The Sovereign Default Risk of Giant Oil Discoveries*

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Abstract

This study 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, three-sector production, and oil discoveries. Following a discovery, borrowing and investment increase. Capital reallocates from manufacturing toward oil and non-traded sectors, increasing the volatility of tradable income. Borrowing increases default risk and higher volatility increases the risk premium, which drive the increase in spreads. Discoveries generate welfare gains of 0.44 percent. Insurance against low oil prices increases gains to 0.60. (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 estimate that 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. This investment reallocation is accompanied by an appreciation of the real exchange rate. Arezki, Ramey, and Sheng (2017) find weak evidence of real exchange rate appreciation following oil discoveries for all countries in the world. In contrast, I find that the evidence is stronger for the 37 emerging economies considered in this paper.

To reconcile these facts, I develop a small-open economy model of sovereign default with risk-averse foreign lenders, capital accumulation and production in three intermediate sectors: a

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

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.[3] When a country has a larger oil field, their tradable income becomes more volatile as it is more exposed to swings in the price of oil. This endogenous increase in volatility raises the risk premium that the risk-averse lenders charge. Overall, higher investment decreases spreads and higher foreign borrowing increases them. However, the effect of investment is weakened by the increase in the risk premium due to the reallocation of production capital away from the manufacturing sector.

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.[4] This lack of discoveries allows me to discipline the parameters of the model with business cycle data that does not have any variation that could be driven by oil discoveries. Additionally, I use the oil discoveries data from Arezki, Ramey, and Sheng (2017) to discipline the size and probability of discoveries in the model. The model responses to oil discoveries are qualitatively and quantitatively in line with

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

[4]An interesting case would be the Mexican default in 1982, which was preceded by two giant oil discoveries (in 1977 and 1979), each with an estimated net present value of potential revenues of 50 percent of Mexico's GDP at the time. Unfortunately, we lack data on sovereign spreads for those years, which are crucial to discipline the parameters in the model that control default incentives.

those from the data. This is a nice feature of the model since none of these responses are targeted in the calibration.

I use the model to perform three counterfactual exercises. For the first counterfactual I consider a model in which the price of oil follows the same stochastic process as productivity; I call this the *same-volatility* case. This case mutes the effect of the change in the conditional volatility of tradable income, since it would now be the same for any production bundle. 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. Default events become more frequent in all but the *patient* case, in which defaults are virtually nonexistent. These results stress two important points. First, the frictions in this economy that explain default events and high spreads are market incompleteness (affecting both the government and the risk-averse lenders), lack of commitment, and high borrowing driven by 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. Oil discoveries yield gains of 0.44 percent in consumption-equivalent units. These remain virtually unchanged in the *same-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). Welfare gains are much larger in the *patient* case (0.66 percent), indicating that there are significant foregone gains due to default risk and high indebtedness driven by government impatience. These results support 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 access to these options yields additional gains of 0.2 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.[5]

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

[5]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.

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 with this 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 affects 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 document, for oil exporting countries, how variations in proved oil reserves impact the dynamics of the Institutional Investor Index (III), which is a measure of sovereign risk. 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 key differences between Hamann, Mendoza, and Restrepo-Echavarria (2020) and my the empirical work. 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. The second is 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. 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 data on oil discoveries allow for a quasi-natural experiment approach to identify their effect. The different nature of the shocks 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. 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.

Layout.—Section 2 presents the empirical analysis and discusses the evidence that motivates the theoretical framework. Section 3 presents the model. Section 4 performs the quantitative analysis. 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).[6] Due to data availability, I restrict the analysis to these economies and the years between 1993 and 2012. I work with annual data since the date of discoveries only reports the year. 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

[6] 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.

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 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:[7]

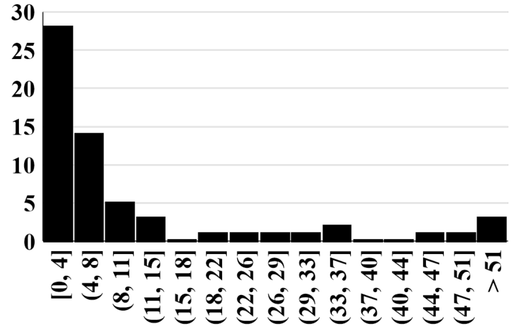
$$NPV_{i,t} = \frac{\sum_{j=5}^{J} \frac{q_{i,t+j}}{(1+r_i)^j}}{GDP_{i,t}} \times 100 \tag{1}$$

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 authors allow for country-specific risk-adjusted discount rates r_i. These are constructed based on the historical relationship between sovereign spreads and political risk ratings. This way, the $NPV_{i,t}$ measure discounts flows more in countries where political risk is high. 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.[8] 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.

[7] 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).

[8] Gross revenues $q_{i,t+j}$ consider the same price of oil for subsequent years, assuming that the price of oil follows a random walk. 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

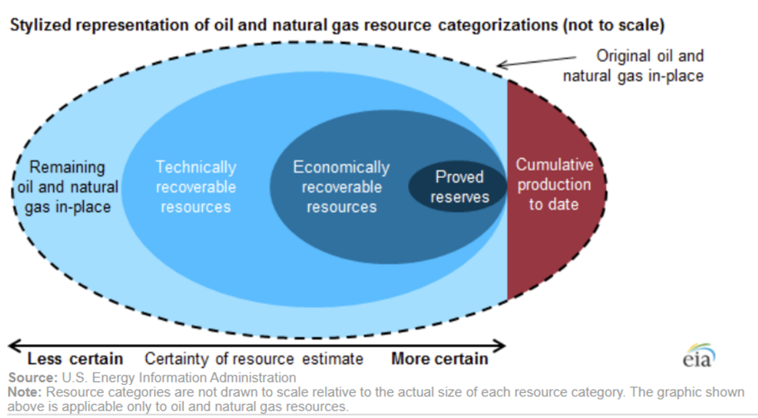


Percent of GDP, EMBI countries, 1993 –2012.

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.[9] 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,

[9] 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 are less accurate with short time series.[10]

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.[11] 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.[12] 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.[13]

In my benchmark regressions, the vector X contains contemporaneous and up to ten lags of the

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

[11] 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.

[12] 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.

[13] 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.

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

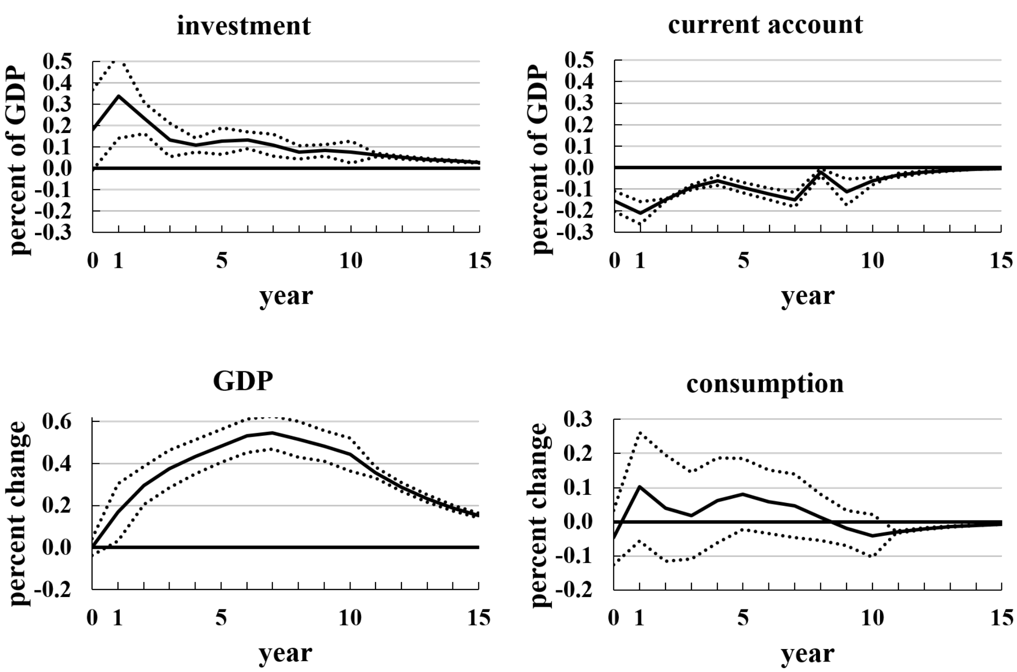
My investment, current account, GDP, and consumption data come from the IMF (2013) and the World Bank (2013). GDP and consumption are measured in constant prices in local currency units. Investment and the current account are measured as a percentage of GDP. Spreads data are from JP Morgan's Emerging 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).[14]

The top left panel shows that investment 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, which supports the hypothesis that these countries issue foreign debt to finance investment. In contrast with the findings in Arezki, Ramey, and Sheng (2017), I find that the current account does not revert even after oil production starts.

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.

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

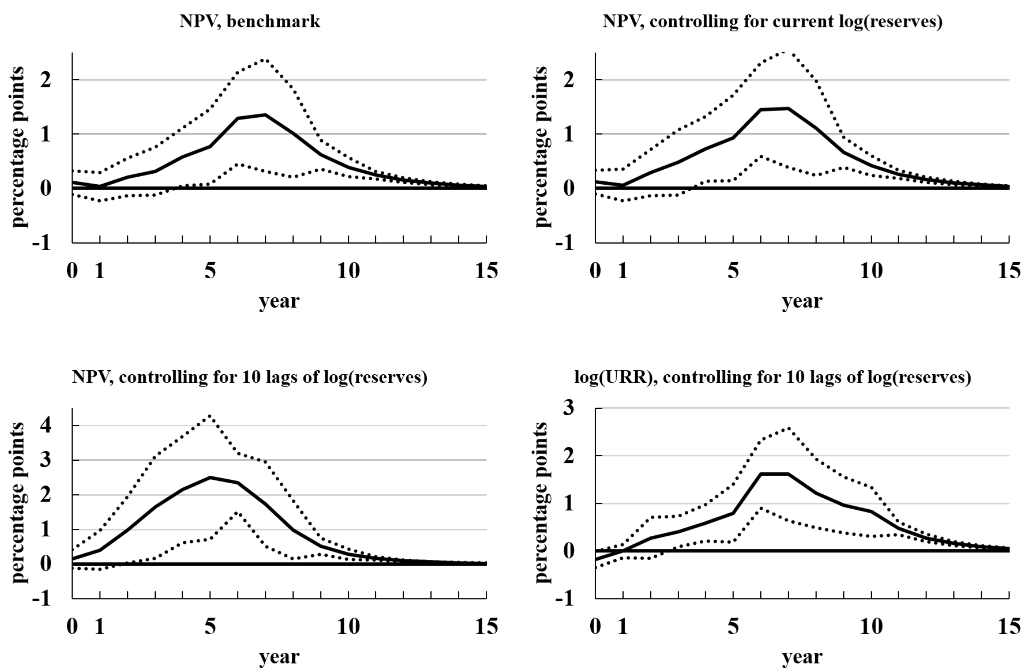
[14]The Appendix reports point estimates and their standard errors for the coefficients in equation 2.

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.

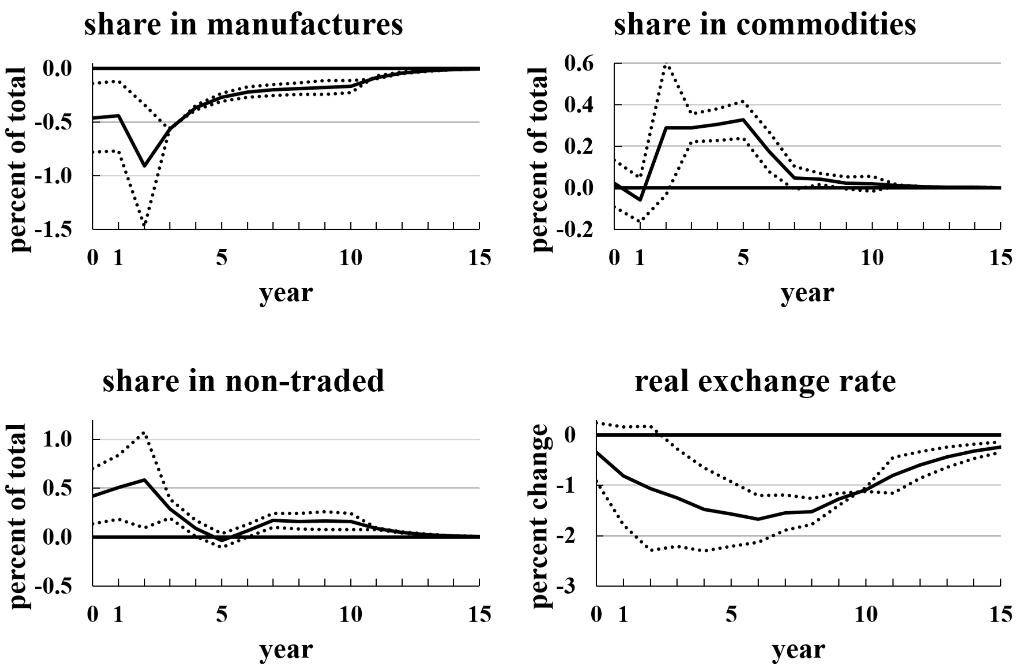
These results are striking in the light of the evidence from the previous Subsection and also in Arezki, Ramey, and Sheng (2017). Income increases during the years following the discovery, which would indicate that the country has a higher ability to service its debt. However, both investment and foreign 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 manufacturing, commodities, and non-traded sectors.[15] Commodities comprise agricultural, fishing, mining and querying activities. The non-traded sector includes construction and wholesale, retail, and logistics services.

[15] Due to limited data availability for the 37 emerging economies considered above, the estimations for the shares of total investment consider a wider set of 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 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 a benevolent government that makes borrowing, investment, and production decisions and cannot commit to repay its debt. The government debt is purchased by risk-averse international lenders.

3.1 Environment

Preferences and technology.—The government has preferences over consumption sequences of a final non-traded good $\{c_t\}_{t=0}^{\infty}$ represented by $\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t u(c_t)\right]$, where $u(c)=\frac{c^{1-\sigma}-1}{1-\sigma}$ and β is the discount factor. The final good can be used for consumption and investment. 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: manufacturing goods $c_{M,t}$ and oil, $c_{oil,t}$:

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

where η is the elasticity of substitution and ω_i are the weights of each intermediate good i in the production of the final good. Intermediate non-traded and manufacturing goods are produced using capital k_N and k_M with decreasing returns to scale technologies $y_{N,t}=z_tAk_{N,t}^{\alpha_N}$ and $y_{M,t}=z_tAk_{M,t}^{\alpha_M}$, where z_t is a persistent productivity shock that affects both sectors, $0<\alpha_N<1$, $0<\alpha_M<1$, and A is a scaling parameter.[16] There is a general stock of capital k_t that can be freely allocated in these two sectors within the same period such that $k_{N,t}+k_{M,t}=k_t$.[17]

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:

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

[16] Decreasing returns to scale captures the presence of a fixed factor (labor) which is immobile within sectors.

[17] The assumption about the free allocation of capital between these sectors is made for simplicity. As it will become clear later, the key assumption is that the capital to extract oil is sector specific.

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 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 be used to extract oil from another (newly discovered) field in a different geographical location. 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:

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

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 good, and $\Psi(x', x) = \phi\,(x' - x)^2$ is a capital adjustment cost function.[18] 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.

Rest of the world and international prices of goods.—There is a rest of the world economy with international lenders and with a market where the small-open economy trades oil and the manufacturing good (which is the nummeraire). I assume that the small-open economy is small enough so that neither its actions nor its oil discoveries have an effect on the relative price of oil. This price is pinned down in the rest of the world and for simplicity I assume it follows some exogenous stochastic process that is more volatile and more persistent than the process for z. As I discuss in Subsection 4.4, the important assumption is that the price of oil is relatively more

[18] 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.

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_{wait} periods from then, that is $n_{t+T_{\text{wait}}} = n_H$. Then, n_t remains high for a stochastic number of periods and with probability π_{ex} it returns to the value n_L.[19] Let $s_t = (z_t, p_{oil,t}, \chi_t)$ be the exogenous state, where $\chi_t \in \{-1, 0, 1, ..., T_{\text{wait}}\}$ captures both the news shock and keeps track of the time between news and production. If $\chi_t = -1$ then $n_t = n_L$ and the economy has not discovered an oil field yet. A news shock happens when $\chi_t = 0$. Then, for $\chi_t = 0 ... T_{\text{wait}} - 1$ the economy's oil field is still $n_t = n_L$ but all agents know that there was news of an oil field discovery in $t - \chi_t$. Finally, $n_t = n_H$ when $\chi_t = T_{\text{wait}}$. For $\chi_t = -1$ we have $Pr(\chi_{t+1} = 0) = \pi_{\text{disc}}$ is the probability of an oil discovery. For $\chi_t = 0, ..., T_{\text{wait}}$ we have $Pr(\chi_{t+1} = \chi_t + 1) = 1$ and $Pr(\chi_{t+1} = -1) = \pi_{\text{ex}}$ for $\chi_t = T_{\text{wait}}$.[20]

Debt structure.—The government issues long-term bonds denominated in units of the manufacturing good. Following Hatchondo and Martinez (2009) and Chatterjee and Eyigungor (2012), I assume bonds 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.

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;

[19] 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.

[20] 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.

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 particular the counterciclicality of spreads and the current account (see the discussions in Arellano (2008) and Chatterjee and Eyigungor (2012)).[21]

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 the manufacturing good and oil, respectively. Equation (9) implies that in default trade in goods has to be balanced: imports to increase consumption of one traded good have to be financed by exports of the other.

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

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

where q_t is the market price of newly issued debt. Equation (10) shows how payments of debt obligations γb_t are supported by net exports of goods and by the issuance of new debt.

Risk-averse foreign lenders.—There is a vast literature that argues that risk premia are an important component of sovereign spreads. Aguiar, Chatterjee, Cole, and Stangebye (2016) show that defaults are not tightly connected to poor fundamentals, which points to the role of global factors related to lender risk-aversion. Wu (2022) documents that a large share of observed credit default swap spreads can be attributed to the risk premium. In earlier work, Longstaff, Pan, Pedersen, and Singleton (2011) also document that the majority of sovereign credit risk can be linked to global factors and that the risk premium represents about a third of spreads.

To model the risk premium I modify the parsimonious approach in Arellano and Ramanarayanan

[21] 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.

(2012) and Bianchi, Hatchondo, and Martinez (2018). Foreign lenders price government debt using the following stochastic discount factor

$$m_{t,t+1} = e^{-\left(r^{*}+\alpha_0 \tilde{y}_{T,t+1}+0.5\alpha_0^2\sigma_{T,t}^2\right)} \tag{11}$$

where $\alpha_0 > 0$ is a primitive parameter that controls the degree of lender-risk aversion; $\tilde{y}_{T,t+1} = \log y_{T,t+1} - \mathbb{E}_t\left[\log y_{T,t+1}\right]$ is the difference between the log of total tradable income $y_T = y_M + p_{oil}y_{oil}$ and its conditional expectation in period t; and $\sigma_{T,t}^2$ is the conditional variance of $\tilde{y}_{T,t+1}$. The key innovation is that the conditional variance of $\tilde{y}_{T,t+1}$ is variable and endogenous, while in the papers mentioned above it is fixed. This is because those models have an endowment of a unique tradable good that follows an exogenous stochastic process, while this model features two sources of tradable income that depend on different shocks and endogenous production decisions. This formulation allows the price of risk to vary with the current realization of s_t because shocks are persistent. More importantly, the price of risk also responds to investment choices, since these affect the possible realizations of y_{T+1} and its variance: the mix of k_{t+1} and $k_{oil,t+1}$ affects $\sigma_{T,t}^2$. Similar to the papers above, the assumption $\alpha_0 > 0$ introduces a positive risk premium because bond payoffs are more valuable to the lenders in states where default is more likely (i.e. states that imply low realizations of y_T).

3.2 Recursive formulation and timing

The state of the economy is the vector of shocks 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 $V\left(s,k,k_{oil},b\right)$ 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, $d = 1$:

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

where $V^{P}\left(s,k,k_{oil},b\right)$ is the value of repaying and $V^{D}\left(s,k,k_{oil}\right)$ is the value of default.[22]

[22] Alternative timing assumptions can give rise to multiplicity of equilibria (see for example Cole and Kehoe (2000)).

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 the manufacturing sector and the non-traded intermediate sector $K = \{k_N, k_M\}$, net exports of the manufacturing good and oil $X = \{x_M, x_{oil}\}$, and consumption of final and intermediate goods $C = \{c, c_N, c_M, c_{oil}\}$ to solve:

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

subject to the resource constraint of the final good (5), the resource constraint of general capital $k = k_N + k_M$, 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 the manufacturing sector and in the non-traded intermediate sector $K = \{k_N, k_M\}$, net exports of the manufacturing good and oil $X = \{x_M, x_{oil}\}$, and consumption of final and intermediate goods $C = \{c, c_N, c_M, c_{oil}\}$ to solve:

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

subject to the resource constraints goods and capital, the laws of motion of capital, the law of motion of bonds (8), 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 the stochastic discount factor defined in 11, the lenders price the bonds according to:

$$q\left(s,k',k'_{oil},b'\right) = \mathbb{E}_{s'|s} \left\{ m\left(s,s',k',k'_{oil}\right) \left[1 - d\left(s',k',k'_{oil},b'\right) \right] \left[\gamma + (1-\gamma) q\left(s',k'',k''_{oil},b''\right) \right] \right\} \tag{12}$$

where k'', k''_{oil} and b'' are lenders' expectations about the government's investment and borrowing

For detailed discussions and literature reviews see Aguiar and Amador (2014) and Aguiar, Chatterjee, Cole, and Stangebye (2016).

policies in the following period.[23]

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 (12). In a recent paper Galli (2021) 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 (12), 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 (12).

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.[24] The value functions V^D and V^P and the price schedule for

[23] When computing $\tilde{y}_{T,t+1}$ and its moments for the stochastic discount factor, I assume balanced trade in $t+1$ (i.e. given k,the static capital allocation k_M is invariant to current and future borrowing). This assumption provides a great deal of computational tractability at a very low cost since the quantitative results are not too sensitive to it.

[24] 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. For debt I search for the best policy over a grid (using current capital stocks as policies) and use these as an initial guess in a nonlinear optimization routine. The code used to compute the solution of the model is written in the Julia language. I use the Nelder-Mead routine from the Optim.jl package, which follows the algorithm developed by Nelder and Mead (1965).

bonds q are approximated using linear interpolation, and expectations over z and p_{oil} are calculated using a Gauss-Legendre quadrature. See the Appendix for more details of the solution method.

4.2 Calibration

I calibrate the model to the Mexican economy. There are two reasons why 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, so the parameters of the model are disciplined with business cycle data that do not include endogenous variation induced by giant oil discoveries. This allows me to validate the theory by comparing model responses to oil discoveries with those from the data.

A period in the model is one year. 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.[25] I set the elasticity of substitution $\eta = 0.83$, following the literature.[26] I set the weights $\omega_N = 0.60$, $\omega_M = 0.34$, and $\omega_{oil} = 0.06$ using aggregate consumption shares. I set the CRRA parameter to $\sigma = 2$, the capital depreciation rate to $\delta = 0.05$, and the risk free interest rate to $r^* = 0.04$, which are standard values in the international macroeconomics literature.

[25] To my knowledge, there is no empirical guidance applicable to a macroeconomic model for this parameter. The results are not sensibly altered by different (lower than 1) values of this parameter.

[26] See Mendoza (2005) and Bianchi (2011).

Table 1: Parameters calibrated directly from the data

Parameter		Value	Parameter		Value
capital shares	α_N	0.66	oil rent	ζ	0.38
	α_M	0.57	CRRA	σ	2.00
	α_{oil}	0.49	capital depreciation rate	δ	0.05
output shares	ω_M	0.34	bonds maturity rate	γ	0.14
	ω_{oil}	0.06	elasticities of substitution	φ	0.40
	ω_N	0.60		η	0.83
scaling parameter	A	0.85	risk free rate	r^*	0.04
probability of discovery	π_{disc}	0.01	probability of reentry	θ	0.40
probability of exhaustion	π_{ex}	0.02	waiting time	T_{wait}	6
persistence of price of oil	ρ_{oil}	0.94	persistence of productivity	ρ_z	0.91
volatility of price of oil	σ_p	0.28	volatility of productivity	σ_z	0.02
size of small oil field	n_L	0.22	size of large oil field	n_H	0.26

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. For the price of oil I also assume an AR(1) process $\log p_{oil,t} = \rho_{oil} \log p_{oil,t-1} + \sigma_p \varepsilon_{oil,t}$, where $\varepsilon_{oil,t}$ are iid with a standard normal distribution, σ_p is the standard deviation, and ρ_{oil} is the persistence parameter (the mean of the price of oil in the model is normalized to 1). To estimate the persistence and standard deviation I use a long time series of the average real price of crude oil from the World Bank Commodity Price Data between 1960 and 2021. The source includes annual data of the average of the Brent, Dubai, and West Texas Intermediate prices in 2010 US dollars. My estimates for the AR(1) process parameters are $\rho_{oil} = 0.94$ and $\sigma_p = 0.28$.[27]

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

[27] This assumption treats oil prices differently than in the empirical section, where they are assumed to follow a random walk. Introducing a random walk would result infeasible in terms of the computation of the model. Higher levels for the persistence parameter ρ_{oil} amplify the responses of spreads to oil discoveries and do not sensibly change the responses of other variables (this comment refers to the responses in Subsection 4.3 below).

real GDP using base-year 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 $A = 0.85$ and $n_L = 0.22$ so that in the steady state production of the manufacturing good is $y_{M,ss} = 1$ and net exports of oil are 2.7% of GDP $\frac{x_{oil,ss}}{GDP_{ss}} = 0.027$ (which is the average of Mexican oil exports as a fraction of GDP between 1993 and 2021).[28]

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.[29] I set the waiting time to $T_{\text{wait}} = 6$ so that for $\chi_t = 0...5$ the economy is in the waiting period between discovery and production, which is the average lag observed in the data. The probability of exhaustion is $\pi_{\text{ex}} = 0.02$ for an average field life of 50 years.

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

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

where $k^H_{oil,ss}$ and $k^L_{oil,ss}$ are steady state levels of oil capital for $n = n_H$ and $n = n_L$, respectively, $p_{oil,ss} = z_{ss} = 1$, and $r_{ss} = 0.075$ is the interest rate consistent with a target for spreads of 3.5% (see Table 2 below). That is, NPV_{ss} is the net present value of the incremental flows of oil income from a large field with typical duration of 50 years (as a fraction of steady state-GDP). This calculation is akin to the calculation made by Arezki, Ramey, and Sheng (2017) with actual data following equation (1). I set $n_H = 0.26$ so that $NPV_{ss} = 4.5\%$, which is the median NPV of the discoveries used for the impulse-responses in Section (2).

Table 2 summarizes the parameters calibrated by simulating the model. To compute the moments in the model I consider 300 economies in their ergodic state without any oil discoveries in the past 50 periods and that have been in good financial standing for at least 25 periods, as is

[28]The *Banco de Información Económica (BIE)* published by the National Institute of Statistics and Geography (INEGI) reports Mexican oil exports in current USD. I use average nominal exchange rates and GDP data from National Accounts to compute the average ratio.

[29]I consider oil discoveries in countries that had not had a discovery in the previous 6 years. The reason to do this is that, for tractability, the model does not accommodate subsequent discoveries. The unconditional probability of discovery in the data is 0.045.

standard in the literature. Each time series has 50 periods.

The remaining five parameters β, α_0, d_0, d_1, and ϕ are chosen to match five moments from the data: a mean level of spreads of 3.5 percentage points, a default probability of 1 percent, an average risk-premium-to-spreads ratio of 0.33, a total public debt-to-GDP ratio of 0.43, and a volatility of investment relative to the volatility of GDP of 2.0. For investment and real GDP I take the natural logarithm and HP-filter the data using a smoothing parameter of 100.

Table 2: Parameters calibrated simulating the model

Parameter		Value	Parameter		Value
discount factor	β	0.86	default cost	d_0	-0.42
capital adjustment cost	ϕ	2.0	default cost	d_1	0.58
risk-premium parameter	α_0	17.3			

Moment	Data	Model
$Av(r-r^*)$	3.5	5.1
default probability	0.01	0.01
$RP/(r-r^*)$	0.33	0.37
B/GDP	0.43	0.36
$\sigma_{inv}/\sigma_{GDP}$	2.0	1.7

Moments are computed by simulating 300 economies in their ergodic state without any oil discoveries in the past 50 periods and that have been in good financial standing for at least 25 periods.

To compute spreads I consider the implicit annual yield of government bonds given by $r_t^b = \log(q_t/\gamma + (1-\gamma)q_t)$; then, the spread is $r_t^b - r^*$. To compute the risk premium consider the actuarially fair price of holding the debt for one period:

$$q_t^{af} = \mathbb{E}_t\left[e^{-r^*}(1-d_{t+1})(\gamma + (1-\gamma)q_{t+1})\right] \tag{13}$$

where d_{t+1} and q_{t+1} are the default decision and market price of bonds in $t+1$, respectively. Then, the implicit actuarially fair yield is $r_t^{af} = \log\left(q_t^{af}/\gamma + (1-\gamma)q_t^{af}\right)$ and the risk premium is $RP_t = r_t^b - r_t^{af}$. Spreads data are documented by Aguiar, Chatterjee, Cole, and Stangebye (2016) from the EMBI+. I take the average $RP/\left(r^b - r^*\right) = 0.33$ from Longstaff, Pan, Pedersen, and Singleton (2011). Data of public debt-to-GDP ratio are from the IMF. The debt-to-GDP ratio in the model is computed as the ratio of the stock of debt to nominal GDP $\frac{b_t}{GDP_t}$. For the relative volatility of investment I use HP-filtered data of the log of real investment and GDP from Mexican national accounts and compute the standard deviation of their cyclical components. Table 2 reports the moments from the calibration that most closely resemble these targets based on a sup-norm measure of distance.

4.3 Model fit

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 the relative variance of consumption *vis-a-vis* GDP. The model generates spreads that are slightly more volatile than those in the data.[30]

Table 3: Untargeted moments

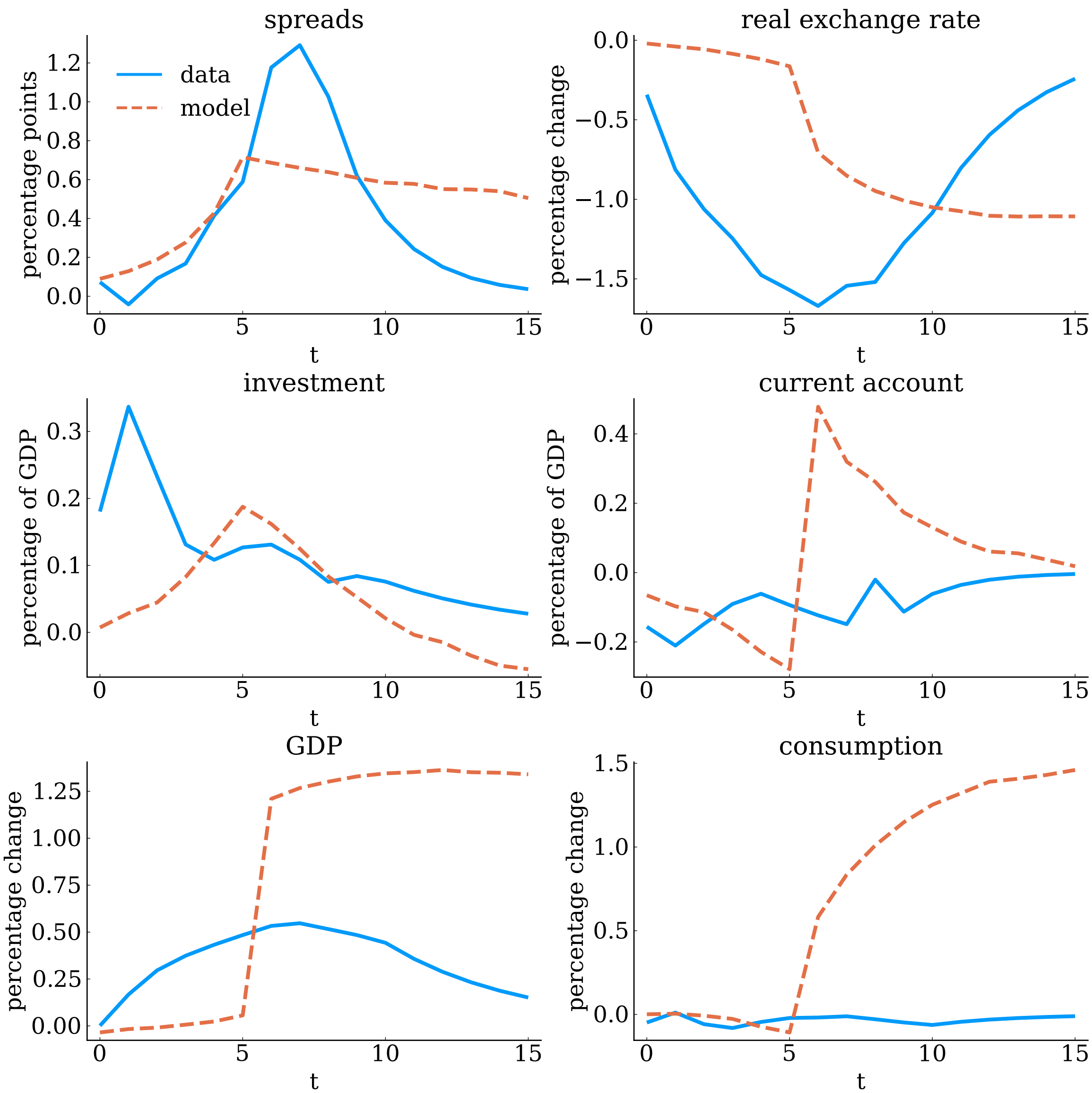
Moment	Data	Model
st. dev. of spreads (percentage)	1.3	1.7
$\sigma_{cons}/\sigma_{GDP}$	1.1	1.1
corr$\left(\frac{CA}{GDP}, GDP\right)$	-0.6	-0.4
corr$\left(\frac{TB}{GDP}, GDP\right)$	-0.3	-0.4

Moments are computed by simulating 300 economies in their ergodic state without any oil discoveries in the past 50 periods and that have been in good financial standing for at least 25 periods.

Responses to oil discoveries.—Figure 6 compares the responses to oil discoveries of key macroeconomic variables in the model to those estimated from the data. Following a discovery, spreads steadily increase and peak around the year when production starts. Investment increases before the new field becomes productive and this increase is accompanied by a current account deficit of similar magnitude. The real exchange rate appreciates and both GDP and consumption increase. The main quantitative result from this figure is that the model is able to explain 75 out of the 120 basis points-increase in spreads. It is worth noting that in the model the price follows an AR(1) process, while int he data it is treated as a random-walk. Increasing the persistence parameter in the calibration from $\rho_{oil} = 0.94$ to $\rho_{oil} = 0.97$ roughly doubles the response of spreads while leaving the other responses mostly unchanged (responses for all counterfactual cases are reported in the appendix). From this I conclude that the results in Figure 6 are conservative.

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

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



The solid blue lines correspond to the data. The dotted orange lines correspond to the model. To compute the model responses I consider 1000 economies in their ergodic state without any oil discoveries in the past 50 periods and that have been in good financial standing for at least 25 periods. I then consider two versions of each economy: one with a discovery in period 0 and one without. I compute the difference between the two paths and average these paths of differences across all 1000 economies.

The model captures most of the joint behavior following news of an oil discovery, which is an important result since none of these responses were targeted in the calibration. However, there are some discrepancies that are worth addressing, mostly around and after the time when production in the new field starts. In the model, there is a current account-reversal to surplus, which is what the permanent income hypothesis would suggest. This behavior of the current account is similar to what Arezki, Ramey, and Sheng (2017) find in the data for a larger set of countries and is also featured in their model. The fact that the reversal is not observed for the countries considered in this paper is puzzling. However, despite the reversal in the current account, spreads in the model remain high for longer than in the data. This is because the risk-premium in the model remains high due to the higher variance of tradable income. It is worth noting that, for tractability, the calibration assumes a Poisson exhaustion rate for oil fields targeting an average life of 50 years. A richer process for this duration that considers higher probability of fields lasting shorter would allow the model to also fit the reversal of spreads.

GDP and the real exchange rate in the model move in the correct direction but the magnitude is much more pronounced once the new field becomes productive. For the real exchange rate, 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, so there is no incentive to anticipate it. Between period 0 and 5, the appreciation is a response to the current account deficit, while the larger one after period 5 comes from higher oil income. Regarding GDP, the model behavior 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 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.[31] 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

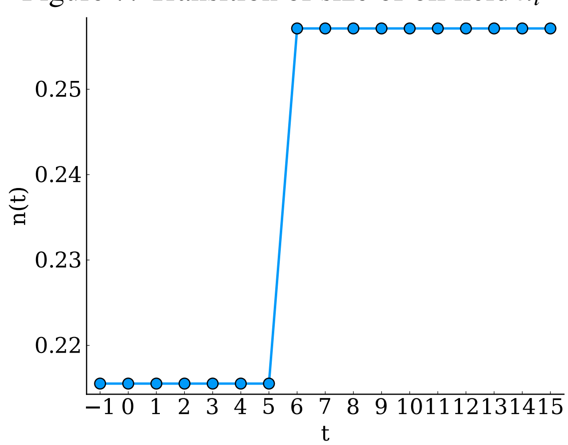
[31] Recall that consumption in the data includes both private and public consumption, the latter having potentially a lot of measurement error, in particular from unreported public transfers (see Esquivel, Kehoe, and Nicolini (2020) for a discussion of such transfers during different economic crises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

expensive.

4.4 Discussion of assumptions and mechanism

Five model assumptions drive the responses to oil discoveries: (i) capital adjustment costs, (ii) production of non-traded goods, (iii) high volatility of the international price of oil, (iv) long-term debt, and (v) risk-averse lenders. The mechanism can be summarized as follows. After an oil discovery in t, all agents know that the government will have access to a larger field in $t+T_{\text{wait}}$ (as depicted in Figure 7). 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—which is used to support debt payments—more dependent on oil revenue and thus more volatile. Risk-averse lenders will, in turn, demand a higher (positive) risk premium since they value debt payments more when default is more likely. With long-term debt, this higher future risk premium affects the spreads in all the preceding periods, starting with the period when the information of a discovery arrives and being increasingly affected as production in the new field approaches.

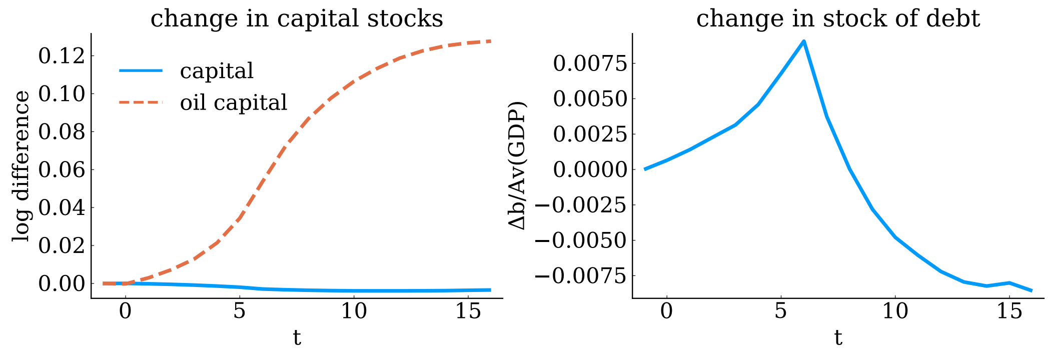
Figure 7: Transition of size of oil field n_t



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

Borrowing to invest.—After a discovery in period $t=0$, the government will want to have a higher level of installed capital for the oil sector k_{oil} by period $t=T_{\text{wait}}$. Absent capital adjustment costs, all the additional capital in the oil sector could be installed in $T_{\text{wait}}-1$. The adjustment costs incentivize the government to smooth this investment through the preceding periods. Also, adjustment costs for both stocks of capital prevent reallocation from k to k_{oil}, since this would result in paying the adjustment cost twice. Figure 8 shows the change in the stock of debt b and the two stocks of capital, k and k_{oil}.

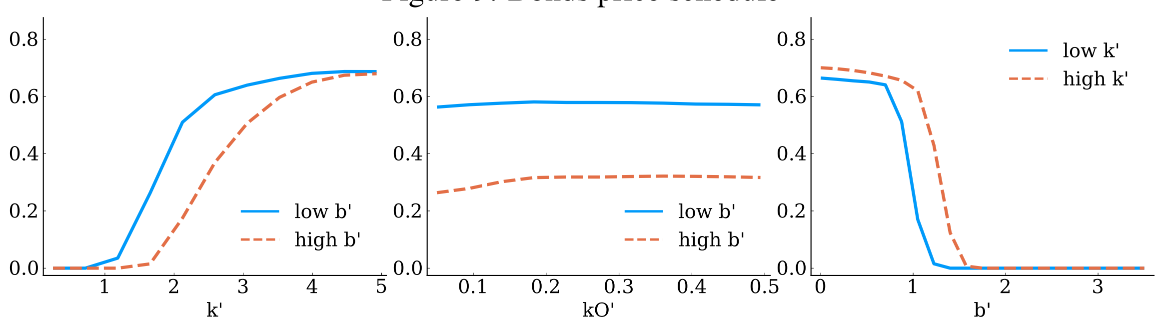
Figure 8: Transition of borrowing and investment



To compute the model responses I consider 1000 economies in their ergodic state without any oil discoveries in the past 50 periods and that have been in good financial standing for at least 25 periods. I then consider two versions of each economy: one with a discovery in period 0 and one without. I compute the difference between the two paths and average these paths of differences across all 1000 economies.

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

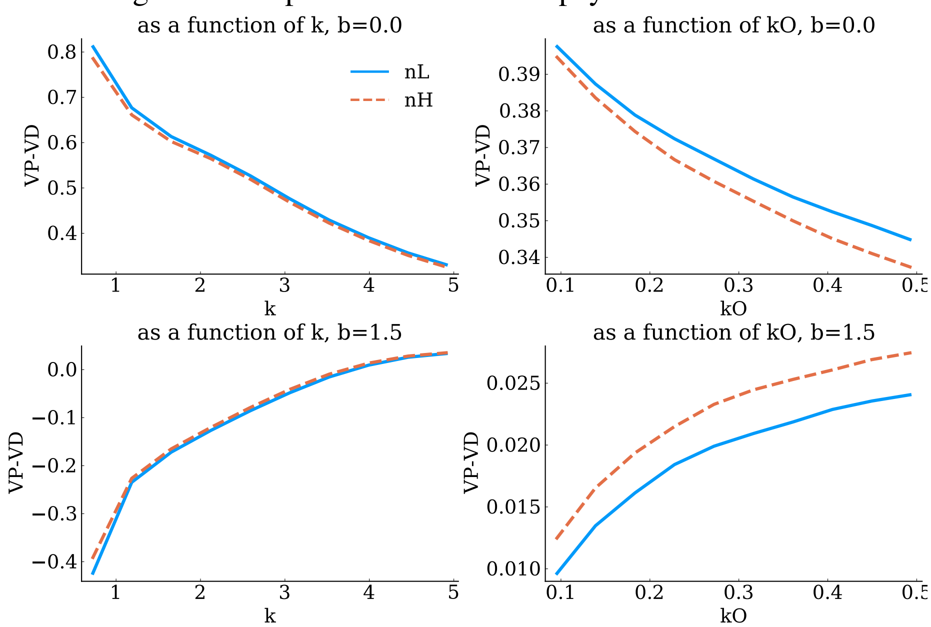


The price schedule is evaluated at the mean of the productivity and price of oil shocks and at the small oil field n_L. The left graph depicts the price of bonds as a function of capital in the next period k', for high and low values of issued debt. The middle graph shows the price of bonds as a function 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 right 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 right graph 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. The left and middle graphs show that, given a level of debt issued, the price of bonds is increasing in both types of capital. This implies that higher levels of capital help sustain higher levels of debt.

Capital, oil fields, and default incentives.—As Gordon and Guerron-Quintana (2018) show, capital causes a tension in default incentives. On one hand, more capital gives the government 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. However, 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 orange 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.[32] The relation between the size of the oil field and default incentives is similar to that of capital. A larger field increases the incentives to repay when the government is highly indebted (the orange dashed lines are higher in the bottom graphs) and reduces them when debt is low.

Capital reallocation and volatility of tradable income.—Within each period, general capital k can be freely allocated into the manufacturing and the non-traded intermediate sectors. Given the state of the economy, k_M is pinned down by:

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

where $X=\gamma b-q(\cdot)\left[b'-(1-\gamma)\,b\right]$ is payment to foreign lenders 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 14 is increasing in k_M and the left-hand side is decreasing. Thus, increases in n and k_{oil} (while keeping k fixed) increase y_{oil} and lower the equilibrium allocation of capital into the manufacturing sector k_M. This is the classic "Dutch-disease" effect. Now, note that from the balance of payments

$$X = x_M + p_{oil}x_{oil} \tag{15}$$

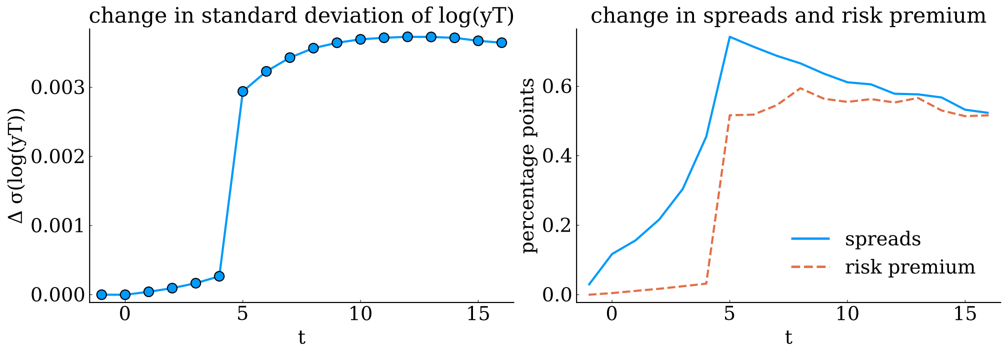
we have that payments to foreign lenders X are supported with exports of the manufacturing good $x_M = zk_M^{\alpha_N}-c_M$ and oil $x_{oil}=y_{oil}-c_{oil}$. A larger oil field n_H and higher capital in the oil sector k_{oil} imply a higher oil production and lower production of the manufacturing good. These make the right-hand-side of 15 more volatile since it is now more exposed to swings in p_{oil} and less exposed to the productivity shock z, which has a much lower variance.

Default premium and risk premium.—The left graph in Figure 11 shows how the standard deviation of tradable income increases following an oil discovery.[33] Right after the discovery, this standard deviation gradually increases with the anticipated accumulation of oil capital. Once the field becomes productive it sharply increases reflecting the full effect described above.

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

[33] Formally, $\sigma_{y_T,t}$ is the standard deviation of tradable income $y_{T,t+t}$ conditional on the information at t.

Figure 11: Decomposition of the cumulative change in spreads

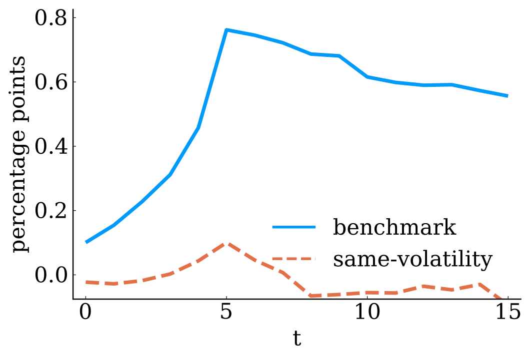


To compute the model responses I consider 1000 economies in their ergodic state without any oil discoveries in the past 50 periods and that have been in good financial standing for at least 25 periods. I then consider two versions of each economy: one with a discovery in period 0 and one without. I compute the difference between the two paths and average these paths of differences across all 1000 economies.

Everything else constant, the stochastic discount factor defined in 11 implies that lenders will value the government bonds less when the variance of total tradable income is high. The right graph in Figure 11 shows how most of the increase in spreads in the model is driven by a higher risk premium at the time production is about to start to compensate the lenders for the increase in volatility. It is worth noting that default risk also increases (which explains the remainder increase in spreads) but only between the period when the news arrives and the start of production. Once the field is productive, the default premium decreases because of the reduction in the stock of debt (reversal of the current account) but the risk premium remains high because of the higher volatility.

To further highlight the role of the endogenous volatility of tradable income, I consider a counterfactual case in which the persistence and variance of the price of oil are the same as those for the productivity shock. I call this the *same-volatility* case. This case mutes the effect of the change in the conditional volatility of tradable income, since it would now be the same for any production bundle. Figure 12 compares the response of spreads to an oil discovery in the *same-volatility* case to that from the benchmark model.

Figure 12: Response of spreads to a giant oil discovery



To compute the model responses I consider 1000 economies in their ergodic state without any oil discoveries in the past 50 periods and that have been in good financial standing for at least 25 periods. I then consider two versions of each economy: one with a discovery in period 0 and one without. I compute the difference between the two paths and average these paths of differences across all 1000 economies.

In both cases lenders are risk-averse. However in the *same-volatility* case the average risk-premium does not change since the conditional volatility of tradable income remains the same in all periods. Absent this endogenous change in volatility, the increase in spreads is purely driven by the increase in default premium, which is explained by the increase in borrowing and the fact that, in some states, the larger oil field makes it easier to flaunt creditors. Quantitatively, however, this channel is much smaller than the increase explained by the change in the risk premium due to higher volatility.

4.5 Welfare gains of oil discoveries

The empirical findings from Section 2 are puzzling because following an oil discovery economic conditions appear to improve (GDP and investment increase) and yet sovereign spreads, which are typically counter-cyclical in the data (see Aguiar, Chatterjee, Cole, and Stangebye (2016)), also increase. The model presented above reconciles these findings in an environment where a benevolent government optimally chooses to exploit the larger oil field despite the increase in default risk and spreads. Given this, it is natural to expect that there are positive welfare gains from oil discoveries (the government could always choose not to increase oil production); however, the higher default and risk premia suggest that these gains could potentially be larger in the absence of default risk and also if the government could hedge against swings in the price of oil.

To calculate the welfare gains of an oil discovery I compute the permanent consumption compensation that would leave the government indifferent between discovering or not discovering oil. That is, welfare gains are $\lambda^* = 100 * \left[(W_D/W_{ND})^{\frac{1}{1-\sigma}} - 1 \right]$, where $W_D = \mathbb{E}\left[V\left(z, p_{oil}, 0, k, k_{oil}, b\right)\right]$ is the average of the value of discovering oil in good financial standing over $\left(z, p_{oil}, k, k_{oil,} b\right)$ in the ergodic distribution. Similarly, $W_{ND} = \mathbb{E}\left[V\left(z, p_{oil}, -1, k, k_{oil}, b\right)\right]$ is the corresponding average of not discovering oil. Under the benchmark calibration, the welfare gains of discovering oil are $\lambda^* = 0.44$. That is, discovering a giant oil field is equivalent to permanently increasing consumption by 0.44 percent.

In order to explore how large the foregone gains are, I analyze three counterfactual exercises. The first is the *same-volatility* case, which, as described above, mutes the effect of the change in the conditional volatility of tradable income. 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 oil 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 lenders $\beta = 0.91$ (the average between $e^{-r^*} = 0.96$ and the benchmark $\beta = 0.86$).

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 the simulated 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	2.08	2.19	4.5	4.6	4.2	4.7
same-volatility	4.38	5.22	3.2	3.0	1.4	1.4
options	2.88	3.02	4.3	5.2	4.0	5.2
patient	0.40	0.45	4.0	4.4	4.2	4.8

To compute default probabilities I simulate an economy for 11,000 periods and drop the first 1,000. Using the data for all default episodes, the default probability in any 10 years reported in Column (1) is $1 - Pr$(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 300 economies with $n = n_L$ for 1,050 periods, I drop the first 1,000 and use the remaining data. I only consider economies that have been in good financial standing for at least 25 periods. 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. I use a smoothing parameter of 100 to filter the data.

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). This is true in the data as well, although in the data these probabilities increase from 12 to 18 percent.[34] Interestingly, default probabilities are much higher in the *same-volatility* case. This is because tradable income is less volatile in general (see both columns (5) and (6)), which implies a lower risk premium. Thus, the government faces lower spreads and accumulates more debt (the debt-to-output ratio is 0.40 up from 0.36 in the benchmark case). This higher level of indebtedness increases the long-run default frequency and spreads are mostly explained by this (the risk-premium-to-spreads ratio is 0.04 down from 0.37 in the benchmark).

Table 5 reports the welfare gains of oil discoveries within each counterfactual.

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

	welfare gains λ^*
benchmark	0.44
same-volatility	0.45
options	0.60
patient	0.66

Welfare gains of oil discoveries in the *same-volatility* case are almost the same as in the benchmark economy, which suggests that losses from higher volatility of consumption are offset by gains

[34] The lower default probabilities are a result of calibrating for Mexico, where spreads and default frequencies in the data are smaller. A calibration targeting riskier countries like Argentina or Russia would yield higher default probabilities, but it would also include data with oil discoveries in the targeted moments.

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*. 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.

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 endogenous increase in the risk premium. The latter follows from an endogenous increase in the volatility of tradable income due to a reallocation of capital. Hedging against the excess volatility of the price of oil would reduce the increase in the risk premium and improve borrowing terms for the government. However, observed default probabilities 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 0.44 percent, despite the higher spreads. There are foregone gains due to high impatience of at least 0.26 percent. Completely eliminating the excess volatility of the price of oil has virtually no effect on the welfare gains of oil discoveries despite its potential to reduce the increase in spreads. This is 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 0.2

percent, which is almost as high as the foregone gains from high impatience.

These results favor policies aimed at limiting arbitrary front-loading of spending from 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, especially 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.

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