RER



Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The dotted lines indicate 90 percent 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.

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 5 shows that for the 37 countries studied in this paper, the evidence of appreciation is more conclusive than when all countries are 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, capital accumulation, 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.

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 that combines a bundle of an intermediate non-traded good $c_{N,t}$ and two intermediate traded goods: manufactures $c_{M,t}$ and oil, $c_{oil,t}$:

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

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 with decreasing returns to scale technologies $y_{N,t} = z_t k_{N,t}^{\alpha_N}$ and $y_{M,t} = z_t k_{M,t}^{\alpha_M}$, where z_t is a productivity shock that affects both sectors 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 capacity n_t. To produce oil, the economy uses the field's capacity n_t and capital $k_{oil,t}$ that is specific to the oil sector. The technology to extract oil is:

$$y_{oil,t} = \left[(1-\zeta)\left(k_{oil,t}^{\alpha_{oil}}\right)^{\frac{\varphi-1}{\varphi}} + \zeta\left(n_t\right)^{\frac{\varphi-1}{\varphi}}\right]^{\frac{\varphi}{\varphi-1}} \tag{4}$$

[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 oil is sector specific. Having specific capital in all three sectors would add an additional endogenous state, significantly complicating the computation without adding much to the informativeness to the model.

where $\zeta \in (0,1)$ is the weight that corresponds to the oil field, $k_{oil,t}^{\alpha_{oil}}$ is value added in the oil sector, and φ is the elasticity of substitution between value added and the oil field capacity. As with the other intermediate goods, $\alpha_{oil} \in (0,1)$ captures the presence of a unit of labor in the oil sector that, for simplicity, I assume is supplied inelastically. The key difference between the oil and the manufacturing sector (the two sources of tradable income in the economy) is that in order to produce oil the economy needs both capital *and* an oil field. In the data, capital to extract oil from an existing field has to be installed on-site. Moreover, capital installed on one field cannot typically be used to extract oil from a different (newly discovered) field. The CES formulation in equation (4) allows the model to capture this high degree of complementarity between oil capital and oil fields.

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

$$c_t + i_{k,t} + i_{k_{oil},t} = Y_t - \Psi\left(k_{t+1}, k_t\right) - \Psi\left(k_{oil,t+1}, k_{oil,t}\right), \tag{5}$$

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 $\Psi\left(x', x\right) = \phi\left(x' - x\right)^2$ is a capital adjustment cost function.[20] The laws of motion for the stocks of capital are:

$$k_{t+1} = (1-\delta)\,k_t + i_{k,t} \tag{6}$$

$$k_{oil,t+1} = (1-\delta)\,k_{oil,t} + i_{k_{oil},t} \tag{7}$$

where δ is the capital depreciation rate. As discussed in Subsection 4.4, 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

[20] 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.

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 4.4, 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.—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 with probability π_{disc} receives news that its oil capacity will be larger $T_{\text{wait}} + 1$ periods from then, that is $n_{t+T_{\text{wait}}+1} = n_H$. For simplicity I assume that n_t remains high for a stochastic number of periods and with probability π_{ex} it returns to the value n_L.[21]

In each period the economy experiences one of finitely many events s_t that follow a Markov chain governed by transition matrix $\pi(s_{t+1}|s_t)$. This shock is a vector $s_t = (z_t, p_{oil,t}, \chi_t)$, where $\chi_t \in \{-1, 0, 1, ..., T_{\text{wait}} + 1\}$. If $\chi_t = -1$ then $n_t = n_L$ and the economy has not discovered an oil field yet. If $\chi_t = 0 ... T_{\text{wait}}$ then $n_t = n_L$ but there was news of a giant oil field discovery in period $t - \chi_t$. Finally, if $\chi_t = T_{\text{wait}} + 1$ then $n_t = n_H$. When $\chi_t = -1$, then $Pr(\chi_{t+1} = 0 | \chi_t = -1) = \pi_{\text{disc}}$ is the probability of an oil discovery. For $\chi_t = 0, ..., T_{\text{wait}}$ this variable keeps track of the time between discovery and production, which is exogenously given by the value of T_{wait} and thus $Pr(\chi_{t+1} = \chi_t + 1 | 0 \leq \chi_t \leq T_{\text{wait}}) = 1$.[22]

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 $u(c) = \frac{c^{1-\sigma}-1}{1-\sigma}$ and β_G is the government's discount factor. As is standard in the sovereign default literature, I model the government as a relatively impatient agent. In particular, I assume that the government's discount factor is smaller than the discount factor of the households $\beta_G < \beta_{HH}$.[23] In Subsection 4.5 I analyze the implications that this assumption has on

[21] The average duration of a giant oil field is 50 years, which will be the calibration target for π_{ex}. This is 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, like the model in Hamann, Mendoza, and Restrepo-Echavarria (2020). However, the focus of this paper is on the effect of oil discoveries and the transition between discovery and production, rather than on the cyclical implications of the exploitation of existing oil fields.

[22] Given this formulation, χ captures both the news shock and keeps track of the time between news and production. Unlike Arezki, Ramey, and Sheng (2017), I assume the oil field takes two values rather than allowing for richer depletion dynamics. This is a simplifying assumption made for computational tractability because, unlike the model in Arezki, Ramey, and Sheng (2017), the model presented here requires a global solution in order to accurately compute default probabilities.

[23] 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

spreads after an oil discovery and on the welfare gains of oil discoveries.

Debt structure.—The government issues long-term bonds that mature probabilistically at a rate γ. The law of motion of bonds is:

$$b_{t+1} = (1-\gamma)\, b_t + i_{b,t} \tag{8}$$

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.[24] 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 productivity is $z_t^d \leq z_t$. 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, in particular the counterciclicality of spreads and the current account (see the discussions in Arellano (2008) and Chatterjee and Eyigungor (2012)).[25]

In default, the balance of payments is:

$$0 = x_{M,t} + p_{oil,t} x_{oil,t} \tag{9}$$

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 (9) 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

(2012, Working Paper.).

[24]For a similar formulation see Hatchondo and Martinez (2009), Arellano and Ramanarayanan (2012), and Chatterjee and Eyigungor (2012).

[25]Mendoza and Yue (2012) develop a general equilibrium model of sovereign default and business cycles in which default can endogenously trigger an efficiency loss similar to the one captured by z_t^d.

markets and can issue new debt $i_{b,t}$. In this case, the balance of payments is:

$$\gamma b_t = x_{M,t} + p_{oil,t} x_{oil,t} + q_t \left(b_{t+1} - (1-\gamma) b_t\right) \tag{10}$$

where q_t is the price of newly issued debt. Equation (10) 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 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 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 $V(s,k,k_{oil},b)$ 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, $d=1$:

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

where $V^P(s,k,k_{oil},b)$ is the value of repaying and $V^D(s,k,k_{oil})$ is the value of default.[26]

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

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

[26]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).

subject to the resource constraint of the final good (5), the resource constraint of general capital $k_t = k_N + k_M$, the laws of motion of capital (6) and (7), 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 (9). 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' for 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:

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

subject to the resource constraint of the final good (5), the resource constraint of general capital $k_t = k_N + k_M$, the laws of motion of capital (6) and (7), the law of motion of bonds (8), 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 (10).

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, the equilibrium price of bonds is such that lenders make zero profits in expectation. Given that the lenders are risk-neutral they price the bonds according to:

$$q\left(s,k',k'_{oil},b'\right) = \frac{\mathbb{E}_{s'|s}\left\{\left[1-d\left(s',k',k'_{oil},b'\right)\right]\left[\gamma+(1-\gamma)\,q\left(s',k'',k''_{oil},b''\right)\right]\right\}}{1+r^{\star}} \tag{11}$$

where k'', k''_{oil} and b'' are lenders' expectations about the government's investment and borrowing policies in the following period.

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 (11). 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, V^D, and V^P; policy functions for capital in default $\hat{k}^D$ and $\hat{k}^D_{oil}$; policy functions for capital and debt in repayment, $\hat{k}$, $\hat{k}_{oil}$, and $\hat{b}$; a default policy function d; policy functions for static allocations in repayment and in default; and a price schedule of bonds q such that: (i) given the price schedule q, the value and policy functions solve the government's problem, (ii) the price schedule satisfies (11), and (iii) lenders have rational expectations about the government's future decisions, that is $k'' = \hat{k}\left(s', k', k'_{oil}, b'\right)$, $k''_{oil} = \hat{k}_{oil}\left(s', k', k'_{oil}, b'\right)$, and $b'' = \hat{b}\left(s', k', k'_{oil}, b'\right)$ in equation (11).

4 Quantitative analysis

4.1 Model solution

I solve the functional equations of the government's problem and of the price of bonds using value function iteration. Following Hatchondo, Martinez, and Sapriza (2010), I compute the limit of the finite-horizon version of the economy. To solve for the optimal investment and debt issuance I use a nonlinear optimization routine taking the current state as an initial guess.[27] The value functions V^D and V^P and the price schedule for bonds q are approximated using linear interpolation. I use 25 grid points for bonds, capital, oil capital, productivity shocks, and shocks to the price of oil. See Appendix B for more details of the implementation of this algorithm to the model in the previous section.

[27] In the presence of convex capital adjustment costs, the policy functions for capital are not too far away from the 45 degree line, which makes the current state a good initial guess. The algorithm is robust to using any value for the debt policy as an initial guess. The code used to compute the solution of the model is written in the Julia language. I use the Nelder-Mead algorithm from the Optim.jl package, which follows the gradient free non-linear optimization algorithm developed by Nelder and Mead (1965).

4.2 Calibration

I calibrate the model to the Mexican economy using the period 1993–2012.[28] There are two reasons that make Mexico an ideal example for the purposes of this paper. The first is that Mexico has been widely studied in the sovereign debt literature because its business cycle has the same properties as other emerging economies (see for example Aguiar and Gopinath (2007), and Aguiar, Chatterjee, Cole, and Stangebye (2016)). In addition, as noted by Bianchi, Hatchondo, and Martinez (2018), Mexico gives calibration targets for average levels of debt and spreads that are close to the median value for emerging economies. In short, Mexico is a typical emerging economy. The second desirable property is that Mexico did not have any giant oil field discoveries during the period of study. This lack of discoveries allows me to discipline parameters of the model with business cycle data that do not include variation in endogenous variables induced by giant oil discoveries. This property is important because in the following subsection I validate the model by simulating a panel of economies and running the same regressions as in Section 2.

A period in the model is one year.[29] 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 generated by model simulations match their data counterparts. I set the capital shares to $\alpha_N = 0.66$ and $\alpha_M = 0.57$ following Mendoza (1995). I set the share of oil rent to $\zeta = 0.38$ and the capital share in the value added of the oil sector to $\alpha_{oil} = 0.49$ as in Arezki, Ramey, and Sheng (2017). For the elasticity of substitution between oil and field capacity I set $\varphi = 0.4$, which implies a high level of complementarity between these to factors.[30] I use data on sectoral GDP for Mexico between 1993 and 2012 to estimate the elasticity of substitution $\eta = 0.74$.[31] I set the weights $\omega_N = 0.60$, $\omega_M = 0.34$, 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 set

[28] Except for the spreads data, which starts in 1998 for Mexico.

[29] 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.

[30] To my knowledge, there is no empirical guidance applicable to a macroeconomic model regarding this level of complementarity. The results discussed in the remainder of the paper are not sensibly altered by different values of this parameter.

[31] 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.

the household's discount factor to be $\beta_{HH} = \frac{1}{1+r^{\star}}$, that is, I assume households are as patient as the foreign lenders. This parameter will be important for the welfare calculations in Subsections 4.5 and 4.6.

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 method proposed by Tauchen (1986).

I assume that the price of oil also follows an AR(1) process $\log p_{oil,t} = (1-\rho_{oil}) \log \bar{p}_{oil} + \rho_{oil} \log p_{oil,t-1} + \sigma_p \varepsilon_{oil,t}$, where $\varepsilon_{oil,t}$ are iid with a standard normal distribution, ν_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. I take the first difference of the above equation, $\bar{\Delta} \log p_{oil,t} = \rho_{oil} \bar{\Delta} \log p_{oil,t-1} + \sigma_p \varepsilon_{oil,t}$, and estimate that the persistence parameter is $\rho_{oil} = 0.92$ and the standard deviation of the iid shock is $\sigma_p = 0.18$. I use these estimates to approximate the process with a finite state Markov-chain using the Tauchen method and normalizing $\bar{p}_{oil} = 1$.

Table 1: Parameters calibrated directly from the data

Parameter		Value	Source
capital shares	α_N	0.66	Mendoza (1995)
	α_M	0.57	
	α_{oil}	0.49	Arezki, Ramey, and Sheng (2017)
oil rent	ζ	0.38	
elasticity of substitution	η	0.74	estimated for Mexico
intermediate	ω_N	0.60	shares in aggregate consumption
output	ω_M	0.34	
shares	ω_{oil}	0.06	
risk aversion	σ	2.00	standard values
capital depreciation rate	δ	0.05	
risk free rate	r^*	0.04	
household's discount factor	β_{HH}	0.96	as impatient as foreign lenders
bonds maturity rate	γ	0.14	7 year average duration
probability of reentry	θ	0.40	2.5 years exclusion
probability of discovery	π_{disc}	0.01	probability of discoveries in the data
probability of exhaustion	π_{ex}	0.02	average field life of 50 years
waiting time for field to be available	T_{wait}	5	average lag in the data
persistence of price of oil	ρ_{oil}	0.92	AR(1) estimation for
volatility of price of oil	σ_p	0.18	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	0.35	steady state oil net exports=1% of GDP
size of large oil field	n_H	0.51	steady state NPV of discovery=18% of GDP
scaling parameter	A	0.84	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 $GDP_t = P_t Y_t + x_{M,t} + p_{oil,t} x_{oil,t}$, 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 $RGDP_t = P_0 Y_t + x_{M,t} + p_{oil,0} x_{oil,t}$, where $t = 0$ is the base period. I define the GDP deflator in the model to be $\tilde{p}_t = \frac{GDP_t}{RGDP_t}$ and the real exchange rate to be $\frac{1}{\tilde{p}_t}$.

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. I set $A = 0.84$ and $n_L = 0.35$ 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).

I set the probability of an oil discovery to $\pi_{\text{disc}} = 0.01$, which is the probability of new discoveries observed in the data after excluding subsequent discoveries in the same country.[32] I set the waiting time between discovery and production to $T_{\text{wait}} = 5$, which is the average lag observed in the data, and the probability of exhaustion to $\pi_{\text{ex}} = 0.02$ for an average life of 50 years for a discovered large field.

The net present value of an oil discovery as a percentage of nominal GDP in the steady state is:

$$NPV_{ss} = 100 * \frac{\sum_{s=0}^{50} \left(\frac{1}{1+r_{ss}}\right)^{s+T_{\text{disc}}+1} p_{oil,ss} \left[f^{oil}\left(k_{oil,ss}, n_H\right) - f^{oil}\left(k_{oil,ss}, n_L\right)\right]}{GDP_{ss}}$$

where $p_{oil,ss} = z_{ss} = 1$ and $r_{ss} = 0.069$ is the interest rate consistent with a target for spreads of 2.9% (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 $n_H = 0.51$ so that $NPV_{ss} = 18\%$, which is the average NPV of the discoveries studied in Section (2).

Table 2 summarizes the parameters calibrated by simulating the model. This calibration con-

[32] I consider oil discoveries in countries that had not had a discovery in the previous 6 years. The reason to do this is that the model does not accommodate subsequent discoveries. The unconditional probability of discovery in the data is 0.045. The main results of the paper remain unchanged if this probability was used instead.

siders 50 periods of 100 simulated economies in their ergodic state with $n = n_L$. That is, economies in their ergodic state without any oil discoveries during the sampled period, like Mexico in the data.

Table 2: Parameters calibrated simulating the model

Parameter		Value	Parameter		Value
discount factor	β	0.8775	default cost	d_0	-0.16
capital adjustment cost	ϕ	2.0	default cost	d_1	0.222

Moment	Data	Model
average spread (percentage)	2.9	2.7
$\sigma_{cons}/\sigma_{GDP}$	1.0	1.1
$\sigma_{inv}/\sigma_{GDP}$	3.0	3.1
public external debt-to-GDP ratio	0.15	0.14

Moments are computed by generating 100 samples of 550 periods and considering only the last 50 observations. Only samples with no oil discoveries in the last 50 periods are considered.

There are four parameters chosen to match four moments from the data: the average spreads, the volatility of consumption relative to the volatility of GDP, the volatility of investment relative to the volatility of GDP, and the public external debt-to-GDP ratio. The value of the discount factor β mainly determines the debt-to-GDP ratio; average spreads and relative consumption volatility 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 $r_t = \frac{\gamma - \gamma q_t}{q_t}$. Data of external public debt-to-GDP ratio are from the World Bank (2013). 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 consumption and investment I use HP-filtered data of the log of real consumption, investment and GDP from Mexican national accounts and compute the standard deviation of their cyclical components. In the model, I compute real consumption, investment, and GDP by dividing by the GDP deflator $\frac{P_t c_t}{\tilde{p}_t}$, $\frac{P_t\left(i_t + i_{oil,t}\right)}{\tilde{p}_t}$, and $\frac{P_t GDP_t}{\tilde{p}_t}$. I apply the HP-filter to the log of the series and compute the standard deviation of the cyclical components.

The following subsection 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.

4.3 Model fit

Default episodes 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 0.12.[33] Considering only ten-year periods that follow a giant oil discovery, this probability is 0.18. In the model these probabilities are 0.11 and 0.14, respectively. To compute the model probabilities I simulate an economy for 100,500 periods, drop the first 500, and use the data for all default episodes and those that happen in the 10 years that follow an oil discovery.

Non-targeted business-cycle moments.—Table 3 shows business-cycle moments that are not targeted. The model does a good job in generating counter-cyclical trade balances and current accounts, as well as their relative variances *vis-a-vis* GDP. The model generates spreads that are slightly less volatile than those in the data.[34]

Table 3: Untargeted moments

Moment	Data	Model
st. dev. of spreads (percentage)	1.3	0.7
σ_{TB}/σ_{GDP}	0.5	0.6
σ_{CA}/σ_{GDP}	0.5	0.9
$\text{corr}\left(\frac{CA}{GDP}, GDP\right)$	-0.6	-0.4
$\text{corr}\left(\frac{TB}{GDP}, GDP\right)$	-0.3	-0.4

Moments are computed by generating 100 samples of 550 periods and considering only the last 50 observations. Only samples with no oil discoveries in the last 50 periods are considered.

Estimated responses to oil discoveries.—In order to assess the model's ability to explain the responses to oil discoveries observed in the data, I simulate a panel of economies and run the same

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

[34] In the model, the current account is defined as the change in the net foreign asset position, which is $ca_t = -(b_{t+1} - b_t)$.

regressions as in Section 2.

The model-generated panel data consist of 50 periods and 100 economies. Each economy $i = 1 \dots 100$ is simulated for 550 periods and then the first 500 periods are dropped to remove any dependence from initial conditions. All 100 economies face the same shocks to oil prices $\left\{p_{oil,t}\right\}_{t=1}^{550}$ and are ex-ante identical. Heterogeneity arises from different realizations of productivity shocks $\tilde{z}_i = \{z_{i,t}\}_{t=1}^{550}$ (which generate different choices $\left(d_{i,t}, k_{i,t}, k_{oil,i,t}, b_{i,t}\right)$) and, most importantly, because some economies experience oil discoveries during the sample period and some do not. If economy i discovers an oil field in period t, I compute the net present value $NPV_{i,t}$ as:

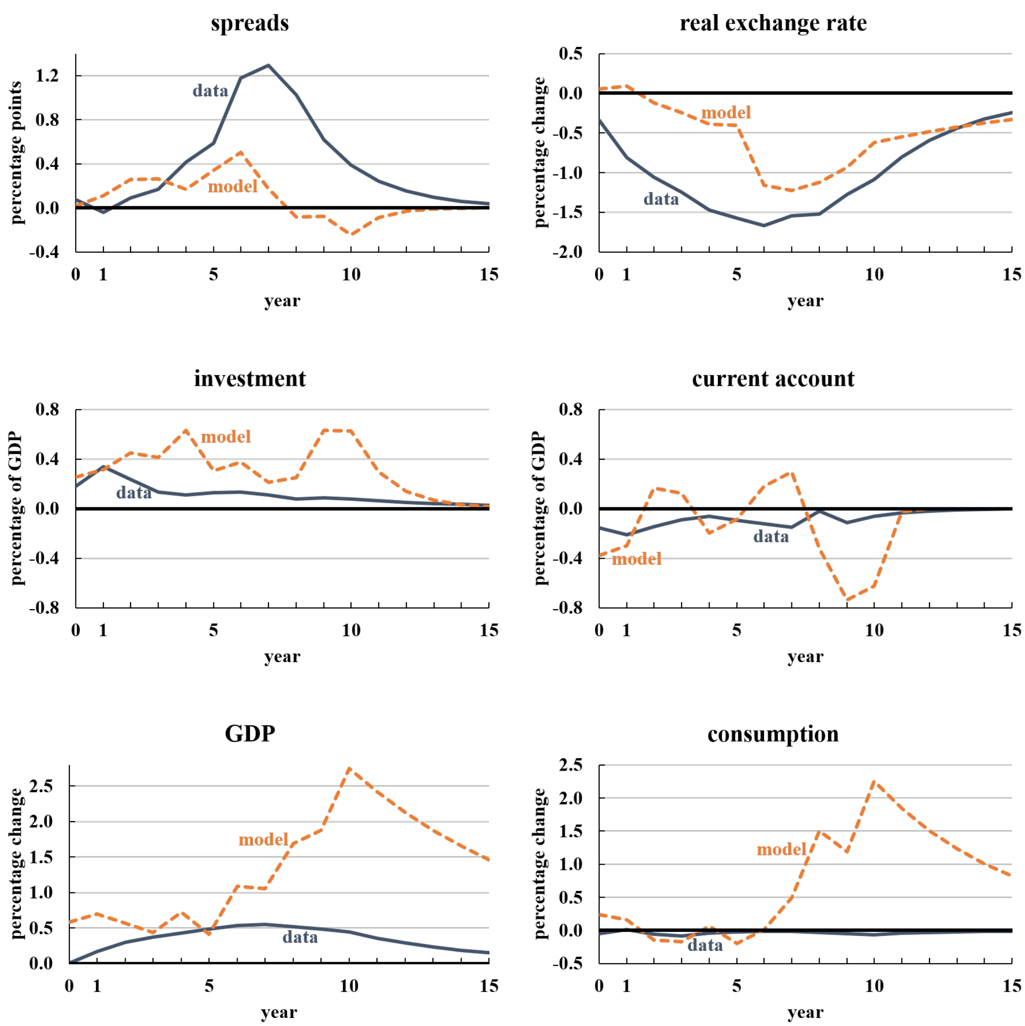
$$NPV_{i,t} = 100 * \frac{\sum_{j=0}^{50} \left(\frac{1}{1+r_{i,t}}\right)^{s+T_{\text{disc}}+1} p_{oil,t} \left[f^{oil}\left(k_{oil,i,t}, n_H\right) - f^{oil}\left(k_{oil,i,t}, n_L\right)\right]}{GDP_{i,t}}$$

where $r_{i,t} = \frac{\gamma - \gamma q_{i,t}}{q_{i,t}}$ is the interest rate that country i faces in period t, with $q_{i,t} = q\left(s_{i,t}, k'_{i,t}, k'_{oil,i,t}, b'_{i,t}\right)$. Note that even though n_H and n_L are fixed, there is vast heterogeneity in the $NPV_{i,t}$ generated by the model. This is because, by construction, the $NPV_{i,t}$ (both in the model and in the data) is not only a measure of the quantity of oil in the ground, but also a measure of the relative increase in permanent income that the discovery implies for the country in question. For instance, a discovery when the price $p_{oil,t}$ is relatively high will have a much larger net present value than when the price is low. Similarly, a discovery in a country with relatively high default risk (high $r_{i,t}$) will have a lower net present value because high interest rates hamper the country's ability to transform income from future oil revenues into present consumption.

I use the model simulated data to estimate the coefficients in equation (2) using spreads, total investment, the current account, the real exchange rate, GDP, and consumption as dependent variables. I then use these coefficients to construct impulse-response functions like the ones in Figures 3, 4, and 5.

Figure 6 compares the impulse-response functions estimated with model and actual data. The model's ability to qualitatively reproduce these untargeted responses is remarkable. Following a discovery, spreads steadily increase and peak around the year when production starts. Investment immediately increases and this increase is accompanied by a current account deficit of similar magnitude. The real exchange rate appreciates and both GDP and consumption increase.

Figure 6: Impulse-response functions to a giant oil discovery of median size



The solid blue lines correspond to the data, where the median net present value of oil discoveries is 4.5 percent of GDP. The dotted orange lines correspond to the model, where the median and average net present value of oil discoveries is 18 percent of GDP.

Quantitatively, however, the responses of spreads and the real exchange rate in the model fall short, while the responses of GDP and consumption are overstated. It is important to note that the main objective of this quantitative exercise is not to adjust the model to exactly fit these responses, but rather to asses if the directions of the responses jointly generated by the model are consistent with those from the data.[35] The remainder of this subsection discusses some possible explanations for the main quantitative discrepancies and points to inefficiencies that are not present in the model

[35]For example, lower GDP, lower spreads, lower investment, or a real exchange rate depreciation would be more concerning results.

that could reconcile them. However, exploring the plausibility and quantitative implications of such inefficiencies is beyond the scope of this paper since they would amplify an effect that the parsimonious model from Section 3 already captures.

In the data, spreads increase by up to 1.3 percentage points, but only by up to half a percentage point in the model. It is important to note that the model data is a panel of the same country in different states (a "panel of Mexicos" with different histories of shocks). In the data, however, there is richer heterogeneity related to the primitives of the economy (countries face different productivity processes and may have governments with different levels of impatience and different costs to default). While Mexico is indeed a typical emerging economy, these other dimensions of heterogeneity could introduce higher responses of spreads. Also, the government in the model has the ability to exactly pin down all investment and borrowing allocations, which in turn affect the interest rate the government faces. If investment was chosen by the private sector there could be a pecuniary externality from private investors not internalizing the effect that their decisions have on the interest rates that the government faces. This inefficiency could also amplify the response of spreads.

In the model, the real exchange rate is the reciprocal of the GDP deflator $\tilde{p}_t$. In both the model and the data the real exchange rate appreciates following an oil discovery. 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 within the same period.

Regarding GDP, the increase in the model is moderate the years right after a discovery is announced and much larger once production in the oil field starts. This is consistent with what Arezki, Ramey, and Sheng (2017) find in the data for a larger set of countries. 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. The response of GDP in the model is also much larger than the response in the data. One possible reason for this large effect could be due to inelastic labor supply. Arezki, Ramey, and Sheng (2017) find that hours decline following oil discoveries, which could be generated by a model with separable preferences for leisure. In addition, an environment with rent-seeking agents running the government like the one studied in Tornell and Lane (1999) could generate a lower response of GDP. In their model, a "voracity effect" generates a more-than-proportionate increase in rent-extracting fiscal redistribution as a response to a terms of trade windfall. This redistribution hampers investment and limits GDP growth.

Finally, consumption in the model starts increasing only after production in the oil field starts, while the data show weak evidence of any movement at all.[36] On average, the government in the model cannot smooth consumption too much before production starts because the debt level is already too high in the ergodic state. In other words, borrowing to consume is already too expensive.

4.4 Discussion of assumptions and mechanism

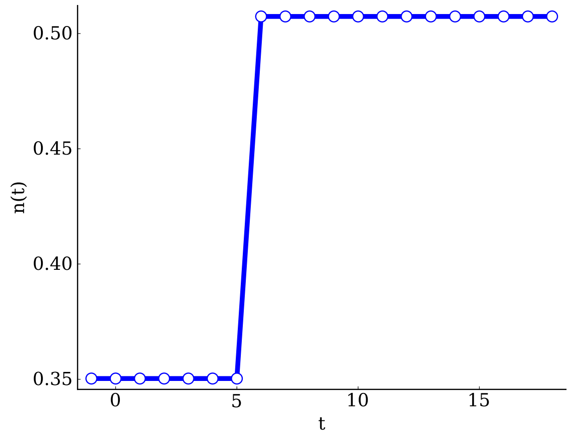
There are four key assumptions in the model that allow it to produce similar responses to oil discoveries as we observe in the data: (i) capital adjustment costs, (ii) production of non-traded goods, (iii) high volatility of the international price of oil, and (iv) long-term debt. This Subsection discusses 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 (as well as higher future borrowing) affects the spreads in all the preceding periods, starting with the period when the information of a discovery arrives and being more affected once production in the new field is about to start.

Throughout this Subsection, I use the equilibrium policy functions and price defined in Subsection 3.3 that result from the calibration described in Subsection 4.2. I look at the path of different endogenous variables in the twenty periods following an oil discovery. For illustrative purposes, I fix the productivity shock at its mean value ($z_t = \mu_z = 1$) and consider three paths for the price

[36]Recall that consumption in the data includes both private and public consumption, the latter having potentially a lot of measurement error, in particular from unreported public transfers (see Esquivel, Kehoe, and Nicolini (2020) for a discussion of such transfers during different economic crises in Latin America).

of oil: one with the price fixed at its mean $p_{oil,t} = \mu_p = 1$, another with a the price of oil fixed at the mean minus one standard deviation $p_{oil,t} = \mu_p - \sigma_p$ and one with $p_{oil,t} = \mu_p + \sigma_p$. Given an oil discovery in $t = 0$, the path of the size of the available oil field in the economy is depicted in Figure 7.

Figure 7: Transition of size of oil field n_t

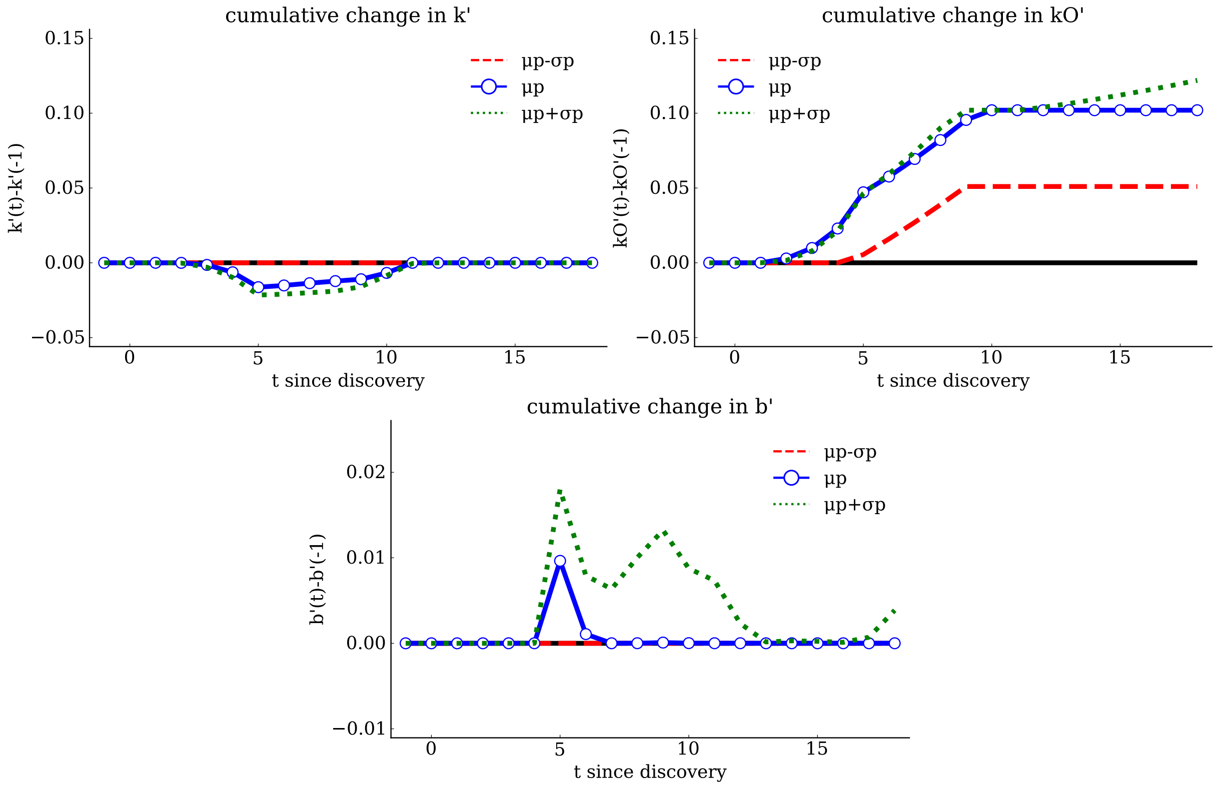


In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

To ease notation, let $\tilde{s}(p) = \{(\mu_z, p, \min\{t, 6\})\}_{t=-1}^{20}$ be the path of the exogenous states given a level for the price of oil. Similarly, let $x_t = \left(d_t, k_{t+1}, k_{oil,t+1}, b_{t+1}\right)$ be the vector of policies in period t and $\tilde{x}(p, x_{-2}) = \left\{\left(d_t, k_{t+1}, k_{oil,t+1}, b_{t+1}\right)\right\}_{t=-1}^{20}$ be the path of policies that correspond to $\tilde{s}(p)$ and some initial state x_{-2}. Given a price p, the initial state of x_{-2} is the resulting values of policies after simulating 500 periods keeping all shocks equal to $(\mu_z, p, -1)$.

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 $T_{\text{wait}} + 1$. Thus, the government will want to have a higher level of installed capital for the oil sector k_{oil} by then. 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 absence of adjustment costs, all the additional capital in the oil sector would be installed in period T_{wait} in the model. The quadratic capital adjustment costs incentivize the government to smooth this investment through the preceding periods. Figure 8 shows the cumulative change the stock of debt b and the two stocks of capital, k and k_{oil}, from paths $\tilde{x}(\mu_p - \sigma_p)$, $\tilde{x}(\mu_p)$, and $\tilde{x}(\mu_p + \sigma_p)$.

Figure 8: Transition of borrowing and investment

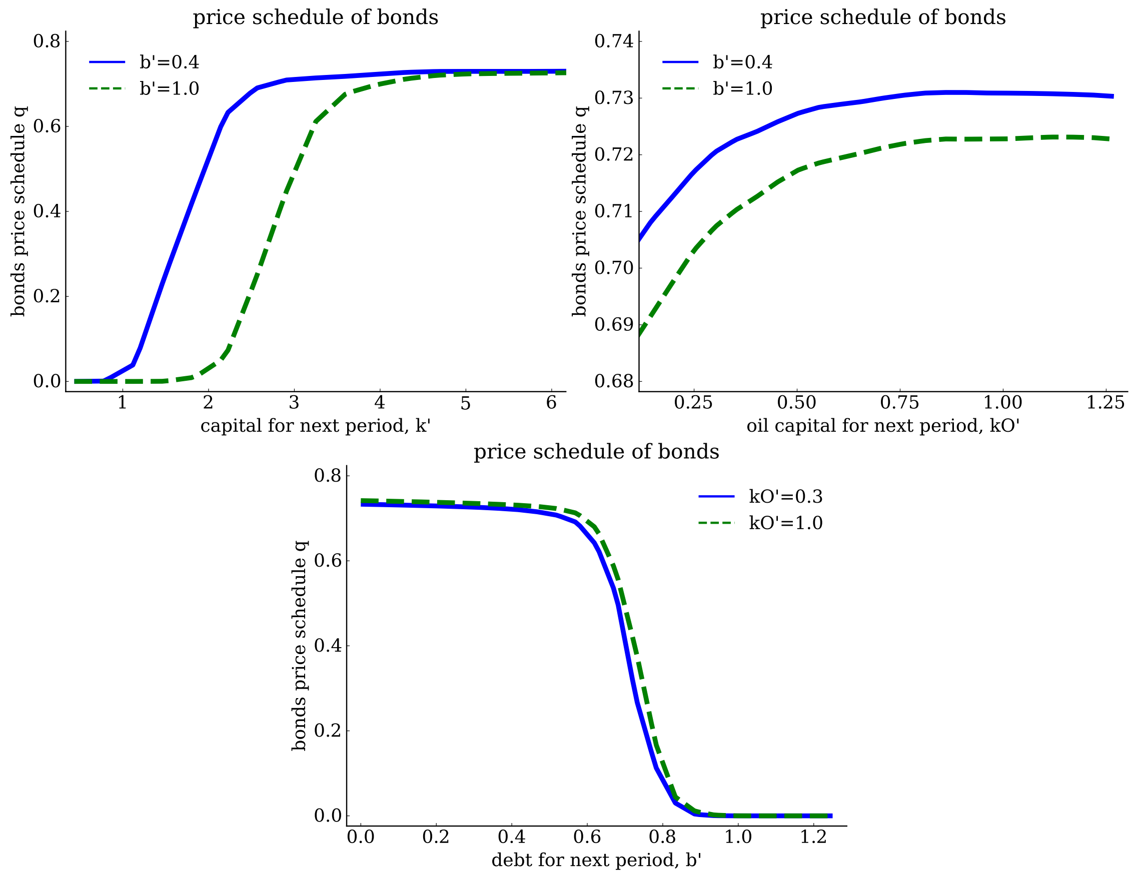


The productivity shock is fixed at its mean value. The three lines in each plot correspond to paths with the price of oil kept fixed at one standard deviation below its mean (red dashed line), at its mean (blue line), and one standard deviation above mean (green dotted line). The values are the change with respect to period $t = -1$. In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

First, note that when the price of oil is relatively low (the red dashed lines) there is no anticipation effect: oil in the capital sector starts to increase only after the larger field becomes available and there is no change to the stock of capital for the other sectors or to debt. For higher prices, however, the government wants to install more capital in the oil sector at a faster pace in order to take advantage of possible higher prices immediately in $t = T_{\text{wait}} + 1$ (recall that the price of oil is highly persistent). In period $t = 2$, the stock of capital in the oil sector starts to increase at the expense of the stock of capital in the other sectors. This increase accelerates as $T_{\text{wait}} + 1$ approaches and, by period $t = T_{\text{wait}}$, the cost of installing the desired k_{oil} at the expense of k surpasses the cost of borrowing to invest, so the government starts to borrow. Borrowing is higher the higher the current price of oil is.

Borrowing increases spreads while investment, in general, reduces them. Figure 9 illustrates this by showing the equilibrium price schedule of government bonds as a function of next period capital k', next period oil capital k'_{oil}, and next period debt b' (both productivity and the price of oil are set equal to their mean and $\chi = -1$, which corresponds to $n = n_L$ and no discovery).

Figure 9: Bonds price schedule



These graphs show the price function of bonds 11 using the parameter values from Section **??** evaluated at the mean of the productivity and price of oil shocks and at the small oil field n_L. The top-left graph depicts the price of bonds as a function of capital in the next period k', for high and low values of issued debt. The top-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 botton graph shows 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 bottom panel shows how, given a level of investment in both types of capital, higher levels of next-period debt reduce the market price of bonds, which is the standard effect in this class of models.[37] The top-left and top-right panels show that, given a level of debt issued, the price of bonds is increasing in both capital and oil capital for the next period. This implies that higher levels of both types of capital help sustain higher levels of debt.

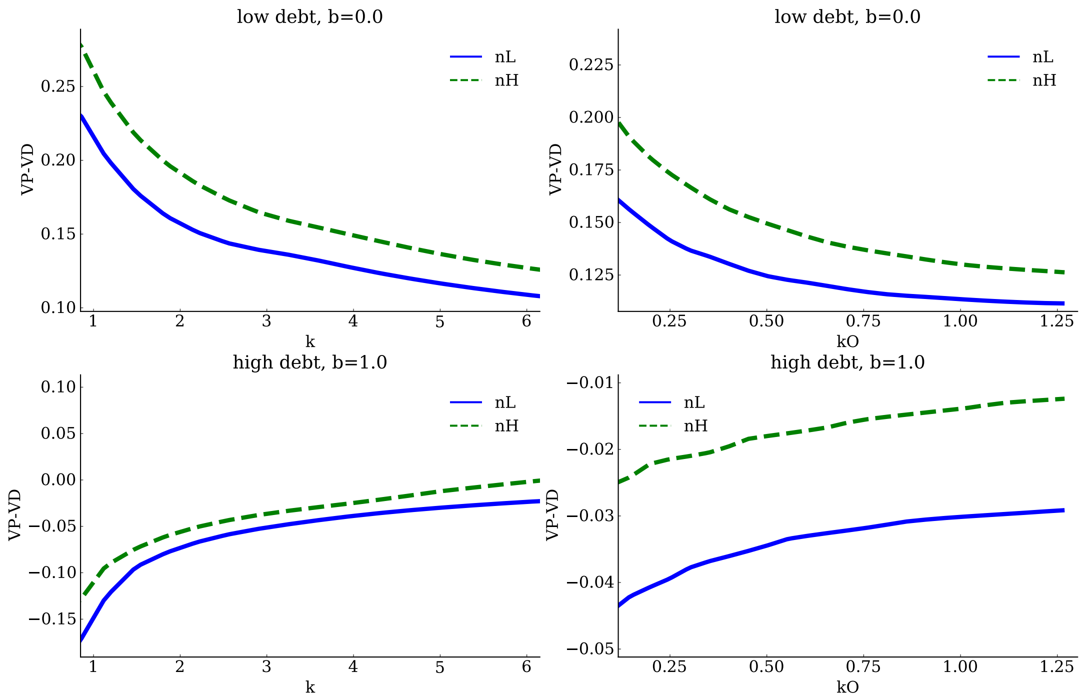
Capital, oil fields, and default incentives.—As Gordon and Guerron-Quintana (2018) show, capital can cause a tension in default incentives. On one hand, more capital gives the government

[37] As described in Section 4.2, 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 $r_t = \frac{\gamma - \gamma q_t}{q_t}$

the ability to avoid default in bad times because it increases the ability to repay debt; on the other, higher levels of capital increase the value of default V^D in the future, which in turn could increase the default set and spreads in the current period. Capital also increases the future value of repayment V^P, so an increase in default sets depends on whether each additional unit of capital increases or decreases the gap between V^P and V^D.

Figure 10 illustrates how this gap changes with both types of capital for different levels of debt issued b and for small and large available oil fields $n = n_L$ and $n = n_H$.

Figure 10: Gap between value of repayment and default



These graphs show the difference between the value of repayment V^P and the value of default V^D as a function of both types of capital. In each of the four graphs, the value functions are evaluated at the mean of the productivity and price of oil shocks. The blue solid lines correspond to the value functions evaluated at the small oil field n_L and the green dashed lines at the large oil field n_H. The top graphs correspond to the value functions evaluated at a low value of debt and the bottom at a high value. The graphs on the left correspond to the value functions evaluated at the average level of oil capital k_{oil} and the right graphs to the value functions evaluated at the average level of capital k.

For low levels of debt (the top graphs), the gap between V^P and V^D is positive and decreasing. This means that, even though the government prefers to repay its debt, the incentives to do so are decreasing in both stocks of capital since more capital improves the value of autarky more than it improves the value of repayment. The two bottom graphs show that the opposite is true for high levels of debt. For a highly indebted government, the effect of capital on default incentives is mostly driven by the higher ability to repay and not by higher value of autarky.[38] Finally, note that, for the calibration in Subsection 4.2, a larger oil field increases the incentives to repay regardless of the level of debt or capital in the economy. This is illustrated by the fact that the green dashed lines are always above the blue solid lines.

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:

$$\left(\frac{\alpha_M}{\alpha_N}\frac{(k-k_M)^{1-\alpha_N}}{(k_M)^{1-\alpha_M}}\right)^{\eta} z\,(k-k_M)^{\alpha_N} = \frac{\omega_N\left[z{k_M}^{\alpha_M} + p_{oil}y_{oil} - X\right]}{\omega_M + \omega_{oil}\,(p_{oil})^{1-\eta}} \tag{12}$$

where $X = \gamma b - q(\cdot)\left[b' - (1-\gamma)\,b\right]$ is payment to foreigners of debt principal and interests net of new debt issuance, and y_{oil} is oil production given (k_{oil}, n). Note that the right-hand side of equation 12 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) increases y_{oil} and lowers the equilibrium allocation of capital into the manufacturing sector. This is strengthened if k_{oil} also increases.

An intuitive interpretation of the economic forces driving this reallocation can be drawn from the version of equation (12) in a decentralized economy:

$$p_N z k_N^{\alpha_N} = \frac{\omega_N\,(p_N)^{1-\eta}\left[z k_M^{\alpha_N} + p_{oil}y_{oil} - X\right]}{\omega_M + \omega_{oil}\,(p_{oil})^{1-\eta}} \tag{13}$$

where p_N is the price of the non-traded intermediate good. Equation (13) shows that expenditure in the non-traded intermediate good ($c_N = z k_N^{\alpha_N}$) is tradable income net of debt payments scaled by a factor that depends on relative prices and consumption shares. 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.

[38] See Gordon and Guerron-Quintana (2018) for a deeper discussion of this point.

Volatility of tradable income.—Recall that the balance of payments is:

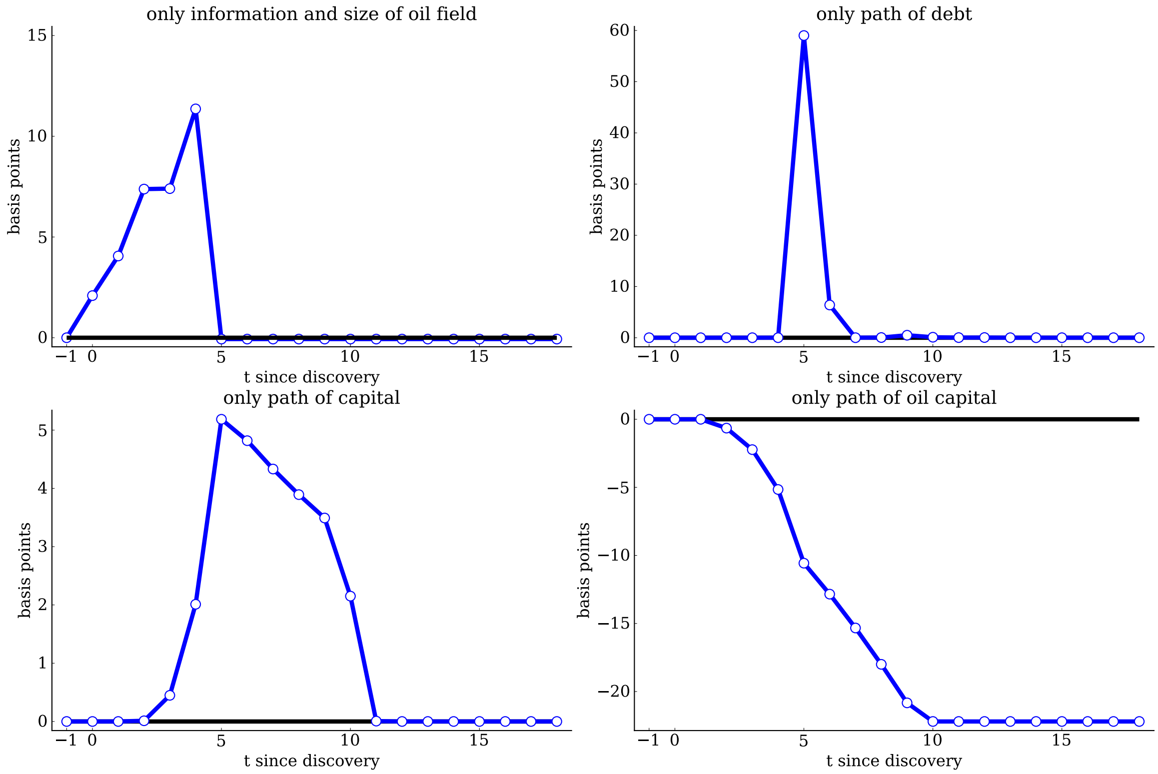
$$\gamma b - q(\cdot)\left[b' - (1-\gamma)b\right] = x_M + p_{oil}x_{oil} \tag{14}$$

where $x_M = zk_M^{\alpha_N} - c_M$ and $x_{oil} = y_{oil} - c_{oil}$ are net exports of manufactures and oil, respectively. Net debt payments to the rest of the world (left-hand-side of 14) have to be financed with net exports of tradable goods. As discussed above, a larger oil field n_H and higher capital in the oil sector k_{oil} imply a higher oil production and lower production of manufactures. These effects make the right-hand-side of 14 more volatile since it is now more exposed to swings in p_{oil} and less exposed to productivity shocks z, which have a much lower variance. This endogenous increase in volatility explains why, even though the price of bonds is increasing in both types of capital (Figure 9), it is much less increasing in capital for the oil sector, since the effect of higher ability to repay (by having a higher level of oil income) is hampered by the higher implied volatility of tradable income.

Slow adjustment of spreads.—Note that the larger oil field only becomes available in period $T_{\text{wait}}+1$. This directly affects the price function of bonds from the perspective of period T_{wait}. However, if the debt is long-term (i.e. $\gamma < 1$), a change in the price of bonds in T_{wait} affects the price of bonds in $T_{\text{wait}}-1$, as can be seen in equation (11). Note that, following the same logic, future borrowing and investment decisions affect current bond prices and spreads.

In order to illustrate this, the top-left panel of Figure 11 shows the path of spreads following $\tilde{s}(p=\mu_p)$ with all policies fixed at their initial values $\left(d_{-1}, k_0, k_{oil,0}, b_0\right)$. Spreads increase in period 4 because debt is expected to either increase (for high levels of p_{oil}) or remain the same (for low levels of p_{oil}) in period 5, as can be seen in the lower panel of Figure 8. This is the "debt dilution" effect present in models with long-duration bonds studied in Hatchondo, Martinez, and Sosa-Padilla (2016).

Figure 11: Decomposition of the cumulative change in spreads

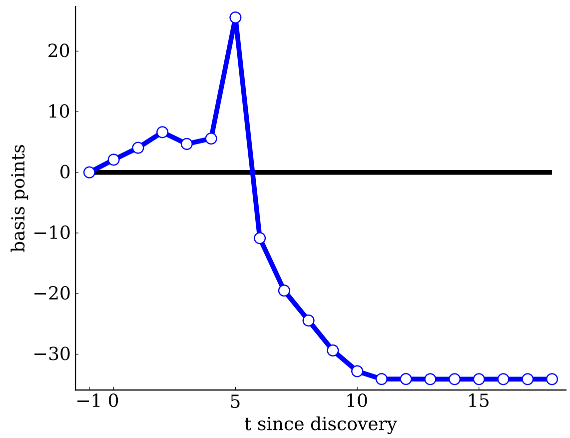


All shocks are kept fixed at their mean value. The values are the change with respect to period $t = -1$. In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

The other three panels show the path of spreads if there was no oil discovery but if each of the policies followed the path described by $\tilde{x}(\mu_p)$ (the solid blue lines in Figure 8). The bottom-left panel considers only the path of capital, whose decrease implies an increase in spreads. The top-right panel considers only the path of debt, which implies no change in spreads until period $t = 5$, when they increase 60 basis points because additional debt is issued. The bottom-right panel considers only the path of oil capital and shows how investment in this sector steadily decreases spreads by up to 20 basis points. The top- and bottom-right panels stress the tension between higher spreads due to higher borrowing and lower spreads due to higher future income from investment in the oil sector.

Finally, Figure 12 depicts the actual change in spreads throughout the transition, considering all shocks and policies. Spreads steadily increase during the years following the announcement of the discovery and sharply decrease once production starts.

Figure 12: Actual cummulative change in spreads



All shocks are kept fixed at their mean value. The values are the change with respect to period $t = -1$. In period $t = 0$ news about an oil discovery arrives, the larger oil field becomes available in period $t = 6$.

There are two reasons for the decrease in spreads after period $T_{\text{wait}} + 1$: investment in the oil sector continues to increase and borrowing stops.

4.5 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, I take as a starting point a draw from the ergodic distribution of endogenous and exogenous states without an oil discovery. Let $\tilde{s}_i^{-1} = \left\{s_t^{-1}\right\}_{t=1}^{500}$ be the ith sequence of 500 periods of shocks $s_{i,t}^{-1} = \left(z_{it,}^{-1}, p_{oil,i,t}^{-1}, -1\right)$ with no oil discoveries and consider a sequence of policies $\tilde{x}_i^{-1}\left(\tilde{s}_i^{-1}\right) = \left\{\left(d_{i,t}^{-1}, k_{i,t+1}^{-1}, k_{i,oil,t+1}^{-1}, b_{i,t+1}^{-1}\right)\right\}_{t=1}^{T}$ generated by these shocks and the policy functions of the government. A starting point $(s_{i,-1}, x_{i,-1})$ is the tuple of the final elements of $\tilde{s}_i^{-1}$and $\tilde{x}_i^{-1}\left(\tilde{s}_i^{-1}\right)$.

Then, given a starting point $(s_{i,-1}, x_{i,-1})$, consider two series of $T = 100$ shocks: (i) one with an oil discovery in period $t = 0$, that is $\tilde{s}_i^d = \left\{s_{i,t}^d\right\}_{t=0}^T$, $s_{i,t}^d = \left(z_{i,t}, p_{i,oil,t}, \min\{t, 6\}\right)$; and (ii) one without an oil discovery $\tilde{s}_i^{nd} = \left\{s_{i,t}^{nd}\right\}_{t=0}^T$, $s_{i,t}^{nd} = \left(z_{i,t}, p_{i,oil,t}, -1\right)$. Note that both $\tilde{s}_i^d$ and $\tilde{s}_i^{nd}$ contain the same series of shocks to productivity and the price of oil, the only difference is the discovery in $t = 0$. Using the states generated by $\tilde{s}_i^d$ and $\tilde{s}_i^{nd}$, and the policy functions of the government, I generate the sequences of consumption with and without discovery, $\tilde{c}_i^d = \left\{c_{i,t}^d\right\}_{t=0}^T$ and $\tilde{c}_i^{nd} = \left\{c_{i,t}^{nd}\right\}_{t=0}^T$, respectively.

Finally, I take $N = 1000$ of these consumption sequences $C = \left\{\tilde{c}_i^d, \tilde{c}_i^{nd}\right\}_{i=1}^N$ and define:

$$W_D(C) = \mathbb{E}\left[\sum_{t=0}^{\infty} \beta_{hh}^t u\left(c_t^d\right)\right] \approx \sum_{t=0}^{T} \frac{1}{N} \sum_{i=1}^{N} \beta_{HH}^t u\left(c_{i,t}^d\right)$$

$$W_{ND}(C, \lambda) = \mathbb{E}\left[\sum_{t=0}^{T} \beta_{hh}^t u\left((1+\lambda) c_t^{nd}\right)\right] \approx \sum_{t=0}^{T} \frac{1}{N} \sum_{i=1}^{N} \beta_{HH}^t u\left((1+\lambda) c_{i,t}^{nd}\right)$$

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

$$\lambda^\star = \left(\frac{W_D}{W_{ND}}\right)^{\frac{1}{1-\sigma}} - 1$$

where $1/\sigma$ is the elasticity of intertemporal substitution.

Under the calibration in Subsection 4.2, the welfare gains of discovering oil are of $\lambda^\star = 0.021$. That is, discovering a giant oil field is equivalent to giving the household a permanent increase in consumption of 2.1 percent.

4.6 Volatility, options, and impatience

It is no surprise that giant oil discoveries generate welfare gains since they are positive shocks to permanent income. However, they are also followed by higher volatility of tradable income and consumption, and a higher probability of experiencing costly default episodes, which suggest that these gains could be higher.

In order to explore how large these foregone welfare gains are, I analyze three counterfactual exercises. The first is the *no-price-volatility* case, which considers an environment where the price of oil is fixed at $p_{oil,t} = 1$. The second is the *options* case, in which I assume the price of oil fluctuates as in the benchmark case, but the government always has the option to sell its oil production at either the realized international price $p_{oil,t}$ or at a given predetermined option price $\hat{p}_{oil} = 1$. Effectively, the government sells its oil production for $p = \max\left\{p_{oil,t}, \hat{p}_{oil}\right\}$. Finally, I consider the *patient* case, in which the environment is identical to the benchmark case but the discount factor of the government is closer to that of the household $\hat{\beta}_{GG} = 0.92$ (the average between $\beta_{HH} = 0.96$ and the benchmark $\beta_{GG} = 0.8775$).

Columns (1) and (2) in Table 4 report default probabilities over all periods and right after oil discoveries for the benchmark economy and all counterfactual cases. Columns (3) and (4) report the standard deviation of consumption for economies with a small ($n = n_L$) and with a large oil field ($n = n_H$), respectively. Columns (5) and (6) do the same comparison for the standard deviation of total tradable income $y_T = y_M + p_{oil}y_{oil}$. I take natural logarithms and use the cyclical component of the HP-filter applied to all series of consumption and tradable income.

Table 4: Default and volatility after oil discoveries

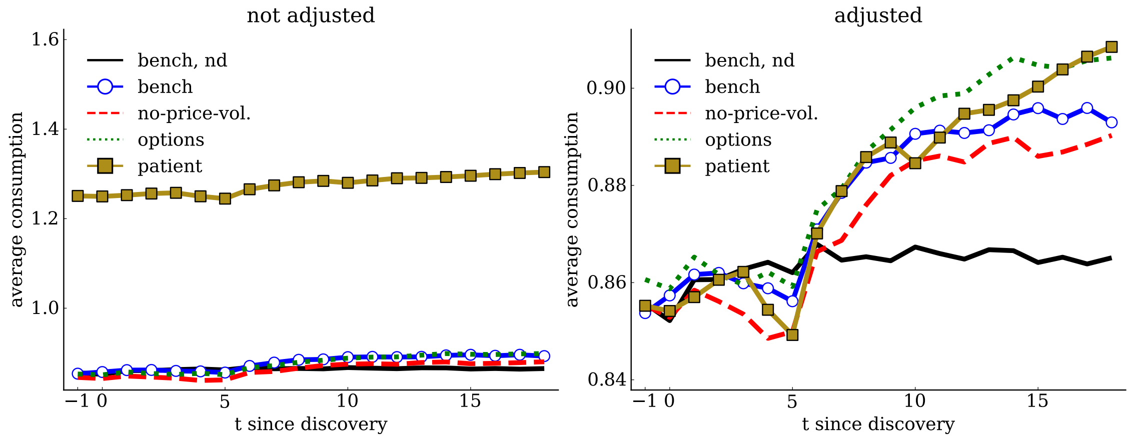
	default probability (10 years)		σ_c		σ_{y_T}	
	any	after discovery	small field	large field	small field	large field
	(1)	(2)	(3)	(4)	(5)	(6)
benchmark	0.115	0.143	2.1	2.2	4.2	4.9
no-price-volatility	0.108	0.136	2.1	1.9	1.6	1.5
options	0.134	0.154	2.1	2.1	4.2	4.9
patient	0.0066	0.0071	2.1	2.1	3.3	3.9

To compute default probabilities I simulate an economy for 100500 periods and drop the first 500. Using the data for all default episodes, the default probability in any 10 years reported in Column (1) is $1 - Pr(\text{no default in 10 years})$, where $Pr(\text{no default in 10 years}) = [1 - Pr(\text{default})]^1 0$. Column (2) reports the same calculation considering only data for ten-period windows that follow an oil discovery. To compute the standard deviations of consumption and total tradable income in columns (3) and (5), I simulate 100 economies with $n = n_L$ for 600 periods, I drop the first 500 and use the remaining data. For Columns (4) and (6) I follow the same procedure but set $n = n_H$. I take natural logarithms and use the cyclical component of the HP-filter applied to all series of consumption and tradable income.

Default events are more likely during the ten years that follow an oil discovery in all cases (even though default events are extremely rare in the *patient* case). Note that default probabilities, and their increase following oil discoveries, are very similar in the benchmark and the *no-price-volatility* case. Since the price of oil is fixed, tradable income is less volatile (columns (5) and (6)), which implies smaller default sets and more favorable borrowing terms for the government. However, the impatient government chooses higher borrowing until it becomes too costly under the more favorable price schedule. This is why default probabilities are still high in the benchmark, *no-price-volatility*, and *options* cases. It does not matter if the government is able to hedge against fluctuations in the price of oil, impatience drives high borrowing and default.

Before comparing welfare gains of discoveries in the different counterfactual cases, it is important to note that a more patient government chooses to accumulate higher levels of both types of capital. This higher accumulation yields higher levels of output and consumption, regardless of the size of the available oil field. The left panel in Figure 13 depicts the average path of consumption after an oil discovery in $t = 0$ in the benchmark and all three counterfactual cases. 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 i, of consumption without discovery in the benchmark case. Similarly, let $\bar{c}^{nd}_{\text{no-pr-vol}}$, $\bar{c}^{nd}_{\text{options}}$, and$\bar{c}^{nd}_{\text{patient}}$ be the corresponding averages for the *no-price-volatility*, *options*, and *patient* cases, respectively. Given an observation of consumption from each of the counterfactual cases $c^m_{t,i}$, with $m \in \{\text{no-pr-vol}, \text{options}, \text{patient}\}$, I define its adjusted counterpart as $\hat{c}^m_{t,i} = c^m_{t,n} + \left(\bar{c}^{ND}_{\text{bench}} - \bar{c}^{ND}_m\right)$. I do this adjustment for the simulated consumption series in all three counterfactual cases with and without discoveries. The right panel in Figure 13 shows the adjusted average consumption paths after an oil discovery in $t = 0$.

Figure 13: Average path of consumption after an oil discovery in $t = 0$



Column (1) in Table 5 reports the welfare gains of oil discoveries in each counterfactual, calculated as described in Subsection 4.5. As expected, oil discoveries yield lower welfare gains in the patient case because consumption parts from a much higher level. Column (2) reports the same calculations, but using the re-scaled consumption series described above, which yield more comparable results.

Table 5: Welfare gains of oil discoveries (percent increase in consumption)

	original	adjusted
	(1)	(2)
benchmark	2.1	2.1
no-price-volatility	2.1	2.1
options	2.5	2.5
patient	1.9	2.7

Welfare gains of oil discoveries in the *no-price-volatility* case are the same as in the benchmark economy, which suggests that losses from higher volatility of consumption are offset by gains from high consumption in states with high oil prices and not-so-low consumption in states with low oil prices (since default is always an option that the government has to avoid even lower consumption in these states). On the other hand, welfare gains are considerably higher in the *options* and *patient* cases (in Column (2)). In fact, they are much closer to each other than to the benchmark case. This suggests that giving the impatient government access to insurance against low realizations of the price of oil brings almost as many welfare gains as institutional changes that would make the government less impatient, which are likely less feasible to implement.

It is important to note that, while the responses in Figure 6 qualitatively match the data (i.e. the direction is correct), some magnitudes do not match well. As mentioned before, several refinements to the model —like elastic labor supply or investment inefficiencies —could improve this match, which would in turn change the magnitude of the welfare gains reported in Table 5. However, what is interesting from these welfare exercises is not the actual magnitude of the gains, but rather the comparison among the different scenarios. This comparison is unlikely to change since it is mostly driven by the endogenous changes in income volatility and government impatience, which are the key elements the model is already capturing.

Finally, I do a welfare decomposition similar to the one presented in Aguiar, Amador, and Fourakis (2020) in order to quantify the foregone welfare gains of oil discoveries due to government impatience and the incremental gains from insuring against low realizations of the oil price. Following the notation in Subsection 4.5, let $W_D^B = \sum_{t=0}^{T} \frac{1}{N} \sum_{i=1}^{N} \beta_{HH}^t u\left(c_{i,t}^d\right)$ be the value of discovery where $c_{i,t}^d$ are the consumption values from the benchmark economy. Similarly, let W_{ND}^B be the value of no discovery in the benchmark economy, and $\left(W_D^O, W_{ND}^O\right)$ and $\left(W_D^P, W_{ND}^P\right)$ the corresponding values for the *options* and *patient* cases, respectively, using the adjusted consumption series. The welfare gains of an oil discovery can be decomposed as:

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

where $\lambda^\star = 0.021$ are the 2.1 percent welfare gains in the benchmark case. The value $\lambda^P = 0.029$ means that welfare gains could be of 2.9 percent if the government started behaving like in the *patient* case following a discovery. $\lambda^{\text{impatientce}} = 0.008$ indicates foregone welfare gains of 0.8 percent from high indebtedness and costly default episodes during the years that follow an oil discovery, which are driven by government impatience.

The welfare gains of giving the government access to price options after an oil discovery are:

$$\begin{aligned}
\left(1+\lambda^{\text{options}}\right) &= \left(\frac{W_D^B}{W_{ND}^B}\right)^{\frac{1}{1-\sigma}} \left(\frac{W_D^O}{W_D^B}\right)^{\frac{1}{1-\sigma}} \\
&= \underbrace{(1+\lambda^{\star})}_{\text{benchmark gains}} \underbrace{(1+\lambda^{\text{access}})}_{\text{additional gains}}
\end{aligned}$$

where $\lambda^{\text{access}} = 0.005$ and $\lambda^{\text{options}} = 0.026$ indicate that giving the benchmark government access to price options after an oil discovery would yield additional welfare gains of 0.5 percent. These incremental gains are almost as large as the gains from making the government behave more like a patient one. However, institutional reforms to improve the behavior of the government could be infeasible in such a short horizon, while purchasing price options seems to be a more viable alternative.

5 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 median size, sovereign spreads increase by up to 1.3 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. Hedging against the volatility of the price of oil would reduce default sets and improve borrowing terms for the government. However, observed default probabilities and spreads remain high because the impatient government uses the more favorable terms to further increase borrowing.

Oil discoveries generate welfare gains equivalent to a permanent increase in consumption of 2.1 percent, despite the higher frequency of default episodes. The foregone gains due to high government impatience are 0.8 percent. Completely eliminating the volatility of the price of oil has virtually no effect on the welfare gains of oil discoveries because losses from higher volatility of consumption are offset by gains from high consumption in states with high oil prices and not-so-low consumption in states with low oil prices. Insurance against low realizations of the price of oil, like “put” options, yields additional welfare gains of 0.5 percent, which is almost as high as the foregone gains from high impatience.

These results favor policies aimed at limiting arbitrary spending of oil revenue (current and future) such as fiscal rules and sovereign wealth funds. The cases of Norway (for oil) and in Chile (for copper) are examples of successful implementations of these types of policies. Implementing such policies may require costly and lengthy institutional reforms, which may not be feasible for some emerging economies, specially when an unexpected giant oil discovery happens. An important result of this paper is that accessing “put” options yields additional welfare gains of oil discoveries that are almost as large as the foregone gains from government impatience. This result is promising for emerging countries with newly discovered fields because using these financial instruments may be policially more feasible than ambitious fiscal reforms like the ones in Norway or Chile.

An important shortcoming of this paper is that the response of spreads in the model is about half of that in the data. Inefficiencies such as pecuniary externalities in private investment and rent-seeking agents running the government could improve the quantitative performance of the model. Exploring the plausibility and quantitative implications of such inefficiencies is an exciting avenue for future research.

A Data appendix

A.1 Benchmark estimations

Tables A1 and A2 show estimation results for equation (2) in the paper.

Table A1: Estimation 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}	0.626	0.818	0.577	0.807	0.703	0.741
	(0.111)	(0.059)	(0.083)	(0.037)	(0.049)	(0.200)
NPV_t	2.330	4.009	-3.469	0.029	-1.040	-7.596
	(2.905)	(2.534)	(0.640)	(0.535)	(1.072)	(7.769)
NPV_{t-1}	-0.756	4.208	-2.675	3.698	3.007	-12.454
	(3.285)	(2.407)	(1.002)	(1.823)	(2.193)	(14.576)
NPV_{t-2}	4.231	-0.949	-0.594	3.576	-0.700	-10.191
	(4.618)	(0.520)	(0.440)	(1.079)	(1.985)	(20.275)
NPV_{t-3}	4.107	-1.318	-0.112	3.007	-0.229	-10.214
	(5.423)	(0.749)	(0.408)	(0.971)	(1.673)	(17.806)
NPV_{t-4}	8.500	0.021	-0.193	2.904	1.097	-12.294
	(6.340)	(0.274)	(0.478)	(0.792)	(1.659)	(16.665)
NPV_{t-5}	8.978	0.849	-1.298	3.005	0.833	-10.611
	(7.775)	(0.697)	(0.432)	(0.699)	(1.337)	(15.277)
NPV_{t-6}	18.004	0.607	-1.537	3.163	0.039	-11.280
	(9.409)	(0.364)	(0.530)	(0.677)	(1.172)	(13.272)
NPV_{t-7}	11.974	0.028	-1.726	2.604	0.120	-6.809
	(10.694)	(0.519)	(0.674)	(0.618)	(1.189)	(12.179)
NPV_{t-8}	3.860	-0.298	1.455	1.658	-0.458	-8.367
	(7.609)	(0.274)	(0.498)	(0.716)	(0.859)	(10.377)
NPV_{t-9}	-0.441	0.498	-2.242	1.510	-0.618	-3.344
	(1.048)	(0.255)	(0.851)	(0.563)	(0.682)	(8.435)
NPV_{t-10}	0.054	0.155	0.077	1.165	-0.624	-3.108
	(0.819)	(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 columns include country and year fixed effects as well as a constant. All columns 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.

The estimated coefficients in Table A1 are used to construct the impulse-response functions for spreads, investment, the current account, GDP, consumption, and the real exchange rate.[39] Table A2 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 A2: 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)

Robust standard errors for panel regressions with cross-sectional dependence are in parenthesis.

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.

Table A3 presents the estimation results for equation (2) in the paper that generate the impulse-response functions in Figure (4). Column (1) presents the benchmark results, columns (2) and (3)

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

control for contemporaneous and up to ten lags of proved reserves, column (4) presents the results using URR as a measure of the size of a discovery instead of their NPV.

Table A3: Regressions for spreads, main variables, benchmark and robustness

	(1) benchmark	(2) $\log(res_{i,t})$	(3) $\log(res_{i,t-0...10})$	(4) $URR_{i,t}$
y_{t-1}	0.626	0.623	0.574	0.575
	(0.111)	(0.110)	(0.096)	(0.099)
NPV_t	2.330	2.557	3.193	-0.025
	(2.905)	(2.933)	(3.559)	(0.015)
NPV_{t-1}	-0.756	-0.258	7.043	0.014
	(3.285)	(3.602)	(7.214)	(0.015)
NPV_{t-2}	4.231	5.600	16.737	0.040
	(4.618)	(5.530)	(12.051)	(0.038)
NPV_{t-3}	4.107	6.587	23.920	0.036
	(5.423)	(7.319)	(17.777)	(0.024)
NPV_{t-4}	8.500	9.470	26.651	0.052
	(6.340)	(6.793)	(17.117)	(0.028)
NPV_{t-5}	8.978	10.550	28.020	0.065
	(7.775)	(8.767)	(19.415)	(0.045)
NPV_{t-6}	18.004	19.260	20.425	0.168
	(9.409)	(9.288)	(6.009)	(0.051)
NPV_{t-7}	11.974	12.760	8.433	0.099
	(10.694)	(11.126)	(11.391)	(0.062)
NPV_{t-8}	3.860	4.176	-0.171	0.041
	(7.609)	(8.100)	(7.679)	(0.040)
NPV_{t-9}	-0.441	-0.563	-1.187	0.039
	(1.048)	(1.045)	(1.138)	(0.034)
NPV_{t-10}	0.054	0.026	-0.369	0.039
	(0.819)	(0.824)	(0.851)	(0.031)
N	430	421	383	388
within R-squared	0.556	0.561	0.600	0.611

All columns include country and year fixed effects as well as a constant and country specific quadratic trends. All columns 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.

Table (A4) below shows the estimated coefficients for proved reserves and their lags.

Table A4: Effect of reserves, point estimates

	(1) benchmark	(2) $\log(res_{i,t})$	(3) $\log(res_{i,t-0...10})$	(4) $URR_{i,t}$
$\log(res_{i,t})$		0.008	0.0251	0.023
		(0.015)	(0.015)	(0.012)
$\log(res_{i,t-1})$			0.014	0.012
			(0.011)	(0.009)
$\log(res_{i,t-2})$			0.011	0.016
			(0.012)	(0.012)
$\log(res_{i,t-3})$			0.011	0.008
			(0.009)	(0.007)
$\log(res_{i,t-4})$			0.006	0.007
			(0.010)	(0.010)
$\log(res_{i,t-5})$			0.017	0.015
			(0.013)	(0.012)
$\log(res_{i,t-6})$			0.020	0.022
			(0.015)	(0.015)
$\log(res_{i,t-7})$			-0.004	-0.004
			(0.018)	(0.018)
$\log(res_{i,t-8})$			-0.017	-0.013
			(0.013)	(0.013)
$\log(res_{i,t-9})$			-0.009	-0.010
			(0.006)	(0.006)
$\log(res_{i,t-10})$			0.001	0.002
			(0.006)	(0.006)

Robust standard errors for panel regressions with cross-sectional dependence are in parenthesis.

A.2 Estimations without interaction control variables

Table A5 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 A5: Estimation of main variables, no interaction term

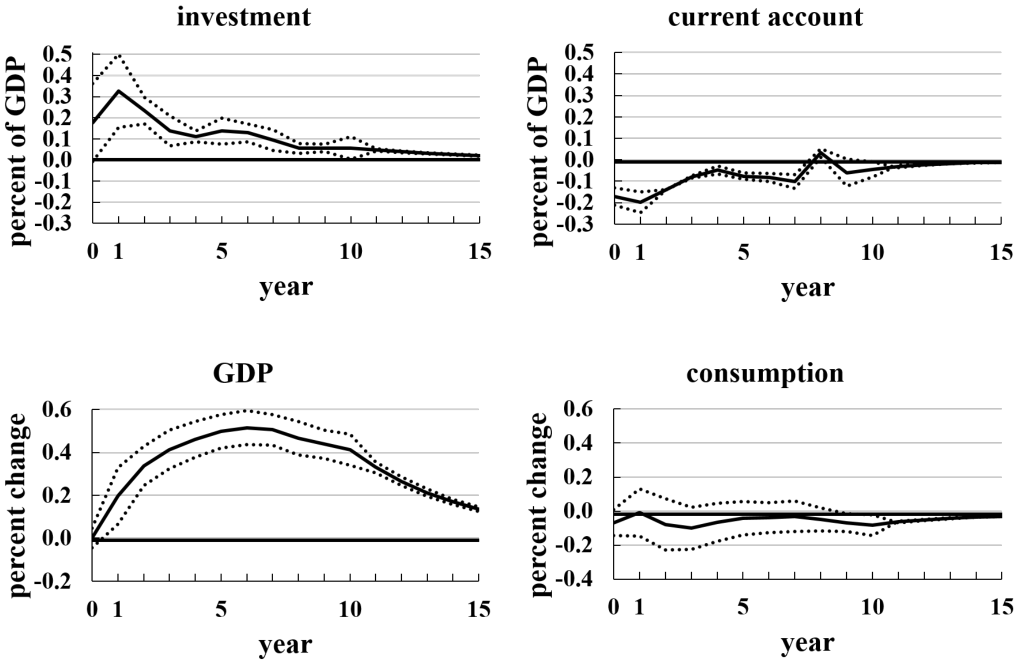
	(1) spreads	(2) inv/GDP	(3) CA/GDP	(4) ln(GDP)	(5) ln(cons)	(6) ln(RER)
y_{t-1}	0.621	0.820	0.582	0.807	0.701	0.744
	(0.118)	(0.060)	(0.084)	(0.036)	(0.050)	(0.197)
NPV_t	-1.491	3.937	-3.600	0.262	-1.078	-8.304
	(2.799)	(2.479)	(0.551)	(0.620)	(1.030)	(7.972)
NPV_{t-1}	-7.769	4.050	-2.082	4.394	0.996	-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 columns 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.

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 A5 with those from Table A1 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 A1, A2, and A3 show the impulse-response functions constructed with the point estimates from Table A5.

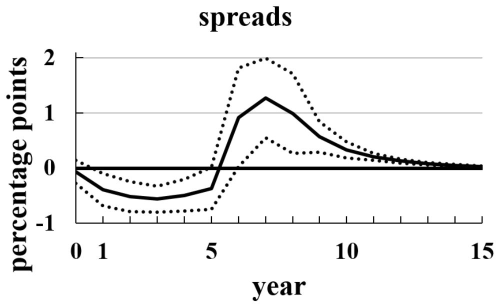
Figure A1: Impact of giant oil discoveries on macroeconomic aggregates, no interaction term



Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The dotted lines indicate 90 percent 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.

As is clear from comparing Figure A1 above with Figure 2 in the paper, the impulse-response functions of investment, the current account, GDP, and consumption remain virtually unchanged if we exclude the interaction controls. By comparing Figure A2 below with Figure 3 in the paper, we can observe that the impact of oil discoveries on the dynamics of spreads is sensitive to the inclusion of these interaction controls.

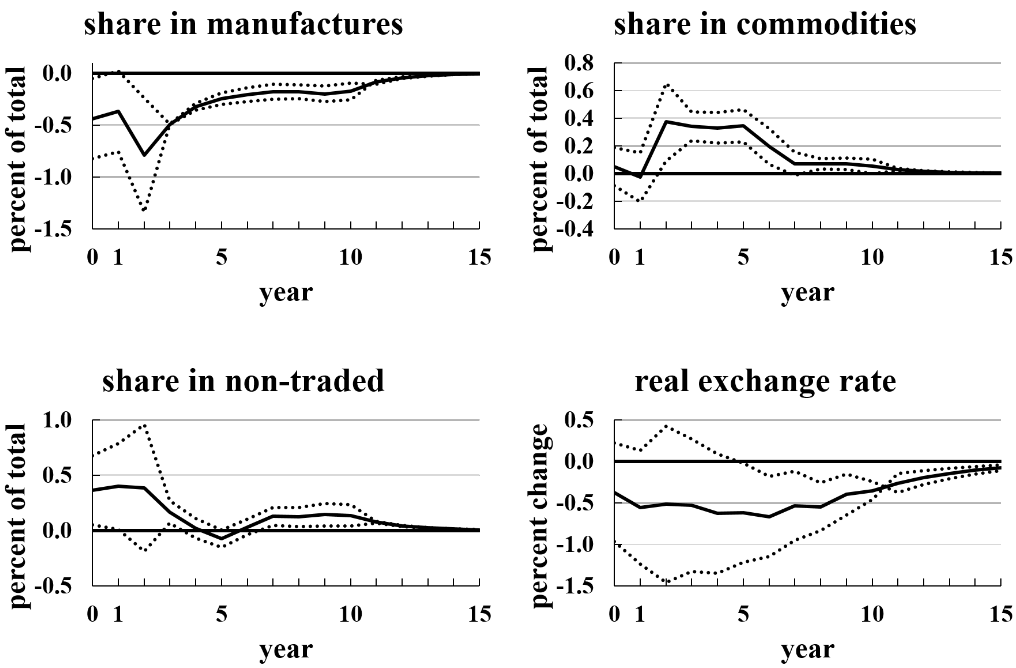
Figure A2: Impact of giant oil discoveries on spreads, no interaction term



Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The dotted lines indicate 90 percent 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.

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 A2. 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 A3: Impact of giant oil discoveries on sectoral investment and the RER, no interaction term



Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The dotted lines indicate 90 percent 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.

Figure A3 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 A3 above with Figure 4 in the paper, only the response of the real exchange rate is affected by the omission.[40] Given the sign of the coefficients reported in column (6) of Table A2, the coefficients of $NPV_{i,t-s}$ for $s = 1 \ldots 10$ are biased upward when the interaction terms are omitted.

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

[40] Note how the coefficients in column (6) of Table A2 are much larger than the coefficients reported in Table A8.

countries for which sectoral investment data for the period 1993–2012 are available.[41]

The data of investment by sector are from the National Accounts Official Country Data collected by the United Nations following the International Standard Industrial Clasification, Revision 3 (ISIC Rev. 3). It considers investment per country for 11 sub-items. Table A6 summarizes the sub-items and how I classify them into non-traded, manufacturing, and commodities.

Table A6: 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 A7 and A8 show the estimation results for equation (2) in the paper. The estimated coefficients in Table A7 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 in the paper.

[41] 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 A7: 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 columns include country and year fixed effects as well as a constant. All columns 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.

Table A8 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 A8: 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)

Robust standard errors for panel regressions with cross-sectional dependence are in parenthesis.

Finally, Table A9 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 A9: 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.

B Computation

B.1 Simplifying the recursive problems

The value of the government in repayment, defined in Subsection 3.2, is:

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

subject to the following constraints:

$$\begin{aligned}
c + i_k + i_{k_{oil}} &= Y - \Psi\left(k',k\right) - \Psi\left(k'_{oil},k_{oil}\right) \\
k' &= (1-\delta)k + i_k \\
k'_{oil} &= (1-\delta)k_{oil} + i_{k_{oil}} \\
Y &= f^Y(c_N,c_M,c_{oil}) \\
c_N &= zf^N(k_N) \\
c_M + x_M &= zf^M(k_M) \\
k_N + k_M &= k \\
c_{oil} + x_{oil} &= f^{oil}(k_{oil},n) \\
x_M + p_{oil}x_{oil} &= \gamma b - q\left(s,k',k'_{oil},b'\right)\left[b' - (1-\gamma)b\right]
\end{aligned}$$

where $C = \{c,c_N,c_M,c_{oil}\}$,$K = \{k_N,k_M\}$, $X = \{x_M,x_{oil}\}$ are all the static allocations, $f^Y(c_N,c_M,c_{oil}) = A\left[\omega_N^{\frac{1}{\eta}}(c_{N,t})^{\frac{\eta-1}{\eta}} + \omega_M^{\frac{1}{\eta}}(c_{M,t})^{\frac{\eta-1}{\eta}} + \omega_{oil}^{\frac{1}{\eta}}\left(c_{oil,t}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$, $f^N(k) = k^{\alpha_N}$, $f^M(k) = k^{\alpha_M}$, and $f^{oil}(k_{oil},n) = \left[\alpha_{oil}^{\frac{1}{\varphi}}(k_{oil})^{\frac{\varphi-1}{\varphi}} + \zeta^{\frac{1}{\varphi}}(n)^{\frac{\varphi-1}{\varphi}}\right]^{\frac{\varphi}{\varphi-1}}$. The above set of constraints can be simplified by defining the production possibility frontier for the final good as:

$$\begin{aligned}
F^P(s,k,k_{oil},T) = &\max_{c_N,c_M,c_{oil},\lambda} f^Y(c_N,c_M,c_{oil}) \\
&s.t. \quad c_N = zf^N((1-\lambda)k) \\
c_M + p_{oil}c_{oil} + T &= zf^M(\lambda k) + p_{oil}f^{oil}(k_{oil},n)
\end{aligned}$$

where $T = \gamma b - q\left(s, k', k'_{oil}, b'\right)\left[b' - (1-\gamma) b\right]$ are net debt payments to the rest of the world and $\lambda \in [0,1]$ is the share of capital allocated in the manufacturing sector. Given the state and a choice for $\left(k', k'_{oil}, b'\right)$, the first-order conditions of the maximization problem in the right-hand-side of F^P pin down the efficient static allocations for the current period:

$$c_N = zf^N\left((1-\lambda)k\right) \tag{15}$$

$$c_M = \frac{\omega_M}{\omega_{oil}}\left(p_{oil}\right)^{\eta} c_{oil} \tag{16}$$

$$p_{oil} c_{oil} = \frac{\omega_{oil}\left(p_{oil}\right)^{1-\eta}}{\omega_M + \omega_{oil}\left(p_{oil}\right)^{1-\eta}}\left[zf^M(\lambda k) + p_{oil} f^{oil}\left(z, k_{oil}, n\right) - T\right] \tag{17}$$

$$\left(\frac{\alpha_M}{\alpha_N}\frac{(1-\lambda)^{1-\alpha_N}}{\lambda^{1-\alpha_M}}(k)^{\alpha_M-\alpha_N}\right)^{\eta} zf^N\left((1-\lambda)k\right) = \frac{\omega_N}{\omega_M + \omega_{oil}\left(p_{oil}\right)^{1-\eta}}\left[zf^M(\lambda k) + p_{oil} f^{oil}\left(z, k_{oil}, n\right) - T\right] \tag{18}$$

The value function of the government in repayment can be rewritten as:

$$\begin{aligned}
V^P\left(s,k,k_{oil},b\right) &= \max_{c,k',k'_{oil},b'}\left\{u(c) + \beta \mathbb{E}_{s'|s} V\left(s',k',k'_{oil},b'\right)\right\} \\
s.t. \quad c + i + i_{oil} &= F^P\left(s,k,k_{oil},b,T\right) - \Psi\left(k',k\right) - \Psi\left(k'_{oil},k_{oil}\right) \\
k' &= i + (1-\delta)k \\
k'_{oil} &= i_{oil} + (1-\delta)k_{oil} \\
T &= \gamma b - q\left(s,k',k'_{oil},b'\right)\left[b' - (1-\gamma)b\right]
\end{aligned}$$

Doing the same for the value in default we get:

$$\begin{aligned}
V^D\left(s,k,k_{oil}\right) &= \max_{c,k',k'_{oil}}\left\{u(c) + \beta \mathbb{E}_{s'|s}\left[\theta V\left(s',k',k'_{oil},0\right) + (1-\theta) V^D\left(s',k',k'_{oil}\right)\right]\right\} \\
s.t. \quad c + i + i_{oil} &= F^D\left(s,k,k_{oil}\right) - \Psi\left(k',k\right) - \Psi\left(k'_{oil},k_{oil}\right) \\
k' &= i + (1-\delta)k \\
k'_{oil} &= i_{oil} + (1-\delta)k_{oil}
\end{aligned}$$

where

$$
\begin{aligned}
F^D(s,k,k_{oil}) = & \max_{c_N,c_M,c_{oil},k_N,k_M} f^Y(c_N,c_M,c_{oil}) \\
s.t. \quad & c_N = z^d(z)\, f^N(k_N) \\
c_M + p_{oil}c_{oil} = & z^d(z)\, f^M(k_M) + p_{oil} f^{oil}(k_{oil},n)
\end{aligned}
$$

B.2 Pre-computing output

Evaluating F^P and F^D involves finding the root of equation (18), which can become computationally burdensome within a value function iteration algorithm.

Note that F^D does not depend on the value functions or the price of the debt q, which change as the algorithm converges, so it can be pre-calculated exactly for all possible states (s,k,k_{oil}) and stored in memory. This pre-calculation, however, cannot be done for F^P, since the static allocations depend also on the current borrowing and investment choices through $T = \gamma b - q\left(s,k',k'_{oil},b'\right)[b' - (1-\gamma)b]$. In order to achieve similar gains, I pre-calculate F^P for all possible states (s,k,k_{oil},b) and for a grid of plausible trade balances T.

In order to evaluate F^P at a given state and policy choice, I compute $T = \gamma b - q\left(s,k',k'_{oil},b'\right)[b' - (1-\gamma)b]$ and approximate F^P by linearly interpolating over the pre-calculated values for T (for the chosen value of η, $F(s,k,k_{oil},\cdot)$ is close to linear). This is much faster than finding the root of equation (18) inside each iteration on the Bellman equations and less computationally demanding than storing in memory all the values of F^P for all possible combinations of $\left(s,k,k_{oil},b,k',k'_{oil},b'\right)$.

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