The Sovereign Default Risk of Giant Oil Discoveries*

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Abstract

I study the impact of giant oil field discoveries on default risk. I document that interest rate spreads of emerging economies increase by 1.2 percentage points following a discovery of median size. This is puzzling from the point of view of canonical sovereign default models because spreads in these models decrease when expected future income increases. I develop a model with production in three-sectors, oil discoveries, and risk-averse lenders that explains this estimate. Following a discovery, oil investment increases and capital reallocates from manufacturing toward oil and non-traded sectors, increasing the volatility of tradable income. This endogenously higher volatility increases the risk premium that lenders require to hold government debt, which generates an increase in spreads despite the increase in present and future income. Discoveries generate positive welfare gains and these gains are twice as large with access to insurance against low oil prices. (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] This paper studies how the discovery and exploitation of natural resources impact debt and sovereign risk.

I use data of giant oil field discoveries to document the effect of a large increase in available natural resources on sovereign interest rate spreads. I build on the work by Arezki, Ramey, and Sheng (2017), who calculate the net present value of potential future revenues from an oil discovery relative to the GDP of the country where it happened.[2] I 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 1.2 percentage points following a discovery of median size. Following a discovery, these countries run a current account deficit and GDP, total investment, foreign direct investment (FDI), 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.

The above evidence is consistent with the permanent income hypothesis, but the effect on spreads is puzzling from the point of view of canonical sovereign default models (i.e. the class of models following Eaton and Gersovitz (1981), Aguiar and Gopinath (2006), and Arellano (2008)). In these models default incentives and spreads decrease following a persistent increase in income, like when giant oil fields are discovered. This is because the cost of defaulting is assumed to be larger when income is high in order to generate countercyclical spreads, which is a feature of the data.

To reconcile theory and data I develop a small-open economy model of sovereign default with risk-averse foreign lenders, FDI in the oil sector, oil discoveries, and production in three intermediate sectors: a non-traded sector, a traded "manufacturing" sector, and a traded "oil" sector. All

[1] A giant oil field contains at least 500 million barrels of ultimately recoverable oil. "Ultimately recoverable reserves" is an estimate (at the time of the discovery) of the total amount of oil that could be recovered from a field.

[2] The data of giant oil discoveries in the world was collected by Horn (2014) and the Global Energy Systems research group at Uppsala University.

sectors use capital for production and the oil sector additionally requires an oil field, which is a fixed factor of production that increases when an oil discovery occurs. Following a discovery, FDI in the oil sector increases and the economy runs a current account deficit. In addition, there is a reallocation of capital away from manufacturing and toward the non-traded sector.

Following previous sovereign default studies with risk-averse lenders (see for example Arellano and Ramanarayanan (2012) and Bianchi, Hatchondo, and Martinez (2018)) I assume that lenders demand a positive risk premium for holding government bonds that depends on the economy's tradable income. Unlike in the previous papers, the conditional mean and variance of tradable income are endogenous objects that depend on production decisions. Following a discovery, the relative size of the oil sector increases because of FDI inflows and the Dutch disease. This increases the conditional volatility of total tradable income because the price of oil is assumed to be relatively more volatile than the price of the other traded goods.[3] This endogenous increase in volatility raises the risk premium.

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 responses to oil discoveries in the benchmark model are in line with those from the data. I also study the responses of two counterfactual parameterizations: one with a higher risk premium and another with risk-neutral lenders. With the exception of spreads, the responses of all macroeconomic aggregates are similar in all three cases. Spreads increase more in the case with a higher risk premium and decrease in the risk-neutral case, which is consistent with the intuition discussed above. These results highlight the role of the production structure of the economy on the

[3]Prices of commodities have always been more volatile than those for manufacturing goods, as Jacks, O'Rourke, and Williamson (2011) document 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.

risk premium that sovereign governments pay on their debt.

Despite the increase in spreads and risk premium, giant oil discoveries generate welfare gains equivalent to a permanent increase in consumption of 0.66 percent. I compute the welfare gains of discoveries for two counterfactual cases: (i) the *full insurance* case, in which the economy is able to trade oil at a fixed price equal to its long-run mean, and (ii) the *put options* case, in which the economy is able to trade oil at a price equal to its mean if the current market price is low. Eliminating the volatility of the price of oil has a small effect on the welfare gains, which increase to 0.72 percent. This is because losses from higher volatility are offset by gains from high consumption in states with high oil prices and not-so-low consumption in states with low oil prices (for which the option to default allows the government to contain large drops in consumption). In the put options case, however, oil discoveries generate welfare gains of 1.1 percent, which implies that insurance against low realizations of the price of oil is highly valuable.

Related literature.—This paper contributes to 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 countercyclicality 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, which allows the models to jointly account for the debt level, the level and volatility of spreads around default episodes, and other cyclical factors. Gordon and Guerron-Quintana (2018) analyze the quantitative properties of sovereign default models with capital accumulation and long-term debt. They show that the model can fit cyclical properties of investment and GDP while also remaining consistent with other business cycle properties of emerging economies. 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. The model in Section 3 builds on these models and introduces FDI in the oil sector.

This paper is closely related to Hamann, Mendez-Vizcaino, Mendoza, and Restrepo-Echavarria (2023). They study the relationship between oil exports, proved oil reserves, and sovereign risk. There are three key differences between their and my empirical work. The first has to do with the magnitude of the shocks that are studied. 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 third is that the data on oil discoveries in my paper 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. They 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). 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 paper also contributes to the literature that studies the role of news as drivers of business cycles (see Beaudry and Portier (2014), Jaimovich and Rebelo (2008), and Arezki, Ramey, and Sheng (2017)). 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.

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 in JP Morgan's Emerging Markets Bonds Index (EMBI).[5] Due to data availability, I restrict the analysis to yearly data between 1993 and 2012. I use a measure of the net present value (NPV) of oil discoveries as a percentage of the GDP of the country in the year of discovery, which was constructed

[5]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.

by Arezki, Ramey, and Sheng (2017). I follow their empirical strategy to estimate the effects of 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 and the permanent income hypothesis. My contribution is to estimate the effect of discoveries on sovereign interest rate spreads. Spreads increase by up to 1.2 percentage points in the years following a discovery of median size. In addition, I estimate the effect of discoveries on the real exchange rate and investment by sectors and find evidence of the Dutch disease.

2.1 Giant oil field discoveries data

Giant oil discoveries increase the availability and potential exploitation of natural resources. Their size is large relative to the GDP of the countries where they happen. 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:[6]

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

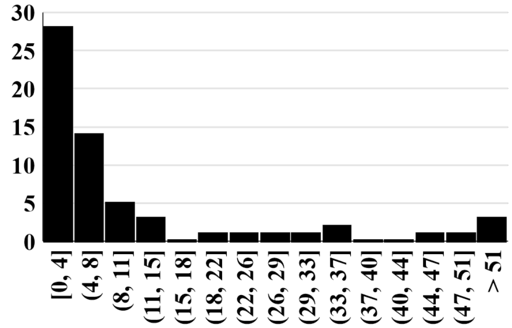
where $q_{i,t+j}$ is the annual gross revenue in year $t+j$ from the field discovered in country i in period t, r_i is the annual discount rate for country i, and $GDP_{i,t}$ is annual GDP of country i at year t. The authors use country-specific risk-adjusted discount rates r_i, which are constructed using the relationship between the average of sovereign spreads over a long period, available for a small set of emerging countries, and an index of political risk ratings, available for a wider set of countries. This way, the $NPV_{i,t}$ measure discounts flows more for countries where political risk is high. In the data there is a time delay of 5.4 years on average between a discovery and the start of production. The annual gross revenue $q_{i,t+j}$ is derived from an approximated production profile that starts 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.[7] Crucially, the calculation of $q_{i,t+j}$ is scaled by the size

[6] 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).

[7] 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. This assumption is made for convenience because projecting future oil prices is complicated and oil

of the discovery, which is measured in terms of “ultimately recoverable reserves” (URR). This is an estimate (at the time of the discovery) of the amount of oil that could be eventually recovered from a field given the existing technology.

Figure 1: Distribution of NPV of giant oil discoveries



Percent of GDP, EMBI countries, 1993 –2012. The largest discovery in the sample was in Kazakhstan in 2000 with a NPV of 467.

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. Figure 1 depicts the distribution of the NPV of these discoveries.

2.2 Empirical strategy

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.[8] This significant delay allows the treatment of giant oil discoveries as news shocks about higher future income.

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 discoveries:

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

prices are highly persistent in the data. See Appendix B of Arezki, Ramey, and Sheng (2017) for a detailed explanation of the approximation of the production profile of giant oil discoveries.

[8] 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.

where $y_{i,t}$ is the dependent variable; $NPV_{i,t}$ is the discounted net present value of a discovery in country i in year t; α_i controls for country fixed effects; μ_t are year fixed effects; $X_{i,t}$ is a vector of additional control variables; and $\varepsilon_{i,t}$ is the error term.[9]

The vector X includes contemporaneous and up to ten lags of the interaction $\mathbb{I}_{\text{disc},i,t-s} * \log p_{oil,t}$, where $\log p_{oil,t}$ is the natural logarithm of the international price of oil in year t and $\mathbb{I}_{disc,i,t-s}$ is an indicator function of whether country i had an oil discovery in period $t-s$. These interaction terms allow the response to the price of oil to vary after a discovery in anticipation of higher oil income in the near future. In addition, the vector X includes the term $R^{oil}_{i,1993} * \Delta \log p_{oil,t}$, where $\Delta \log p_{oil,t}$ is change in the natural logarithm of the international price of oil from period $t-1$ to t and $R^{oil}_{i,1993}$ are oil rents as a percentage of GDP for country i at the beginning of the sample. This controls for shocks to the price of oil scaled by the sector's relative importance in 1993, predating any discoveries in the sample.[10]

2.3 Response to discoveries

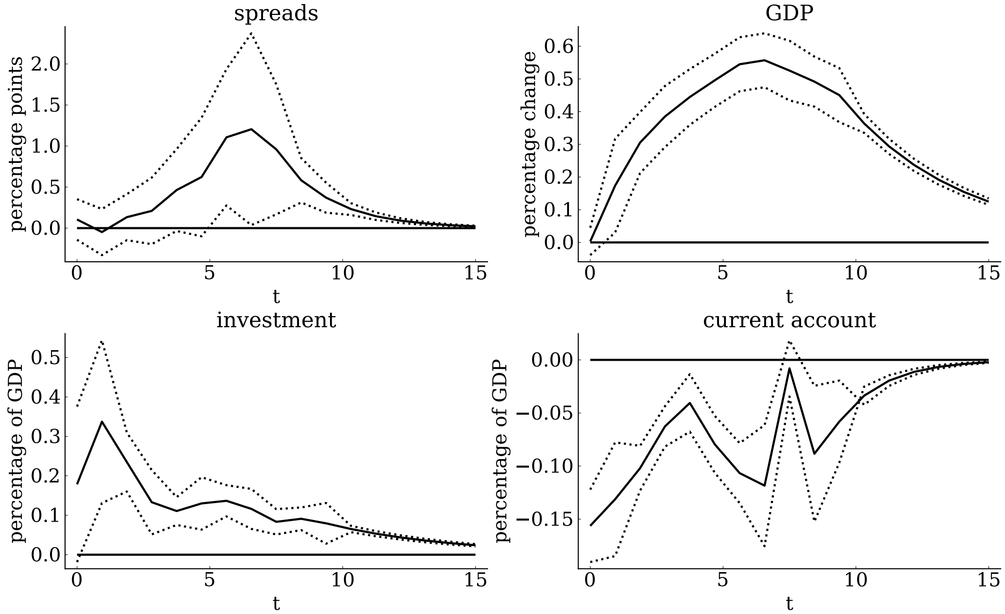
This Subsection reports impulse-response functions to oil discoveries for different dependent variables given by $\Delta y_{i,t} = \rho \Delta y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s}$ using the estimated coefficients of equation (2).

Macroeconomic aggregates.—Figures 2 and 3 show the dynamic response of main macroeconomic aggregates to an oil discovery of median size. The data for investment, the current account, GDP, and consumption are 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.

[9]Following Arezki, Ramey, and Sheng (2017), 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.

[10]As documented by Hamann et al. (2023), the dynamics of proved oil reserves have a significant impact on the evolution of credit worthiness of emerging economies who are oil exporters. The online appendix contains robustness checks for the regression of spreads in which I 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. The results are robust to these controls.

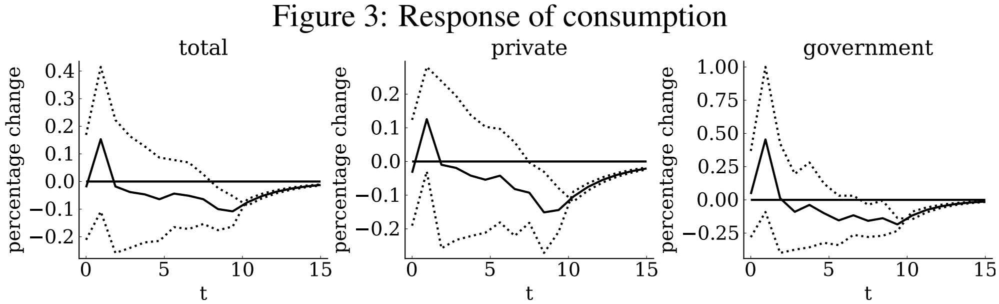
Figure 2: Response of macroeconomic aggregates



Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The dotted lines indicate 90 percent confidence intervals based on a Driscoll and Kraay (1998) estimation of standard errors, which yields standard error estimates that are robust to general forms of spatial and temporal clustering.

The top left panel of Figure 2 shows that following a discovery spreads steadily increase and, by the sixth year after the discovery was announced, the increase peaks at 1.2 percentage points. Similarly, GDP starts increasing following the discovery and the increase peaks after six years. Investment increases immediately after the discovery is announced, which is mirrored by a current account deficit. In contrast with the findings in Arezki, Ramey, and Sheng (2017) for a larger set of countries, there is no current account surplus after oil production starts.

Figure 3: Response of consumption

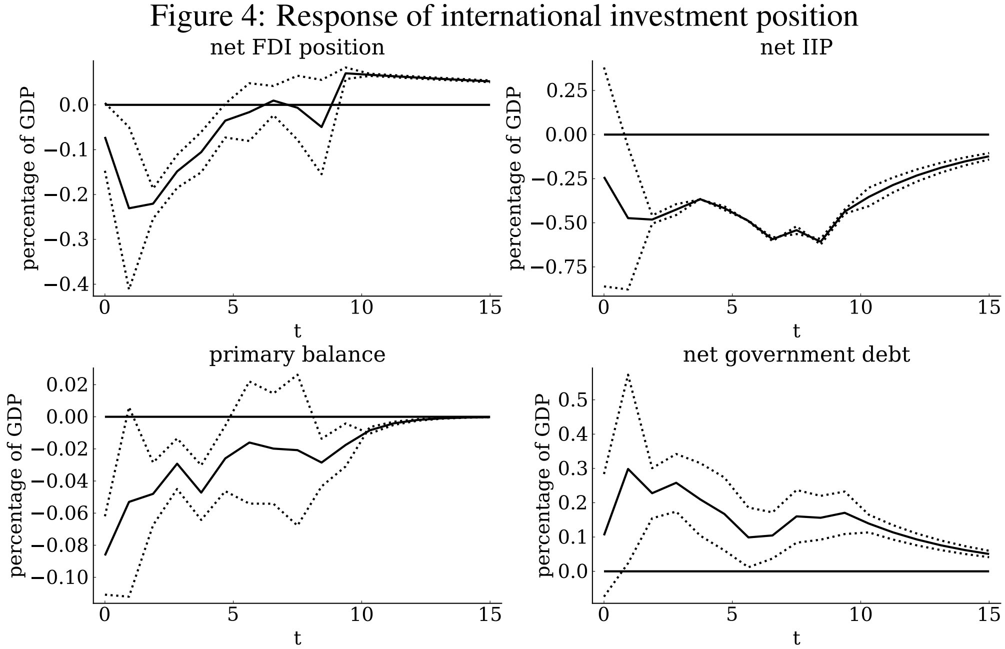


Impulse response to an oil discovery with net present value equal to 4.5 percent of GDP, which is the median size of discoveries in the sample. The dotted lines indicate 90 percent confidence intervals based on a Driscoll and Kraay (1998) estimation of standard errors, which yields standard error estimates that are robust to general forms of spatial and temporal clustering.

Consumption initially increases, but the estimates are not precise.[11] Although it is noisy, the response of government consumption is larger in magnitude. Figure 4 below presents evidence of the response of government debt and the primary balance that is consistent with this observation.

International investment position.—Figure 4 shows the dynamic response of foreign direct investment (FDI), the country's international investment position (IIP), the government's primary balance, and net government debt.[12] FDI inflows mirror the response of aggregate investment and have a similar magnitude, which suggests that investment in the oil field is financed directly by foreigners. This is consistent with the findings by Toews and Vézina (2022) and Sheng and Zhao (2024). Government borrowing increases to finance a larger primary deficit which is indicative of higher government consumption, as weakly suggested by Figure 3.

Figure 4: Response of international investment position



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.

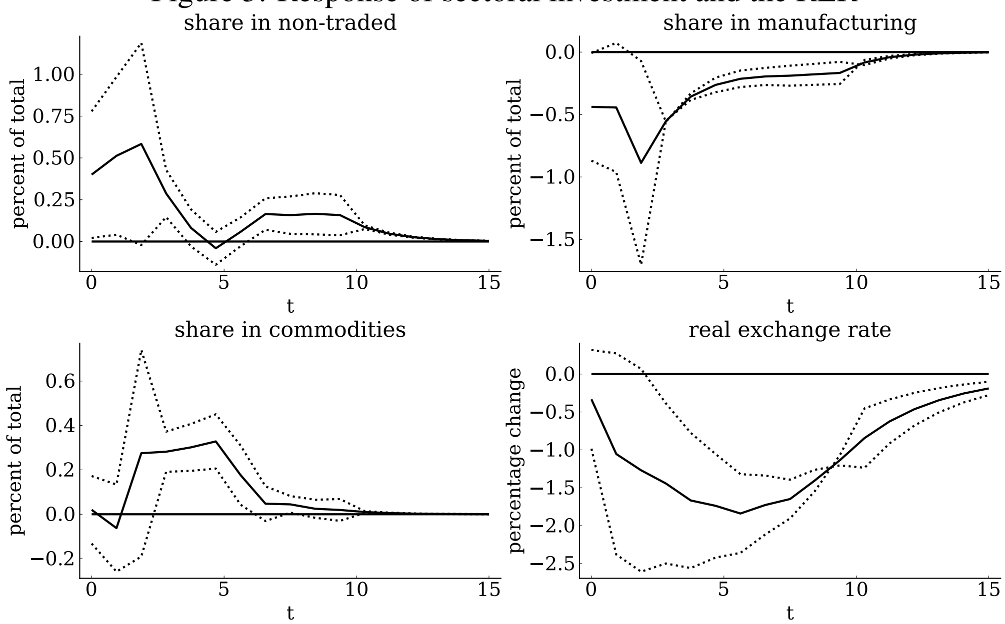
Dutch disease.—Figure 5 shows the dynamic response of the real exchange rate, as well as the

[11] Arezki, Ramey, and Sheng (2017) find similarly noisy estimates for a larger set of countries, which could be a result of measurement error in the consumption data. In particular, for emerging economies measurement error in public consumption could arise from unreported public transfers, which are larger during crises (see Esquivel, Kehoe, and Nicolini (2021) for a discussion of such transfers during different economic crises in Latin America).

[12] The data for FDI and IIP are from the updated and extended version of a dataset constructed by Lane and Milesi-Ferretti (2007). The data for the primary balance and net government debt are from the IMF Fiscal Monitor.

share of total investment in manufacturing, commodities, and non-traded sectors.[13] Commodities comprise agricultural, fishing, mining and querying activities. The non-traded sector includes construction and wholesale, retail, and logistics services. The data on investment by sector is in terms of the share of total investment and is from the United Nations Statistics Division (2017). 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).

Figure 5: Response of 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;

[13]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. See the online appendix for details on these data.

however, their estimates are not significantly different from zero.

3 Model

This section presents a small-open economy model in the Eaton and Gersovitz (1981) tradition with risk-averse bond holders, production in multiple sectors, foreign direct investment in the oil sector, and discovery of oil fields. There is a benevolent government that makes borrowing and default decisions on behalf of domestic households. The economy owns an oil field that is operated by a competitive foreign investor. In exchange for being allowed to operate the field the investor pays an oil rent to the government, which is defined as the difference between the market value of production and total production costs. Every period there is a probability of an oil discovery, which increases the size of the oil field and attracts additional foreign direct investment and shifts production factors away from other traded sectors into non-traded ones. The government debt is purchased by risk-averse foreign lenders whose stochastic discount factor depends on the economy's total tradable income—that is, the income available to service the debt. This assumption generates a risk-premium for government bonds that varies endogenously with the relative size of the oil sector.

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. This good is a CES aggregate of an intermediate non-traded good $c_{N,t}$ and two intermediate traded goods: manufacturing goods $c_{M,t}$ and oil, $c_{oil,t}$:

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

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 $y_{N,t}=z_t k_{N,t}^{\alpha_N}$ and $y_{M,t}=z_t k_{M,t}^{\alpha_M}$, where z_t is a persistent productivity shock that affects both sectors, and $0 < \alpha_N < 1$, $0 < \alpha_M < 1$.[14] There is a general fixed stock of capital normalized to $\bar{k} = 1$ that can be freely allocated in these two sectors within the same period such that $k_{N,t} + k_{M,t} = \bar{k}$.[15]

FDI and oil discoveries.—There is an oil field in the economy with capacity n_t which is rented to a foreign oil producer. The technology to extract oil is:

$$y_{oil,t} = k_{oil,t}^{1-\zeta} n_t^{\zeta} \tag{4}$$

where $\zeta \in (0,1)$ is the weight that corresponds to the oil field, and $k_{oil,t}$ is capital specific to the oil sector. Oil capital depreciates at a rate δ and there is a capital adjustment cost $\Psi\left(k_{oil,t+1}, k_{oil,t}\right) = \phi\left(k_{oil,t+1} - k_{oil,t}\right)^2 / k_{oil,t}$. The oil producer makes investment decisions on the field to maximize its lifetime utility $\mathbb{E}_t\left[\sum_{s=t}^{\infty} (\beta^*)^{s-t} u^*\left(c_t^*\right)\right]$, where $\beta^* = 1/(1+r^*)$ is a discount factor consistent with the international risk-free interest rate and u^* is a concave function, subject to the budget constraint

$$P^*\left[c_t^* + k_{oil,+1} - (1-\delta) k_{oil,t} + \Psi\left(k_{oil,t+1}, k_{oil,t}\right)\right] \leq p_{oil,t} y_{oil,t} - R\left(p_{oil,t}, k_{oil,t}, n_t\right) \tag{5}$$

where R is the oil rent paid to the government, P^* is the relative price of the foreign consumption good (assumed to be constant), and $p_{oil,t}$ is the international price of oil, which the producer takes as given. The oil rent is equal to the market value of oil production minus total production costs

$$R\left(p_{oil,t}, k_{oil,t}, n_t\right) = p_{oil,t} y_{oil,t} - r_{oil,t} k_{oil,t} \tag{6}$$

where $r_{oil,t}$ is the marginal product of capital in the oil sector.

The capacity of the oil field can take one of two values $n_t \in \{n_L, n_H\}$ with $0 \leq n_L < n_H$. Capacity n_t follows a Markov chain whose transition probabilities are governed by the probability of an oil discovery $P\left(n_{t+1} = n_H | n_t = n_L\right) = \pi_{\text{disc}}$ and the probability of exhaustion of a giant oil field $P\left(n_{t+1} = n_L | n_t = n_H\right) = \pi_{\text{ex}}$.

Rest of the world and international prices of goods.—There is a rest of the world economy

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

[15] 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.

with international lenders and with a market where the small-open economy trades oil and the manufacturing good (which is the numeraire). 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 an AR(1) process

$$\log p_{oil,t} = \rho \log p_{oil,t-1} + \sigma_{oil,t} \varepsilon_{oil,t},$$

where the variance $\sigma^2_{oil,t}$ is time-varying and follows a two-state Markov chain. This allows the international price of oil to have two regimes: one with high and one with low variance, which is a feature of the data. The crucial assumption, however, is that the price of oil is more volatile than the productivity shock z in either regime, which is the case for the standard calibration described below.[16]

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:

$$b_{t+1} = (1-\gamma)\, b_t + i_{b,t} \tag{7}$$

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; the government gets re-admitted to financial markets with probability θ and zero debt. While in default, the aggregate consumption good is $c_t^d \leq c_t$. Following Arellano (2008), I assume an asymmetric penalty to consumption so that $c_t^d = \min\{c_t, \underline{c}\}$. This implies that the penalty is zero when $c_t \leq \underline{c}$ is low and rises more than proportionately when $c_t > \underline{c}$. This asymmetry in the default penalty is crucial in generating default dynamics that are in line with the data, and in particular with the countercyclicality of spreads and the current account (see the discussions in Arellano (2008)

[16] For a richer model of the international oil industry see Bornstein, Krusell, and Rebelo (2022).

and Chatterjee and Eyigungor (2012)).[17]

In default, the balance of payments is:

$$0 = x_{M,t} + p_{oil,t} x_{oil,t} - r_{oil,t} k_{oil,t} \tag{8}$$

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 (8) implies that in default trade in goods (net of factor payments to foreigners) 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:

$$\gamma b_t = x_{M,t} + p_{oil,t} x_{oil,t} - r_{oil,t} k_{oil,t} + q_t \left(b_{t+1} - (1-\gamma) b_t\right) \tag{9}$$

where q_t is the market price of newly issued debt. Equation (9) 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 on average for a set of emerging economies.

To model the risk premium I modify the parsimonious approach in Arellano and Ramanarayanan (2012) and Bianchi, Hatchondo, and Martinez (2018). Foreign lenders price government debt using the following stochastic discount factor

$$m_{t,t+1} = e^{-\left(r^* + \alpha_0 \tilde{y}_{T,t+1} + 0.5 \alpha_0^2 \sigma_{T,t}^2\right)} \tag{10}$$

[17] 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 c_t^d.

where $\alpha_0 > 0$ is a primitive parameter that controls the degree of lender-risk aversion; $\tilde{y}_{T,t+1} = \log y_{T,t+1} - \mathbb{E}_t [\log y_{T,t+1}]$ 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 $\sigma^2_{T,t}$ 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 state. 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 $\sigma^2_{T,t}$. 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 $s = (z, p_{oil}, n, \sigma_{oil})$, the stock of capital for the oil sector k_{oil}, the outstanding government debt b, and an indicator of whether the government is in default or not.

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

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

where $V^P(s, k_{oil}, b)$ is the value of repaying and $V^D(s, k_{oil})$ is the value of default.[18]

If the government decides to default then its debt obligations are erased and it gets excluded from financial markets. Then, the government chooses static allocations of general capital in the manufacturing sector and the non-traded intermediate sector $K = \{k_N, k_M\}$, net exports of oil and the manufacturing good $X = \{x_{oil}, x_M\}$, and consumption of intermediate goods $C = \{c_N, c_M, c_{oil}\}$

[18] Alternative timing assumptions can give rise to multiplicity of equilibria (see for example Cole and Kehoe (2000)). For detailed discussions and literature reviews see Aguiar and Amador (2014) and Aguiar, Chatterjee, Cole, and Stangebye (2016).

to solve:

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

subject to the resource constraint of general capital $k = k_N + k_M$, 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 (8). The government takes the law of motion of oil capital (and, thus, of its income from oil rents) as given.

If the government decides to repay then it chooses 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 oil and the manufacturing good $X = \{x_{oil}, x_M\}$, and consumption of intermediate goods $C = \{c_N, c_M, c_{oil}\}$ to solve:

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

subject to the resource constraints of intermediate goods and capital, the law of motion of oil capital, the law of motion of bonds (7), and the balance of payments under repayment (9).

Oil producer.—Note that oil production is not affected by the productivity shock or the decisions made by the government, so the state of the oil producer is $(p_{oil}, n, \sigma_{oil}, k_{oil})$. The oil producer chooses its consumption and capital allocation for the next period k'_{oil} to maximize its value

$$\Omega(p_{oil}, n, \sigma_{oil}, k_{oil}) = \max_{\{c^*, k'_{oil}\}} \left\{u^*(c^*) + \beta^* \Omega\left(p'_{oil}, n', \sigma'_{oil}, k'_{oil}\right)\right\}$$

subject to its budget constraint (5).

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 10, the lenders price the bonds according to:

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

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

3.3 Equilibrium

A Markov equilibrium is value functions Ω, V, V^D, and V^P; policy functions for capital and debt $\hat{k}_{oil}$ 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 and oil producer's problems, (ii) the price schedule satisfies (11), and (iii) lenders have rational expectations about the government's and oil producer's future decisions, that is $k''_{oil} = \hat{k}_{oil}\left(s', k'_{oil}, b'\right)$, and $b'' = \hat{b}\left(s', k'_{oil}, b'\right)$ in equation (11).

4 Quantitative analysis

4.1 Model solution

I solve the oil producer's problem using value function iteration (VFI). For the government's problem and the functional equation for the price of bonds I follow Hatchondo and Martinez (2009) and compute the limit of the finite-horizon version of the economy. To solve for the optimal debt issuance I use a nonlinear optimization routine.[19] The value functions V^D and V^P and the price schedule for bonds q are approximated using linear interpolation, and expectations over z and p_{oil} are calculated using a Gauss-Legendre quadrature.

4.2 Calibration

I calibrate the model to the Mexican economy. There are two reasons why Mexico is 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

[19] I search for the best borrowing policy over a grid and use it 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 GoldenSection routine from the Optim.jl package, which implements a Golden Search optimization algorithm.

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. Unless specified otherwise, all data are annual data for the years 1993 to 2012, which are the sample years in the empirical section. 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). I set the elasticity of substitution $\eta = 0.83$, following the literature.[20] I set the weights $\omega_N = 0.60$, $\omega_M = 0.34$, and $\omega_{oil} = 0.06$ using aggregate consumption shares for Mexico. I set the CRRA parameter to $\sigma = 2$, the capital depreciation rate to $\delta = 0.05$, the discount factor to $\beta = 0.92$, and the risk free interest rate to $r^* = 0.04$, which are standard values in the sovereign default literature.

Table 1: Parameters calibrated directly from the data

Parameter		Value	Parameter		Value
	α_N	0.66	oil rent	ζ	0.38
capital shares	α_M	0.57	CRRA	σ	2.00
	α_{oil}	0.49	discount factor	β	0.92
	ω_M	0.34	capital depreciation rate	δ	0.05
output shares	ω_{oil}	0.06	bonds maturity rate	γ	0.14
	ω_N	0.60	elasticity of substitution	η	0.83
probability of discovery	π_{disc}	0.01	risk free rate	r^*	0.04
probability of exhaustion	π_{ex}	0.02	price of foreign consumption good	P^*	0.0625
persistence of productivity	ρ_z	0.3737	volatility of productivity	σ_z	0.0194
persistence of price of oil	ρ_{oil}	0.854	probability of reentry	θ	0.40
oil volatility transition	π_{LH}	0.211	oil volatility transition matrix	π_{HL}	0.500
low volatility, price of oil	σ_{pL}	0.230	high volatility, price of oil	σ_{pH}	0.314
size of small oil field	n_L	0.00694	size of large oil field	n_H	0.00847

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

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

$\varepsilon_{z,t}$ are iid with a standard normal distribution. I estimate the persistence $\rho_z = 0.3737$ and standard deviation $\sigma_z = 0.0194$ of the productivity shock using a series of TFP constructed from Mexican National Accounts data. These data are detrended using an HP-filter with a smoothing parameter of 100. For the price of oil I use a long time series of the real price of crude oil from the World Bank Commodity Price Data between 1960 and 2021. The source includes monthly data of the average of the Brent, Dubai, and West Texas Intermediate prices. I deflate the time series using the US CPI and normalize it so that the long-run average is 1. I then construct an annual time-series of the average and standard deviation of the natural logarithm of the price of oil in each year and classify each year's standard deviation as high or low depending on whether it is above its mean over the entire sample. As mentioned before, the normalized price of oil is assumed to follow an AR(1) process $\log p_{oil,t} = \rho_{oil} \log p_{oil,t-1} + \sigma_{p,t}\varepsilon_{oil,t}$, where ρ_{oil} is the persistence parameter (the mean of the price of oil in the model is normalized to 1), $\varepsilon_{oil,t}$ are iid with a standard normal distribution, and $\sigma_{p,t} \in \{\sigma_{pL}, \sigma_{pH}\}$ follows a Markov chain with transition probabilities π_{ij}, $i,j \in \{L,H\}$.[21] Given the data $\left\{\left(\log p_{oil,t}, i_t\right)\right\}_{t=1960}^{2021}$ where $i_t = H, L$, I jointly estimate the vector $(\rho_{oil}, \sigma_{pL}, \sigma_{pH}, \pi_{LH}, \pi_{HL})$ using maximum likelihood. This yields the estimated values $\rho_{oil} = 0.854$, $\sigma_{pL} = 0.230$, $\sigma_{pH} = 0.314$, $\pi_{LH} = 0.211$, and $\pi_{HL} = 0.500$.

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

To calibrate some parameters I need to compute nominal and real GDP. In the model, nominal GDP in period t is $GDP_t = P_t Y_t + x_{M,t} + p_{oil,t} x_{oil,t}$, where P_t is the standard CES price index for the production function in equation 3. To be consistent with national accounts for Mexico, I compute real GDP using base-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 size of the small oil field to $n_L = 0.00694$ so that in the steady state without borrowing net exports of oil are 2.7% of GDP $\frac{x_{oil,ss}}{GDP_{ss}} = 0.027$ (which is the average of Mexican oil

[21] This assumption treats oil prices differently than in the empirical section, where they are assumed to follow a random walk in the computation of NPV by Arezki, Ramey, and Sheng (2017). This assumption is made so that the model remains stationary and tractable.

exports as a fraction of GDP between 1993 and 2021).[22] The median size of giant oil discoveries in the sample is 1.2 billion barrels of ultimately recoverable reserves and Mexico's proven reserves are 5.5 billion barrels, so an average discovery would imply a 22 percent increase in Mexico's oil production capacity.[23] I set $n_H = 1.22 * n_N = 0.00847$. The probability of a discovery is $\pi_{\text{disc}} = 0.01$, which is the probability of new discoveries observed in the data. The probability of exhaustion is $\pi_{\text{ex}} = 0.02$ for an average field life of 50 years. Finally, I set the capital adjustment cost parameter $\phi = 0.4199$ so that the average transition from $k^L_{oil,ss}$ to $k^H_{oil,ss}$ is equal to 5.4 years and the price of the foreign consumption good $P^* = 0.0625$ so that the FDI on a year of discovery is 0.4 percent of GDP in the steady state (as estimated in Figure (2)).

Table 2 summarizes the parameters calibrated by simulating the model. To compute the moments in the model I consider 400 economies in their ergodic state without any oil discoveries and that are in good financial standing in the initial period, as is the case with the Mexican data. Each time series has 20 periods. The parameters governing the default cost and the risk premium, $\underline{c}$ and α_0, are chosen to jointly match a mean level of spreads of 2.9 percentage points, which is the average for Mexico between 1997 and 2012, and an average risk-premium-to-spreads ratio of 0.52, which is the ratio that Longstaff, Pan, Pedersen, and Singleton (2011) document for Mexico.

Table 2: Parameters calibrated simulating the model

Parameter		Value
default cost	$\underline{c}$	0.475
risk-premium parameter	α_0	3.0
Moment	**Data**	**Model**
$Av(r - r^*)$	2.9	3.1
$RP/(r - r^*)$	0.52	0.52

Moments are computed by simulating 400 economies in their ergodic state without any oil discoveries and that are in good financial standing in the initial period.

To compute spreads I consider the implicit annual yield of government bonds given by $r^b_t = \log(q_t/\gamma + (1-\gamma)q_t)$; then, the spread is $r^b_t - r^*$. To compute the risk premium, consider the

[22]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.

[23]This is the most recent figure reported in the OPEC annual statistical bulletin, Table 3.1.

actuarially fair price of holding the debt for one period:

$$q_t^{af} = \mathbb{E}_t \left[e^{-r^*} (1 - d_{t+1}) (\gamma + (1-\gamma) q_{t+1}) \right] \tag{12}$$

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).

4.3 Results

Business-cycle moments.—Table 3 shows targeted and untargeted business-cycle moments from the data and several model parameterizations. The second row shows that, under the benchmark calibration, the model generates a debt-to-output ratio and spread dynamics (volatility and countercyclicality) that are consistent with the data.[24] Interestingly, the trade balance and the current account are procyclical in the model but countercyclical in the data. This is a result of the relatively important role of the oil sector in the model and highlights how FDI allows the government to share the risk from oil production with the foreign producer. The current account is the change in the net foreign asset position, which in the model is $ca_t = -q_t (b_{t+1} - (1-\gamma) b_t) - P^* \left(k_{oil,t+1} - (1-\delta) k_{oil,t} \right)$. When the price of oil increases, higher FDI increases the current account deficit. From the government's point of view, however, oil rents increase at no cost since the government did not pay for the investment in the oil sector, which reduces the marginal utility of additional borrowing in "good times". In addition, a larger oil sector increases the risk premium of government bonds due to the higher volatility of total traded income, which incentivizes the government to reduce its debt burden. These forces counter the motive to front-load consumption, which is driven by the persistence of shocks and the government's relative impatience.

[24] For debt I consider the total external debt stocks reported by the world bank.

Table 3: Business cycle moments

	$Pr(d=1)$	μ_{r-r^*}	$\frac{RP}{r-r^*}$	σ_{r-r^*}	$\frac{b}{y}$	$\frac{\sigma_c}{\sigma_y}$	σ_y	$\sigma_{\frac{tb}{y}}$	$\sigma_{\frac{ca}{y}}$	σ_{rer}	$\rho_{r-r^*,y}$	$\rho_{\frac{tb}{y},y}$	$\rho_{\frac{ca}{y},y}$	$\rho_{rer,y}$
data	3.00	2.9	0.52	1.3	0.25	1.0	2.3	0.5	0.8	5.2	-0.2	-0.4	-0.1	-0.5
model	0.02	3.1	0.52	2.2	0.28	0.7	2.4	5.1	1.4	3.1	-0.3	0.2	0.4	0.05
$\beta = 0.82$	3.64	9.6	0.26	3.9	0.42	1.3	3.5	6.1	2.3	3.6	-0.3	0.1	-0.3	0.01
$\alpha_0 = 12$	0.00	5.4	0.96	1.6	0.06	0.8	2.4	5.2	1.2	2.9	0.2	0.2	0.5	0.06

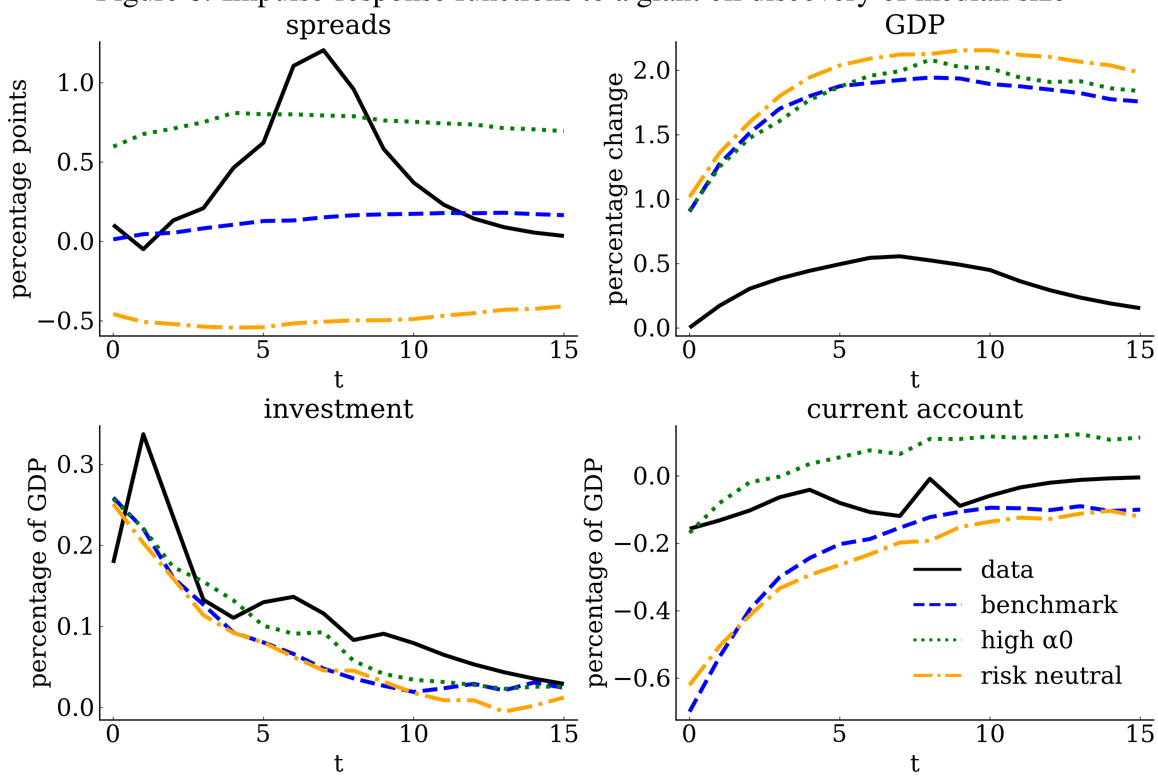
Moments are computed by simulating 400 economies in their ergodic state without any oil discoveries and that are in good financial standing in the initial period. Moments for GDP, consumption, and the real exchange rate correspond to the cyclical component of real variables detrended by the HP-filter with a smoothing parameter of 100.

The third row presents the moments that correspond to an economy with a much lower discount factor. Naturally, default is more frequent and spreads are higher. The current account in this case is countercyclical, which illustrates the above point that with enough impatience the motive to front-load consumption in periods with high income dominates the motive to reduce the debt burden due to a higher risk premium. The final row presents the moments of an economy with a much higher risk-premium parameter α_0. Spreads are higher and almost entirely driven by the risk premium. In this case the current account is more strongly positively correlated with output and the government cannot sustain as much debt as in the benchmark.

Responses to oil discoveries.—Figure 6 compares the data responses to oil discoveries in Figure 2 with their model counterparts. The model paths are the averages of 10,000 paths around an oil discovery. The state in the initial period $t = -1$ of each path is a draw from the ergodic distribution with a small oil field. Then, an oil discovery is introduced in period $t = 0$. The model lines in Figure 6 (dashed and dotted lines) are the differences with respect to period $t = -1$. The model responses are from the benchmark calibration and two counterfactual cases: one with a high risk premium ($\alpha_0 = 12$) and one with risk-neutral lenders.

Overall, the model does a good job reproducing the dynamics of investment, GDP and the current account. As was the case with the high frequency fluctuations analyzed above, the response of spreads to less frequent oil discoveries features two counteracting forces from the risk premium and default incentives. On one hand, the risk premium increases with the relative size of the oil sector because tradable income, which is used to service foreign debt, becomes more volatile (see the discussion of Figure 7 below). On the other hand, default risk decreases because the real default cost is higher with higher output, which is expected to increase following an oil discovery. This is the usual effect that persistent increases in income (such as the discovery of long-lasting giant oil fields) have on the canonical sovereign default model, which is what makes the empirical findings regarding spreads in Figure 6 puzzling. The green dotted line illustrates how spreads increase more when the parameter that governs the risk premium becomes higher, while the orange dash-dotted line shows how spreads decrease in an economy with risk-neutral lenders.

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



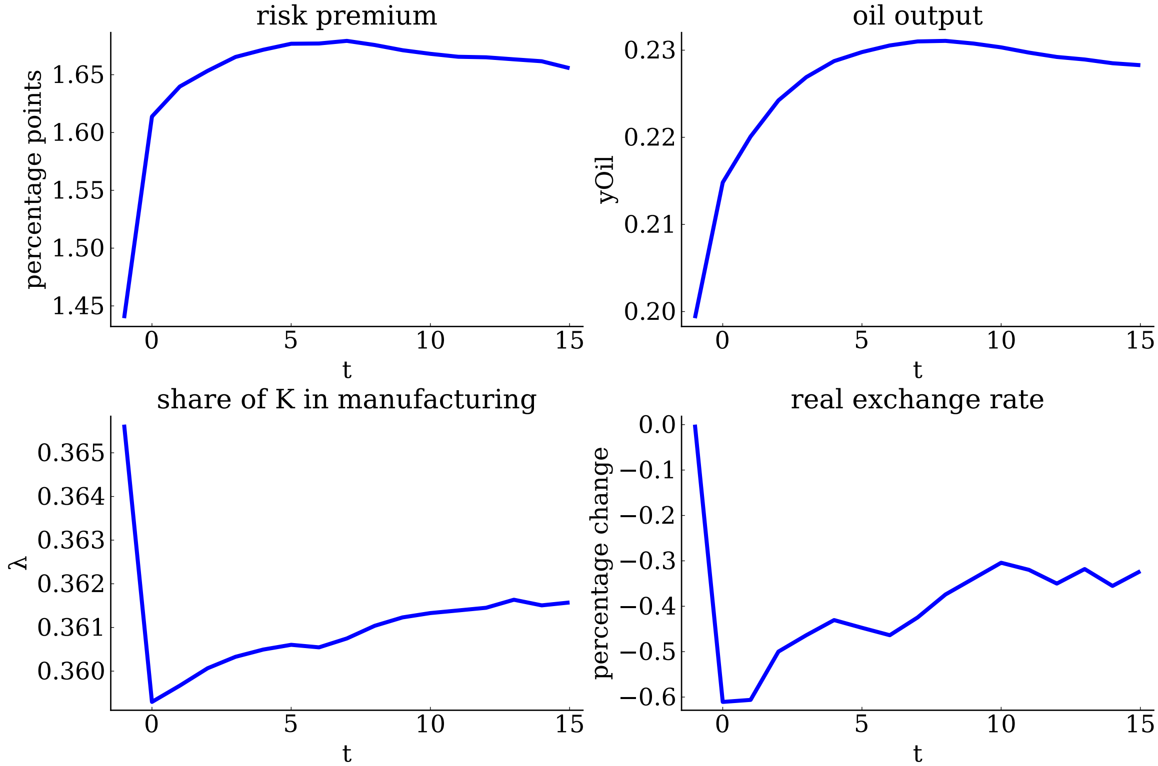
The solid black lines correspond to the data. The dotted lines correspond to the model. To compute the model series I consider 10,000 economies in their ergodic state without any oil discoveries in the past 50 periods and that are in good financial standing in the initial period $t = -1$, (one period before an oil discovery). The lines are the difference between the values in each period and the values in period t_{-1}. The dashed blue line corresponds to the benchmark calibration, the green dotted line to a model with higher risk premium, and the orange dash-dotted line to a model with risk-neutral lenders.

The Dutch disease and volatility of tradable income.—The stochastic discount factor of lenders in equation 10 introduces a positive risk premium with $\alpha_0 > 0$ because lenders value repayment more when total tradable income (the source of debt payments) is low. This is a standard assumption in sovereign default models with risk-averse lenders. The innovation in this model is that the conditional variance of total tradable income is an endogenous object that depends on the size of the oil field, the investment in the oil sector, and the share of capital in the manufacturing sector. Within each period, general capital k can be freely allocated to the manufacturing and the non-traded intermediate sectors. Let $\lambda \in [0,1]$ be the share of capital allocated to the manufacturing sector, given the state of the economy. This share is pinned down by:

$$\left(\frac{\alpha_M}{\alpha_N}\frac{((1-\lambda)k)^{1-\alpha_N}}{(\lambda k)^{1-\alpha_M}}\right)^{\eta} z((1-\lambda)k)^{\alpha_N} = \frac{\omega_N\left[z(\lambda k)^{\alpha_M} + R_{oil} - Tr\right]}{\omega_M + \omega_{oil}(p_{oil})^{1-\eta}} \tag{13}$$

where $Tr = \gamma b - q(\cdot)[b' - (1-\gamma)b]$ is payment to foreign lenders of debt principal and interest net of new debt issuance, and R_{oil} is oil rents given (p_{oil}, k_{oil}, n). Note that the right-hand side of equation 13 is increasing in λ and the left-hand side is decreasing. Thus, increases in R_{oil} lower the equilibrium allocation of capital into the manufacturing sector k_M. This is the classic "Dutch-disease" effect. Thus, a larger oil field n_H and higher capital in the oil sector k_{oil} imply higher oil rents and lower production of the manufacturing good. These effects make total tradable income 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.

Figure 7: Impulse-response functions to a giant oil discovery of median size



To compute the model series I consider 10,000 economies in their ergodic state without any oil discoveries in the past 50 periods and that are in good financial standing in the initial period $t = -1$, (one period before an oil discovery). The change in the real exchange rate is relative to its value in period t_{-1}.

Figure 7 presents the evolution of the risk premium, oil output, the share λ, and the change in the real exchange rate following an oil discovery in the benchmark economy. The risk raises on impact in the year of the discovery $t = 0$ because the economy's oil field n is now larger and because the manufacturing sector shrinks. This generates an appreciation of the real exchange rate.[25] After the initial impact, the risk premium continues to increase as FDI inflows further enlarge the oil sector.

4.4 Welfare gains of oil discoveries

The empirical findings from Section 2 are puzzling because following an oil discovery, economic conditions improve (GDP and investment increase) and yet sovereign spreads, which are typically countercyclical in the data (see Aguiar, Chatterjee, Cole, and Stangebye (2016)), also increase. The model above reconciles these findings with risk-averse lenders that require a risk premium that is

[25]The real exchange rate in the model is defined as P^*/P_t where P_t is the GDP deflator.

endogenously larger when tradable income is more dependent on the more volatile oil sector. From a welfare point of view, there may be a tension between higher potential output from a giant oil discovery and paying a higher risk premium on debt. Is it worth it to find and exploit giant oil fields?

I compute welfare gains of an oil discovery in terms of consumption equivalent units, meaning they are the percentage increase in permanent consumption that would leave a household in the economy indifferent between discovering and not discovering an oil field in that period. Welfare gains are $\chi^*(s, k_{oil}, b) = 100 * \left[(W_D/W_{ND})^{\frac{1}{1-\sigma}} - 1\right]$, where $W_D = V(z, p_{oil}, n_H, k_{oil}, b)$ and $W_{ND} = V(z, p_{oil}, n_L, k_{oil}, b)$ are, respectively, the value of discovering and not discovering an oil field given shocks (z, p_{oil}) and the state (k_{oil}, b). I compute the average $\chi^*(s, k_{oil}, b)$ from simulating 1,000 economics starting in their ergodic state for the benchmark calibration, the case with higher $\alpha_0 = 12$ from above, and two alternative cases for insurance against fluctuations in the oil price: (i) the *full insurance* case, in which the economy is able to trade oil at a fixed price $p_{oil} = 1$, and (ii) the *put options* case, in which the economy is able to trade oil at a price $p^{opt}_{oil,t} = \max\{p_{oil,t}, 1\}$ (I assume that both the government and the oil producer have access to these insurance specifications in both cases). Table (4) summarizes these calculations.

Table 4: Welfare gains of oil discoveries

	benchmark	high α_0	full insurance	put options
average welfare gains χ^*	0.66	0.66	0.72	1.10

Welfare gains are the average of 1,000 draws of $\chi^*(s, k_{oil}, b) = 100 * \left[(W_D/W_{ND})^{\frac{1}{1-\sigma}} - 1\right]$, where $W_D = V(z, p_{oil}, n_H, k_{oil}, b)$ and $W_{ND} = V(z, p_{oil}, n_L, k_{oil}, b)$ are, respectively, the value of discovering and not discovering an oil field given shocks (z, p_{oil}) and the state (k_{oil}, b) drawn from the ergodic distribution.

Welfare gains of oil discoveries are positive in all three cases and virtually the same in the benchmark case and the case with a higher parameter α_0, which suggest negligible losses from the additional risk premium. In the full insurance case, gains are barely larger than in the benchmark economy, despite eliminating the main source of volatility in the economy. This suggests that losses from the risk premium associated with the volatility of the oil sector are offset by gains from high consumption in states with high oil prices and not-so-low consumption in states with low oil prices (since default is always an option for the government to avoid even lower consumption in these states). On the other hand, welfare gains almost double in the put options case, which indicates that avoiding low price realizations more than compensates for higher borrowing costs due to the risk premium from oil discoveries.

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 1.2 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.

These findings are consistent with the permanent income hypothesis, but the fact that spreads increase is puzzling from the point of view of canonical sovereign default models. The reason is that in these models default incentives and spreads decrease following a persistent increase in income, which is the effect that giant oil discoveries produce. To reconcile theory and data I developed a sovereign default model with production, oil discoveries, and risk-averse lenders. Lenders demand a positive risk premium that depends on tradable income, whose variance endogenously varies with production decisions and oil discoveries. Following a discovery, the relative size of the oil sector increases because of FDI inflows and the Dutch disease. This, in turn, makes total tradable income more volatile and increases the risk premium on debt.

Despite the increase in spreads, oil discoveries generate positive welfare gains. Completely eliminating the excess volatility of the price of oil has a small effect on the welfare gains from discoveries despite its potential to reduce the increase in spreads. This is because losses from higher volatility are offset by gains from high consumption in states with high oil prices and not-so-low consumption in states with low oil prices. On the other hand, insurance against low realizations of the price of oil, like "put" options, practically doubles the welfare gains.

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