Sovereign Risk and Dutch Disease*

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Abstract

This paper studies the impact of natural resource discoveries on default risk. I use data of giant oil field discoveries to estimate their effect on the spreads of 37 emerging economies and find that spreads increase by up to 530 basis points following a discovery of average size. I develop a quantitative sovereign default model with capital accumulation, production in three sectors, and oil discoveries. Following a discovery, investment and foreign borrowing increase. These choices have opposite effects on spreads: borrowing increases them and investment reduces them. The discovery also generates a reallocation of capital away from manufactures and toward oil extraction and the non-traded sector, the so-called Dutch disease. This reallocation increases the volatility of tradable income used to finance debt payments, which undermines the effect of investment on spreads. Under the benchmark calibration the model accounts for 300 out of the 530 basis points of the increase in spreads observed in the data, out of which 200 result from the Dutch disease.

JEL Codes: E30, F34, F41

Keywords: Sovereign risk, Dutch disease, emerging economies

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1 Introduction

Between 1970 and 2012 sixty-four countries discovered at least one giant oil field, and twelve of these countries had a default episode in the following five years.[1] Among all countries in the world, the unconditional probability of default in any given five year period was 6%. Conditional on discovering a giant oil field, this probability was 11%.[2] This seems counter-intuitive: why would a country that just became richer also become more likely to default on its debt? This paper studies how the discovery and exploitation of natural resources impact default risk. Following the sovereign default literature, I focus on emerging economies as they are more prone to default episodes.

I use data of giant oil field discoveries to document the effect of a sudden increase in available natural resources on sovereign interest rate spreads. I build on the work by Arezki, Ramey, and Sheng (2017), who 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 these effect is large and positive: spreads increase by up to 530 basis points following a discovery of average size. I also estimate their effect on the current account, investment, GDP, and consumption. Following a discovery, these countries run a current account deficit and GDP, investment, and consumption increase. I also 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 investment in commodities and non-traded sectors. This investment reallocation is accompanied by an appreciation of the real exchange rate.

To reconcile these facts, I develop a small-open economy model of sovereign default with long-term debt, capital accumulation, and production in three intermediate sectors: a non-traded sector, a traded "manufacturing" sector, and a traded "oil" sector. All three sectors use capital for production and the oil sector additionally requires an oil field of a certain capacity. The economy starts with a small oil field and at some point in time it receives unexpected news about the discovery of a

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

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

larger one, which will become productive at a determined time in the near future. This lag between the discovery and when production on the field starts is important because the actions in between, along with uncertainty about the price of oil once production starts, are what drive the increase in spreads. In the data, the average waiting period between discovery and production is of 5.4 years.

After an oil discovery, investment increases to exploit the larger field once it is productive. The economy runs a current account deficit by issuing foreign debt to finance investment. Also, once exploitation of the larger field starts, there is a reallocation of capital away from the manufacturing sector toward the non-traded sectors, which is the so-called Dutch disease.

In the model, as in the data, the international price of oil is relatively more volatile than the international price of the other tradable goods.[3] Higher investment decreases spreads and higher foreign borrowing increases them. The latter effect dominates because the reallocation of production factors implied by the Dutch disease makes tradable income more dependent on oil revenue and thus more volatile. It is worth noting that, in the model, there is nothing inefficient about the Dutch disease (i.e. it is not really a disease). The reallocation of production factors is the optimal response to the increase in the availability of natural resources, which takes into account the implied increase in the cost of borrowing and in the probability of default in the future.

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 is desirable because it allows me to discipline the parameters of the model with business cycle data that does not have any variation that could be driven by oil discoveries. I then validate the theory by contrasting the co-movement of model variables in response to unexpected oil discoveries with the responses estimated from the data.[5] Additionally, I use the oil discoveries data from Arezki, Ramey, and Sheng (2017) to discipline the size of discoveries in the model.

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

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

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

Under the benchmark calibration, the model explains 3 out of the 5.3 percentage points of the maximum increase in spreads following an oil discovery, out of which 2 are accounted for by the Dutch disease. There are other complementary forces that could also make spreads increase that the model abstracts from. Growth externalities in the manufacturing sector could make the Dutch disease inefficient if they are not internalized. This could hamper future growth and increase spreads in the present.[6] Also, deterioration of institutions following giant oil discoveries could also cause spreads to increase. For example, Lei and Michaels (2014) find evidence that giant oil field discoveries increase the incidence of internal armed conflicts.

I compare the results from the model under the benchmark calibration with those from a model in which the price of oil is not volatile; I call this the *no-risk* case. This exercise illustrates the counterfactual response of all variables if the economy was able to effectively hedge against swings in the price of oil. Additionally, I also compare the results to those from an economy in which there is no default risk; I call this the *patient-government* case. In both counterfactual cases, as well as in the benchmark, the economy increases foreign borrowing to invest and all three feature the Dutch disease. These are the co-movements that, together with the uncertainty about the price of oil, explain the increase in spreads in the benchmark case. However, spreads increase by less than one percentage point in the *no-risk* case and by virtually nothing in the *patient-government* case. These results stress two important points. First, the frictions in this economy that explain high spreads are market incompleteness, the lack of commitment from the government, and its high relative impatience. None of these frictions are directly related to the incentives to borrow to invest in the larger oil field or the incentives that drive the reallocation of capital due to the Dutch disease. Second, in the presence of these frictions, the volatility of the price of oil, the choice of borrowing to invest, and the choices that generate the Dutch disease generate an increase in spreads following an oil discovery, even though there is nothing inefficient about any of these choices.

Related literature.—This paper contributes to the literature that studies the role of news and expectations as drivers of business cycles.[7] Beaudry and Portier (2004) were the first to propose a model that generates an economic expansion in response to news. In a later paper, Beaudry and Portier (2007) characterize the class of models that are able to generate business cycles driven by

[6]See Hevia, Neumeyer, and Nicolini (2013b) for an example of such an externality.

[7]See Beaudry and Portier (2014) for an extensive review of this literature and its future challenges.

news or changes in expectations. They find that most neo-classical business cycle models fail to do so unless they allow for a sufficiently rich description of the production technology. 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. In a later paper, Jaimovich and Rebelo (2009) do the same study for a closed economy and find three key elements for the model to generate news-driven business cycles: variable capital utilization, adjustment costs to investment, and preferences that feature weak wealth effects on the labor supply. 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. 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.

This paper also builds on the quantitative sovereign default literature following Aguiar and Gopinath (2006) and Arellano (2008).[8] They introduce sovereign default models that feature counter-cyclicality of net exports and interest rates, which is consistent with the data from emerging markets. Hatchondo and Martinez (2009) and Chatterjee and Eyigungor (2012) extend the baseline framework of quantitative models of sovereign default to include long-term debt. Their extension allows the model to better 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 production, capital accumulation and long-term debt. They show that the model is able to fit cyclical properties of investment and GDP while also remaining consistent with other business cycle properties of emerging economies. They also find that capital has non-trivial effects on sovereign risk but that increased capital almost always reduces risk premia in equilibrium. The model presented in Section 3 extends their framework to have production in different sectors, with at least one also using natural resources for production. Arellano, Bai, and Mihalache (2018) document how sovereign debt crises have disproportionately negative effects on non-traded sectors. They develop a model with production in two sectors and one period debt.

Hamann, Mendoza, and Restrepo-Echavarria (2018) study the relation between oil exports, oil

[8] These papers extend the approach developed by Eaton and Gersovitz (1981).

reserves, and sovereign risk. They find that an oil exporting country is perceived as less risky if its oil production is high. In contrast, they also find that country risk increases as unexploited oil reserves increase. In this paper I document how country risk increases after large discoveries of natural resources, this contrasts with what these authors documents in the sense that they look at the co-movement of risk with oil exports and reserves for countries that already have a large endowment of natural resources. They develop a model that highlights the strategic decision to exploit oil reserves and its effects on sovereign risk. In this paper I abstract from this strategic motive and instead focus on the effects of oil discoveries on the sectoral allocation of capital and their consequences on sovereign risk.

Finally, this paper relates to the literature that studies the macroeconomic effects of commodity-related shocks and the Dutch disease. Pieschacon (2012) studies the role of fiscal policy as a transmission mechanism of oil price shocks to key macroeconomic variables. She documents evidence that the predictions of the Dutch disease hold for the case of Mexico but not for that of Norway, and argues that fiscal policy is a key determinant of this difference. Hevia, Neumeyer, and Nicolini (2013a) analyze optimal policy in a New Keynesian model of a small-open economy with shocks to terms of trade that generate Dutch disease periods. Their model features complete markets and an externality in the manufacturing sector that makes the Dutch disease inefficient. In contrast, the model I present in Section 3 has incomplete markets and does not feature any externality.

Arezki and Ismail (2013) study the implications that changes in expenditure policy have on real effective exchange rate movements. They find that the real exchange rate appreciates when the oil export unit value increases, but, asymmetrically, that the real exchange rate does not change much when this unit value decreases. Hevia and Nicolini (2015) analyze optimal monetary policy in a small-open economy with price and wage nominal frictions that specializes in the production of commodities. They find that, under both frictions, the Dutch disease implies inefficiencies and full price stability is not optimal.[9] Ayres, Hevia, and Nicolini (2019) argue that shocks that move primary commodity prices account for a large fraction of the volatility of real exchange rates between developed economies and the US dollar. They suggest that considering trade in primary

[9] Hevia and Nicolini (2013) find that in an economy with only price frictions, domestic price stability is optimal, even if fiscal policy cannot respond to shocks. In other words, as they explain it, the Dutch disease is not a disease.

commodities could help models generate real exchange rate volatilities that are more in line with the data.

Layout.—Section 2 describes the data, documents the effect of giant oil discoveries on sovereign spreads and other macroeconomic aggregates, and discusses the empirical evidence that motivates the theoretical framework. Section 3 presents the model and discusses the theoretical mechanism. Section 4 describes the calibration. Section 5 presents the quantitative results and Section 6 concludes.

2 Giant oil discoveries in emerging economies

This section documents the effects of giant oil discoveries on thirty-seven emerging economies considered in JP Morgan's Emerging Markets Bonds Index (EMBI).[10] Due to data availability I restrict all analyses in this section to these thirty-seven economies and the years between 1993 and 2012. I use a measure of the net present value (NPV) of oil discoveries as a percentage of GDP constructed by Arezki, Ramey, and Sheng (2017). I follow their empirical strategy to estimate the effects of oil discoveries on investment, the current account, GDP, and consumption. As they do for a larger set of countries, I find evidence for the intertemporal approach to the current account (as developed by Obstfeld and Rogoff (1995)) and the permanent income hypothesis. Next, I estimate the effect of giant oil discoveries on the sovereign spreads of these economies and find spreads increase by up to 530 basis points following a discovery. Finally, I estimate the effect of giant oil discoveries on the real exchange rate and investment by sectors and find evidence of the Dutch disease.

2.1 Data and empirical strategy

Giant oil discoveries are a measure of changes in the future availability and potential exploitation of natural resources. As Arezki, Ramey, and Sheng (2017) argue, giant oil discoveries have three unique features that allow the use of a quasi-natural experiment approach: they indicate significant

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

increases in future production possibilities, the timing of discoveries is exogenous due to uncertainty around oil and gas exploration, and there is a time delay of 5.4 years, on average, between discovery and production.[11]

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:[12]

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

where $NPV_{i,t}$ is the discounted sum of gross revenue for country i at the year of discovery t. The gross revenue $q_{i,t+j}$ is derived from an approximated production profile starting five years after the field discovery up to an exhaustion year J, which is higher than 50 years for a typical field of 500 million barrels of ultimately recoverable reserves.[13]

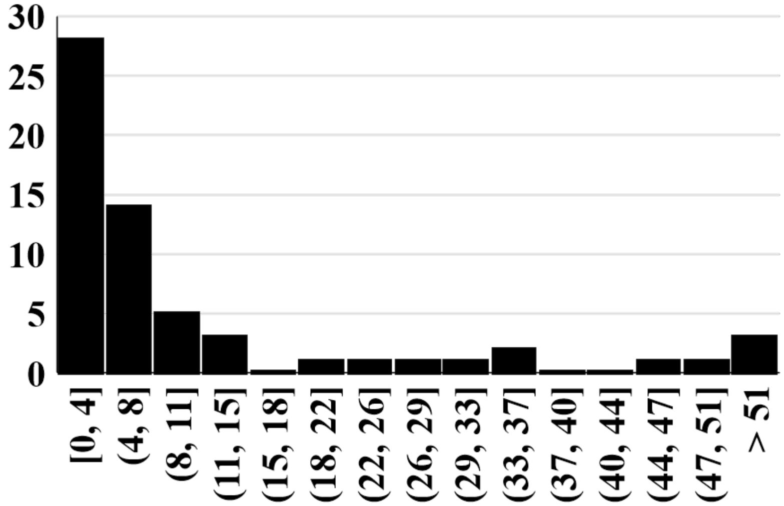
Considering the thirty-seven economies in the EMBI and the years 1993–2012 the data show 61 giant oil discoveries in 15 of the 37 countries. The average NPV of a discovery was 18 percent of GDP, the median was 9, and the largest was 467. Figure 1 depicts the distribution of the NPV of these discoveries.

[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] They use the data on giant oil discoveries in the world collected by Horn (2014). For more details of the construction of the NPV see Section IV.B. in Arezki, Ramey, and Sheng (2017).

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

Figure 1: Distribution of NPV of giant oil discoveries



Percent of GDP, EMBI countries, 1993 –2012.

Investment, current account, GDP, and consumption data 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. The index tracks liquid, US dollar emerging market fixed and floating-rate debt instruments issued by sovereign and quasi-sovereign entities. Spreads are measured against comparable U.S. government bonds.[14] 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 share of total investment and is from the United Nations Statistics Division (2017).

To estimate the effect of giant oil discoveries on different macroeconomic variables I use a dynamic panel model with a distributed lag of giant oil discoveries:

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

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

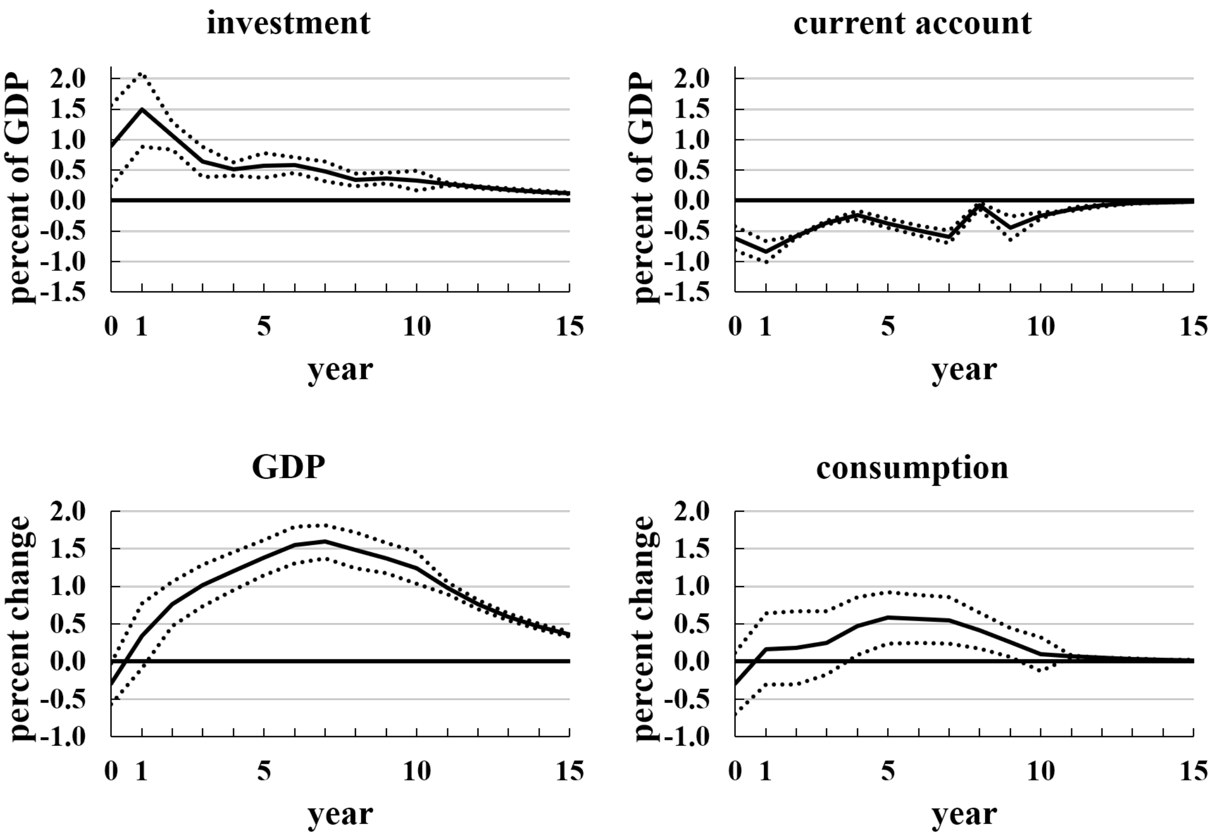
where $y_{i,t}$ is the dependent variable, including investment, the current account, log of real GDP, log of real consumption, sovereign spreads, log of the real exchange rate, and the share of investment by sector; $NPV_{i,t}$ is the NPV of a giant oil discovery in country i in year t; α_i controls for country fixed effects; μ_t are year fixed effects; $p_{oil,t}$ is the international price of oil at time t; $\mathbb{I}_{disc,i,t-s}$ is an indicator function of whether country i had an oil discovery in period $t-s$; and $\varepsilon_{i,t}$ is the error term. Country fixed effects control for any unobservable and time-invariant characteristics, while year fixed effects control for common shocks like world business cycles and the international price of oil.[15] The interaction of the international price of oil with the indicator function controls for the fact that the reaction of the dependent variable to this common shock may differ conditional on having a recent discovery. As Arezki, Ramey, and Sheng (2017) do, I exploit the dynamic feature of the panel regression and use impulse response functions to capture the dynamic effect of giant oil discoveries given by $\Delta y_{i,t} = \rho \Delta y_{i,t-1} + \sum_{s=0}^{10} \psi_s NPV_{i,t-s}$.

2.2 Permanent income hypothesis

Figure 2 shows the dynamic response of investment, the current account, GDP, and consumption to an oil discovery of average size, based on the estimated coefficients of equation (2). The dotted lines are 90% confidence intervals based on a Driscoll and Kraay (1998) estimation of standard errors, which yields standard error estimates that are robust to general forms of spatial and temporal clustering.

[15]As noted by Nickell (1981), estimates of the 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 instead. Given the order of the Nickell bias and to keep the results comparable with those of Arezki, Ramey, and Sheng (2017) I use the above approach as the benchmark.

Figure 2: Impact of giant oil discoveries on macroeconomic aggregates



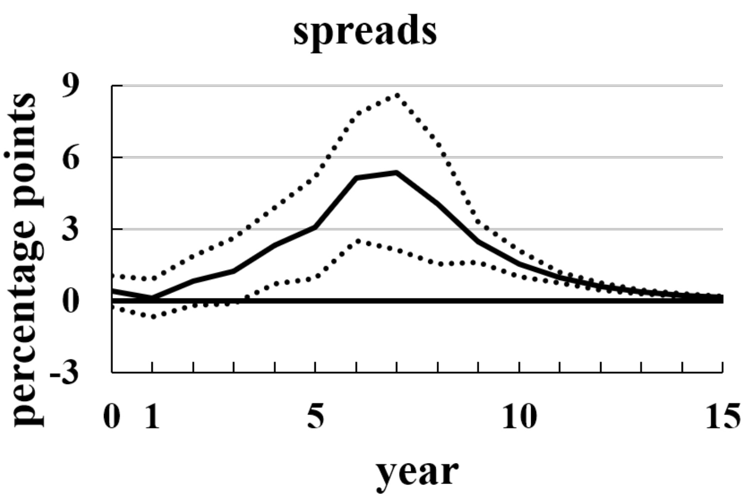
Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

The top left panel shows that the investment-to-GDP ratio increases immediately after an oil discovery and continues to be higher in the subsequent years. The top right panel shows that oil discoveries have a negative effect on the current account-to-GDP ratio, which supports the hypothesis that these countries issue foreign debt to finance higher consumption and investment. The bottom panels show that both GDP and consumption increase after an oil discovery. A giant oil discovery indicates that income will be higher in the future, when the oil field becomes productive.

2.3 Effect on sovereign spreads

Figure 3 shows the dynamic response of the spreads. On the year of the discovery this effect is small and not significantly different from zero. However, by the sixth year after the discovery is announced, spreads have increased by 530 basis points on average.

Figure 3: Impact of giant oil discoveries on spreads



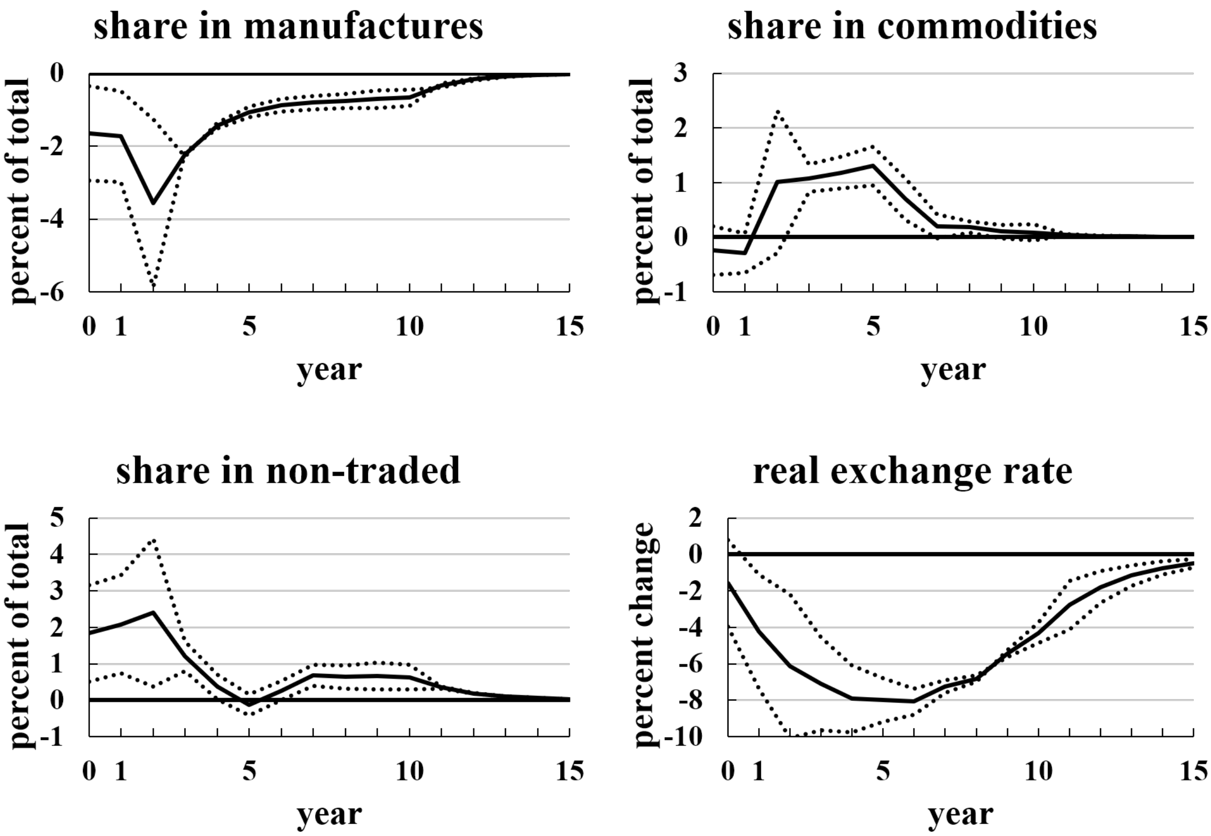
Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

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

2.4 The Dutch disease

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

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



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

Following a discovery, the share of investment in the manufacturing sector decreases and the shares in both the commodities and the non-traded sectors increase. The real exchange rate appreciates, which is in line with the theoretical predictions of the Dutch disease: higher income from the commodity sector increases the consumption of non-traded goods. This in turn increases the price of non-traded goods and production factors are moved out of manufacturing into non-traded sectors and resource extraction.

3 Model

This section presents a dynamic small-open economy model with long-term debt, production in different sectors, capital accumulation, and discovery of natural resources. There is a benevolent government that makes borrowing, investment, and production decisions and cannot commit to repay its debt.[16]

3.1 Environment

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

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

where η is the elasticity of substitution and ω_i are the weights of each intermediate good i in the production of the final good. Intermediate non-traded goods and manufactures are produced using capital k and technologies:

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

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

where z_t is aggregate productivity in the economy. There is a general stock of capital k_t that can be freely allocated in these two sectors within the same period such that $k_{N,t} + k_{M,t} = k_t$. 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, capital $k_{oil,t}$ that is specific to the oil sector, and technology:

$$y_{oil,t} = z_t k_{oil,t}^{\alpha_{oil}(1-\zeta)} n_t^{\zeta} \tag{6}$$

[16] In Appendix A I show how all the allocations and default decisions in this economy can be supported in a decentralized economy where households choose labor and capital investment and firms choose capital and labor allocations in different sectors.

where $\zeta \in (0,1)$ is the share of oil revenue that corresponds to the oil rent.

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

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

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

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

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

where $i_{k,t}$ and $i_{k_{oil},t}$ are investment in general and oil capital, respectively; δ is the capital depreciation rate; and $\Psi\,(k_{t+1},k_t) = \phi\left(\frac{k_{t+1}+k_t}{k_t}\right)^2 k_t$ and $\Psi_{oil}\left(k_{oil,t+1},k_{oil,t}\right) = \phi_{oil}\left(\frac{k_{oil,t+1}+k_{oil,t}}{k_{oil,t}}\right)^2 k_{oil,t}$ are sector specific capital adjustment cost functions.[17] As discussed in Subsection 3.4, capital adjustment costs allow the model to reproduce the anticipation effect in investment observed in the data, that is, have the economy increase investment before production with the larger oil field starts.

Rest of the world and international prices.—All prices are in terms of the final non-traded good in the rest of the world. The rest of the world, with which the small-open economy trades, is a large and closed economy that has access to the same technology. The price of the final non-traded good in the rest of the world is:

$$P_t^{\star} = 1 = \left[\omega_N\left(p_{N,t}^{\star}\right)^{1-\eta} + \omega_M\left(p_{M,t}\right)^{1-\eta} + \omega_{oil}\left(p_{oil,t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{10}$$

where $p_{M,t}$ and $p_{oil,t}$ are the international prices of manufactures and oil, respectively, which the small-open economy takes as given; and $p_{t,N}^{\star}$ is the price of the non-traded intermediate good, which is inconsequential for the small-open economy. I assume that the shocks in the rest of the world are such that the international price of manufactures is fixed and the price of oil is volatile.

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

As it will be discussed in Subsection 3.4, what is key for the results in this paper is that the price of oil is relatively more volatile than the price of other traded goods.

Shocks and oil discoveries.—In each period, the economy receives a small transitory income shock $m_t \in [-\bar{m}, \bar{m}]$ drawn independently from a mean zero probability distribution with continuous CDF.[18] Additionally, in each period the economy experiences one of finitely many events s_t that follow a Markov chain governed by transition matrix $\pi(s_{t+1}|s_t)$. The shock s_t determines aggregate productivity in the economy z_t and summarizes the shocks in the rest of the world that pin down the international price of oil $p_{oil,t}$.

The capacity of the oil field can take one of two values $n_t \in \{n_L, n_H\}$ with $0 \leq n_L < n_H$. The economy starts with $n_t = n_L$ and in some period τ receives *unexpected* news that its oil capacity will be larger six periods from then, that is $n_{\tau+6} = n_H$. The unexpected nature of the news is in line with the assumption made in Section 2 that, in the data, the timing of discoveries cannot be anticipated. Additionally, this is in line with how some of the literature on news-driven business cycles models news shocks, see for example Jaimovich and Rebelo (2008), Jaimovich and Rebelo (2009), and Arezki, Ramey, and Sheng (2017). For simplicity I assume that n_t remains high forever.[19]

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

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

where $u(c,l) = \frac{c^{1-\sigma}-1}{1-\sigma}$ and β is the discount factor.

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

$$b_{t+1} = (1-\gamma) b_t + i_{b,t} \tag{11}$$

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

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

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.[20] The bonds are denominated in terms of the numeraire good and are purchased by risk-neutral, deep-pocketed foreign lenders who have access to a risk free bond that pays an interest rate $r^\star$.

Default and the balance of payments.—At the beginning of every period the government has the option to default. If the government defaults it gets excluded from international financial markets—although it can still trade in goods—for a stochastic number of periods; the government gets re-admitted to financial markets with probability θ and zero debt. While in default productivity is $\tilde{z}_t \leq z_t$ and the transitory income shock is $-\bar{m}$.[21] In default, the balance of payments is:

$$0 = p_M x_{M,t} + p_{oil,t} x_{oil,t} \tag{12}$$

where $x_{oil,t} = y_{oil,t} - c_{oil,t}$ and $x_{M,t} = y_{M,t} - c_{M,t}$ are net exports of oil and manufactures, respectively. Equation (12) implies that in default trade in goods has to be balanced; imports to increase consumption of manufactures (oil) have to be financed by exports of oil (manufactures).

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

$$[\gamma + (1-\gamma)\kappa]\, b_t = p_M x_{M,t} + p_{oil,t} x_{oil,t} + q_t i_{b,t} \tag{13}$$

where q_t is the price of newly issued debt. Equation (13) shows how payments of debt obligations (left-hand side) are supported by net exports of goods and issuance of new debt.

3.2 Recursive formulation

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

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

[21] For a discussion of the advantages of this formulation see Chatterjee and Eyigungor (2012). The income shock is set to its minimal possible value to ease the computation of the equilibrium.

Let $V(s,m,k,k_{oil},b)$ be the value of the government that starts the period not in default. Then, the government chooses to repay its debt obligations, $d=0$, or to default, $d=1$:

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

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

If the government decides to default then its debt obligations are erased and it gets excluded from financial markets. Then, the government chooses the stocks of capital next period k' and k'_{oil}, static allocations of general capital in manufactures and the non-traded intermediate sector $\overrightarrow{K}=\{k_N,k_M\}$, net exports of manufactures and oil $\overrightarrow{X}=\{x_M,x_{oil}\}$, and consumption of final and intermediate goods $\overrightarrow{C}=\{c,c_N,c_M,c_{oil}\}$ to solve:

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

subject to the resource constraint of the final good (7), the resource constraint of general capital $k_t=k_N+k_M$, the laws of motion of capital (8) and (9), the resource constraints of intermediate goods $c_N=y_N$, $c_M+x_M=y_M$ and $c_{oil}+x_{oil}=y_{oil}$, and the balance of payments under default (12). 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 chooses the stocks of capital k' and k'_{oil}, and debt b' in the next period, static allocations of general capital in manufactures and the non-traded intermediate sector $\overrightarrow{K}=\{k_N,k_M\}$, net exports of manufactures and oil $\overrightarrow{X}=\{x_M,x_{oil}\}$, and consumption of final and intermediate goods $\overrightarrow{C}=\{c,c_N,c_M,c_{oil}\}$ to solve:

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

subject to the resource constraint of the final good (7), the resource constraint of general capital $k_t=k_N+k_M$, the laws of motion of capital (8) and (9), the law of motion of bonds (11), the resource constraints of intermediate goods $c_N=y_N$, $c_M+x_M=y_M$ and $c_{oil}+x_{oil}=y_{oil}$, and the balance of payments under repayment (13).

3.3 Equilibrium

A Markov equilibrium is value functions $V\left(s,m,k,k'_{oil},b\right)$, $V^D\left(s,k,k'_{oil}\right)$, and $V^P\left(s,m,k,k'_{oil},b\right)$; policy functions for capital in default $k^D(s,k,k_{oil})$ and $k^D_{oil}(s,k,k_{oil})$; policy functions for capital $k'(s,m,k,k_{oil},b)$ and $k'_{oil}(s,m,k,k_{oil},b)$ and debt issuance $b'(s,m,k,k_{oil},b)$ in repayment; a default policy function $d(s,m,k,k_{oil},b)$; policy functions for static allocations in repayment and in default; and a price schedule of bonds $q\left(s,k',k'_{oil},b'\right)$ such that: (i) given the price schedule q, the value and policy functions solve the government's problem, and (ii) given the policy functions, the price schedule is such that lenders break even in expectation:

$$q\left(s,k',k'_{oil},b'\right)=\frac{\mathbb{E}_{m,s'|s}\left\{\left[1-d\left(s',m',k',k'_{oil},b'\right)\right]\left[\gamma+(1-\gamma)\left(\kappa+q\left(s',k'',k''_{oil},b''\right)\right)\right]\right\}}{1+r^{\star}} \tag{14}$$

where $k''=k'\left(s',m',k',k'_{oil},b'\right)$, $k''_{oil}=k'\left(s',m',k',k'_{oil},b'\right)$ and $b''=b'\left(s',m',k',k'_{oil},b'\right)$ are the government's decisions in next period's state. Note that, given the i.i.d. nature of the transitory income shock, the price schedule q does not depend on the current realization of m.

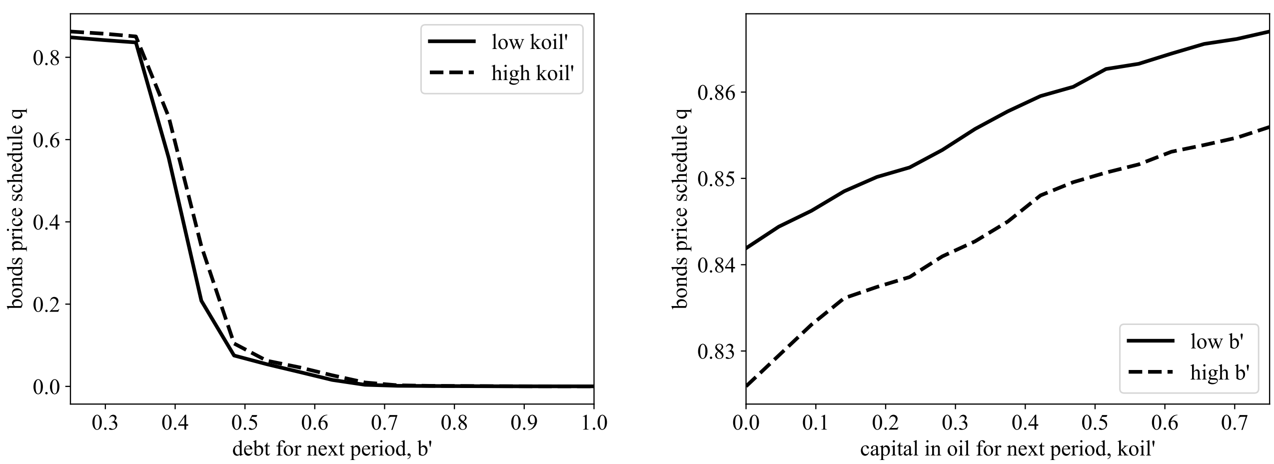
3.4 Higher spreads and the Dutch disease

This Subsection discusses in detail the mechanism through which spreads increase following an oil discovery, which can be summarized as follows. After an oil discovery, the economy borrows to invest in capital for the oil sector. Borrowing increases spreads and investment reduces them. The former effect dominates because once the large oil field is being exploited, capital is drawn away from the manufacturing sector. This reallocation makes tradable income—used to support debt payments—more dependent on oil revenue and thus, more volatile.

Borrowing to invest.—An oil discovery in period τ is news that the economy will have access to a larger oil field with capacity $n=n_H$ in period $\tau+6$. Thus, the economy will want to have a higher level of capital for the oil sector k_{oil} in that period. Here is where capital adjustment costs in both laws of motion for capital play a role in generating the anticipation effect in investment. First, recall that in the data investment increases much earlier than a year before production in the newly discovered field starts. In the model, all the additional capital in the oil sector would be installed in period $\tau+5$ in the absence of adjustment costs. The quadratic capital adjustment costs incentivizes the economy to smooth this investment through the preceding periods. Because of the adjustment costs for general capital, the government does not reallocate capital already installed for the other sectors to the oil sector. Instead, it borrows from the rest of the world in order to install new capital.

Borrowing increases spreads and investment, in general, reduces them.[22] Figure 5 illustrates this by showing the equilibrium price schedule of government bonds through two dimensions: bonds and capital in the oil sector chosen for the next period. The left panel shows how higher indebtedness reduces (increases) the market price of bonds (spreads), while the right panel shows how higher capital for the next period increases (reduces) it (them).

Figure 5: Bonds price schedule



Note that all other state variables are kept fixed in Figure 5. The purpose of this figure is to illustrate how the two dynamic decisions (borrowing and investment) affect the price of bonds differently, effects which the government takes into account when making its decisions.

Dutch disease.—Recall that, within each period, general capital k can be freely allocated into the non-traded intermediate sector and the manufacturing sector. Let $\lambda_k \in [0,1]$ be the share of k

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

allocated in manufactures. Given the state of the economy this share is pinned down by:

$$\left(p_M \frac{\alpha_M}{\alpha_N} (k)^{\alpha_M - \alpha_N} \frac{(1-\lambda_k)^{1-\alpha_N}}{(\lambda_k)^{1-\alpha_M}}\right)^{\eta} f^N(z,(1-\lambda_k)k) = \frac{\omega_N \left[p_M f^M(z,\lambda_k k) + p_{oil} f^{oil}(z,k_{oil},n) - X\right]}{\omega_M (p_M)^{1-\eta} + \omega_{oil}(p_{oil})^{1-\eta}} \tag{15}$$

where $X = [\gamma + (1-\gamma)\kappa] b - q(\cdot) i_b$ is payments of debt principal and interest net of new debt issuance. Note that the right-hand side is increasing in λ_k and the left-hand side of equation 15 is decreasing. Thus, increasing n lowers the equilibrium share of capital allocated in manufactures smaller.

An intuitive interpretation of the economic forces driving this reallocation can be drawn from the version of equation (15) in a decentralized economy:[23]

$$p_N f^N(z,k_N) = \frac{\omega_N (p_N)^{1-\eta} \left[p_M f^M(z,k_M) + p_{oil} f^{oil}(z,k_{oil},n) - X\right]}{\omega_M (p_M)^{1-\eta} + \omega_{oil}(p_{oil})^{1-\eta}} \tag{16}$$

where p_N is the price of the non-traded intermediate good. Equation (16) shows that expenditure in the non-traded intermediate good (since $c_N = f^N(z,k_N)$) is a fraction of tradable income net of debt payments. Higher n implies higher income, so in order to increase consumption of the non-traded intermediate good the economy has to produce more of it—as opposed to consumption of manufactures, which can be increased by increasing imports. In the decentralized economy this higher production is supported by a higher p_N, which increases the marginal revenue of capital in that sector.

Higher volatility and spreads.—To highlight the role of volatility I will borrow a simple example laid out in Arellano (2008). Consider a small-open economy that each period receives a stochastic endowment of a tradable good $y \in Y = [\underline{y}, \bar{y}]$, which is iid across time and follows a cumulative distribution function F. There is an agent in the economy with preferences for lifetime consumption of the commodity $U(\{c_t\}_{t=0}^{\infty}) = \mathbb{E}[\sum_{t=0}^{\infty} \beta^t u(c_t)]$ where u is strictly concave. The agent can issue one period non-contingent bonds b' and cannot commit to repay its debt. If the agent defaults on its debt it remains in autarky forever, which implies that the value of defaulting when income is y is $V^D(y) = u(y) + \frac{\beta}{1-\beta}\mathbb{E}[u(y')]$. If the agent repays then it chooses consumption

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

and debt issuance to maximize its utility subject to its budget constraint $c+b \leq y+q(b')b'$. It can be shown that the sets of endowments $Y^D(b) \subseteq Y$ for which the agent decides to default given a debt level b can be characterized by an interval where only the upper bound is a function of assets $Y^D(b) = \left[\underline{y}, y^\star(b)\right)$. The cutoff $y^\star(b)$ is the income level at which the agent is indifferent between repaying and defaulting $V^P(y^\star(b), b) = V^D(y^\star(b))$.[24] The debt of the agent is bought by a large number of risk-neutral competitive lenders with access to a risk free asset that pays interest rate r. Thus, the price of bonds b' in equilibrium is characterized by:

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

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

Going back to the model in this paper, the reallocation of production factors once n is higher increases the volatility of traded income, as can be seen in the balance of payments equation:

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

where the right-hand side is more dependent on oil revenue with high n, which, by assumption, is more volatile than manufacturing revenue. This reallocation is expected to happen in period $\tau+6$, which increases the spreads from the perspective of period $\tau+5$. Since debt is long-term, a higher spread in $\tau+5$ increases the spreads in $\tau+4$, as can be seen in equation (14). This in turn increases spreads in the previous periods up until period τ, when the news about the oil discovery arrives.

From period $\tau+6$ onward the level of income is higher on average, due to the higher n. This makes spreads lower in the long-run. Right after $\tau+6$, if the government did not default, it repays

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

the debt that had been issued to invest between τ and $\tau+6$.

4 Calibration

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

A period in the model is one year. There are two sets of parameters: the first (summarized in table 1) is calibrated directly from data and the second (summarized in table 2) is chosen so that moments generated by the model match their data counterparts. I set the capital shares to $\alpha_N = 0.32$ and $\alpha_M = 0.37$ following Valentinyi and Herrendorf (2008), who calculate labor shares for the US for different sectors and aggregate them into tradable and non-tradable. I set the share of oil rent to $\zeta = 0.38$ and the capital share in the oil sector to $\alpha_{oil} = 0.49$ as in Arezki, Ramey, and Sheng (2017). I use data on sectoral GDP for Mexico between 1993 and 2012 to estimate the elasticity of substitution $\eta = 0.73$.[25] I set the weights $\omega_N = 0.79$, $\omega_M = 0.15$, and $\omega_{oil} = 0.06$ using aggregate consumption shares. I set the relative risk aversion parameter to $\sigma = 2$ and the risk free interest rate to $r^\star = 0.04$, which are standard values in the literature.

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

Table 1: Parameters calibrated directly from the data

Parameter		Value	Source
capital shares	α_N	0.32	Valentinyi and Herrendorf (2008)
	α_M	0.37	
	α_{oil}	0.49	Arezki, Ramey, and Sheng (2017)
oil rent	ζ	0.38	
elasticity of substitution	η	0.73	estimated for Mexico
intermediate output shares	ω_N	0.79	shares in aggregate consumption
	ω_M	0.15	
	ω_{oil}	0.06	
risk aversion	σ	2	standard values
risk free rate	r^*	0.04	
bonds maturity rate	γ	0.14	7 year average duration
bonds coupon rate	κ	0.03	Chatterjee and Eyigungor (2012)
probability of reentry	θ	0.40	2.5 years exclusion
support of i.i.d. shock	$\bar{m}$	0.018	Chatterjee and Eyigungor (2012)
standard deviation of i.i.d. shock	σ_m	0.009	bound is +/- 2 standard deviations
persistence of price of oil	ρ_{oil}	0.48	AR(1) estimation of innovations in the real price of oil
volatility of price of oil	ν_p^2	0.23	
mean price of oil	$\bar{p}_{oil}$	1.0	normalization
price of manufactures	p_M	1.0	

I normalize the international price of manufactures to $p_M = 1$. As discussed in Subsection 3.4, what is key is that the price of oil is relatively more volatile than the price of manufactures. I assume that the price of oil in the model follows an AR(1) process:

$$\log p_{oil,t} = (1-\rho_{oil})\log \bar{p}_{oil} + \rho_{oil}\log p_{oil,t-1} + \nu_p \varepsilon_t \tag{17}$$

where ε_t are iid with a standard normal distribution and $\bar{p}_{oil}$ is the mean of the price of oil also normalized to $\bar{p}_{oil} = 1$. Now, for the persistence and variance of the price of oil I take the first difference of equation (17) to get:

$$\Delta \log p_{oil,t} = \rho_{oil}\Delta \log p_{oil,t-1} + \nu_p \Delta\varepsilon_t. \tag{18}$$

I use data on the West Texas Intermediate price of oil divided by the US GDP deflator to calculate a real price and estimate that the persistence parameter in (18) is $\rho_{oil} = 0.48$ and the variance of the iid shock is $\nu_p^2 = 0.23$. Then I use these estimates and the normalized average price of oil $\bar{p}_{oil}$ to approximate the process with a finite state Markov-chain using the Rouwenhorst method.[26]

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, as documented for recent default episodes by Gelos, Sahay, and Sandleirs (2011). 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) and I set the coupon payments $\kappa = 0.03$ as in Gordon and Guerron-Quintana (2018). For the transitory income shock m I follow Chatterjee and Eyigungor (2012) and assume $m \sim$ trunc $N\left(0, \sigma_m^2\right)$ with points of truncation $-\bar{m}$ and $\bar{m}$. I set $\bar{m} = 0.018$ and $\sigma_m = 0.009$. For Chatterjee and Eyigungor (2012) these values are 0.006 and 0.003, respectively. I re-scale these values so that the size of the maximum transitory component of income relative to the average production of the final good remains the same.

The productivity shock is assumed to follow an AR(1) process:

$$\log z_t = \rho_z \log z_{t-1} + \sigma_z \nu_t$$

where ν_t are iid with a standard normal distribution. The persistence ρ_z and variance σ_z are calibrated to match the persistence and volatility of the business cycle of the Mexican GDP (more details below).

Table 2 summarizes the parameters calibrated by simulating the model. This calibration is made in two steps: first, all parameters except n_H are chosen to match some business cycle moments for the Mexican economy in the period 1993–2012. This first step only considers simulated economies that do not have an oil discovery, as was the case for Mexico in those years. The second step considers all simulated economies and calculates the net present value of oil discoveries as a fraction of GDP, as explained below, to discipline n_H.

[26]This method was first proposed by Rouwenhorst (1995); for a discussion on its properties see Kopecky and Suen (2010).

Table 2: Parameters calibrated simulating the model

Parameter		Value	Parameter		Value
discount factor	β	0.925	capital depreciation rate	δ	0.10
productivity	d_0	-0.40	persistence of productivity	ρ_z	0.95
default cost	d_1	0.412	volatility of productivity	σ_z	0.009
capital adjustment	ϕ	7.5	high oil for extraction	n_H	0.28
costs	ϕ_{oil}	7.5	high oil for extraction	n_H	1.12

Moment	Data	Model
Average spread	266	214
St. dev. of spreads	134	135
Debt-to-GDP ratio	0.13	0.09
Capital-to-GDP ratio	1.90	1.91
$\sigma_{inv}/\sigma_{GDP}$	2.3	1.8
ρ_{GDP}	0.30	0.42
σ_{GDP}	2.22	2.35
$\frac{oil_{GDP}}{GDP}$	0.06	0.07
$\frac{NPV}{GDP}$	19	22

For simplicity, I assume the capital adjustment cost functions are the same $\phi_{oil} = \phi$. Then, there is a total of nine parameters chosen to match nine moments from the data: the average and standard deviation of spreads, the debt-to-GDP ratio, the capital-to-GDP ratio, the relative volatility of investment to GDP, the persistence and variance of GDP, the average oil GDP to total GDP ratio, and the net present value of oil discoveries as a fraction of GDP.

The value of the discount factor β mainly determines the debt-to-GDP ratio. The average and standard deviation of spreads are mainly pinned down by the default cost parameters d_0 and d_1. The capital-to-GDP ratio and the relative volatility of investment are mostly determined, respectively, by the capital depreciation rate δ and the capital adjustment cost parameters ϕ and ϕ_{oil}. The values of ρ_{GDP} and σ_{GDP} are estimated using data of the cyclical component of Mexican GDP and GDP series generated by the model. Both are HP Filtered with a smoothing parameter of 100 for yearly data. These values for the data simulated by the model are pinned down by the persistence ρ_z and variance σ_z of the productivity shock. Finally, I choose n_H to match the average net present value of oil discoveries as a fraction of GDP. These net present values are calculated as:

$$NPV_t = \sum_{s=6}^{\infty} \left(\frac{1}{1+r_t} \right)^s p_{oil,t} \left[f^{oil}\left(z_t, k_{oil,t}, n_H\right) - f^{oil}\left(z_t, k_{oil,t}, n_L\right) \right] \tag{19}$$

where r_t is the implied yield of the government bonds at the time of discovery t. This calculation is akin to the calculation made by Arezki, Ramey, and Sheng (2017) with actual data following equation (1).

Table 3 shows the performance of the model with non-targeted moments. The model does well with the over-volatility of consumption relative to output. The model also does a good job producing counter-cyclical spreads and trade balance, as well as predicting a lower correlation between investment and output relative to that of output and consumption. However, the volatility of the trade balance is not well reproduced by the model.

Table 3: Non-targeted moments

Moment	Data	Model
σ_c/σ_{GDP}	1.11	1.09
σ_{TB}	4.07	0.80
$Corr(c, GDP)$	0.85	0.98
$Corr(inv, GDP)$	0.81	0.37
$Corr(TB, GDP)$	-0.03	-0.26
$Corr(\text{spreads}, GDP)$	-0.37	-0.38

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

5 Quantitative Results

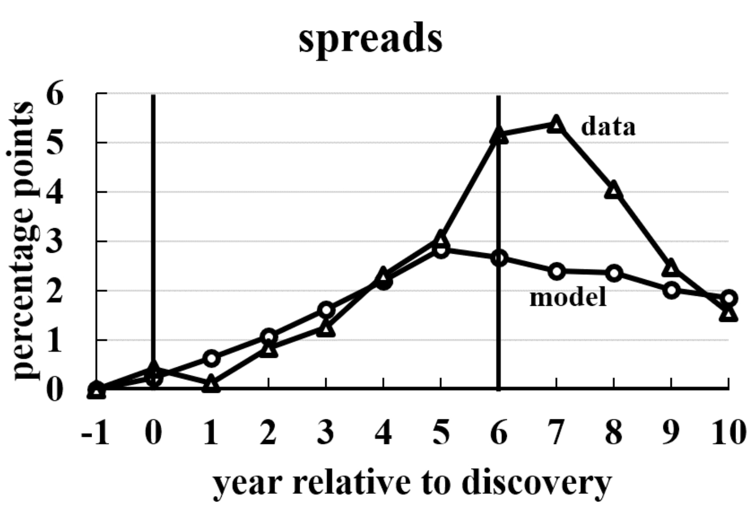
This section presents the main quantitative results. First, Subsection 5.1 compares the model predictions of the change in spreads and other macroeconomic variables to the estimates from the data laid out in Section 2. Then, Subsection 5.2 disentangles the effect that the Dutch disease has on the increase in spreads and the co-movement of other macroeconomic variables following an oil discovery in the model.

All the impulse-response functions from the model are computed as follows: (i) simulate 300 economies for 5001 periods without any oil discoveries, (ii) drop the first 5000 to eliminate any effect of initial conditions and take period 5001 as the starting point, (iii) make the economy experience an unexpected oil discovery in period 5002 and simulate 50 more periods, (iv) center all economies such that $t = 0$ is the period when the discovery is announced and calculate the average of all paths, (v) calculate the impulse-response function of variable x as the change with respect to its value before the oil discovery in period $t = -1$, $IR(x_t) = x_t - x_{-1}$.

5.1 Model vs data

Figure 6 compares the impulse-response of spreads in the model to the estimates from Figure 3. In the data, spreads start increasing when the news of the discovery is realized and continue to increase until they peak in year 7, when they reach a maximum increase of 5.3 percentage points. In the model under the calibration from the previous section, spreads also increase when the news is realized and continue to do so until period 5, when they reach a maximum increase of almost 3 percentage points. The peak in the model happens exactly one period before the larger oil field is available.

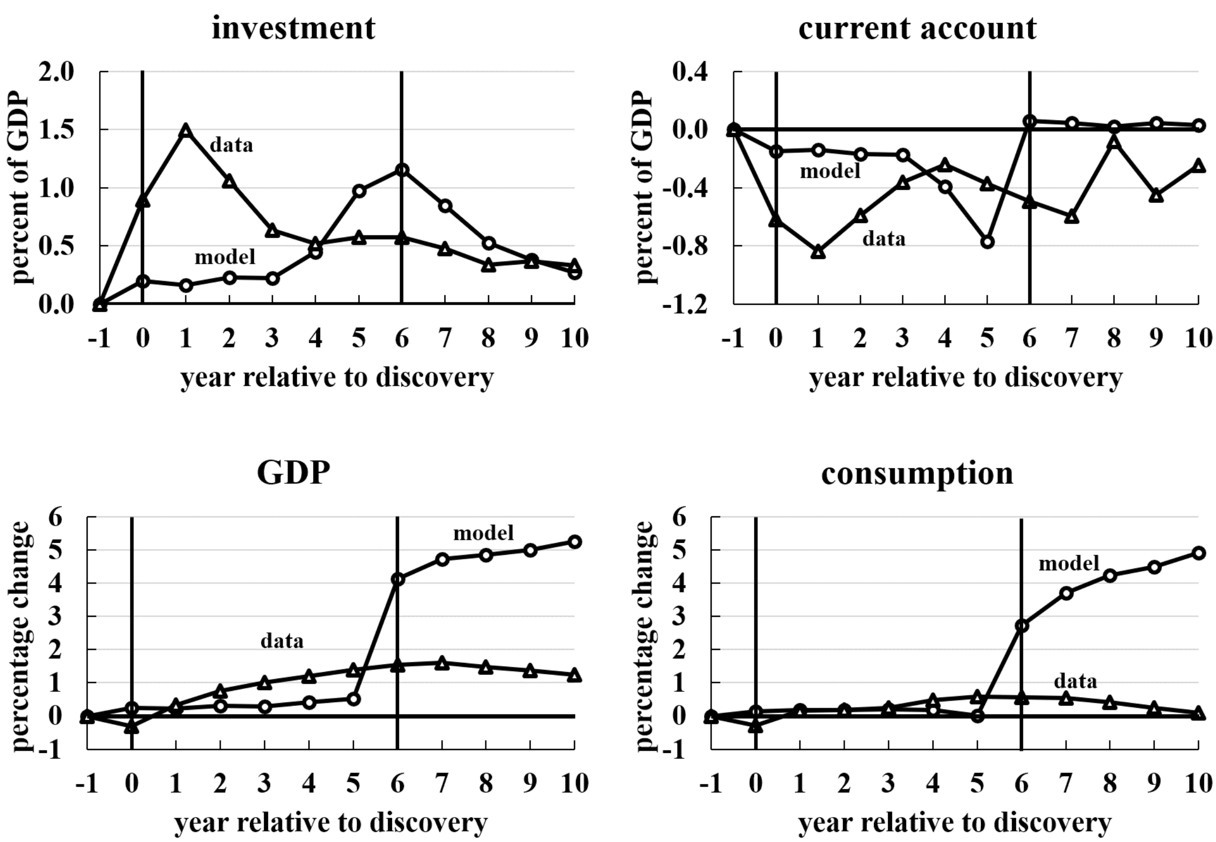
Figure 6: Impulse-response to a discovery of average size



The model explains virtually all the increase up until period 5. The model also explains the subsequent decrease after spreads reach their peak. In the data, however, spreads continue to increase until period 7, after which they also start decreasing. One potential explanation is that the oil fields in the sample I consider took longer than average to start being productive. If I assumed the larger field in the model became available in year 8 rather than in year 6, the increase would continue until year 7, as in the data.

Figure 7 compares the impulse-response of spreads in the model to the estimates from Figure 2. In the model, as in the data, investment increases and the current account goes into deficit between the announcement of the discovery and the start of production. The orders of magnitude of these changes are of around 1 percentage point of GDP. The changes in the model happen closer to when production starts, while in the data they happen closer to the announcement. This may be due to the timing assumption. In the model, the agent has to wait 6 years to access the oil in the field, while in the real world this waiting period depends on the intensity, speed, and efficiency of investment in the sector.

Figure 7: Impulse-response to a discovery of average size



GDP and consumption increase both in the data and in the model. However, the increases in the model are more concentrated in the year when production starts. The government in the model cannot smooth consumption more because the debt level is already too high in the ergodic state. In other words, borrowing to consume is already too expensive. Regarding GDP, Arezki, Ramey, and Sheng (2017) find that, for a larger set of countries, GDP in the data also does not increase right away. The fact that it does for the sample of emerging economies considered in this paper is puzling and a direction for future work.

5.2 The Dutch disease and the increase in spreads

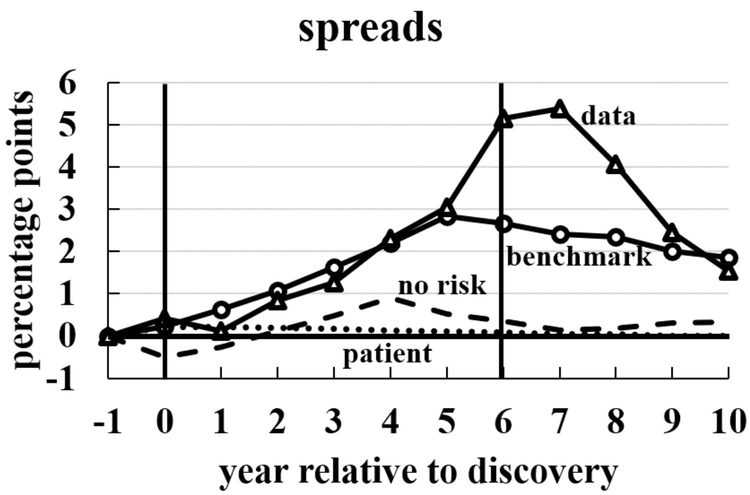
To decompose the effect of the Dutch disease I compare impulse-responses from the model under the benchmark calibration to those from a model in which the price of oil is fixed. To calculate these I recalibrate the parameters from Table 2 to match the same moments when the price of oil is fixed.

As discussed in Subsection 2.4, the reallocation of production factors implied by the Dutch disease increases the volatility of tradable income, which in turn undermines the effect of investment on spreads. The counterfactual case with no volatility in the price of oil shuts down this effect while still allowing for the efficient reallocation of capital.

Additionally, as a reference, I also compare these responses to those from a model in which the government is as patient as the rest of the world, meaning $\beta = \frac{1}{1+r}$. This reference economy is an economy in which the government almost never defaults because it does not accumulate much debt.

Figure 8 shows the impulse-response of spreads for each of these cases. Spreads still increase in the model with no volatility in the price of oil, but not as much as in the benchmark case or in the data.

Figure 8: Impulse-response to a discovery of average size



The increase peaks a little bit under 1 percentage point, which is one third of the peak under the benchmark calibration. The remaining two thirds of the increase is generated by the Dutch disease. In the economy with a patient government spreads barely change following an oil discovery. This is due to both the lower level of borrowing and the higher valuation of the future, which drive default incentives to the minimum.

The frictions that make spreads high are market incompleteness and lack of commitment of the government. If one assumes that the households are as patient as international markets, then $\beta < \frac{1}{1+r}$ can be interpreted as the government being more impatient than the households. This preference disagreement is an additional source of inefficiency that causes excessive borrowing.[27] Being able to hedge against the volatility of the price of oil brings the change in borrowing costs for the economy closer to the case when the government is patient.[28] In this reference case the preference disagreement is not present and lack of commitment is almost never binding due to the low levels of borrowing.

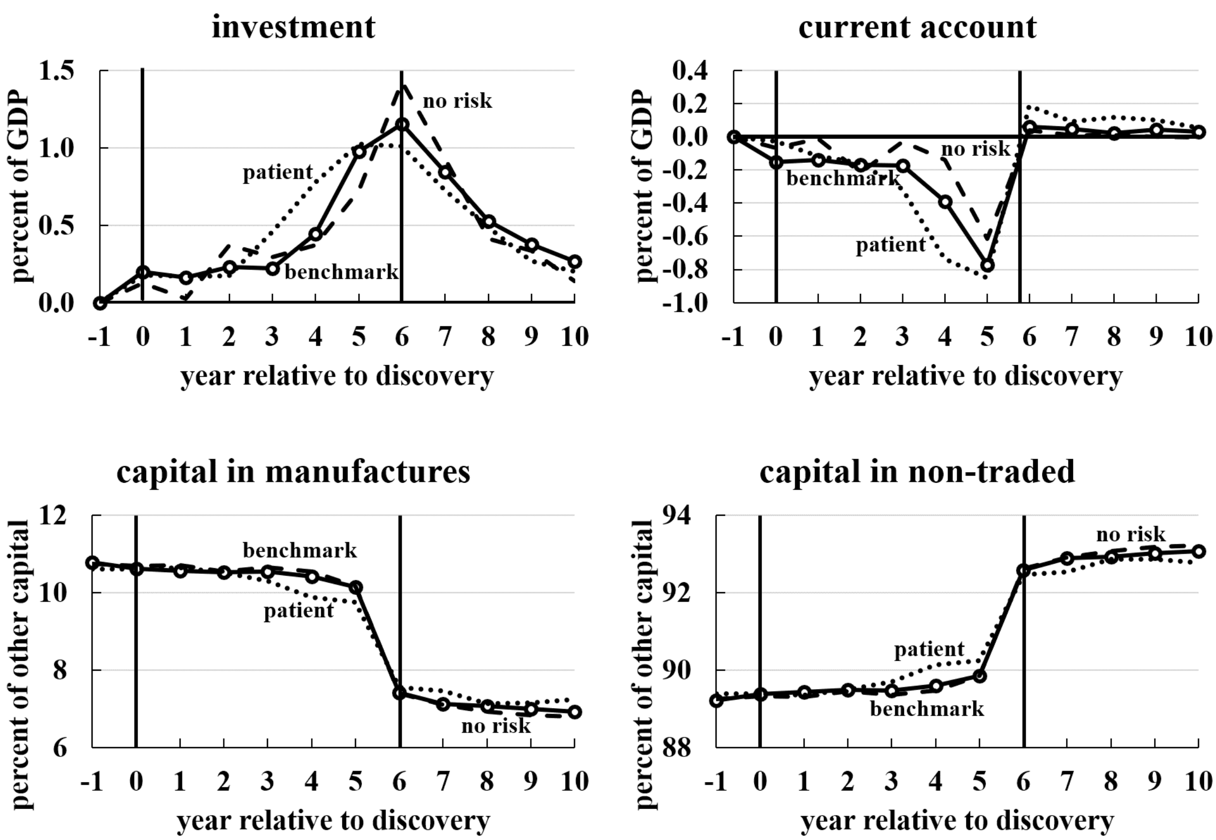
Note that there is nothing inefficient about the reallocation of capital implied by the Dutch

[27] This lower discount factor for the government can be rationalized in political economy models where the government cares more about present consumption due to reelection incentives.

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

disease. Similarly, it is not inefficient that the economy borrows to invest. To illustrate these points, Figure 9 shows, for each of the three cases, the impulse responses of investment, the current account, and the share of general capital allocated to manufactures and the non-traded sector. The responses are virtually identical. Even in the economy where the main distortions are not present, the optimal choices are to borrow to invest and to allocate capital away from manufactures into the non-traded sector.

Figure 9: Impulse-response to a discovery of average size



6 Conclusion

In this paper I documented the effect of giant oil field discoveries on sovereign spreads, the sectoral allocation of capital, and macroeconomic aggregates. Following a giant oil discovery, sovereign spreads increase by up to 530 basis points and the share of investment in manufactures decreases in favor of investment in commodities and non-traded sectors. Countries run a current account deficit to finance imports. GDP, investment, and consumption increase.

I developed a sovereign default model with production in three sectors, investment, and discovery of oil fields. The model accounts for most of the increase in spreads documented from the data. In the model, capital in the oil and non-traded sectors increase and the capital in the manufacturing sector decreases. This shift—referred to in the literature as the Dutch disease—increases the volatility of tradable income that support debt payments since the price of oil is more volatile than the price of manufactures. The Dutch disease accounts for two thirds of the increase in spreads in the model.

In the model presented in this paper, there is nothing inefficient about the Dutch disease (i.e. it is not really a disease). The reallocation of production factors is the optimal response to the increase in the availability of natural resources, which takes into account the implied increase in the cost of borrowing.Whilst hedging against the volatility of the price of oil reduces the increase in spreads it virtually does not change any of the other relevant responses. This highlights the value of financial instruments or institutional arrangements that allow to hedge against the volatility of the international price of oil.

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A Decentralized economy

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

A.1 Environment

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

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

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

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

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

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

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

are produced by competitive firms with access to technologies:

$$y_{N,t} = f^{N}\left(z_t, k_{N,t}\right)$$
$$y_{M,t} = f^{M}\left(z_t, k_{M,t}\right)$$
$$y_{oil,t} = f^{oil}\left(z_t, k_{oil,t}, n_t\right)$$

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

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

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

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

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

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

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

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

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

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

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

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

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

A.2 Equivalence result

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

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

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

where the value in repayment is:

$$
\begin{aligned}
V^P(s,m,k,b) = & \max_{\left\{k',b',l,\overrightarrow{C},\overrightarrow{L},\overrightarrow{K},\overrightarrow{X}\right\}} \left\{u(c)+\beta\mathbb{E}\left[V\left(s',m',k',b'\right)\right]\right\} \\
s.t. \quad c+i_k+i_{k_{oil}} & \leq Y+m \\
k' & = (1-\delta)k+i_k-\Psi\left(k',k\right) \\
k'_{oil} & = (1-\delta)k_{oil}+i_{k_{oil}}-\Psi_{oil}\left(k'_{oil},k_{oil}\right) \\
Y & = f^Y(c_N,c_M,c_{oil}) \\
c_N & = f^N(z,k_N) \\
c_M & = f^M(z,k_M)-x_M \\
c_{oil} & = f^{oil}(z,k_{oil},n)-x_{oil} \\
q\left(s,k',b'\right)\left[b'-(1-\gamma)b\right] & = p_Mx_M+p_{oil}x_{oil}+[\gamma+\kappa(1-\gamma)]b \\
k & = k_N+k_M
\end{aligned}
$$

and the value in default is:

$$
\begin{aligned}
V^D(s,k,k_{oil}) = & \max_{\left\{k',k'_{oil},\overrightarrow{C},\overrightarrow{K},\overrightarrow{X}\right\}} \left\{u(c)+\beta\mathbb{E}\left[\theta V\left(s',m',k',k'_{oil},0\right)+(1-\theta)V^D\left(s',k',k'_{oil}\right)\right]\right\} \\
s.t. \quad c+i_k+i_{k_{oil}} & \leq Y-\bar{m} \\
k' & = (1-\delta)k+i_k-\Psi\left(k',k\right) \\
k'_{oil} & = (1-\delta)k_{oil}+i_{k_{oil}}-\Psi_{oil}\left(k'_{oil},k_{oil}\right) \\
Y & = f^Y(c_N,c_M,c_{oil}) \\
c_N & = f^N(\tilde{z},k_N) \\
c_M & = f^M(\tilde{z},k_M)-x_M \\
c_{oil} & = f^{oil}(\tilde{z},k_{oil},n)-x_{oil} \\
0 & = p_Mx_M+p_{oil}x_{oil} \\
k & = k_N+k_M
\end{aligned}
$$

These problems can be rewritten as:

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

and:

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

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

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

and in default F^D is defined as:

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

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

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

$$f^Y_{c_M}(c_N,c_M,c_{oil}) = \lambda_{C_M} \tag{21}$$

$$f^Y_{c_{oil}}(c_N,c_M,c_{oil}) = \lambda_{C_{oil}} \tag{22}$$

$$f^N_k(z,k_N) = \frac{\lambda_k}{\lambda_{C_N}} \tag{23}$$

$$f^M_k(z,k_M) = \frac{\lambda_k}{\lambda_{C_M}} \tag{24}$$

$$f^{oil}_k(z,k_{oil},n) = \frac{\lambda_k}{\lambda_{C_{oil}}} \tag{25}$$

$$\lambda_{C_{oil}} = \frac{p_{oil}}{p_M}\lambda_{C_M} \tag{26}$$

$$\lambda_{BoP} = \frac{\lambda_{C_M}}{p_M} \tag{27}$$

where λ_{C_N}, λ_{C_M}, $\lambda_{C_{oil}}$, λ_k, and λ_{BoP} are the multipliers of the market clearing constraints for intermediate goods, for capital, and for the balance of payments, respectively. Note that equations (26) and (27) already pin down $\lambda_{C_{oil}}$ and λ_{BoP} in terms of λ_{C_M} and the international prices p_M and p_{oil}. Thus, we are left with a system of 6 first-order conditions plus 5 constraints to solve for 8 static allocations c_N, c_M, c_{oil}, k_N, k_M, k_{oil}, x_{oil}, and x_M and 3 multipliers λ_{C_N}, λ_{C_M}, and λ_k.

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

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

and the intermediate goods firms solve:

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

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

$$f^Y_{c_N}(c_N, c_M, c_{oil}) = \frac{p_N}{\mu^Y} \tag{28}$$
$$f^Y_{c_M}(c_N, c_M, c_{oil}) = \frac{p_M}{\mu^Y} \tag{29}$$
$$f^Y_{c_{oil}}(c_N, c_M, c_{oil}) = \frac{p_{oil}}{\mu^Y} \tag{30}$$
$$f^N_k(z, k_N) = r \tag{31}$$
$$f^M_k(z, k_M) = r \tag{32}$$
$$f^{oil}_k(z, k_{oil}) = r_{oil} \tag{33}$$

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

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

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

Note that if $\mu^Y = \frac{p_M}{\lambda_{c_M}}$, $p_N = \mu^Y \frac{\lambda_{c_N}}{p_M}$, $r = \mu^Y \frac{\lambda_k}{p_M}$, and $w = \mu^Y \frac{\lambda_l}{p_M}$ then the two systems of equations are the same and, thus, the allocations that satisfy them are the same.

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

A.3 Decentralized rest-of-world economy

In order to calibrate the international price of oil I assume that the rest of the world is a large and closed economy populated by a representative household and competitive firms. The household and firms have access to the same technologies as the small-open economy. Then, from the problem of the final good firm in the rest of the world we get the demands for intermediate goods:

$$c_N^\star = \left(\frac{P^\star}{p_N^\star}\right)^\eta Y a_N$$
$$c_M^\star = \left(\frac{P^\star}{p_M}\right)^\eta Y a_M$$
$$c_{oil}^\star = \left(\frac{P^\star}{p_{oil}}\right)^\eta Y a_{oil}$$

which, normalizing $p_M = 1$, imply:

$$p_{oil} = \left(\frac{a_{oil}}{a_M} \frac{c^\star_M}{c^\star_{oil}} \right)^{\frac{1}{\eta}} \tag{34}$$

I assume that the rest of the world has an oil field with capacity $n = n_L$. I solve for the steady state with no shocks in this rest-of-world economy and use (34) to calculate $\bar{p}_{oil}$.