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 discoveries to estimate their effect on the spreads of 37 emerging economies. I find that spreads increase by up to 530 basis points following a discovery of average size. I develop a quantitative sovereign default model with production in three intermediate sectors and oil discoveries. Following a discovery investment and foreign borrowing increase, with opposite effects on spreads. The discovery also generates a reallocation of production factors away from manufactures into oil extraction and to 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 explains 40 percent of the increase in spreads observed in the data, out of which half is accounted for by the Dutch disease.

JEL Codes: E30, F34, F41

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1 Introduction

Between 1970 and 2012 sixty-four countries discovered at least one giant oil field, twelve of them had a default episode in the following five years.[1] Taking into account all the 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] These observations appear counter-intuitive, why would a country that just became richer also become more likely to default on its debt?

This paper studies the impact that the discovery and exploitation of natural resources have on 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 spreads. I build on the work by Arezki, Ramey, and Sheng (2017), who construct a measure of the net present value of a giant oil field discovery relative to the GDP of the country where the discovery happens. I use these data to estimate the effect of a discovery on the sovereign spreads of 37 emerging economies. I find that giant oil discoveries have a large and positive effect on sovereign spreads: spreads increase by up to 530 basis points following a discovery of average size.

I also estimate the effect on the current account, investment, GDP, and consumption and find evidence in favor of the permanent income hypothesis, as Arezki, Ramey, and Sheng (2017) did for a wider set of countries. Following a discovery, the emerging countries considered in this paper run a current account deficit and GDP, investment, and consumption increase. Additionally, I estimate the effects of giant oil discoveries 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 the commodities and non-traded sectors. This reallocation of investment is accompanied by an appreciation of the real exchange rate.

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 "manufac-

[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). 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. These calculations only consider default episodes and oil discoveries between 1970 and 2004.

turing" sector, and a traded "oil" sector. All three sectors use capital and labor for production and the oil sector additionally requires an oil field of a certain capacity. In the model, an economy starts with a small oil field and every period has a positive probability of discovering a larger one. After an oil discovery investment increases to exploit the larger field. 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 production factors away from the manufacturing sector toward the oil and non-traded sectors, 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, however, the latter effect dominates because the reallocation of production factors implied by the Dutch disease makes total tradable income 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.

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. It is important to note that 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 in endogenous variables that could be driven by oil discoveries. This allows me to then validate the theory by contrasting the responses of model variables to oil discoveries with those estimated from the data. Additionally, I use the oil discoveries data from Arezki, Ramey, and Sheng (2017) to discipline the size of discoveries in the model.

Under the benchmark calibration, the model explains 40 percent of the increase in spreads following an oil discovery, out of which half is accounted by the Dutch disease. There are other

[3]Commodities have always shown a higher price volatility than manufactures. This is a stylized fact documented by Jacks, O'Rourke, and Williamson (2011) with 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.

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.[5] Also, deterioration of institutions following giant oil discoveries could also cause spreads to increase. Lei and Michaels (2014) find evidence that giant oilfield discoveries increase the incidence of internal armed conflicts.

I use the model to calculate the welfare costs of the volatility of the price of oil for small open economies. This calculation is indicative of the value for the economy of financial instruments that allow it to hedge against fluctuations in the price of oil. I do this calculation for an economy that never discovers a large oil field and for an economy that does.[6] I find that an economy that never discovers a large oil field is willing to forego 0.4% of lifetime consumption to eliminate the volatility of the price of oil. This number is 0.6% for an economy that does discover a giant oil field. The effect of the Dutch disease on spreads and default incentives is what makes these gains 1.5 larger conditional on discovery. The higher default probability after a discovery implies a higher chance of incurring in the dead-weight loss the model assumes after default. Also, even absent a default episode, the higher borrowing costs after discoveries make it more valuable to eliminate this source of risk.

Related literature.—This paper builds on the quantitative sovereign default literature following Aguiar and Gopinath (2006) and Arellano (2008).[7] They introduce sovereign default models that feature counter-cyclicality of net exports and interest rates, both consistent with what is observed for emerging markets. Hatchondo and Martinez (2009) and later Chatterjee and Eyigungor (2012) extend the baseline framework of quantitative models of sovereign default to include long-term debt. They show how this extension allows models to better account for the debt level as well as the level and volatility of spreads around default episodes, while also improving upon the model's ability to account for 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

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

[6] Even if the economy was not an oil producer it would still be affected by the volatility of the price of oil as long as oil is used to produce other goods, as is the case in the model presented in this paper.

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

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 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. 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 motives in reserves depletion and instead focus on the effects of oil discoveries on the sectoral allocation of capital and their consequences on sovereign risk.

This paper also 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 indicates 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.[8] 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 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).[9] 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 and, as they do, 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.

[8]In another paper (Hevia and Nicolini (2013)) the authors 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.

[9]The thirty-seven countries are: Argentina, Belize, Brazil, Bulgaria, Chile, China, Colombia, Dominican Republic, Ecuador, Egypt, El Salvador, Gabon, Ghana, Hungary, Indonesia, Iraq, Jamaica, Kazahstan, 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.

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 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.[10]

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

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

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.[12]

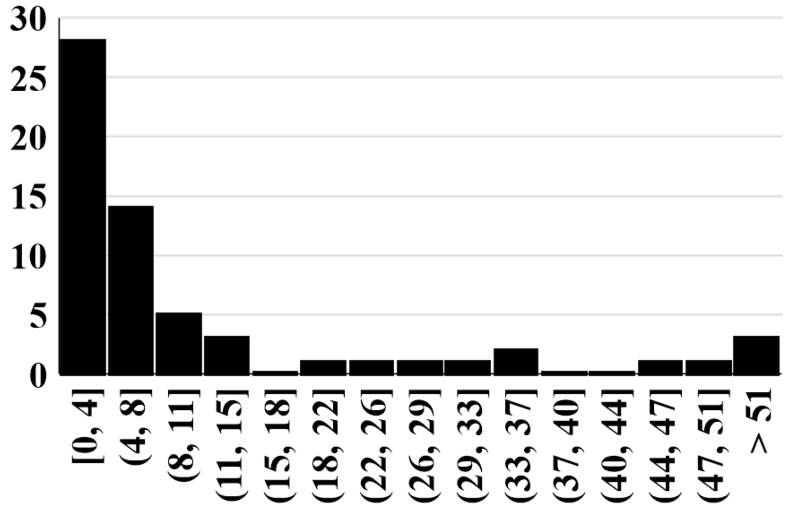
Considering the thirty-seven economies in the EMBI and the years 1993–2012 the data show 61 giant oil discoveries in 15 of the 37 countries. The average NPV of a discovery was 18 percent of GDP, the median was 9, and the largest was 467. Figure 1 depicts the distribution of the NPV of these discoveries.

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

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

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

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.[13] The real exchange rate is calculated as $RER_{i,t} = \frac{e_{i,t}P_t^{US}}{P_t^i}$ where P_t^{US} and P_t^i are the US and country i's GDP deflators, respectively, and $e_{i,t}$ is the nominal exchange rate between country i's currency and the US dollar, these data are also from the IMF (2013). Finally, the data of 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:

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

[13] 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. 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.

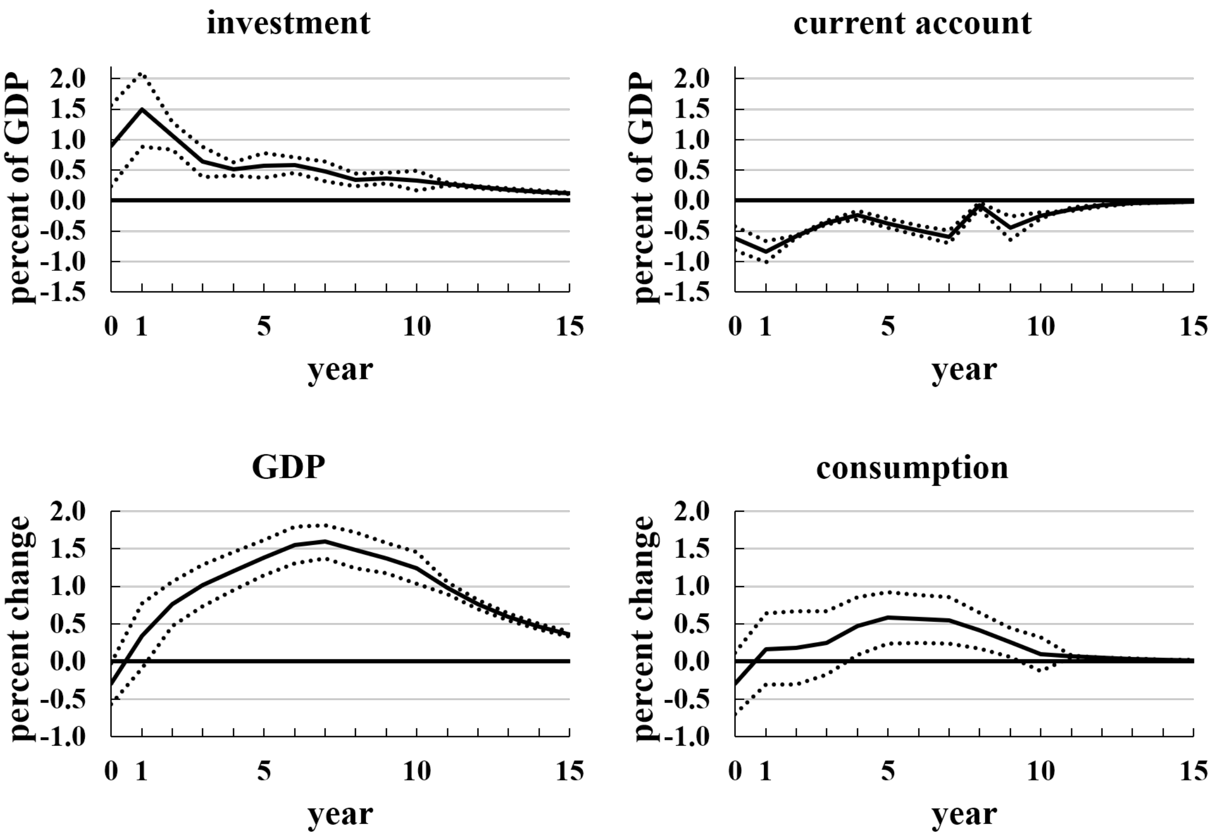
where $y_{i,t}$ is the dependent variable, including investment, the current account, log of real GDP, log of real consumption, sovereign spreads, log of the real exchange rate, and the share of investment by sector; $NPV_{i,t}$ is the NPV of a giant oil discovery in country i in year t; α_i controls 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.[14] 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 (1). The dotted lines are 90% confidence intervals based on Driscoll and Kraay (1998) standard errors.

[14] 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 small time span and large nunber 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



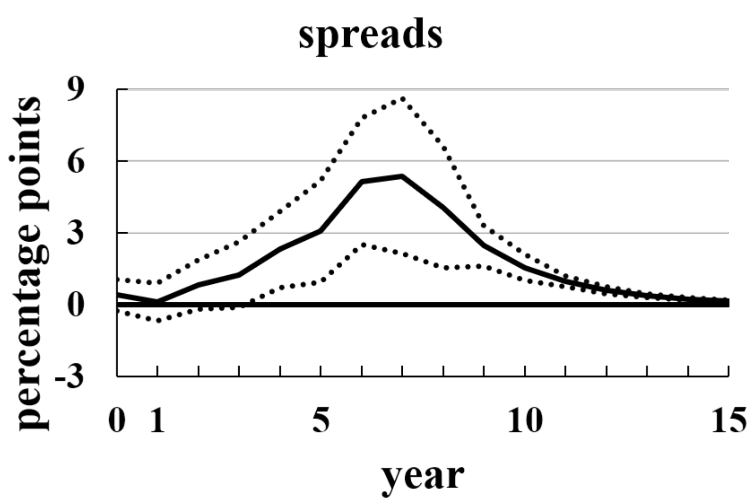
Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

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. 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.

Figure 3: Impact of giant oil discoveries on spreads



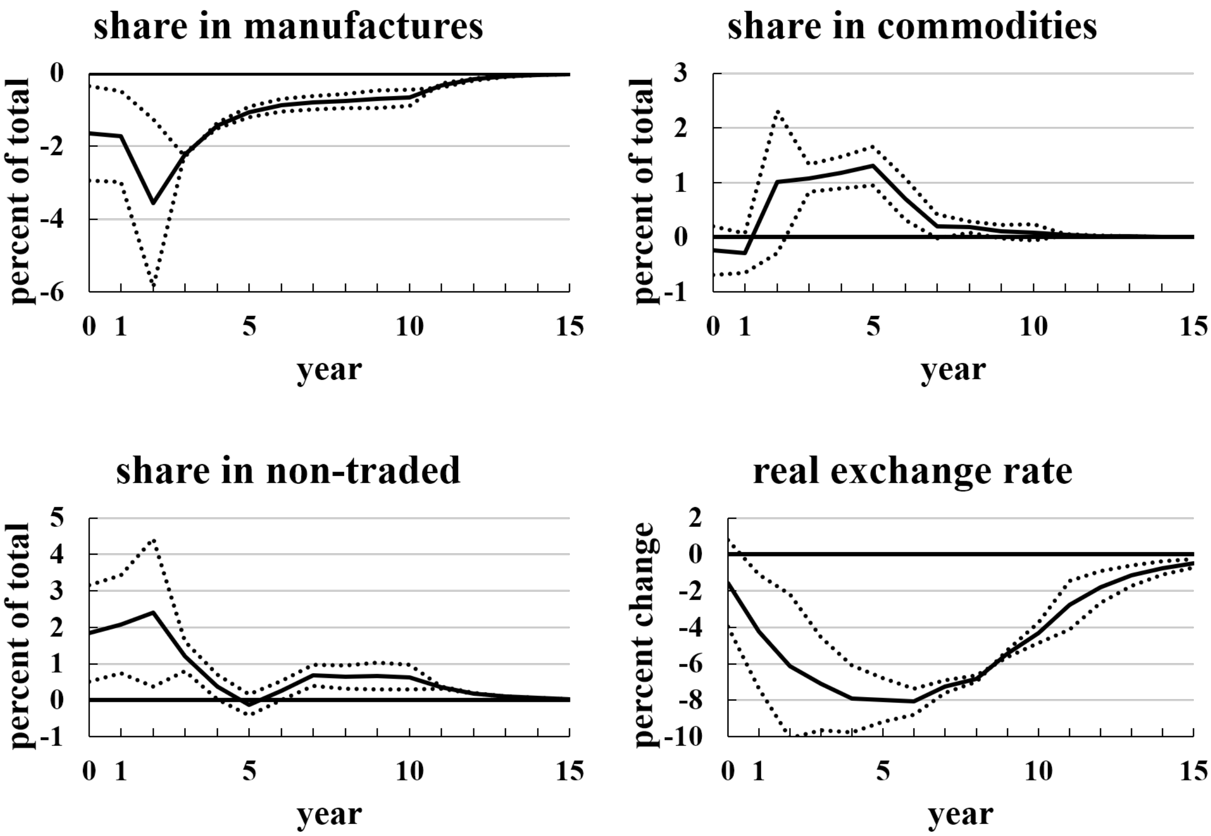
Impulse response to an oil discovery with net present value equal to 18 percent of GDP. The dotted lines indicate 90 percent confidence intervals.

The theoretical model in Section 3 shows how the effects of the Dutch disease can reconcile these empirical observations. Subsection 2.4 shows some evidence of the Dutch disease following oil discoveries.

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 comprises agricultural and fishing activities as well as mining and querying. 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 commodities and 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 crowd out of the 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.[15]

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, $c_{oil,t}$:

$$Y_t = \left[\omega_N^{\frac{1}{\eta}} \left(c_{N,t}\right)^{\frac{\eta-1}{\eta}} + \omega_M^{\frac{1}{\eta}} \left(c_{M,t}\right)^{\frac{\eta-1}{\eta}} + \omega_{oil}^{\frac{1}{\eta}} \left(c_{oil,t}\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{2}$$

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 intermediate non-traded good and manufactures are produced using capital k and labor l with constant returns to scale technologies:

$$y_{N,t} = z_t k_{N,t}^{\alpha_N} l_{N,t}^{1-\alpha_N} \tag{3}$$

$$y_{M,t} = z_t k_{M,t}^{\alpha_M} l_{M,t}^{1-\alpha_M} \tag{4}$$

where z_t is aggregate productivity in the economy. Each period the economy has access to an oil field with maximum capacity $\hat{n}_t$. Oil is produced using part of the field's capacity $n_t \leq \hat{n}_t$, capital and labor:

$$y_{oil,t} = z_t \left(k_{oil,t}^{\alpha_{oil}} l_{oil,t}^{1-\alpha_{oil}}\right)^{1-\zeta} n_t^{\zeta} \tag{5}$$

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

[15] 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.

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

$$c_t + i_{k,t} = Y_t + m_t, \tag{6}$$

where c_t is private consumption, $i_{k,t}$ is investment in capital, Y_t is production of the final non-traded good, and m_t is a transitory income shock described below. At the beginning of each period the economy starts with an aggregate stock of capital k_t that can be freely allocated to each of the three intermediate sectors so that $k_t = k_{N,t} + k_{M,t} + k_{oil,t}$. The law of motion of the aggregate stock of capital is:

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

where $i_{k,t}$ is investment, δ is the capital depreciation rate, and $\Psi\,(k_{t+1}, k_t) = \chi \left(\frac{k_{t+1}+k_t}{k_t}\right)^2 k_t$ is a capital adjustment cost function.[16] Similarly, given an aggregate labor supply l_t, labor is freely allocated within sectors so that $l_t = l_{N,t} + l_{M,t} + l_{oil,t}$.

Shocks and oil discoveries.—In each period, the economy receives a transitory income shock $m_t \in [-\bar{m}, \bar{m}]$ drawn independently from a mean zero probability distribution with continuous CDF.[17] Additionally, in each period the economy experiences one of finitely many events s_t that follow a Markov chain governed by the transition matrix $\pi\,(s_{t+1}|s_t)$. This shock s_t determines four variables: the aggregate productivity in the economy z_t, the international price of oil $p_{oil,t}$, the maximum oil field capacity $\hat{n}_t$, and the number of periods since an oil discovery τ_t.[18]

The maximum capacity of the oil field can take one of two values, that is $\hat{n}_t \in \{n_L, n_H\}$ with $0 \le n_L < n_H$. In order to be able to exploit a giant oil field the economy has to have a minimum

[16] 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) argue, sovereign default models with capital accumulation require capital adjustment costs to sustain positive levels of debt in equilibrium. The reason is that without adjustment costs the cheapest way for the sovereign to hedge against fluctuations is to reduce investment rather than borrowing from the rest of the world.

[17] 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 (6) 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 see Gordon and Guerron-Quintana (2018).

[18] I assume that the international price of manufactures is fixed. As it will be discussed in Subsection 3.4, what is key is that the price of oil is relatively more volatile than the price of other traded goods, thus this assumption can be understood as a normalization.

level of capital installed $\bar{k} \geq 0$, thus the field's capacity that is actually used in production is:

$$n_t = \begin{cases} n_L & \text{if } \hat{n}_t = n_L \\ n_L & \text{if } \hat{n}_t = n_H \text{ \& } k_t < \bar{k} \\ n_H & \text{if } \hat{n}_t = n_H \text{ \& } k_t \geq \bar{k} \end{cases}$$

where $\bar{k} > 0$ ensures that the economy has to invest in order to exploit a newly discovered giant oil field. The economy starts with $\hat{n}_t = n_L$ and with probability $\phi_1 \geq 0$ discovers a giant oil field, which becomes available after five periods. That is, if the economy discovers a giant oil field in period j then $n_{j+\tau_t} = n_L$ for $\tau_t = 0...5$ and then $n_{j+6} = n_H$. This transition is known by all agents and happens with certainty. For $t \geq j+7$ oil extraction capacity is $n_t = n_H$ and with probability $\phi_0 \geq 0$ the giant oil field is exhausted, in which case $n_{t+1} = n_L$.

Preferences.—The government has preferences over private consumption c_t and labor supply l_t represented by:

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

where $u(c,l) = \frac{(c - \chi l^{\nu})^{1-\sigma} - 1}{1-\sigma}$ and β is the discount factor. Following Greenwood, Hercowitz, and Huffman (1988), I assume preferences such that there is no wealth effect on labor supply. This is a convenient formulation that prevents labor supply in the model from displaying counter-cyclical fluctuations and that has been used in sovereign default models with production.[19] Also, as discussed by Jaimovich and Rebelo (2008) and Jaimovich and Rebelo (2009), this type of preferences—along with adjustment costs to capital—are essential for business cycle models to generate co-movement in response to news shocks about fundamentals. In this environment oil discoveries are akin to news about future higher total factor productivity in the oil sector.

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:

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

[19] See for example Mendoza and Yue (2012) and Gordon and Guerron-Quintana (2018).

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 manufactures, which are 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:

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

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, $p_{oil,t}$ is the international price of oil in period t, and p_M is the international price of manufactures, which is assumed to be constant and equal to 1. Equation (9) 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. In this case, the balance of payments is:

$$[\gamma + (1-\gamma)\,\kappa]\, b_t = p_M x_{M,t} + p_{oil,t} x_{oil,t} + q_t i_{b,t} \tag{10}$$

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

[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 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.

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 capital k, the outstanding government debt b, and an indicator of whether or not the government is in default.

Let $V(s,m,k,b)$ 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, $d=1$:

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

where $V^P(s,m,k,b)$ is the value of repaying and $V^D(s,k)$ 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 stock of capital next period k', the labor supply l, static allocations of capital and labor in each sector $\overrightarrow{K} = \{k_N, k_M, k_{oil}\}$ and $\overrightarrow{L} = \{l_N, l_M, l_{oil}\}$, 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:

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

subject to the resource constraint of the final good (6), the resource constraint of capital $k_t = k_N + k_M + k_{oil}$, the resource constraint of labor $l_t = l_{N,t} + l_{M,t} + l_{oil,t}$, the law of motion of capital (7), the resource constraints of intermediate goods $c_N = y_N$, $c_{oil} + x_{oil} = y_{oil}$ and $c_M + x_M = y_M$, and the balance of payments under default (9). Note that the government can trade in goods, but trade has to be balanced since it cannot issue debt.

If the government decides to repay then it chooses the stocks of capital k' and debt b' in the next period, the labor supply l, static allocations of capital and labor in each sector $\overrightarrow{K} = \{k_N, k_M, k_{oil}\}$ and $\overrightarrow{L} = \{l_N, l_M, l_{oil}\}$, 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:

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

subject to the resource constraint of the final good (6), the resource constraint of capital $k_t = k_N + k_M + k_{oil}$, the resource constraint of labor $l_t = l_{N,t} + l_{M,t} + l_{oil,t}$, the law of motion of capital (7), the law of motion of bonds (8), the resource constraints of intermediate goods $c_N = y_N$, $c_{oil} + x_{oil} = y_{oil}$ and $c_M + x_M = y_M$, and the balance of payments under repayment (10).

3.3 Equilibrium

A Markov equilibrium is value functions $V(s,m,k,b)$, $V^D(s,k)$, and $V^P(s,m,k,b)$, a policy function for capital in default $k'^D(s,k)$, a labor supply in default $l^D(s,k)$, policy functions for capital $k'(s,m,k,b)$ and debt issuance $b'(s,m,k,b)$ in repayment, a labor supply in repayment $l(s,m,k,b)$, a default policy function $d(s,m,k,b)$, policy functions for static allocations in repayment and in default, and a price schedule of bonds $q(s,k',b')$ 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:

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

where $k'' = k'(s',m',k',b')$ and $b'' = b'(s',m',k',b')$ are the government's decisions of future capital and debt 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

An oil discovery in period t is news that, with certainty, the economy will have a higher level of oil for extraction n in period $t+6$. With a higher n the economy can achieve a higher level of income. However, as it will be illustrated in Section 5, spreads increase between periods t and $t+5$, that is, between the announcement of a discovery and when higher oil production starts. In order to understand why this is the case, I will discuss first what happens in period $t+6$ and then iterate backwards.

In period $t+6$, the higher level of n increases the allocation of capital and labor in the oil sector. In order to increase consumption, the allocations of capital and labor in the non-traded sector also increase, thus, the shares of capital and labor in the manufacturing sector decrease. This reallocation of production factors is the Dutch disease in the model. Additionally, the aggregate labor supply increases to take advantage of the higher n

Both higher n and higher labor supply increase the return to capital in period $t+6$. This higher return drives an increase in investment in period $t+5$. In order to smooth consumption this higher investment is financed with foreign debt. Investment and debt issuance have opposite effects on spreads: while higher indebtedness raises spreads higher investment reduces them.[22] However, in this environment the effect of higher investment is undermined by the reallocation of production factors away from the manufacturing sector in period $t+6$. This is because the price of oil is more volatile than the price of manufactures, the reallocation increases the volatility of total traded income used to service the debt, as can be seen in the balance of payments equation:

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

where the share of oil revenue on the right-hand side his higher the higher n is. This higher volatility increases the probability of defaulting in period $t+6$ from the perspective of period $t+5$. Since debt is long-term, a higher spread in $t+5$ increases the spreads in $t+4$, as can be seen in equation (11). This in turn increases spreads in the previous periods up until period t, when the news about the oil discovery is realized.

4 Calibration

I calibrate the model to the Mexican economy for 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

[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.

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 $\eta = 0.73$.[23] 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. I set the curvature of the disutility of labor to $\nu = 1.45$ so that the Frisch elasticity of labor supply is $\frac{1}{\nu-1} = 2.2$.[24] I set the scaling parameter of the disutility of labor to $\chi = 0.68$ so that the labor supply in the steady state of the economy without default is 1.

[23] 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.

[24] This value is consistent with estimates for the United States and has been used in similar business cycle models, see for example Neumeyer and Perri (2005) and Mendoza and Yue (2012).

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	
curvature parameter of labor	ν	1.45	Frisch elasticity of 2.2
scaling parameter of labor	χ	0.68	Steady state labor supply equal 1
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
probability of giant oil discovery	ϕ_1	0.00	unexpected oil discovery
probability of exhaustion	ϕ_0	0.00	perpetual oil well
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
volatility of price of oil	ν_p^2	0.23	in the real price of oil
mean price of oil	$\bar{p}_{oil}$	0.28	rest-of-world steady state
price of manufactures	p_M	1.0	normalization
low oil field capacity	n_L	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:

$$\log p_{oil,t} = (1-\rho_{oil}) \log \bar{p}_{oil} + \rho_{oil} \log p_{oil,t-1} + \nu_p \varepsilon_t \tag{12}$$

where ε_t are iid with standard normal distribution and $\bar{p}_{oil}$ is the mean of the price of oil. I set $\bar{p}_{oil} = 0.28$ as the steady state price of oil in a closed rest-of-world economy with oil field with capacity $\hat{n} = n_L$, as detailed in Appendix A.3. Now, for the persistence and variance of the price of oil I take the first difference of equation (12) to get:

$$\Delta \log p_{oil,t} = \rho_{oil} \Delta \log p_{oil,t-1} + \nu_p \Delta \varepsilon_t. \tag{13}$$

I use data on the West Texas Intermediate price of oil divided by the US GDP deflator to calculate a real price and estimate the persistence parameter in (13) $\rho_{oil} = 0.48$ 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.[25]

For simplicity I set the probability of discovering a giant oil field to $\phi_1 = 0.0$, so that oil discoveries are completely unexpected. Similarly, I set the probability of exhaustion to $\phi_0 = 0.0$. 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, not so of the long life-cycle of oil fields.

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 Gordon and Guerron-Quintana (2018). For the transitory income shock m I follow Chatterjee and Eyigungor (2012) and assume $m \sim \text{trunc}\, N\left(0, \sigma_m^2\right)$ with points of truncation $-\bar{m}$ and $\bar{m}$. 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 relative size between the persistent and the maximum transitory component of income 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 standard normal distribution. The persistence ρ_z and variance σ_z are calibrated

[25] Method first proposed by Rouwenhorst (1995), for a discussion on its properties see Kopecky and Suen (2010).

to match the persistence and volatility of the business cycle of the Mexican GDP (more details below). Finally, I normalize the capacity of the initial oil field to $n_L = 1$.

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.

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 cost	ψ	3.5	high oil for extraction	n_H	3.00

Moment	Data	Model
Average spread	266	223
St. dev. of spreads	134	135
Debt-to-GDP ratio	0.13	0.11
Capital-to-GDP ratio	1.90	1.87
$\sigma_{inv}/\sigma_{GDP}$	2.3	2.1
ρ_{GDP}	0.30	0.27
σ_{GDP}	2.22	2.30
$\frac{NPV}{GDP}$	19	22

There is a total of eight parameters chosen to match eight 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, 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 by the capital depreciation rate δ and the capital adjustment cost parameter ψ, respectively. 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. 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:

$$NPV_t = \sum_{s=6}^{\infty} \left(\frac{1}{1+r_t} \right)^s p_{oil,t} \left[y_{oil} \left(s_t, k_t, b_t, n_H \right) - y_{oil} \left(s_t, k_t, b_t, n_L \right) \right] \tag{14}$$

where r_t is the implied yield of the government bonds at time t and $y_{oil}(s_t, k_t, b_t, n_H)$ and $y_{oil}(s_t, k_t, b_t, n_L)$ are what oil production in period t would be with n_H and n_L, respectively, given the current state.

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: Not targeted moments

Moment	Data	Model
σ_c / σ_{GDP}	1.11	1.26
σ_{TB}	4.07	1.06
$Corr(c, GDP)$	0.85	0.92
$Corr(inv, GDP)$	0.81	0.49
$Corr(TB, GDP)$	-0.03	-0.35
$Corr(\text{spreads}, GDP)$	-0.37	-0.17

The following section shows the model's predictions after an oil discovery, with special focus on the model's ability to reproduce the increase in spreads.

5 Quantitative Results

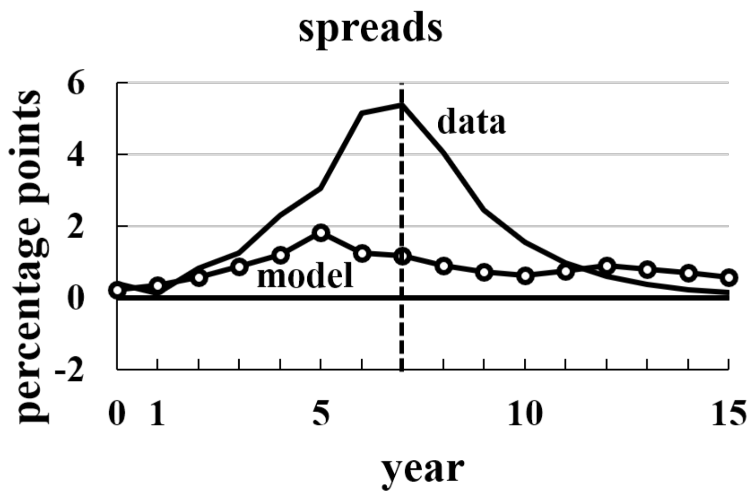
This section presents the main quantitative results. First, Subsection 5.1 shows the model predictions of the change in spreads following an oil discovery and how it explains 40 percent of the increase observed in the data. Then, Subsection 5.2 disentangles the effect that the Dutch disease has on the increase in spreads and the co-movement of other macroeconomic variables following an oil discovery in the model. Finally, Subsection 5.3 explains the procedure to calculate the welfare gains of eliminating the volatility of the price of oil and presents the results.

All the impulse-response functions from the model are computed as follows: (i) simulate 300 economies for 5001 periods without allowing for oil discoveries, (ii) drop the first 5000 to eliminate any effect of initial conditions, (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 path, (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 Response of spreads to an oil discovery

Figure 3 compares the impulse-response of spreads in the model to the estimates in 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, where they reach a maximum increase of 5.3 percentage points. In the model under the benchmark calibration spreads also increase when the news is realized and continue to do so until period 5, where they reach a maximum increase of 2 percentage points. The peak in the model happens exactly one period before the larger oil field is available.

Figure 5: Impulse-response of spreads to a discovery of average size



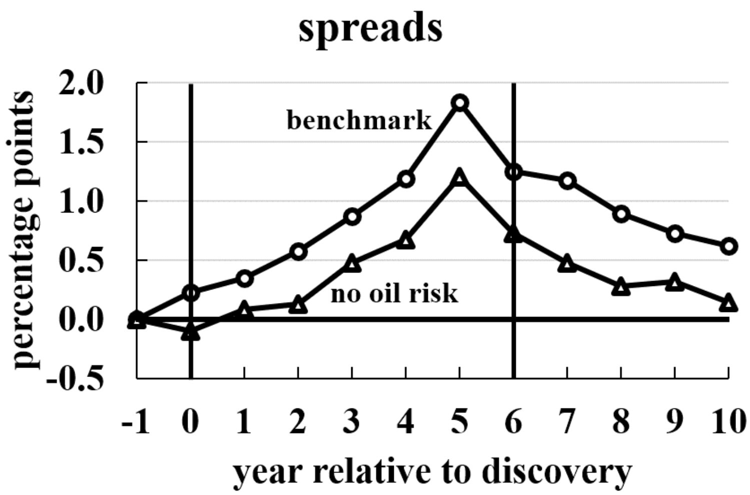
The model explains around 40 percent of the response of spreads following an oil discovery. That is, the integral under the curve labeled "model" in Figure 5 up until the seventh period is approximately 40 percent of the integral under the solid line labeled "data".

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 at its mean. As discussed in Subsection 2.4, the reallocation of production factors implied by the Dutch disease increases the volatility of tradable income, the counterfactual case considered here with no volatility in the price of oil shuts down this effect.

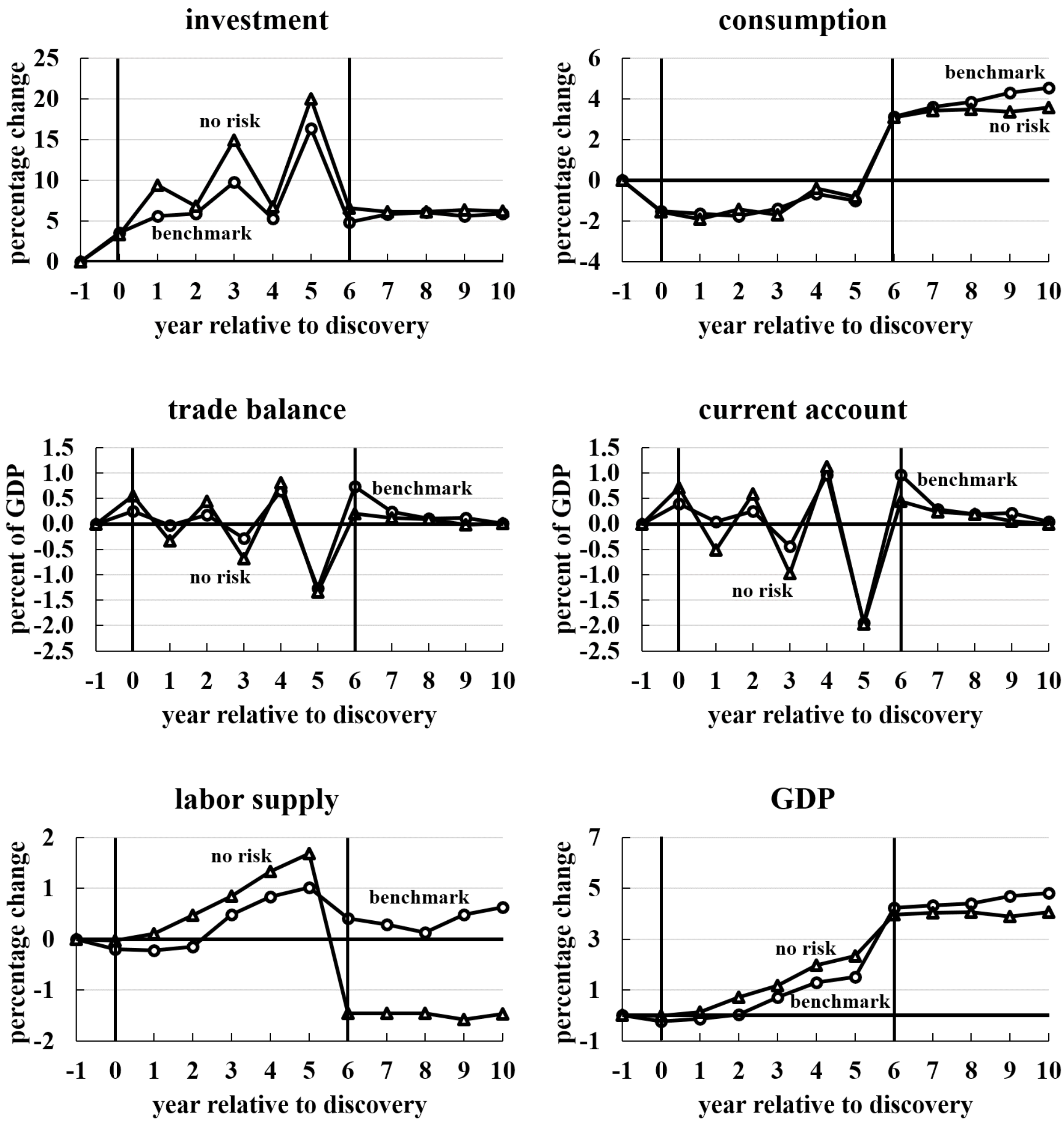
Figure 6 shows the impulse-response of spreads in these two cases. Spreads still increase in the model with no volatility in the price of oil, however this increase is smaller. The area between the two curves is 54 percent of the area under the benchmark curve. The average difference between these two curves is one third of the total increase in the benchmark economy.

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



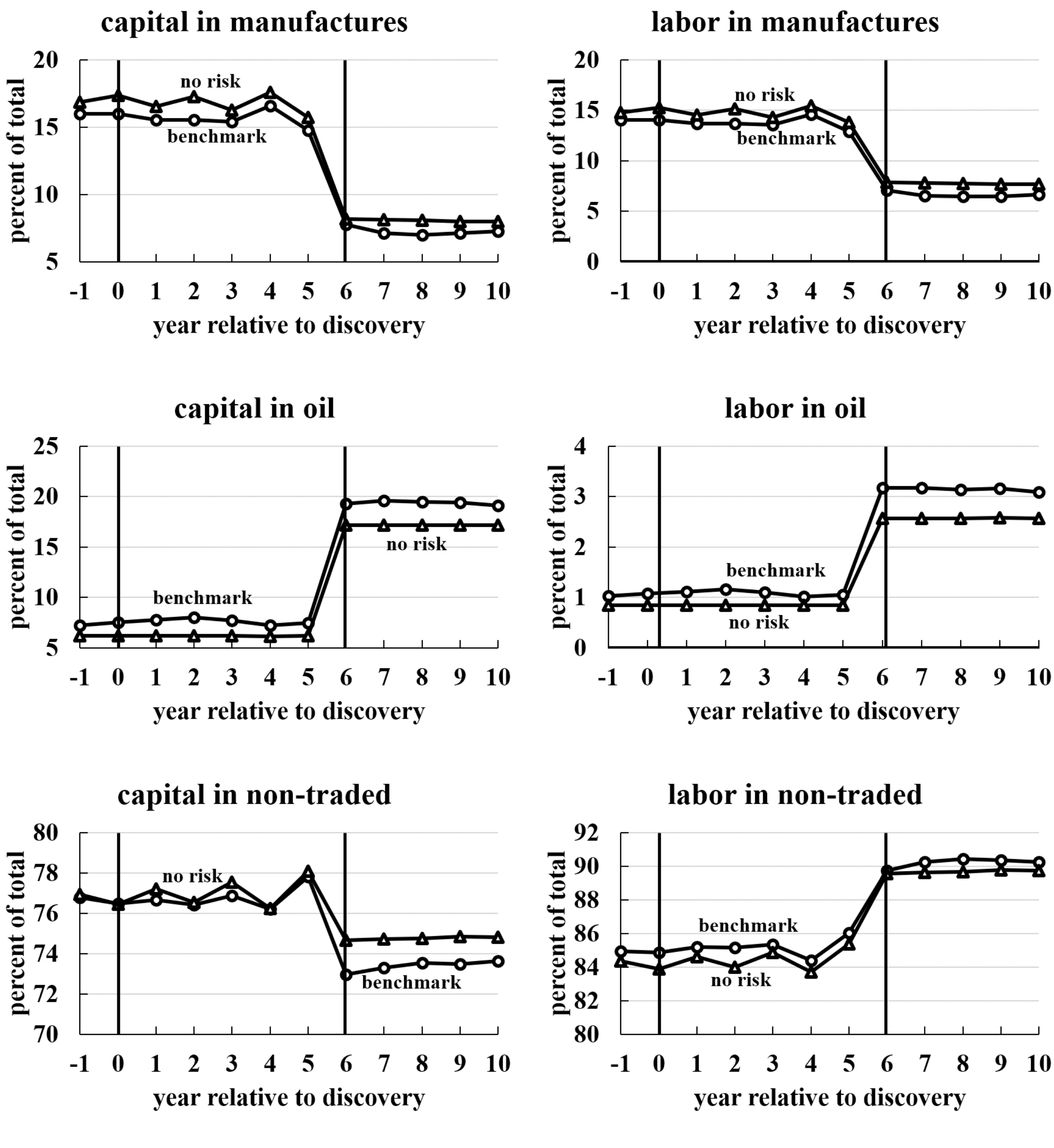
The difference between these two curves is the fraction of the increase in spreads that is generated by the Dutch disease. The remainder in the increase in spreads in the model is explained by the increase in foreign borrowing. Figure 7 shows the impulse-responses of investment, consumption, the trade balance, the current account, labor supply, and GDP. Note that the responses are almost identical in both economies, the volatility of the price of oil only affects the dynamics of the spreads.

Figure 7: Impulse-response of other macroeconomic variables, discovery in $t = 0$



As discussed in Subsection 3.4, investment increases in anticipation of the higher available oil for extraction $\hat{n}$ in period 6. The increases is supported by imports financed with debt issuance, both reflected on the current account and trade balance deficits. GDP starts increasing during the transition. Consumption decreases to finance investment, starts increasing in period 5 and continues to do so in the subsequent periods.

Figure 8: Path of factor shares, discovery in $t = 0$



The increase in investment and the current account deficit have opposite effects on spreads, however, the effect of the latter dominates due to the higher volatility of tradable income starting in period 6. This higher volatility is explained by the reallocation of production factors away from the manufacturing sector, which has a constant international price, into the oil sector, which has a volatile price. This factor reallocation is illustrated in Figure 8, which shows the average paths of the shares of capital and labor in each sector.

Again, note how in both the benchmark economy and in the economy without oil risk the paths are almost identical. In period 6, once a higher $\hat{n}$ is available, the model features a reallocation of production factors away from the manufacturing sector. The share of labor allocated in the oil and non-traded sectors increase, as well as the share of capital in the oil sector. The share of capital in the non-traded sector actually decreases, which is a result of this sector being less intensive in the use of capital.

5.3 Welfare analysis

The purpose of this subsection is to calculate the welfare cost of the volatility of the price of oil. I interpret this calculation as an indication of how valuable it is for a country to have access to financial instruments that allow it to hedge against oil price risk.

I calculate the welfare cost as the fraction of consumption, in all possible histories, that the economy is willing to forego in order to eliminate the volatility of the price of oil. Denote $\mathscr{E}^{Bench}$ as all the equilibrium objects under the benchmark calibration from Section 4. Similarly, denote $\mathscr{E}^{NoRisk}$ as all the equilibrium objects under the same calibration but with no volatility for the price of oil.

Let $V^{bench}(s,k,b)$ and $V^{NoRisk}(s,k,b)$ be the values of the government in good financial standing from $\mathscr{E}^{Bench}$ and $\mathscr{E}^{NoRisk}$, respectively. When the state is (s,k,b), let $\chi(s,k,b)$ be the fraction of consumption—net of labor disutility—that the government is willing to sacrifice to eliminate the volatility of the price of oil if it is in good financial standing . Since the utility function is homothetic in $(c-\chi l^{\nu})$, $\chi(s,k,b)$ is pinned down by:

$$(1-\chi(s,k,b))^{1-\sigma}\left[V^{NoRisk}(s,k,b)+\mathscr{C}\right]=V^{bench}(s,k,b)+\mathscr{C} \tag{15}$$

where $\mathscr{C}=\frac{1}{1-\sigma}\frac{1}{1-\beta}$ is a constant. Similarly, denote $V^{D,bench}(s,k)$ and $V^{D,NoRisk}(s,k)$ as the default values of the government from $\mathscr{E}^{Bench}$ and $\mathscr{E}^{NoRisk}$, respectively. Define $\chi^{D}(s,k)$ in a similar fashion:

$$\left(1-\chi^{D}\left(s,k\right)\right)^{1-\sigma}\left[V^{D,NoRisk}\left(s,k\right)+\mathscr{C}\right]=V^{D,bench}\left(s,k\right)+\mathscr{C} \tag{16}$$

where $\mathscr{C}=\frac{1}{1-\sigma}\frac{1}{1-\beta}$.

To calculate a welfare cost χ_j I simulate a time series of $2500+T$ periods for productivity, price of oil, and oil extraction capacity $\left\{\left(z_t,p_{oil,t},n_t\right)\right\}_{t=1}^{2500+T}$. I use $\left\{\left(z_t,p_{oil,t},n_t\right)\right\}_{t=1}^{2500+T}$ and the policy functions from $\mathscr{E}^{Bench}$ to generate paths of values for the benchmark economy $\left\{V_t^{bench}\right\}_{t=1}^{2500+T}$, taking into account when the economy enters and exits default in the equilibrium path. Similarly, I set $p_{oil,t}=\bar{p}_{oil}$ for all t and use $\{(z_t,n_t)\}_{t=1}^{2500+T}$ and the policy functions from $\mathscr{E}^{NoRisk}$ to generate paths of values for the economy with no oil risk $\left\{V_t^{NoRisk}\right\}_{t=1}^{2500+T}$, also taking into account when the economy enters and exits default in the equilibrium path. I use these paths to calculate a path of welfare costs $\{\chi_t\}_{t=1}^{2500+T}$. I drop the first 2500 to eliminate the effect of initial conditions and average the rest to get the welfare cost χ_j.

I make two welfare exercises. For each of the three I calculate 300 welfare costs $\left\{\chi_j\right\}_{j=1}^{300}$ and average them. The first exercise considers an economy that has a low oil extraction capacity. Note that, even if n_L were equal to 0 the economy would still be exposed to oil price risk since oil is consumed. I follow the procedure described above but setting $n_t=n_L$ in all periods. The second exercise calculates the welfare costs for economies that experience an oil discovery at some point during the path. Table 4 shows the results.

Table 4: Welfare analysis

Exercise	Welfare cost
No discoveries	0.4%
With discoveries	0.6%

An economy that never experiences a discovery is willing to forego 0.4% of consumption permanently in order to eliminate the volatility of the price of oil. Conditional on discovery this figure is 0.6%. Given that preferences are concave, eliminating any source of consumption volatility is always desirable, however, eliminating this particular source of volatility is 1.5 times more valuable for an economy that has an oil discovery than for an economy that does not. Note that even without any endowment of oil, the economy is still exposed to swings in its price since it is a consumed commodity. When the economy is highly indebted, the factor reallocation implied by the Dutch disease increases the probability of states in which the economy would default. This higher probability of experiencing the dead-weight loss implied by default explains the higher value of eliminating the oil price risk.

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 mining 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 40 percent of the increase in spreads documented from the data. In the model, the share of capital in the oil and non-traded sectors increase and the share of capital in the manufacturing sector decreases. This shift—referred to in the literature as the Dutch disease—increases the volatility of exports that support debt payments since the price of oil is more volatile than the price of manufactures. The Dutch disease accounts for 54 percent of the increase in spreads in the model. I interpret these results as a validation of the hypothesis that the future reallocation of production factors is a key determinant of the change in sovereign spreads following an oil discovery.

It is worth noting that, 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.

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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 layout 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 as 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:

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

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:

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

where f^N and f^M are homogeneous of degree 1 in k and l and f^{oil} is homogeneous of degree 1 in k, l and n. Each period, these firms rent capital $k_{i,t}$ and labor $l_{i,t}$ from the household in exchange for a rental rate of capital r_t and a wage w_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 $p_{N,t}$. Note that f^{oil} has decreasing returns to scale with respect to k and l, thus it will make positive profits. The representative household owns all the firms and get these profits which can be interpreted as the oil rent—that is, the payments for the natural resources factor n, which are assumed to be owned by the household as well.

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

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

where $u(c,l) = \frac{(c-\chi l^{\nu})^{1-\sigma}-1}{1-\sigma}$ and β is the discount factor. The household owns all the firms and makes consumption, investment and labor supply decisions subject to its budget constraint:

$$c_t + \left(1+\tau_{k,t}\right)k_{t+1} + \Psi\left(k_{t+1}, k_t\right) \leq \left(1-\tau_{l,t}\right)\frac{w_t}{P_t}l_t + \left(1+\frac{r_t}{P_t}-\delta\right)k_t + \frac{\pi_t^N + \pi_t^M + \pi_t^{oil}}{P_t} + m_t + T_t$$

where $\tau_{k,t}$ and $\tau_{l,t}$ are distortionary taxes, T_t are transfers from the government, m_t is a small income shock, and π_t^N, π_t^M and π_t^{oil} are profits from the intermediate goods firms.[26]

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:

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

[26]Note that in equilibrium only π_t^{oil} will be positive if $n_t > 0$.

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 $\tau_{k,t,}$ and $\tau_{l,t}$ 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. If the government is in good financial standing then its budget constraint is:

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

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:

$$P_t \tau_{k,t} k_{t+1} + \tau_{l,t} w_t l_t = P_t T_t$$

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:

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

where the value in repayment is:

$$
\begin{aligned}
V^P(s,m,k,b) = & \max_{\left\{k',b',l,\overrightarrow{C},\overrightarrow{L},\overrightarrow{K},\overrightarrow{X}\right\}} \left\{u(c,l) + \beta \mathbb{E}\left[V\left(s',m',k',b'\right)\right]\right\} \\
s.t. \qquad c + k' + \phi\left(\frac{k'-k}{k}\right)^2 k & \leq Y + (1-\delta)k + m \\
Y & = f^Y(c_N, c_M, c_{oil}) \\
c_N & = f^N(z, k_N, l_N) \\
c_M & = f^M(z, k_M, l_M) - x_M \\
c_{oil} & = f^{oil}(z, k_{oil}, l_{oil}, n) - x_{oil} \\
q\left(s,k',b'\right)\left[b' - (1-\gamma)b\right] & = p_M x_M + p_{oil} x_{oil} + [\gamma + \kappa(1-\gamma)]b \\
k & = k_N + k_M + k_{oil} \\
l & = l_N + l_M + l_{oil}
\end{aligned}
$$

and the value in default is:

$$
\begin{aligned}
V^D(s,k) = & \max_{\left\{k',l,\overrightarrow{C},\overrightarrow{L},\overrightarrow{K},\overrightarrow{X}\right\}} \left\{u(c,l) + \beta \mathbb{E}\left[\theta V\left(s',m',k',0\right) + (1-\theta) V^D\left(s',k'\right)\right]\right\} \\
s.t. \qquad c + k' + \phi\left(\frac{k'-k}{k}\right)^2 k & \leq Y + (1-\delta)k - \bar{m} \\
Y & = f^Y(c_N, c_M, c_{oil}) \\
c_N & = f^N(\tilde{z}, k_N, l_N) \\
c_M & = f^M(\tilde{z}, k_M, l_M) - x_M \\
c_{oil} & = f^{oil}(\tilde{z}, k_{oil}, l_{oil}, n) - x_{oil} \\
0 & = p_M x_M + p_{oil} x_{oil} \\
k & = k_N + k_M + k_{oil} \\
l & = l_N + l_M + l_{oil}
\end{aligned}
$$

Note that these problems can be rewritten as:

$$
\begin{aligned}
V^P(s,m,k,b) = & \max_{\left\{k',b',l,\overrightarrow{C},\overrightarrow{L},\overrightarrow{K},\overrightarrow{X}\right\}} \left\{u(c,l) + \beta \mathbb{E}\left[V\left(s',m',k',b'\right)\right]\right\} \\
s.t. \qquad c + k' + \phi\left(\frac{k'-k}{k}\right)^2 k & \leq F(s,l,k,X) + (1-\delta)k + m \\
X & = q\left(s,k',b'\right)\left[b' - (1-\gamma)b\right] - [\gamma + \kappa(1-\gamma)]b
\end{aligned}
$$

and:

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

$$s.t. \qquad c + k' + \phi\left(\frac{k'-k}{k}\right)^{2} k \leq F^{D}(s,l,k) + (1-\delta)k - \bar{m}$$

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

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

and in default F^{D} is defined as:

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

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

$$f^Y_{c_N}(c_N, c_M, c_{oil}) = \lambda_{C_N} \tag{17}$$

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

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

$$f^N_k(z, k_N, l_N) = \frac{\lambda_k}{\lambda_{C_N}} \tag{20}$$

$$f^M_k(z, k_M, l_M) = \frac{\lambda_k}{\lambda_{C_M}} \tag{21}$$

$$f^{oil}_k(z, k_{oil}, l_{oil}, n) = \frac{\lambda_k}{\lambda_{C_{oil}}} \tag{22}$$

$$f^N_l(z, k_N, l_N) = \frac{\lambda_l}{\lambda_{C_N}} \tag{23}$$

$$f^M_l(z, k_M, l_M) = \frac{\lambda_l}{\lambda_{C_M}} \tag{24}$$

$$f^{oil}_l(z, k_{oil}, l_{oil}, n) = \frac{\lambda_l}{\lambda_{C_{oil}}} \tag{25}$$

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

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

where λ_{C_N}, λ_{C_M}, $\lambda_{C_{oil}}$, λ_k, λ_l, and λ_{BoP} are the multipliers of the market clearing constraints for intermediate goods, for capital, for labor, 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 9 first-order conditions plus 6 constraints to solve for eleven static allocations c_N, c_M, c_{oil}, k_N, l_N, k_M, l_M, k_{oil}, l_{oil}, x_{oil}, and x_M and 4 multipliers λ_{C_N}, λ_{C_M}, λ_k, and λ_l.

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:

$$\max_{k_N, l_N} f^N(z, k_N, l_N) - rk_N - wl_N$$

$$\max_{k_M, l_M} f^M(z, k_M, l_M) - rk_M - wl_M$$

$$\max_{k_{oil}, l_{oil}} f^{oil}(z, k_{oil}, l_{oil}, n) - rk_{oil} - wl_{oil}$$

The 11 static allocations c_N, c_M, c_{oil}, k_N, l_N, k_M, l_M, k_{oil}, l_{oil}, x_{oil} and x_M, 3 endogenous prices p_N, w, and r, and the multiplier μ^Y of the constraint in the minimization problem of the final good firm are pinned down by the 10 F.O.C.s of these problems:

$$f^Y_{c_N}(c_N, c_M, c_{oil}) = \frac{p_N}{\mu^Y} \tag{28}$$

$$f^Y_{c_M}(c_N, c_M, c_{oil}) = \frac{p_M}{\mu^Y} \tag{29}$$

$$f^Y_{c_{oil}}(c_N, c_M, c_{oil}) = \frac{p_{oil}}{\mu^Y} \tag{30}$$

$$f^N_k(z, k_N, l_N) = r \tag{31}$$

$$f^N_l(z, k_N, l_N) = w \tag{32}$$

$$f^M_k(z, k_M, l_M) = r \tag{33}$$

$$f^M_l(z, k_M, l_M) = w \tag{34}$$

$$f^{oil}_k(z, k_{oil}, l_{oil}) = r \tag{35}$$

$$f^{oil}_l(z, k_{oil}, l_{oil}) = w \tag{36}$$

the balance of payments, and market clearing conditions:

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

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, τ_l, 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. The 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:

$$p_{oil} = \left(\frac{a_{oil}}{a_M} \frac{c^\star_M}{c^\star_{oil}} \right)^{\frac{1}{\eta}} \tag{37}$$

I assume that the rest of the world has an oil field with capacity $\hat{n} = n_L$. I solve for the steady state with no shocks in this rest-of-world economy and use (37) to calculate $\bar{p}_{oil}$.