Boom goes the price: Giant resource discoveries and real exchange rate appreciation

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Abstract

We estimate the effect of giant oil and gas discoveries on bilateral real exchange rates. The size and plausibly exogenous timing of such discoveries make them ideal for identifying the effects of an anticipated resource boom on prices. We find that a giant discovery with the value of a country's GDP increases the real exchange rate by 14% within 10 years following the discovery. The appreciation is nearly exclusively driven by an appreciation of the prices of non-tradable goods. We show that these empirical results are qualitatively and quantitatively in line with a calibrated model with forward looking behaviour and Dutch disease dynamics.

1   Introduction

This paper provides evidence on the effect of a booming extractive industry on the real exchange rate. The standard Dutch-disease theory predicts the real exchange rate to appreciate in the wake of a resource boom (Corden and Neary, 1982). Ample anecdotal evidence supports this prediction. Luanda, Angola's capital city, is frequently ranked as the most expensive city in Africa, an occurrence usually attributed to Angola's income from oil. Similarly, in the summer of 2014 the price of a Big Mac in Oslo was $7.8, roughly 30% above the price of the same burger in Stockholm, also assumed to be the result of differences in income from oil.

For resource exporters, the effect on the real exchange rate of a boom in their extractive sector is of first order importance. More expensive non-tradable goods and deteriorating competitiveness of the tradable goods sector affect living-standards as well as the desired responses in fiscal and monetary policy. With the recent collapse in the oil price, from $110 in 2011 to below $35 in the beginning of 2016, and sharp depreciation in commodity currencies such as

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the Brazilian Real and the Norwegian kroner, the question of what is the relationship between the resource sector and the real exchange rate is very timely.

Surprisingly, there is little cross-country empirical work documenting the effect of resource booms on prices. Such empirical work has to tackle two important challenges: measurement of the real exchange rate and endogenous measures of resource booms. In this paper, we seek to overcome these challenges by combining a self constructed data set on bilateral real exchange rates with a new data set on giant oil and gas discoveries (Horn, 2011; Arezki, Ramey and Sheng, 2015), covering 172 countries for the period 1970 - 2013.

We build on the work of Engel (1999) and Betts and Kehoe (2006; 2008) and focus on the bilateral real exchange rate. This provides us with variation for each country-pair-year, dramatically increasing the data available compared to the unilateral measures previously used.[1] Our focus on country-pairs also allows us to treat a resource boom at home and abroad symmetrically and to control for unobservable country-pair specific characteristics, such as trade frictions.

Much previous work on the effects of natural resources has relied on measures such as natural resource abundance or exports (Brunnschweiler and Bulte, 2008; van der Ploeg and Poelhekke, 2010). These measures are likely to be related to background factors, such as operational costs, that also affect the real exchange rate. To get around this endogeneity problem, we follow Arezki, Ramey and Sheng (2015) and use giant resource discoveries. The timing of individual giant discoveries is arguably exogenous. Only 2% of the total number of exploratory wells lead to a giant discoveries and the relationship between drilling activity and making a giant discovery is weak. The exact timing of such discoveries is therefore difficult to anticipate. Furthermore, the effects of a resource boom entails forward-looking adjustments in consumption and investment paths as well as investments related to the expansion of the resource sector and spending of the windfalls as the production comes online. All these effects are arguably picked up in our estimates (Arezki, Ramey and Sheng, 2015).[2] Finally, these discoveries are large, with an average constructed net present value (NPV) of 50% of pre-discovery GDP, which means that they constitute big shocks that are distinguishable from the many other shocks continuously affecting exchange rates. Together, these characteristics make giant oil discoveries ideal for the identification and quantification of the effect of an expected resource boom on the real exchange rate.

Our identification strategy is essentially a difference-in-differences approach, comparing the growth rate of the bilateral real exchange rate in years around a giant discovery with years further away, as well as with countries without resource discoveries. The growth rate of the

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[1] The real exchange rate has typically been measured with the real effective exchange rate (REER), i.e. an aggregate across different trading partners using trade weights (Cashin, Cspedes and Sahay, 2004; Chen and Rogoff, 2003). The bilateral approach allows us to appropriately study the non-traded component of the real exchange rate as a relative relative price, i.e. relative price of non-tradables to tradables in one country versus another (Engel, 1999). Increasing relative price on non-tradable goods in one country coincide with a real appreciation only to the extent the comparison country does not experience the same increase in the relative price of non-tradables.

[2] Compared to resource prices used in the previous literature (Cashin, Cspedes and Sahay, 2004; Chen and Rogoff, 2003), giant discoveries also come with the advantage of being truly country-specific and they do not have immediate mechanical effects on prices, such as through the use of energy as an input in the economy.

bilateral exchange rate in combination with country-pair fixed-effects, control for country-pair specific levels and trends in the bilateral exchange rates. Year fixed-effects control for global shocks. We allow for separate effects up to five years before and ten years after a discovery.

We find that a country getting lucky with the average discovery in our sample, 50% of a country's GDP, experiences an appreciation of the real exchange rate by about 8 percent over the first ten years following a discovery. The real appreciation in the affected country reaches 14% if the country makes a discovery which has the value of a country's GDP. By decomposing the real exchange rate into its tradable and its non-tradable component we are able to confirm that the appreciation in the real exchange rate is nearly exclusively driven by a change in the prices of non-tradable goods.

A simple small open economy model calibrated to the experience of the United States, qualitatively and quantitatively matches the above empirical findings surprisingly well. A resource discovery of a 100% of GDP in the model, results in a 17% real exchange rate appreciation after 10 years in the model and 14% in the data. Furthermore, the model predicts that this appreciation is driven by changes in non-traded goods prices. Finally, our model predicts an initial jump in the real exchange rate at the news of the discovery followed by a slow and steady appreciation - even before production starts. In the data, the evidence for the initial jump is weaker, but the model does capture the slow and steady appreciation after a resource discovery. In the model, this pattern is due to the existence of debt-elastic interest rates on international borrowing. This assumption is widely used in the literature and arguably captures interest rate behavior in the real world (Schmitt-Grohe and Uribe, 2003; van der Ploeg and Venables, 2011).

We contribute to the literature on the Dutch disease. The empirical literature on the Dutch disease has typically focused on the expected contraction of the manufacturing sector (Ismail, 2010; Allcott and Keniston, 2014) or on non-resource trade (Harding and Venables, Forthcoming), rather than prices. However, a small literature on "commodity currencies" has provided time-series evidence that appreciating resource prices led to appreciating real effective exchange rates in a set of resource exporters (Cashin, Cspedes and Sahay, 2004; Chen and Rogoff, 2003). Kuralbayeva and Stefanski (2013) also provide evidence in favour of a real appreciation due to oil exports. In this paper we improve over the previous literature by using the bilateral real exchange rate, by separating into its tradable and non-tradable components and by using data on discoveries. The latter helps with the econometric identification of the effects of a resource boom and allows for forward looking behaviour, as explained above. Our results are qualitatively in line with van der Ploeg and Venables (2013), who theoretically analyse the dynamic effects of a resource discovery and find an appreciation of the real exchange rate given the existence of absorption constraints. However, our empirical analysis suggest that the appreciation is slower than their immediate effect.

This paper is also relevant for the literature on the so-called "Penn-effect", the positive correlation between price levels and income per capita across countries. The Balassa-Samuelson hypothesis, perhaps the most prominent theory for explaining the "Penn-effect", builds on the idea that the production capacity for tradable goods grow more rapidly than for non-tradable goods. This asymmetric expansion leads in turn to relatively higher prices on non-tradable

goods and therefore an appreciation of the real exchange rate.[3] A resource boom is comparable with enhanced capacity to produce tradable goods (Neary, 1988). The current paper therefore contributes by estimating the effect on the real exchange rate of a country-specific shock hitting the tradable goods sector only. Our results support the idea that a positive shock to the capacity of producing tradable goods does lead to a real appreciation.

Finally, this paper contributes to the discussion in the "New Open Macro" literature on the importance of the prices of tradables versus non-tradables for the determination of real-exchange rates. We find that the appreciation is driven by the non-tradable components of the real exchange rate, rather than the tradable components. This is in line with the "traditional" theory of the real exchange rate, which assumes that local prices of tradable goods are anchored by international prices and adjustments in the real exchange rate come through the prices of non-tradable goods and services. In contrast, the "traditional" theory has been questioned by the previous literature using bilateral exchange rates, i.e. Engel (1999) and Betts and Kehoe (2006; 2008).[4] At least in the context of a resource discovery, the traditional theory seems to have empirical support.

The paper proceeds as follows. The next section (2) presents a theoretical framework to clarify the mechanisms underlying the appreciation of the real exchange rate. Section 3 presents the data, section 4 explains our empirical strategy, section 5 presents the empirical results and section 6 provides concluding remarks.

2 Model

In this section, we set out a simple model to illustrate the mechanism through which inflows of foreign income into a country can affect the country's real exchange rate. We then calibrate the model to test its quantitative implications on relative prices and real exchange rates in the face of a future windfall shock. Finally, we also illustrate how traditional theory could potentially break down and how we can test for this in the data. The model and the calibration are important for several reasons. First, the model pins down the mechanism that we are interested in by showing exactly how inflows of foreign income into a country translate into changes in relative prices. Second, it provides guidance with respect to the identification in the empirical part of the paper by helping us disentangle changes in relative prices driven by the Balassa-Samuelson effect from changes arising from inflows of foreign income. Finally, the careful calibration of the model provides a testable, quantitative prediction of the magnitude of the impact of expected, future windfall shocks on relative prices and the real exchange rate which can be compared to

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[3]See (Asea and Corden, 1994) and (Rogoff, 1996) for surveys on the Penn-effect and deviations from Purchasing Power Parity across countries.

[4]Hsieh and Klenow (2007) find that consumption goods are relatively cheap in developing countries in contrast to investment goods, which is similar to our finding to the extent consumption goods are less tradable than investment goods, as they argue. Engel (1999) demonstrated that almost all of the variance in the bilateral exchange rates of the US and several OECD countries is attributable to fluctuations in the real exchange rate of traded goods and that almost none of the variance is due to fluctuations in the relative prices of non-traded to traded goods.Betts and Kehoe (2006; 2008) expanded the analysis of Engel (1999) to a wider set of data. Whilst their findings were more supportive of the traditional theory, they nonetheless found that movements in the relative price of non-traded goods are much smaller than those in the real exchange rate.

our subsequent empirical results.

Model Setup   Consider a small open economy with a representative agent who solves the following utility maximization problem:

$$\max_{b_{t+1}, c_t^T, c_t^N} \sum_{t=0}^{\infty} \beta^t \left(\gamma \log c_t^T + (1-\gamma) \log c_t^N \right) \tag{1}$$

$$p_t^T c_t^T + p_t^N c_t^N \leq w_t + r_t^T + r_t^N + f_t + T_t$$

$$f_t \equiv R_t p_t^T b_t - p_t^T b_{t+1} + p_t^O e_t^O$$

$$b_{t+1} \geq -\overline{B} \text{ and } b_0, \text{given}$$

Utility takes a simple log form with a discount factor, $0 < \beta < 1$. In each period, t, the agent chooses his consumption of traded goods, c_t^T, and non-traded good, c_t^N, purchased at the (local) price of p_t^T and p_t^N respectively. He also chooses his holdings of foreign bonds, b_{t+1}.[5] Purchasing a foreign bond in period $t-1$, yields R_t units of the traded good the subsequent period. The agent is endowed with a unit of labor which he rents out for a wage rate, w_t and a unit each of two sector-specific types of capital which he rents out for rental rates r_t^T and r_t^N. He is also endowed with a windfall of (tradable) natural resources, e_t^O, which he sells for international (and exogenous) price p_t^O as well as a stock of (risk-free) international bonds, b_t, held from the previous period. Finally, notice that for expositional ease, we split the budget constraint of the household to emphasize the foreign earnings of the agent, f_t.[6] In particular this term captures the inflow of cash from abroad either from changes in the agent's current account, $R_t p_t^T b_t - p_t^T b_{t+1}$, or from (international) sales of natural resources, $p_t^O e_t^O$.

There are two representative, competitive firms producing traded (T) and non-traded (N) goods using labor and sector specific capital - rented from the household. The profit maximization problem of representative firm in sector $s = T, N$ is given by:

$$\max_{L^s, K_t^s} p_t^s Y_t^s - w_t L_t^s - r_t^s K_t^s \quad \text{s.t. } Y_t^s = A_t^s (L_t^s)^{1-\alpha} (K_t^s)^{\alpha}, \tag{2}$$

where L_t^s and K_t^s are sectoral specific employment and sectoral, firm-specific capital respectively.[7] Production technologies are given by Y_t^s and take a Cobb-Douglas form. Exogenous sector-specific productivity at time t is denoted by A_t^s. For simplicity assume that productivities grow at constant, sector-specific, exogenous rates: $g_s \equiv A_{t+1}^s / A_t^s - 1$.

The local price of the traded good, p_t^T, is pinned down by its (exogenous) international price, p_t^{T*}. In particular, we allow for a potential wedge between the local and the international

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[5]These could also potentially be negative and hence represent debt. Notice also, that bond holdings are bounded from below by a large negative number, $-B$, to rule out the possibility of Ponzi schemes.

[6]All values throughout this paper are expressed in local currency.

[7]We assume firm-specific(or fixed) capital as a reduced-form method of introducing decreasing returns to scale in production in each sector. This allows us to capture (in a reduced form way) important features of economies such as sunk capital in the form of structures (like in van der Ploeg and Venables (2013)) or sector specific abilities (like in Kuralbayeva and Stefanski (2013)).

price of the traded good, τ_t, which takes the form of a tax on traded good consumption. Thus, local consumers pay $p_t^T = (1 + \tau_t)p_t^{T*}$ for the traded good. Without loss of generality, we can normalize $p_t^{T*} = 1$. The above tax revenues are then lump-sum rebated to the consumer, and this rebate is denoted by T_t. It is furthermore assumed that the government budget balances period by period, so that $\tau_t p_t^{T*} c_t^T = T_t$. The intuition behind this wedge is that it captures all potential differences in prices of traded goods across countries that may result from any deviations from the law-of-one-price.[8]

We follow Schmitt-Grohe and Uribe (2003) as well as van der Ploeg and Venables (2011) by introducing a debt elastic interest rate. In particular we assume that there exists a potential interest rate premium for debt which rises with higher borrowing (i.e. lower b_t).[9] Thus the agent is able to borrow at the following rate:

$$R_t = R^* + \phi \left(e^{\bar{b} - \frac{b_t}{A_t^T}} - 1 \right). \tag{3}$$

In the above, R^*, is the international, exogenous risk-free rate of borrowing. As levels of debt rise (i.e. b_t falls), this expression allows for borrowing costs to also potentially increase. The extent of this increase is determined by the parameter $\phi \geq 0$. Bond holdings are normalized by trend growth of the traded goods sector, in order to capture the fact that larger economies are able to borrow more. Below, we show that this formulation also allows us to pin down the (de-trended) steady-state level of debt holdings, $\bar{b}$. Since it will be costly to hold above this steady state level of debt, countries will only use debt temporarily to smooth consumption but will not hold permanently higher levels of foreign debt. Following the literature we assume that the household do not internalize the costs of borrowing.[10]

Finally, notice that trade is not necessarily balanced, period-by-period. In particular, both foreign debt and oil exports can be used to pay for imports of traded goods, m_t, so that $p_t^T m_t = f_t$. Markets clear so that $c_t^T = Y_t^T + m_t$, $c_t^N = Y_t^N$, $L_t^T + L_t^N = 1$, $K_t^T = 1$ and $K_t^N = 1$. See Appendix A for the definition of competitive equilibrium.

Solution Given productivity growth, we define de-trended variables that are constant in the long run: $\widetilde{b}_t \equiv b_t/A_t^T$, $\widetilde{c}_t^T \equiv c_t^T/A_t^T$ and $\widetilde{c}_t^N \equiv c_t^N/A_t^N$. From the first order conditions of the household we obtain the following Euler equation that (indirectly) pins down bond holdings:

$$\frac{g_T \widetilde{c}_{t+1}^T}{\widetilde{c}_t^T} = \beta R_{t+1}. \tag{4}$$

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[8]This is a reduced form way of capturing all potential government *and* non-government differences in prices such as trade costs, market failures, imperfect competition effects and so on. In the calibration we will choose $\tau_t = 0$, but we leave the wedge in the model to show how various distortions could be incorporated into the model.

[9]This is both a realistic assumption and one made for technical convenience. It is eminently plausible that the probability of default increases with higher debt levels (especially in poorer country, where many giant resource discoveries tool place). The assumption also eliminates both the dependence of the steady state on initial conditions as well as equilibrium dynamics that potentially posses a random walk component.

[10]Although, allowing households to internalize these costs has very little quantitative and qualitative impact.

We set the subjective discount factor equal to the world interest rate adjusted by the trend growth rate of tradable goods: $\beta = g_T/R^*$. Given this and assuming that $\lim_{t \to \infty} \frac{p_t^O e_t^O}{A_t^T p_t^T} = 0$, the Euler equation implies that $\lim_{t \to \infty} \tilde{b}_t = \bar{b}$.[11] Next, we turn to employment and prices.

From the consumer's first order conditions, for $0 \leq \alpha \leq 1$, we can write:

$$
\begin{aligned}
\frac{p_t^N}{p_t^T} &= \frac{1-\gamma}{\gamma} \frac{c_t^T}{c_t^N} \\
&= \frac{1-\gamma}{\gamma} \frac{Y_t^T + \frac{f_t}{p_T}}{Y_t^N}.
\end{aligned}
\tag{5}
$$

In the above, the second equality follows from the market clearing conditions. Combining the above with the first order conditions of firms, gives us an implicit expression for traded sector employment that holds when $0 \leq \alpha < 1$:

$$
A_t^T (L_t^T)^{-\alpha}(1 - L_t^T) = \frac{1-\gamma}{\gamma}\left(A_t^T (L_t^T)^{1-\alpha} + \frac{f_t}{p_T}\right).
\tag{6}
$$

It is then easy to show (see Appendix A) that the aggregate price index of the economy, p_t, which measures the cost of purchasing a constant quantity of utility is given by:

$$
\begin{aligned}
p_t &= (p_t^T)^\gamma (p_t^N)^{1-\gamma} \\
&= p_t^T (p_t^N/p_t^T)^{1-\gamma}.
\end{aligned}
\tag{7}
$$

We are interested in examining how changes in an agent's foreign earnings, f_t, influence p_t. Changes in f_t can occur for one of two reasons. First, in a given period there could be an unexpected change in the size of the windfall, $p_t^O e_t^O$. This would then directly influence the size of current period f_t and change future values of f_t through changes in savings decisions.[12] Second, the agent could learn of a natural resource discovery whose production would come online in some defined future period. Anticipating this future income, the agent would then adjust his bond holdings to smooth this future income shock over time. Notice, that no matter which type of shock hits the economy, it simply results in a changed f_t. Thus, in what follows, we are interested in seeing how this foreign income shock affects a resource rich economy.

Notice, from the second part of equation (7), if τ_t is exogenous (so that the local traded goods price, p_t^T, is also exogenous) then the overall price level p_t, only adjusts in response to changes in the relative price of non-traded goods. To examine how important changes in f_t are as drivers of relative prices (and hence overall price levels) we consider three cases that depend on the capital intensity of sectors, α.

First, when $\alpha = 1$, sectoral output only depends on the fixed factor and not on employment,

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[11]To see this, notice from equation (3) and equation (4) that in the limit $g_T = \beta(R^* + \phi\left(e^{\bar{b} - \tilde{b}_t} - 1\right))$. The fact that $R^* = g_T/\beta$ then implies that $\tilde{b}_t = \bar{b}$ in the limit.

[12]These types of changes can for example be driven by changes in the price of natural resources. Due to the nature of oil and gas fields - this type of shock is unlikely to take place through the quantity of natural resources discovered. In particularly, as argued by Arezki, Ramey and Sheng (2015) it can take - on average - 5 to 6 years for a discovery to translate into actual production.

and hence $Y_t^s = A_t^s$. As such the model effectively collapses to an endowment economy. By equation (5), relative prices of non-traded goods will then increase with higher foreign windfalls. Since, in this case, employment is not used as an input (and hence equation (6) does not apply), all the adjustment in response to a resource shock takes place through prices.

Second, when $\alpha = 0$, output only depends on employment and is given by $Y_t^s = A_t^s L_t^s$. We can then solve equation (6) to show that:

$$L_t^T = \gamma - (1 - \gamma)\frac{f_t}{p_t^T A_t^T}. \tag{8}$$

Substituting this into equation (5), we can show that non-traded good prices are given by:

$$\frac{p_t^N}{p_t^T} = \frac{A_t^T}{A_t^N}. \tag{9}$$

Thus, in this case, employment in the traded sector decreases in response to higher windfalls, but relative prices of non-traded goods remain unchanged. Thus all the adjustment in response to a resource shock takes place through changes in sectoral employment.

Finally, suppose that $0 < \alpha < 1$. Applying the implicit function theorem to equations (5) and (6) respectively, we can show that $\frac{d(p_t^N/p_t^T)}{dL_t^T} < 0$ and $\frac{dL_t^T}{df_t} < 0$. Putting these two inequalities together implies that $\frac{d(p_t^N/p_t^T)}{df_t} > 0$. Thus, in this case, the economy responds to a resource shock through adjustments in both sectoral employment and relative prices.

Calibration Next, we calibrate the above model and examine the predicted, quantitative impact of anticipated resource shocks. Our approach is to match the features of traded and non-traded sectors of the United States over the 1970-2010 period. We then examine how a resource discovery that starts production five years in the future, lasts 25 years and has a net present value of 100% of GDP, translates into changes in aggregate price levels through its impact on a household's stream of foreign earnings. Throughout the calibration we assume that the US is on a balanced growth path over the entire period - i.e. it has constant interest rates over the period and the growth rate of sectoral output, consumption and bond holdings will be constant (although potentially different across sectors). Since the calibration is relatively standard, we relegate all the details to Appendix B.

Results The results for the above calibration are shown in Figures 1 and 2.[13] We will consider two countries: country P which has no natural resources and country R which has a natural resource discovery in period zero that starts production five years later, lasts 25 years and has a net present value of 100% of GDP.[14] Considering two countries allows us to isolate the impact of a natural resource discovery on prices and to construct real exchange rates, bringing our theoretical model closer to our empirical work. Throughout this section we will assume

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[13]Additional results are shown in Appendix B.

[14]This is roughly chosen to match production profile in Arezki, Ramey and Sheng (2015). In particular, in the data, the average lag between discovery and production is five years. The exact production profile is given in equation (28), in the Appendix.
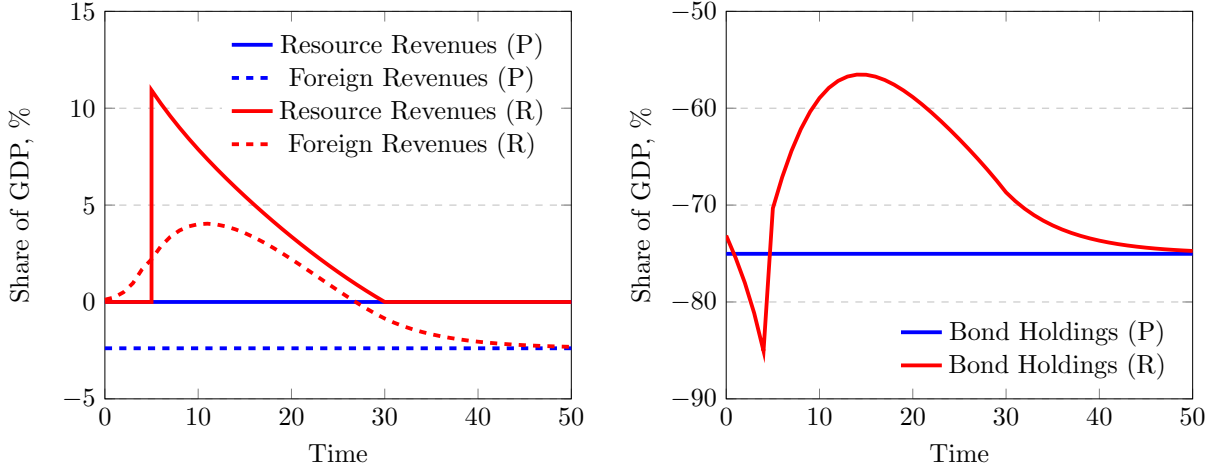
(a) Resource export Revenues, % GDP (solid line);
All foreign revenues, % GDP (dashed line).

(b) Value of bond holdings, % GDP.

Figure 1: Simulation Results showing changes in resource production, foreign inflow of cash and changes in bond holdings. In the above P= Non-Resource Economy; R= Resource Economy.

that the tax-wedges on traded goods in both countries are zero and do not respond to resource discoveries.

The solid lines in Figure 1a show revenues from resource exports relative to GDP in both countries. Country P has zero revenues from resource exports. In country R, revenues jump in period 5 (when production starts) to roughly 11% of GDP and then slowly declines to 0% of GDP 25 years later. Consumers in country R are forward looking and smooth their resource windfalls over time by using foreign bonds. The net bond holdings of each country (relative to GDP) are shown in Figure 1b. Before production begins, the household in country R borrows more from abroad, to smooth consumption. During the discovery, the household borrows less than it would otherwise borrow, spreading out the benefits of the discovery over time. As we get further away from the discovery, net bond holdings in country R approach the steady-state bond holdings in country P. It will be this smoothed foreign revenue along with resource export revenues that will drive price changes in country R. The net foreign revenues (i.e. f_t) of both countries (relative to GDP) are depicted by the dotted lines in Figure 1a. Country P consumers are paying roughly 2.5% of GDP in interest for their steady-state debt holdings. In country R however, as soon as the discovery is made, consumers borrow from abroad to smooth out their export revenues stream.

Figure 2a shows the relative prices of non-traded to traded goods in both economies, whilst Figure 2b shows the resulting ratio of these relative prices. First, observe that in country P relative prices grow at a constant rate of approximately 2.1% per year. This increase is due to the classic Balassa-Samuelson effect driven by faster productivity growth in the traded sector. In the US data, the corresponding growth rate is approximately 1.8% per year. Thus, the model does relatively well in matching the evolution of relative prices over time stemming from the Balassa-Samuelson effect. In country R, prices additionally respond to the inflow of foreign revenues as discussed in the theory section above. When consumers learn of the discovery,
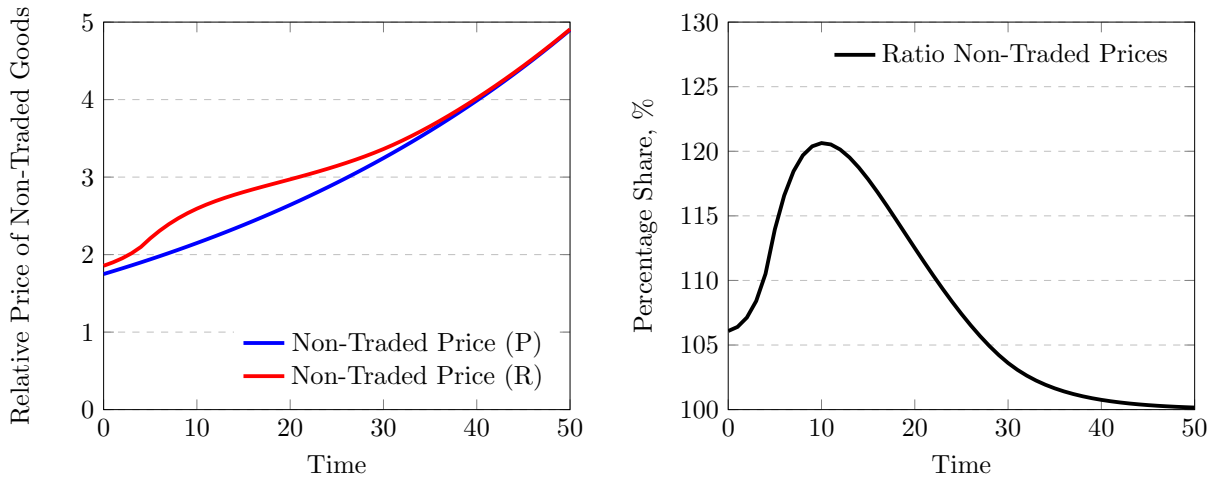
(a) Relative price of traded to non-traded goods.

(b) Ratio of relative non-traded goods price in country R to P.

Figure 2: Simulation Results showing changes in relative prices of non-traded goods. In the above P= Non-Resource Economy; R= Resource Economy.

relative prices immediately jump by 6% in response to the news. This is because, consumers are cutting back on their foreign savings (i.e. borrowing more) in order to smooth consumption, resulting in a larger inflow of foreign goods. As foreign, traded goods become more abundant, the price of non-traded goods must rise. After ten years, the price of non-traded goods is approximately 20% higher than if no oil had been discovered. As the foreign windfalls dwindle, relative prices return to normal in country R.

The above section shows and quantifies what a typical model of Dutch disease with forward looking agents would predict with respect to non-traded good prices in response to a large resource discovery. In the above we have intentionally abstracted from factors that could influence prices but would work through implicit changes of the traded good price wedge, τ_t. In the next section, we show how the results of the model can be brought to the data and how we can test whether whether changes in traded good prices are also potentially playing an important role not captured by the standard model.

Real Exchange Rates To measure the response of price levels to natural resource discoveries in the data, we will use the concept of the bilateral real exchange rate (RER). This is simply the ratio of aggregate price levels of two countries, expressed in the same currency. Following Engel (1999) as well as Betts and Kehoe (2006; 2008) we will decompose the RER for countries i and j according to the following expression:[15]

$$\underbrace{\frac{p_i}{p_j}}_{RER} \equiv \underbrace{\left(\frac{p_i^T}{p_j^T}\right)}_{RERT} \times \underbrace{\left(\frac{p_i/p_i^T}{p_j/p_j^T}\right)}_{RERN} \tag{10}$$

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[15]Throughout this subsection, time subscripts will dropped for clarity and without loss of generality.

The term labeled RERT, captures the ratio of traded goods prices in countries i and j. We think of this term as the traded goods real exchange rate between country i and country j. The term labeled RERN, is the ratio of aggregate to traded-goods prices in each country. Since the aggregate price is a function of both traded and non-traded goods prices, this second term captures the ratio of internal relative non-traded goods prices in a country and as such can be thought of as the real exchange rate of non-traded goods.

To be able to directly compare the results of the model with the data, we perform the above decomposition for our model. We assume the model holds independently for each country i and j. Using equation (7) as well as the relationship between local and international traded goods prices, $p^T = (1 + \tau)p^{T*}$, we get:

$$ RER = \frac{(1 + \tau^i)}{(1 + \tau^j)} \left(\frac{p_i^N / p_i^T}{p_j^N / p_j^T} \right)^{1-\gamma}, \tag{11} $$

$$ RERT = \frac{p_T^i}{p_{T,t}^j} = \frac{(1 + \tau^i)}{(1 + \tau^j)} \quad \text{and} \quad RERN = \frac{p^i / p_T^i}{p^j / p_T^j} = \left(\frac{p_N^i / p_T^i}{p_N^j / p_T^j} \right)^{1-\gamma}. \tag{12} $$

The real exchange rate (RER) depends on the wedges in each country and the internal relative prices of non-traded goods, the traded real exchange rate (RERT) depends on the ratio of wedges in the two countries, whilst the non-traded real exchange rate (RERN) depends on the ratio of internal prices in the two countries. Figure 3 plots the above decomposition for our resource rich and resource poor countries (so that $i = R$ and $j = P$). Since traded-goods price wedges τ_R and τ_N are independent of natural resource endowments and equal to zero, local prices of traded goods are pinned down by international prices and are the same in both countries. A resource discovery in country R will thus not effect the local price of traded goods in either country and RERT will remain constant. This is shown in Figure 3b. Changes in RER (shown in Figure 3a) will instead stem entirely from changes in internal relative prices as captured by RERN and depicted in Figure 3c.[16] The model predicts an initial jump in RER of 5% in period zero followed by a slow appreciation of approximately 17.4% after 10 periods.

Our model thus lines up with so-called traditional theories of real exchange rates going back to Cassel (1918) and Pigou (1923). These theories postulate that the 'law-of-one-price' holds for traded goods, so that variation in the real exchange rate takes place entirely through changes in RERN. There is however a competing New Open Economics Macro (NOEM) literature inspired by the work of Engel (1999), that argues that changes in RER are also at least partially driven by fluctuations in prices of traded goods.[17] In our model this would occur if wedges (for whatever reason) were - for example - correlated with resource discoveries.

Examining the price data through the lens of the decomposition in equation (10) will allows us to narrow down the channels through which natural resources influence the overall price

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[16] As such, in our model, since $RERT = 1$ it is true that $RER = RERN$.

[17] In this literature deviations in the law of one price can occur through - for example - pricing-to-market (Betts and Devereux, 2000) or market segmentation (Dotsey and Duarte, 2008) and such deviations can be sustained through nominal rigidities.
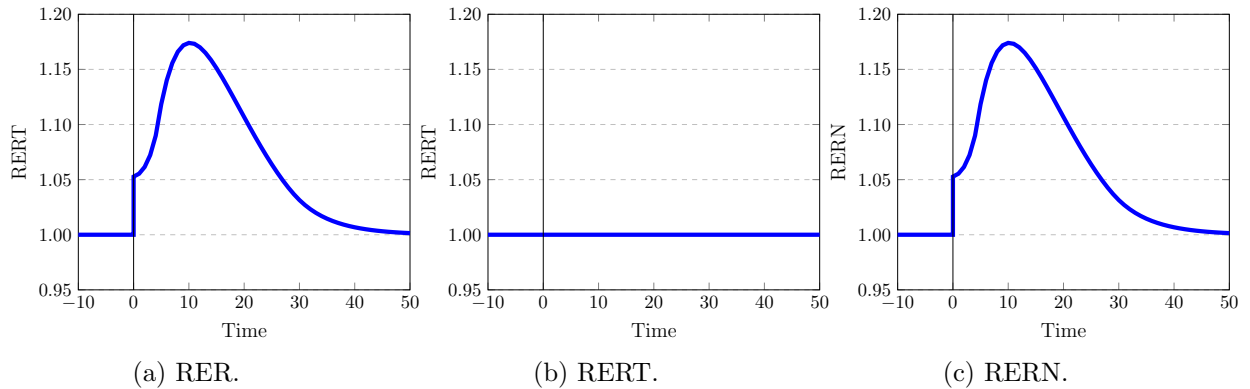
| (a) RER. | (b) RERT. | (c) RERN. |

Figure 3: Decomposition of simulated Real Exchange Rates (RER) into traded Real Exchange Rates (RERT) and non-traded Real Exchange rates (RERN) according to equation (10). The resource discovery in the model takes place in period 0 and production starts in period 5.

level. In particular not only will we be able to determine whether and to what extent shocks to natural resource endowments influence the real exchange rate (RER), we will also be ble to determine whether this takes place predominantly through changes in the 'traditional' non-traded components of the real exchange rates (RERN) or whether the impact occurs more through changes in the traded components of the real exchange rate (RERT) as the NOEM literature would suggest. The contribution of the paper is thus both to quantify the role that shocks to tradable income play in driving real exchange rates but also to test whether this takes place through the traditional mechanism of non-traded goods price adjustments or whether more sophisticated models of traded good prices may be more appropriate.

3 Data

Before proceeding to the empirical results in the next section we provide information on data sources, outline the construction of our variables and present some basic descriptive statistics.

Structure: Consider an economy which consists of mining and utilities, manufacturing as well as non-resource non-manufacturing sectors:[18]

$$Y = \overbrace{\underbrace{A + C + S}_{\text{Non Res. Non-Mfg.}} + \underbrace{M}_{\text{Mfg.}}}^{\text{Non-Resource Economy}} + \underbrace{MU}_{\text{Mining and Utilities}} . \tag{13}$$

Throughout this paper we focus on the non-resource economy only. In particular, we treat the manufacturing sector as the traded-goods sector (T) and the non-resource non-manufacturing sector as the non-traded good sector (NT).[19]

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[18]The lowest level of aggregation is the one sector ISIC classification. Non-manufacturing is defined as the sum of agriculture (A), construction (C) and services (S). Services are defined as the sum of transportation, storage, communication, wholesale, retail, restaurants, hotels and other services.

[19]Altering sectoral specification - by adding agriculture to the traded sector or considering only manufacturing and services as traded and non-traded sectors respectively - does not significantly affect our results.

Real Exchange Rates: Based on the structure outlined above we construct sectoral price indices using current and constant price value added. To do this we use publicly available data from the UN (2014) on one digit ISIC v.3 sectoral value-added in national currency units. Denote by $\overline{VA}_{i,t}^{s}$ the constant (2005) price value added in country i, sector s, at time t and by $VA_{i,t}^{s}$ the corresponding value added in current period prices. We then calculate a sector specific price index in national currency units, $\widetilde{p}_{i,t}^{s} = VA_{i,t}^{s}/\overline{VA}_{i,t}^{s}$, for $s = T, NT$. To convert this price index to a common currency, we use the International Monetary Fund's national currency-United States exchange rates also available from the UN (2014).[20] This nominal exchange rate (national currency units per US dollar), $ner_{i,t}$, is used to transform the price indices in national currency, $\widetilde{p}_{i,t}^{s}$, into comparable price indices expressed in US dollars, $p_{i,t}^{s} = \widetilde{p}_{i,t}^{s}/ner_{i,t}$. We use price indices covering 172 countries over the period 1970-2013 to construct a global data set on bilateral real exchange rates according to the decomposition presented in equation (10)[21]:

$$\underbrace{\frac{p_{i,t}}{p_{j,t}}}_{\equiv RER_t^{ij}} = \underbrace{\left(\frac{p_{i,t}^{T}}{p_{j,t}^{T}}\right)}_{\equiv RERT_t^{ij}} \times \underbrace{\left(\frac{p_{i,t}/p_{i,t}^{T}}{p_{j,t}/p_{j,t}^{T}}\right)}_{\equiv RERN_t^{ij}} \qquad (14)$$

For every year in the sample and for every (unique) pair of countries i and j, we construct three measures of the overall (RER_t^{ij}), traded ($RERT_t^{ij}$) and non-traded ($RERN_t^{ij}$) real-exchange rates defined above. Since we do not want to double-count country pairs the number of observations per year with N countries is $\frac{N^2-N}{2}$. Unfortunately, information on the exchange rate was not available for some country pairs and, thus, our sample contains 12536 unique pairs rather than 14706 as theoretically expected. Moreover, some years were missing for some country pairs such that the total number of observations in our sample is 383934.

Growth Rates vs Levels: As our dependent variable we choose the growth in the bilateral real exchange rate between country i and j which is expressed as the first difference of the natural log. Our choice is motivated by our identifications strategy. It relies on the comparison of **changes** in the real exchange rates around giant discoveries with changes in the real exchange rate further away. In particular, we compare changes in the real exchange rate immediately before and after a discovery with changes in the real exchange rate 5 years before and 10 years after a giant discovery. By additionally controlling for pair specific fixed effects in a specification focusing on growth rate we aim to account for the Balassa-Samuelson effect (see Figure 2a for an illustration). Different growth rates in productivity across countries will theoretically result in a country pair specific appreciation or depreciation in the real exchange rate. Country pair specific fixed effects allow for such a linear trend in the real exchange rate. In Table 1 changes in the natural log of the real exchange rate, $grer_t^{ij} = ln(RER_t^{ij}) - ln(RER_{t-1}^{ij})$, and their tradable

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[20]Notice that the choice of the US as a baseline is irrelevant. Choosing any other country will give the same bilateral real exchange rates.

[21]Note that in the decomposition of the bilateral real exchange rate in equation we exclude a small part of the overall price level in the economy and focus on the non-resource economy as opposed to the decomposition in equation (10).

variable	mean	p50	sd	max	min
grer	0.00	-0.00	0.23	6.48	-6.23
grert	-0.00	0.00	0.27	6.58	-6.38
grern	0.00	0.00	0.16	2.43	-2.44

Source: Own Calculations

Table 1: Descriptive Statistics.

and non-tradable components are presented. There are three things to note. First, the mean and the median are very close to zero suggesting a small year to year variation in the real exchange rates and their components. Second, the tradable component is nearly twice as volatile as the non-tradable component. Third, maximum and minimum values indicate that appreciation and depreciation of the real exchange rate reached 500%. Thus, in the robustness section we will replicate our main results by excluding the top and the bottom 1% in the distribution of changes in the real exchange rate.

Giant Oil and Gas Discoveries   Information on the net present values of giant oil and gas discoveries has been provided to us by Rabah Arezki. Arezki, Ramey and Sheng (2015) used publicly available data to construct net present values of giant oil and gas discoveries. The raw data on discoveries contains information on the timing, the location and the estimated total ultimately recoverable amount of oil and gas (in oil equivalent) of these discoveries (Horn, 2011). Their constructed measure, d_t^i, captures the net present value of a giant discovery at time t in country i as a percent of GDP and is formally defined as:

$$d_t^i = \left(\sum_{j=5}^{J} \frac{p_t^o \times q_{t+j}^i}{(1+r^i)^j} \right) / GDP_t^i. \tag{15}$$

At the core d_t^i consists of a discounted sum of gross revenues derived from an approximated oil production profile, q_{t+j}^i, from the fifth year following the discovery to the exhaustion year, J, valued at the oil price prevailing at the time of the discovery, p_t^o. The approximated production profile follows a piece-wise process in the form of reserve specific plateau production followed by an exponential decline. The value of this production profile is discounted by country-specific risk-adjusted discount rates, r^i. The resulting measure is divided by country-specific GDP.[22] In Figure 4a and 4b the real price of oil with the the total number of discoveries and the net present values of these discoveries relative to nominal GDP are presented respectively. Note how the average size and the total number of discoveries varies with the oil price. This might raise concerns that our results suffer from omitted variable bias as the oil price is very likely to affect the real exchange rate not only via giant oil and gas discoveries. However, all our results are estimated conditional on time fixed effects which are designed to capture global shocks such as the variation in the price of oil.

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[22]See Arezki, Ramey and Sheng (2015) for more information on how the production profile and the risk adjusted discount rates are constructed.
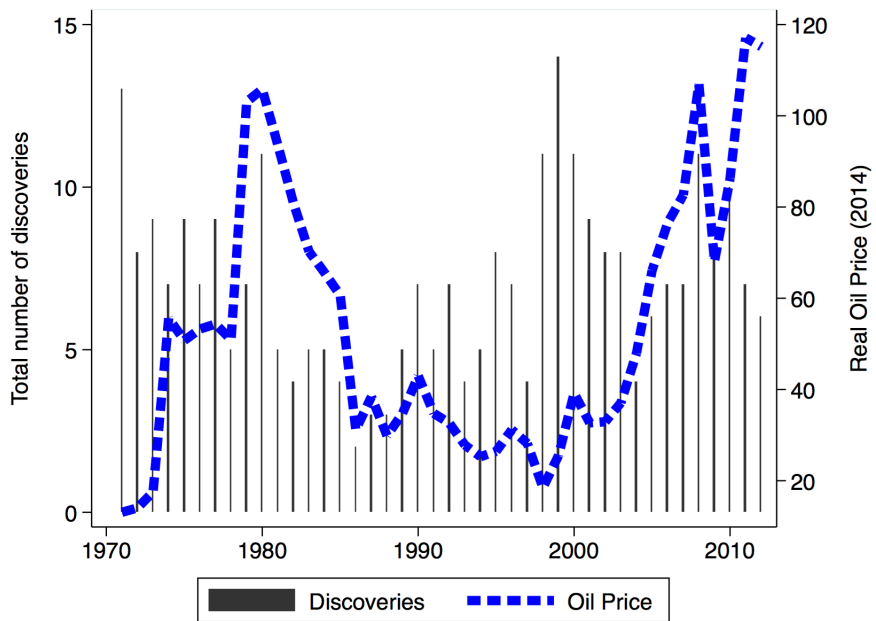
(a) Oil price and number of giant oil and gas discoveries
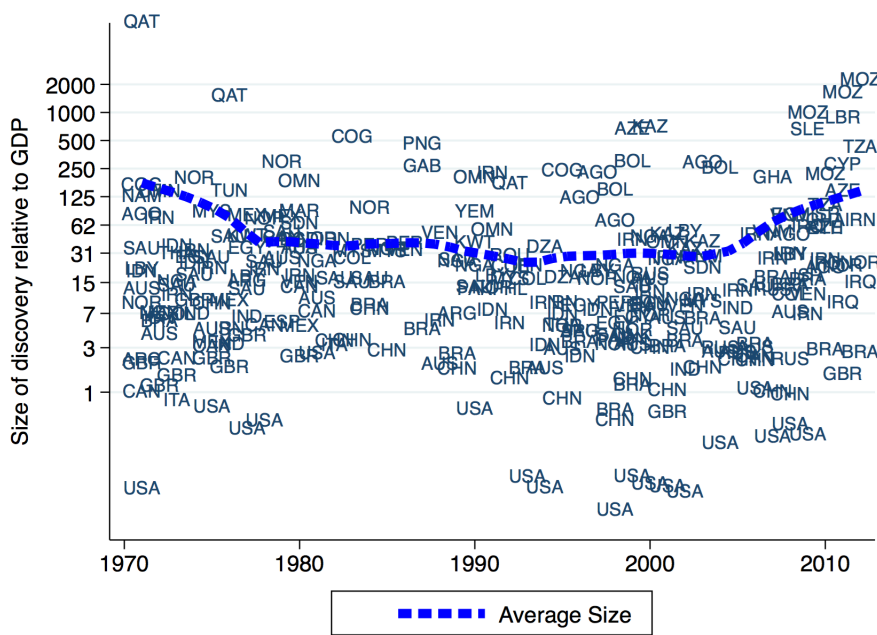
(b) Size of giant oil and gas discoveries

Figure 4: Giant oil and gas discoveries

Bilateral Measure of Discoveries   Working with unique bilateral pairs of countries requires us to adjust the above measure of discoveries as follows:

$$\delta_t^i = \frac{GDP_t^i + \sum\limits_{i=5}^{J} \frac{p_t^o \times q_{t+j}^i}{(1+r^i)^j}}{GDP_t^i} = 1 + d_t^i. \tag{16}$$

The last equality emphasises that it is a simple monotonic transformation of the country-specific measure used in Arezki, Ramey and Sheng (2015). The main reason for this transformation is that it allows us construct our *bilateral* measure of resource-wealth by avoiding zeros in the denominator. In particular, it allows us to capture the role of discoveries in each pair of countries - irrespective in which of the two countries in the pair the discovery was made. Thus we define the bilateral measure of discoveries as:

$$D_t^{ij} \equiv \log\left(\frac{\delta_t^i}{\delta_t^j}\right). \tag{17}$$

Notice, that the above measure has at least two benefits. First, it is symmetric. A resource discovery in country i and country j have the same quantitative impact - but different signs - in the bilateral measure of resource wealth, D_t^{ij}. Second a percentage increase (decrease) in resources in country i (j) is associated with a percentage increase (decrease) in our bilateral measure of resource discoveries, D_t^{ij}. In particular, $\frac{\partial D_t^{ij}}{\partial \log(\delta_t^i)} = -\frac{\partial D_t^{ij}}{\partial \log(\delta_t^j)} = 1$.

4   Identification and Estimation

An ideal identification strategy would allow us to treat countries randomly with oil discoveries and then compare the average change in the real exchange rate of the treated countries to the countries which have not been treated. Such an experiment would allow us to identify the effect of an oil discovery on the real exchange rate. Of course, this is not a feasible option. But equipped with the new data set on giant oil and gas discoveries we will mimic such an experiment by exploiting the timing of a giant discovery.

Identification Strategy   Essentially we adopt a difference-in-differences approach by comparing changes in the bilateral real exchange rate in the years immediately before and after a giant discovery with changes further away in the time dimension, as well as with changes in countries without giant oil discoveries. To identify the effect we use the residual variation after controlling for country-pair fixed effects and time fixed effects. Country-pair fixed effects in this framework allow the trajectory of a bilateral real exchange rate to exhibit not only an independent intercept but also an independent slope. In other words, we allow for country pair specific appreciations or depreciations due to different productivity growth rates across countries. We also account for year specific common shocks such as variations in the price of oil with year fixed effects. Conditional on year and country pair fixed effects we compare changes in the real

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exchange rate for a period of up to 5 years before and 10 years after the discovery to itself.[23] Thus, the timing of a discovery is at the core of our identification strategy and requires a more detailed discussion.

We argue that the *timing* of individual discoveries is plausibly exogenous due to the uncertainty surrounding explorations and the limited ability countries and companies have in triggering giant discoveries. Since 1965, only 2% of all wells drilled resulted in giant oil or gas discoveries (Toews and Vezina, 2016). Thus, countries are very unlikely to get lucky in the first place. On top of that, the relationship between the activity in exploration drilling and the occurrence of giant discoveries appears to be rather weak. Increasing the probability of a giant discovery by only 1pp requires the average country to increase drilling activity by over 50% (Toews and Vezina, 2016). Thus, we argue that the exact timing of a giant oil discovery is very difficult to predict even for operating companies. As a matter of fact, anecdotal evidence suggests that large discoveries are made **within three metres** of where other companies where searching years ago (Kavanagh, 2013). However, we might be still worried that previous discoveries will attract more companies and, thus, trigger an increase in drilling activity which in turn would increase the probability of a giant oil and gas discovery. Intuitively, failing to control for previous discoveries might bias the estimates of our coefficients upwards. To control for that we construct a variable capturing previous discoveries and replicate our main results using this variable as a control.

Following our identification strategy we estimate some variations of the following specification:

$$y_t^{ij} = \sum_{k=-5}^{10} \beta_k D_{t-k}^{ij} + \eta^{ij} + \rho_t + \varepsilon_t^{ij} \tag{18}$$

Our LHS variable y_t^{ij} is a placeholder for $grer_t^{ij}$, $grert_t^{ij}$ and $grern_t^{ij}$ which represent the change in the logged real exchange rate between country i and j in period t, the change in the tradable and the change in the non-tradable component of the logged real exchange rate respectively.[24] Country-pair and time fixed effects are represented by η^{ij} and ρ_t respectively. The country-pair-specific error, ε_t^{ij}, is allowed to arbitrarily correlate with errors of other bilateral pairs containing either country i or country j (two-way clustering). Our main variable of interest is D_{t-k}^{ij} which captures the increase in output due to a giant discovery in period t and consequently β_k terms represent the semi-elasticities of discoveries k periods after the discovery:

$$\frac{\partial grer_t^{ij}}{\partial \log(\delta_{t-k}^i)} = \beta_k \text{ and } \frac{\partial grer_t^{ij}}{\partial \log(\delta_{t-k}^j)} = -\beta_k.$$

Thus, β_k gives us the effect on the growth rate of the real exchange rate relative to the omitted categories k periods after/before a large discovery. Finally, we are interested in the cumulative

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[23] As we show in the robustness section further below the choice of lags does not significantly affects our results.

[24] More formally, recall from equation (21), that $RER_t^{ij} = RERT_t^{ij} \times RERN_t^{ij}$. Taking the logarithms on both sides of this equation and denoting the resulting terms in lower case, we obtain: $rer_t^{ij} = rert_t^{ij} + rern_t^{ij}$. In this equation, for example, $rer_t^{ij} \equiv \log(p_t^i/p_t^j)$ and so on. Taking the first difference of each of these logged exchange rates, we obtain the (approximate) growth rates: $grer_t^{ij} = grert_t^{ij} + grern_t^{ij}$. Thus, for example, in the above $grer_t^{ij} = \log(p_t^i/p_t^j) - \log(p_{t-1}^i/p_{t-1}^j)$ and so on.

effect of a discovery on the real exchange rate k periods after a discovery in period t. This is the sum of year-to-year growth effects for the years t to $t+k$. Thus, we estimate the cumulative effect of an oil discovery on the real exchange rate via summation, $\Omega_k = \sum_{j=0}^{k} \beta_j$, and use these to construct 90%-confidence bounds.
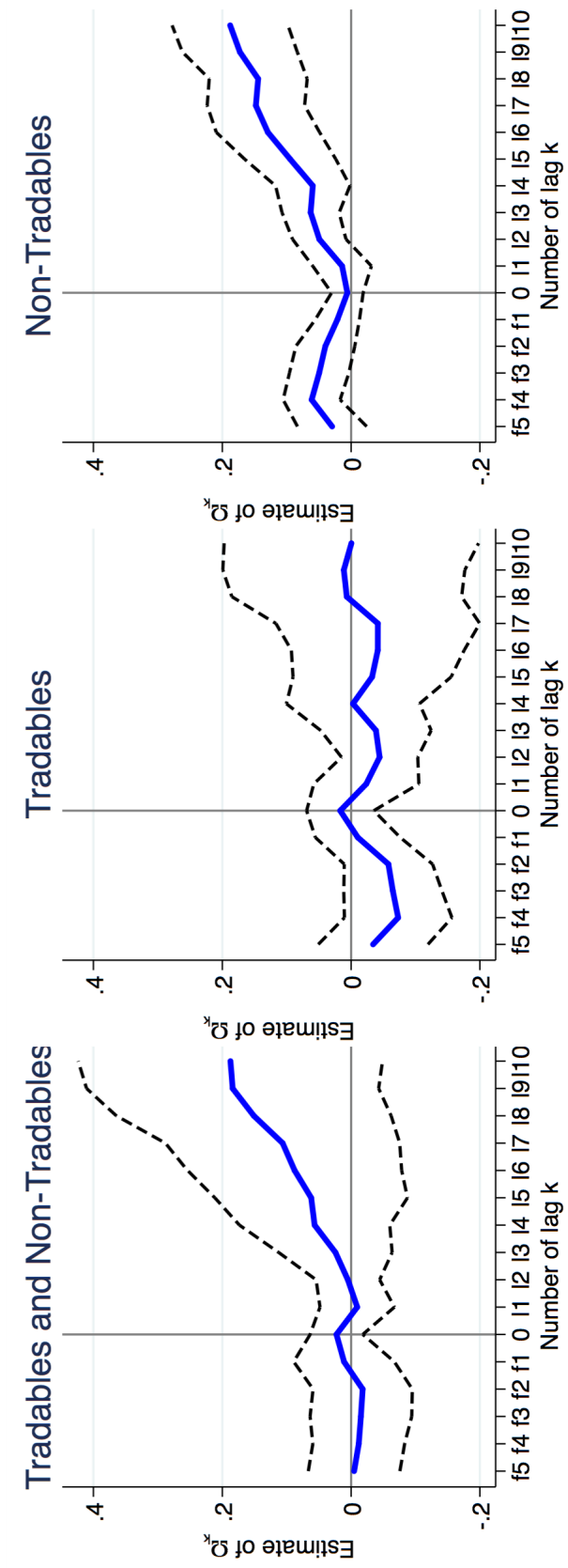
5   Results

5.1   Real Exchange Rate

Main Result   For brevity and clarity, we only present the long-run effects $\Omega_k = \sum_{j=0}^{k} \beta_j$ and omit the presentation of β_k's estimated in equation 18.[25] Our main result is graphically displayed in the three charts of Figure 5. All three charts depict the cumulative impulse response $\Omega_{t \in [-5,10]}$ to a giant discovery. In the first chart the cumulative response of the real exchange rate to a giant discovery is presented. In the second and the third chart the effect on the real exchange rate is decomposed into the effect on the tradable and the non-tradable component respectively. In chart 2 we observe that giant discoveries do not seem to affect the tradable goods component of the real exchange rate. The cumulative response fluctuates around zero and remains insignificant. In chart 3 we see that giant discoveries positively effect the non-tradable goods component of the real exchange rate. Comparing chart 1 and chart 3 suggests that the appreciation of the real exchange rate following a giant discovery is mainly driven by the non-tradable goods component of the real exchange rate. However, the cumulative effect on the real exchange rate is measured imprecisely and remains insignificant on the 10% level. The magnitude of the effect is large. The size of the average discovery since 1970 is around 50% of a country's GDP. A country getting lucky with such a discovery will experience an appreciation of the real exchange rate by $0.2 \times \log(\frac{1+0.5}{1}) = 0.08$ percentage points. A country getting particularly lucky with a discovery which has the size of a country's GDP (90th percentile of discoveries) experiences an appreciation of the real exchange rate by $0.2 \times \log(\frac{1+1}{1}) = 0.14$ percentage points. Comparing our empirical results in Figure 5 to the results of our calibration in Figure 3a-3c three points are noteworthy. First, consistent with the theoretical prediction our empirical results suggest that the appreciation in the real exchange rate is exclusively driven by an increase in the non-tradable goods component of the real exchange rate. Second, we do not find the theoretically predicted initial jump in the year of the discovery but we do capture the slow and steady appreciation of the real exchange rate before production starts. Third, our model predicts that the real exchange rate appreciates by 17% within 10 years following a discovery with a net present value of a country's GDP. Our point estimate of the cumulative effect after 10 years suggest an appreciation of 14% and is not significantly different from the theoretical prediction.

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[25]The estimates of the individual β's are presented in Figure 15 in the Appendix

Figure 5: Cumulative effect of large oil and gas discoveries on the real exchange rate and its tradable and non-tradable components.

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.

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5.2 Robustness

We conduct several robustness tests. We use alternative specifications when estimating equation 18 by applying a different lag structure and by controlling for past discoveries. We adjust the sample by accounting for outliers and by changing our counterfactual. We use alternative definitions of tradable and non-tradable goods. We use a different data set when decomposing the real exchange rate into its tradable and non-tradable component. Finally, we conduct a randomisation test. Our results a very robust.

Alternative specifications We re-estimate our baseline specification with different lag structures. The results are presented in Figure 7 where the adjustment in the lag structure is self explanatory. We also re-estimate our main specification by accounting for past cumulative discoveries within a country-pair. To do that we sum past discoveries up to period $t-1$, $\hat{D}^{ij}_{t-1} = \sum_{k=0}^{t-1} D^{ij}_k$, and add it as a control to equation 18. Figure 8 shows the results.

Alternative samples We re-estimate our main specification by accounting for outliers. We do that by dropping the top and the bottom 1% of the observations in the distribution of changes in the real exchange rate. The results are presented in Figure 9. We re-estimate our main specifications by excluding all the countries which have not had any giant discovery in the last 50 years. Note that by doing that our identification strategy essentially relies on comparing each country's growth rate in the price of non-tradable goods to itself up to 5 years before and 10 years after exposure. The results are presented in Figure 10.

Alternative economic structure In our baseline specification the non tradable goods sector is defined as the non-mining and utilities and non-manufacturing part of the economy. The tradable goods sector is defined as the manufacturing sector. In Figure 11 we present the results from estimating our baseline specification where we exclude the agricultural and the construction sector. Alternatively, we treat the agricultural sector as tradable and the results from estimating our baseline specification are presented in Figure 12.

Alternative data We have chosen the UNCTAD data for our baseline specification because it has the largest coverage in the time and the cross section dimension. However, Betts and Kehoe (2008) suggest that the producer price index might be a superior measure for the prices of traded goods. Thus, we replicate our results by employing information on producer prices when decomposing changes in the real exchange rate into its tradable and its non-tradable component. Using their data reduces the number of countries and years in our sample to 50 and 26 respectively. With 26 times periods we cannot employ as many leads and lags as in our baseline specification. Thus, we reduce the number of leads to 2 and the number of lags to 6. The results are displayed in Figure 13.

Randomisation Inspired by Hsiang and Jina (2014) we conduct a randomisation test to check whether our model is misspecified and, thus, is generating spurious results. To do that we

proceed as follows. First, we randomise the observations of giant discoveries 100 times without replacement. By doing that we simply randomly reassign the value of the treatment variable across the whole sample. Second, we repeatedly re-estimate equation 18 to evaluate the effect of the constructed placebos on changes in the price of non-tradable goods. Third, for each of the 100 samples we construct an estimate of the cumulative effect, $\Omega_{t=10}$, of giant discoveries on the price of non-tradables by adding up the estimated β_k's. Figure 14 display the distribution of the generated point estimates of the cumulative effect after 10 years. Note that the distribution is centred around zero, as expected. The vertical line indicates the point estimate that we get if we use the real data. Using the outcomes of the randomisation the probability of a type 1 error is below 0.001.

6   Concluding remarks

The theoretical literature on the Dutch disease predicts that countries making a resource discovery will experience an appreciation of their real exchange rate through higher prices of nontraded goods. In our sample, covering 172 countries over more than 40 years, we find that giant oil discoveries lead to appreciation of the real exchange rate. A discovery with a net present value of 100% of GDP is estimated to lead to a real appreciation of 14% over the ten years following the discovery. The appreciation is driven by higher prices of nontradables, whilst prices of tradables are unaffected.

The empirical results match well with the effects of a resource discovery in a calibrated, small open economy model with forward looking behaviour, sector-specific fixed-factors of production and standard debt-elastic interest rates.

These findings lend support to the standard theory of the Dutch disease. They are also consistent with the Balassa-Samuelson hypothesis, to the extent that a resource discovery is similar to a productivity shock in the tradeable sector, as suggested by Neary (1988). As discussed by van der Ploeg and Venables (2013), the extent to which the adjustment to a resource discovery happens through prices or quantities, will depend on the presence of absorption constraints in the economy. We leave the analysis of the quantity effects for future research.

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A   Theory Appendix

A.1   Competitive Equilibrium

For any R^* and $\{\tau_t, p_t^{T*}\}_{t=0}^\infty$, a competitive equilibrium of the model is defined as a set of prices $\{p_t^T, p_t^N, w_t, r_t^T, r_t^N, R_t\}_{t=0}^\infty$ and allocations $\{c_t^T, c_t^N, b_t, L_t^T, L_t^N, m_t, K_t^T, K_t^N\}_{t=0}^\infty$ that solve the household and firm problems, government budget balances, the interest rate and trade conditions are satisfied and markets clear.

A.2   Aggregate Prices

Denote the Lagrange multiplier on the households's budget constraint by λ_t. The two first-order conditions for consumption that emerge from the household problem are:

$$\frac{\gamma}{c_t^T} = \lambda_t p_t^T \text{ and } \frac{1-\gamma}{c_t^N} = \lambda_t p_t^N. \tag{19}$$

Combining these we obtain an expression for the ratio of prices:

$$\frac{p_t^N}{p_t^T} = \frac{1-\gamma}{\gamma}\frac{c_t^T}{c_t^N}. \tag{20}$$

Substituting this expression into the budget constraint, we obtain the following expressions for c_t^N and c_t^T in terms of total period-t household expenditures, $E_t \equiv w_t + r_t^T + r_t^N + f_t + T_t$:

$$c_t^N = \frac{(1-\gamma)}{p_t^N}E_t \text{ and } c_t^T = \frac{\gamma}{p_t^T}E_t. \tag{21}$$

These expressions are standard given preferences and state that consumers spend a constant fraction of their income on each good. Substituting these expressions into period preferences, we obtain the indirect utility function:

$$U_t^{opt} \equiv \gamma \log\left(\frac{\gamma}{p_t^T}E_t\right) + (1-\gamma)\log\left(\frac{(1-\gamma)}{p_t^N}E_t\right). \tag{22}$$

We are interested in a price index of the economy that will tell us the cost of purchasing a constant quantity of utility. The particular level of utility one chooses is a normalization and for simplicity it is chosen as $\bar{U}^{opt} \equiv \gamma \log(\gamma) + (1-\gamma)\log(1-\gamma)$. Setting, $U_t^{opt} = \bar{U}^{opt}$ and solving the above expression for E_t, one then gets the expenditure needed to purchase $\bar{U}_t^{opt}$ units of welfare. Denoting this expenditure by p_t, gives an expression for the overall price level in the economy:

$$p_t = (p_t^T)^\gamma (p_t^N)^{1-\gamma}. \tag{23}$$

B Calibration Appendix: United States

B.1 US Data

We divide the economy into one-digit ISIC sectors: agriculture, construction, services, manufacturing as well as mining and utilities. As in the empirical section, for the calibration of the model, we assume that the traded goods sector (T) is composed of manufacturing, whilst the non-traded goods sector (NT) is composed of the non-resource, non-manufacturing sectors (i.e. agriculture, construction and services). Altering the specification of the sectors does not significantly effect our results.

Sectoral value added   We obtain one digit ISIC v.3 sectoral value-added data for the US between 1970 and 2010 from the UN (2014), both in 2005 constant US dollars and in current year US dollars. Denote by $\overline{VA}_{s,t}$ the constant (2005) price value added in sector $s = N, T$, at time t and by $VA_{s,t}$ the corresponding value added in current period prices.

Sectoral price indices   We calculate a sector specific price index for the US between 1970 and 2010 as:

$$p_{s,t} = VA_{s,t}/\overline{VA}_{s,t} \text{ for } T. \tag{24}$$

Sectoral employment   We obtain sectoral and total employment data for the US between 1970 and 2010 from (Timmer, de Vries and de Vries, 2014). Total employment is taken as the non-mining, non-utilities employment in the US. Denote this by L_t. Traded sector employment is taken to be as employment in the manufacturing sector. Denote this by $L_{T,t}$. Non-traded sector employment consists of total employment, less employment in mining, utilities and manufacturing. Denote this by $L_{NT,t}$.

Sectoral value added per worker and growth   Constant price sectoral value added per worker for the US between 1970 and 2010 is calculated as:

$$\overline{va}_{s,t} \equiv \frac{\overline{VA}_{s,t}}{L_{s,t}} \text{ for } s = NT, T. \tag{25}$$

The above sequences are then smoothed using a Hodrick-Prescott filter with smoothing parameter 100. Denote the smoothed sequences byt $\widetilde{va}_{s,t}$. The annualized sectoral growth rates are calculated as:

$$g_s \equiv \left(\frac{\widetilde{va}_{s,2010}}{\widetilde{va}_{s,1970}} \right)^{\frac{1}{40}} - 1. \tag{26}$$

US Real Interest Rate   The real interest rate is calculated by subtracting the average growth rate of nominal traded good prices, $p_{T,t}$, between 1970 and 2010 (approximately 2.7% per year) from the average annual nominal interest rate during the period (approximately 8.2% per year). The interest rate data is obtained from (Officer, 2016). Thus, the implicit real interest rate is approximately $R^* = 8.2\% - 2.7\% \approx 6\%$.

Parameter	Values	Target
A_0^T, A_0^N	1	Normalization
A_t^s	$A_t^s = (g_s)^{t-1970}$	Constant, exogenous sectoral productivity growth in sector $s = T, N$.
$g_T - 1$	0.03	Annualized average growth rate of HP-smooothed traded sector productivity in US, 1970-2010.
$g_N - 1$	0.009	Annualized average growth rate of HP-smooothed non-traded sector productivity in US, 1970-2010.
$1 - \alpha$	0.67	Labor share in each sector.
$b_0 = \bar{b}$	-1.42	Average consolidated Public Sector Debt to GDP ratio in US, 1970-2010
β	0.97	Average real interest rate in the US, 1970-2010.
ϕ	0.08	Elasticity of risk premium, van der Ploeg and Venables (2011)
τ_t	0	Assumption
γ	0.135	Average employment share in traded sector, 1970-2010.
a	0.33	NPV of resource discovery is 100% of time zero GDP.

Table 2: Calibrated parameters

B.2 Calibration

We start by setting the labor share, $1 - \alpha$, to be 0.67 in both the traded and the non-traded goods sector. This is the standard value that is usually assumed for labor share in the literature. This also roughly lines up with average OECD labor shares of 0.64 in the traded goods sector and 0.62 in the non-traded goods sector estimated by Kuralbayeva and Stefanski (2013).

In the above section B.1, we constructed HP-smoothed constant-price sectoral value-added per worker data for the US for the 1970-2010 period. We find that the average annual labor productivity growth rate was 3% in the traded sector and 0.9% in the non-traded sector.[26] Since we assume the economy is on a balanced growth path, sectoral labor productivity growth rates are equal to the growth rates of sectoral total factor productivity. As such, we normalize $A_{1970}^T = A_{1970}^N = 1$ and assume that productivity in each sector grows at the corresponding annualized average. Letting $g_T \equiv 1 + 0.03$ and $g_N \equiv 1 + 0.009$, we thus define sectoral productivity in our model as:

$$A_t^N = g_N^{t-1970} \text{ and } A_t^T = g_T^{t-1970}. \tag{27}$$

Since the US is on a balanced growth path and given the above normalization of sectoral productivity, we choose both the initial endowment of bonds b_0 and the parameter that determines the balanced growth path level of bond holdings, $\bar{b}$, to be equal. Furthermore, we choose both of these parameters to match the 1970-2010 average of the ratio between the consolidated Public Sector Debt and nominal GDP (both obtained from the OECD) equal to approximately 75%. This gives us values of parameters $b_0 = \bar{b} = -1.42$.

Since the US is assumed to be on a balanced growth path, it faces an interest rate of $R^* = \frac{g_T}{\beta}$. Given g_T we choose β to match the average real interest rate in the US between 1970-2010 of approximately 6%, which implies $\beta = 0.97$.

The weight in the preferences on the traded-sector consumption good, γ, influences the

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[26]The annualized growth of a sequence x_t between periods T and $T + N$ is given by $\left(\frac{x_{T+N}}{x_T}\right)^{\frac{1}{N}} - 1$.

employment share in the traded sector via equation (6). As such, we choose $\gamma = 0.135$ to match the average share of employment in the traded goods sector in the US between 1970 and 2010 of approximately 15.5%.

We choose ϕ to match the elasticity of risk premium from van der Ploeg and Venables (2011). In particular, van der Ploeg and Venables (2011) calculate that a one percent increase in the public debt-to-GDP ratio of a country translates into a 1.94% increase in a country's nominal interest rate above the international risk free rate. We thus choose $\phi = 0.084$ so that the model matches a 1.94% increase in period zero interest rate from the steady state interest rate ($R^* = 6\%$) if the US economy were to start with an initial debt that would be 1% higher than the steady state level of debt i.e. $b'_0 = b_0 \times 1.01 = 1.43$.

Finally, we determine a profile for oil production, $p_t^O e_t^O$.[27] To do this we assume that the discovery of oil takes place at time zero, but that production starts five years later.[28] Furthermore, we assume that the production of resources declines by a constant quantity each year after the discovery and that production lasts for 25 years.[29] This gives rise to the following production profile:

$$
p_t^O e_t^O = \begin{cases} a(1 - \frac{t-5}{25}), \text{for } 5 \leq t \leq 29 \\ 0, \text{ otherwise} \end{cases}
\tag{28}
$$

where a is a constant that we need to choose. Notice that the total net present value of the discovery at time zero relative to time zero GDP is given by:

$$
\bar{d}_0 = \left(\sum_{j=5}^{29} \frac{p_j^O e_j^O}{(1 + R_j)^j} \right) / GDP_0^i.
\tag{29}
$$

We set $a = 0.33$ in equation (28) so that $\bar{d}_0 = 1$ - i.e. the net present value of the discovery at time zero is 100% of time zero GDP. All the calibrated parameters are summarized in Table 2.
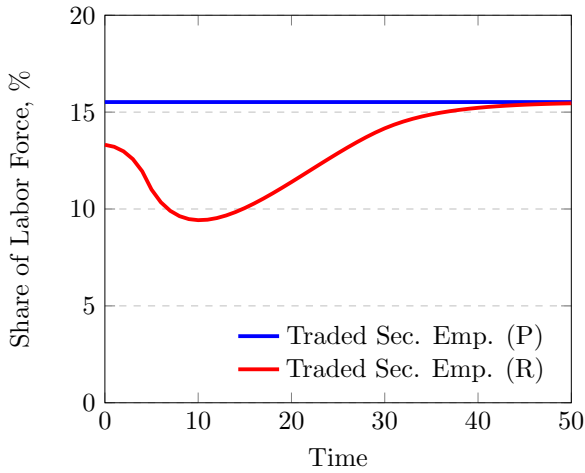
B.3   Results

In the main body of the paper we show the results for bond holdings, resource production revenues, total foreign revenues and relative prices in both country R and country P. Here, we show the results for sectoral employment. The impact of the foreign inflow of cash on

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[27] Notice that since the price of natural resources is exogenous, we cannot disentangle it from the changes in quantities. For our purposes, this does not make a difference, and we can simply assume without loss of generality that the price of resources is fixed to unity, over the period and that changes in resource revenues all stem from changes in e_t^O.

[28] This is the average time after a discovery that production starts after a giant resource discovery in Arezki, Ramey and Sheng (2015).

[29] We make these assumption to attempt to replicate the production patterns used in Arezki, Ramey and Sheng (2015) as best as we can. In their paper the production profile starts of as a plateau - whose length depends on the size of field - and then exponentially declines at a constant depletion rate. Both the depletion rate and the length of the plateau depend on ultimately recoverable reserves which are not made available by Arezki, Ramey and Sheng (2015) and hence cannot be replicated exactly. However, we have tried different specifications of the resource production function such as having a constant level of resource output, having an exponentially declining level of resource output, or having some combination of the two. Importantly, there is no qualitative difference in our results and only a very limited quantitative difference.

(a) Employment shares in the traded sector.
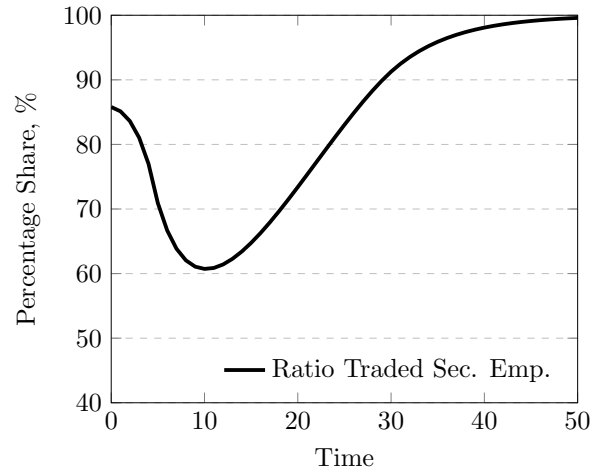
(b) Ratio of traded sector employment in oil economy to traded sector employment in no oil economy.

Figure 6: Simulation Results. In the above P= Non-Resource Economy; R= Resource Economy.

employment is visible in Figure 6. Figure 6a shows employment shares in traded sector in both economies, whilst Figure 6b shows the resulting ratio. Country P has a steady-state employment share in the traded sector of approximately 15.5%. The employment in the traded sector in country R responds to the windfall - according to the theory presented above. In particular, employment in the traded sector falls by roughly 15% (or 2.5 percentage points) at the time of discovery as the consumer adjusts his savings decisions. It then continues to decline as the size of foreign revenues increases falling to 60% of country P employment 10 years after the discovery. As foreign revenues return to their steady state levels, employment in the traded sector in the oil economy returns to normal.
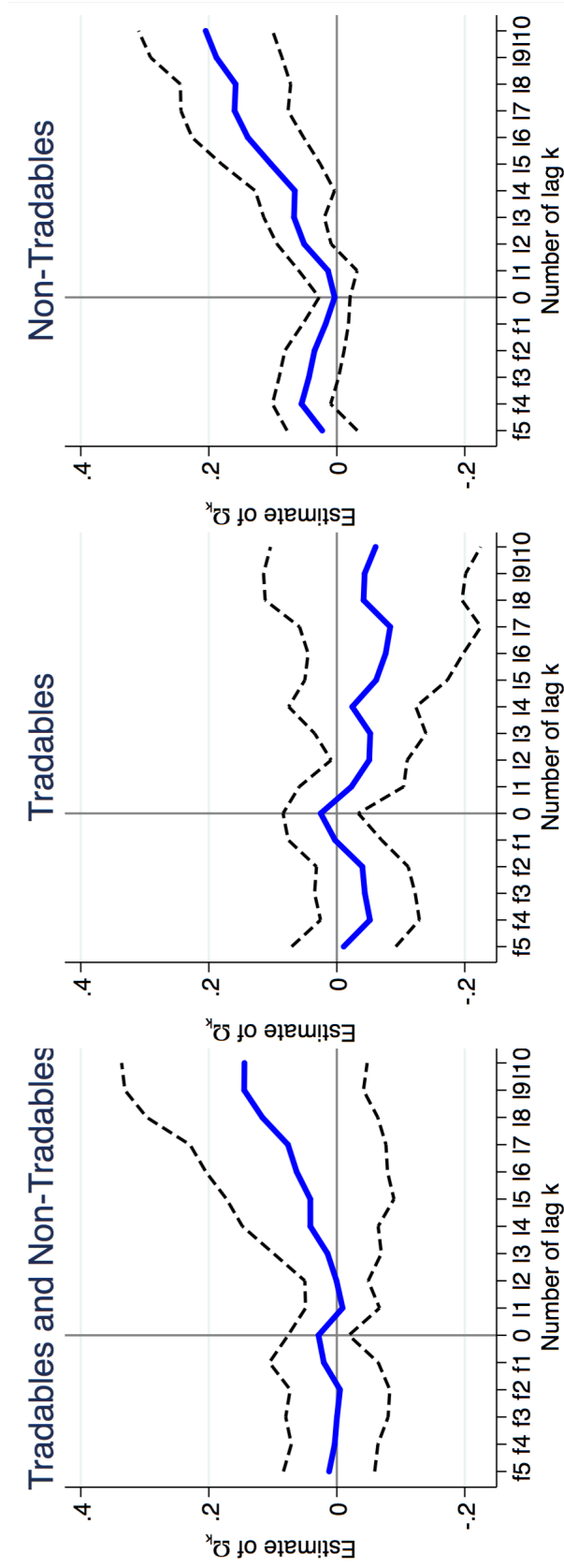
C Empirical Appendix

Figure 7: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Baseline specification with different numbers of lags.**
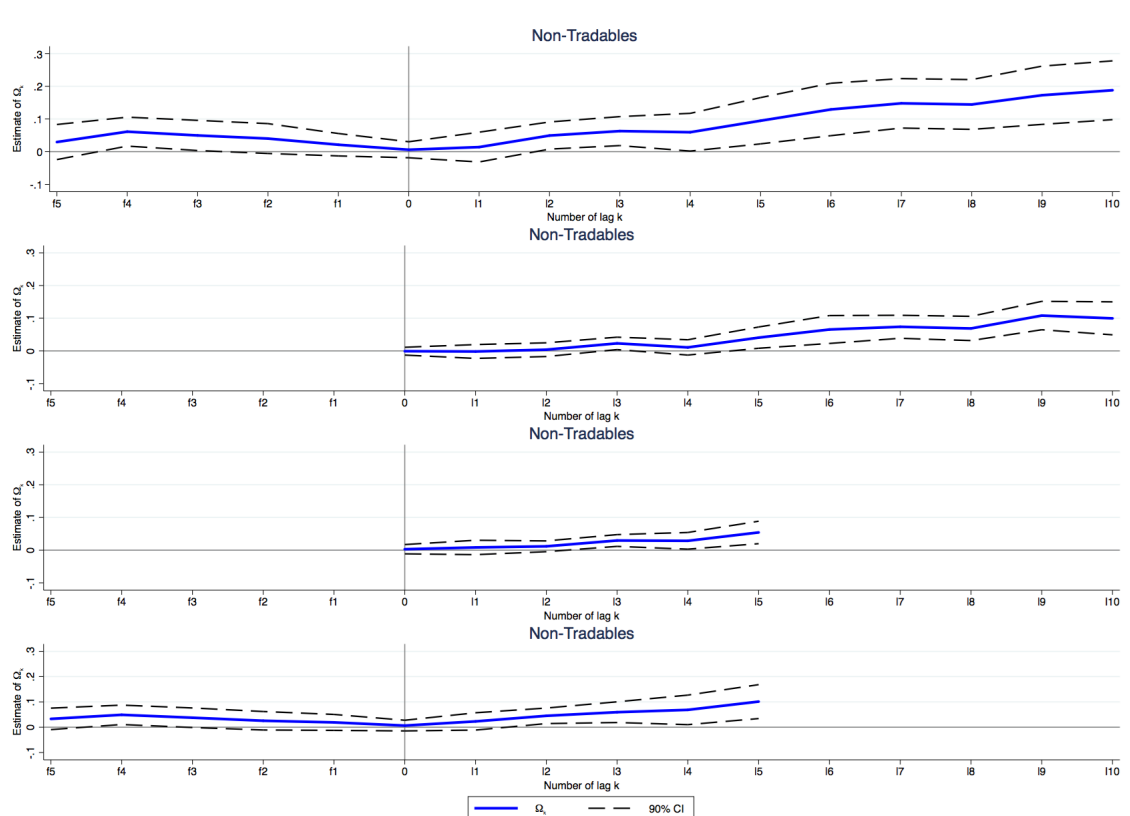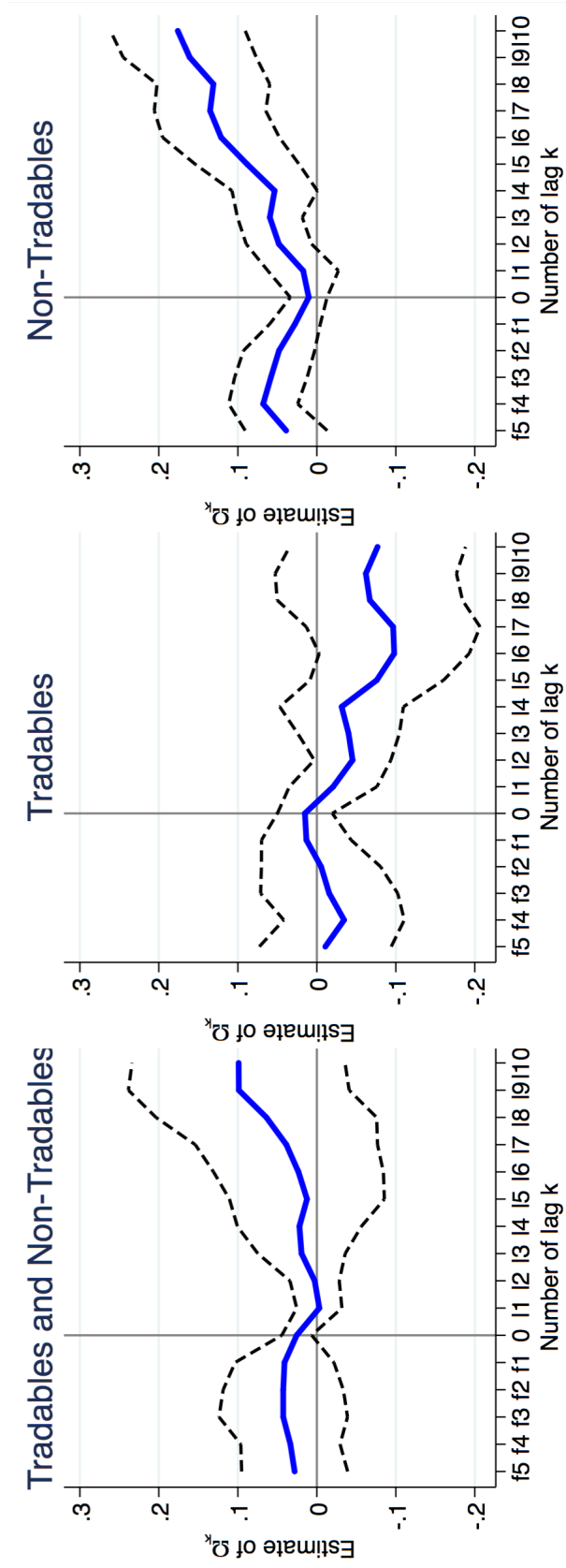

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is change in the logged real exchange rate of non-tradable goods. The blue solid line is the the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.
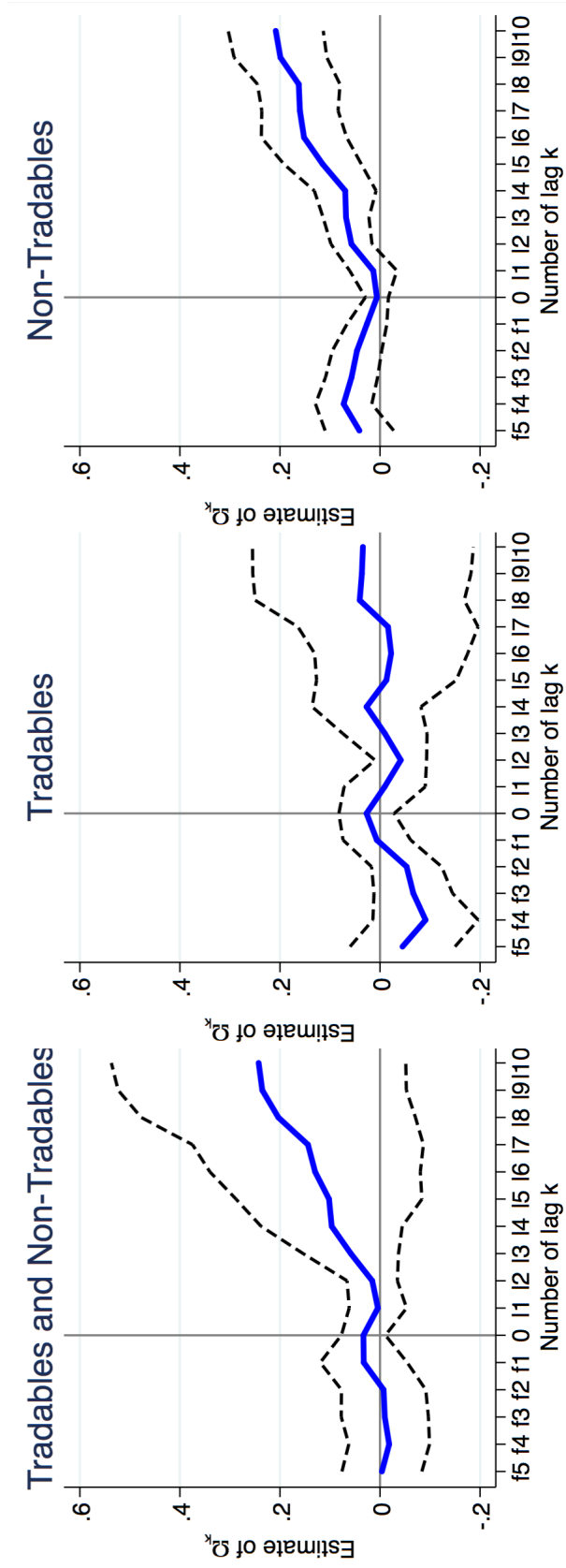
Figure 8: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Estimated conditional on past discoveries.**

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.

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Figure 9: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Drop top and bottom 1% of the distribution to account for outliers.**

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.
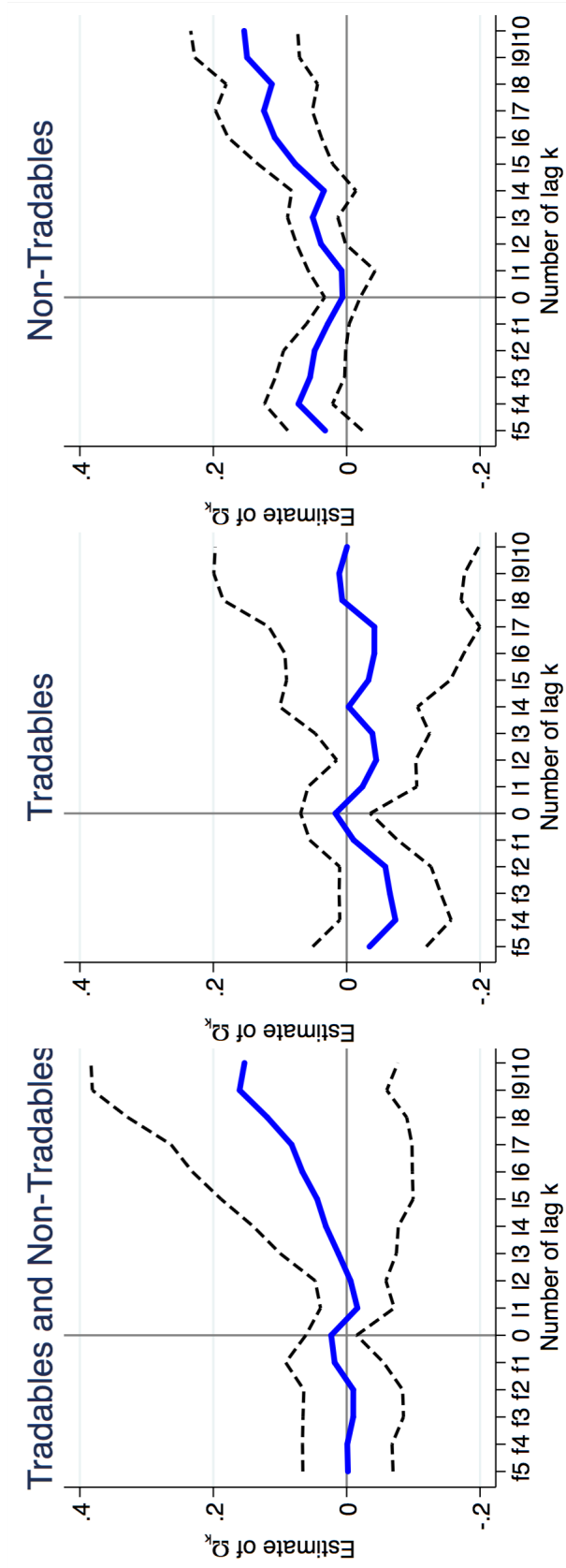
Figure 10: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **We restrict the counterfactual to countries which had at least one giant discovery within the sample period.**
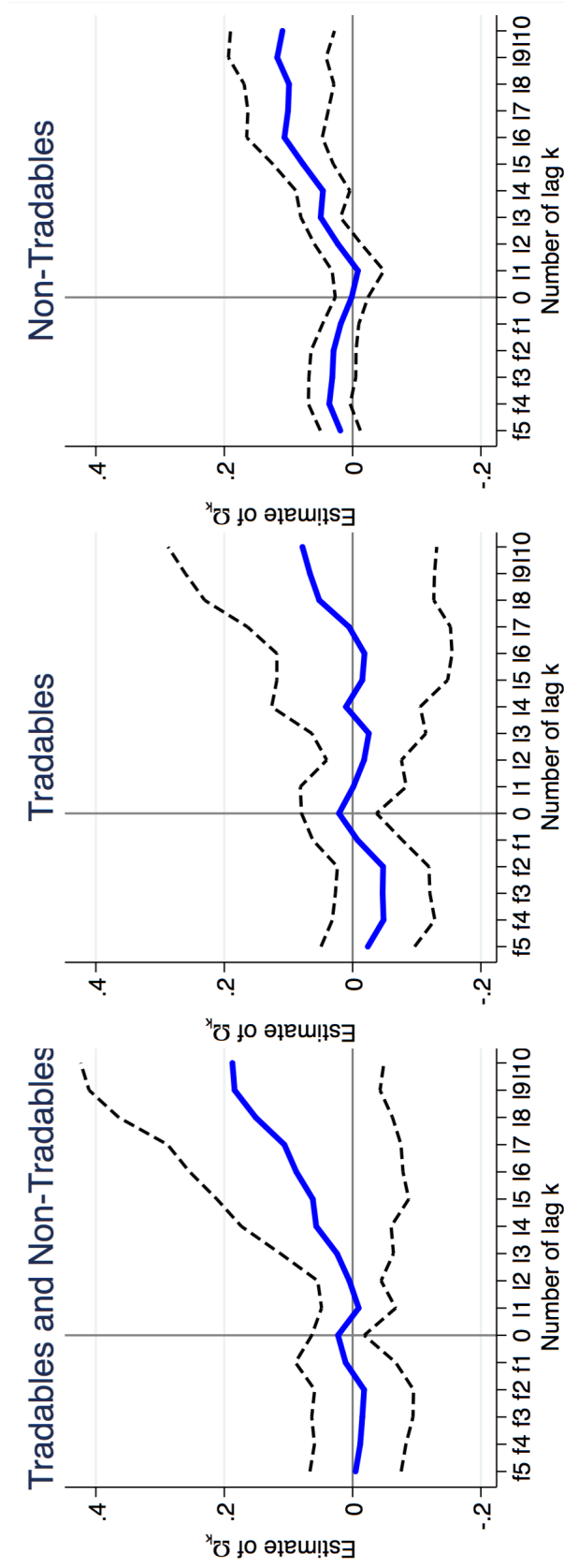

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.

Figure 11: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Agriculture and construction is excluded from the non-tradable sector.**
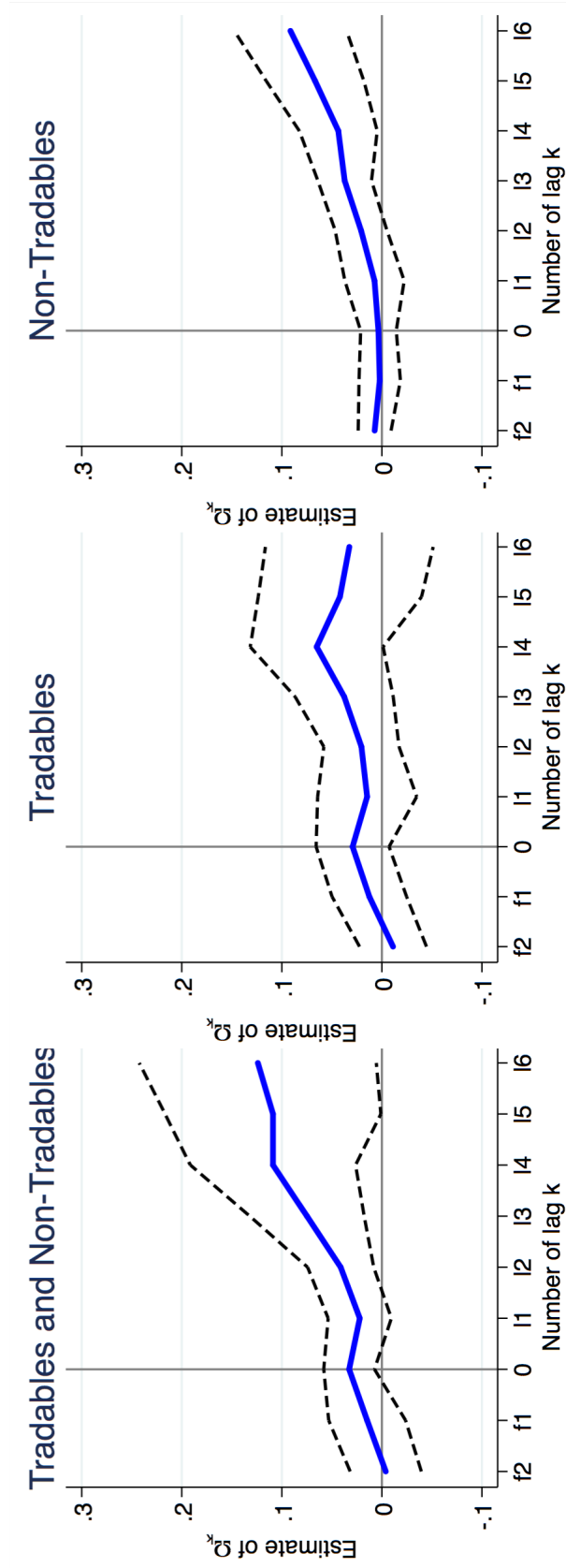
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.

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Figure 12: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Agricultural goods are redefined as being tradable.**
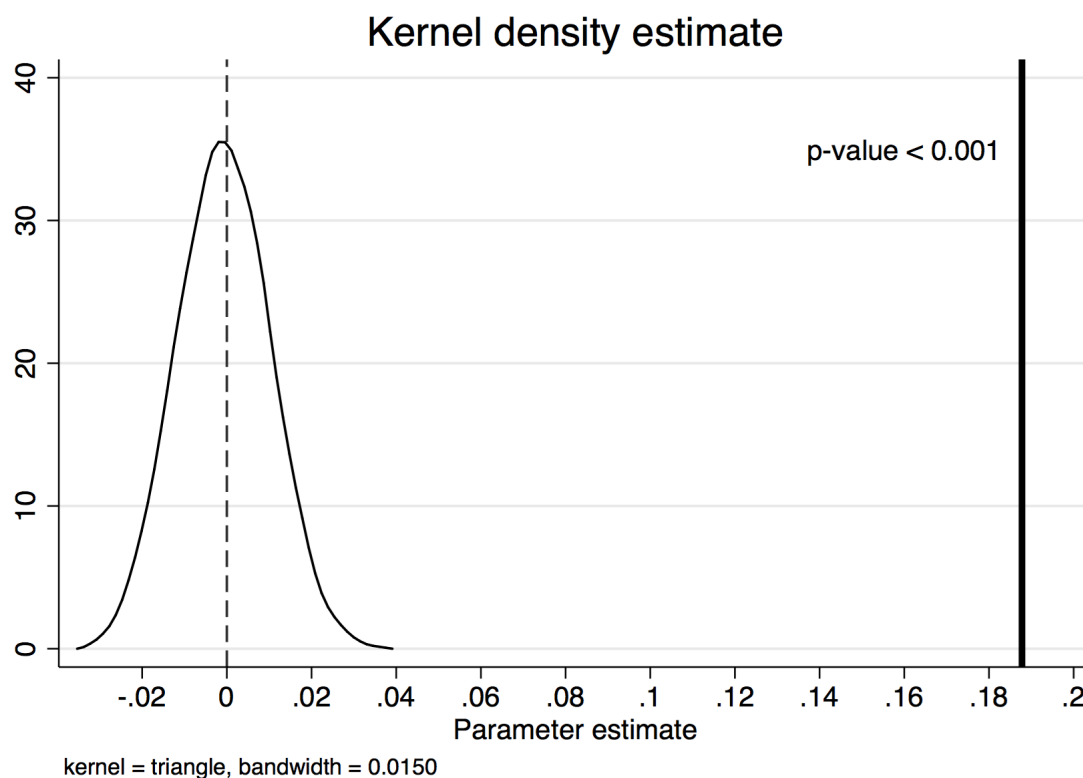
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years t to $t+k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.

Figure 13: Effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Information on producer prices is used to decompose changes in the real exchange into its tradable and its non-tradable component.**
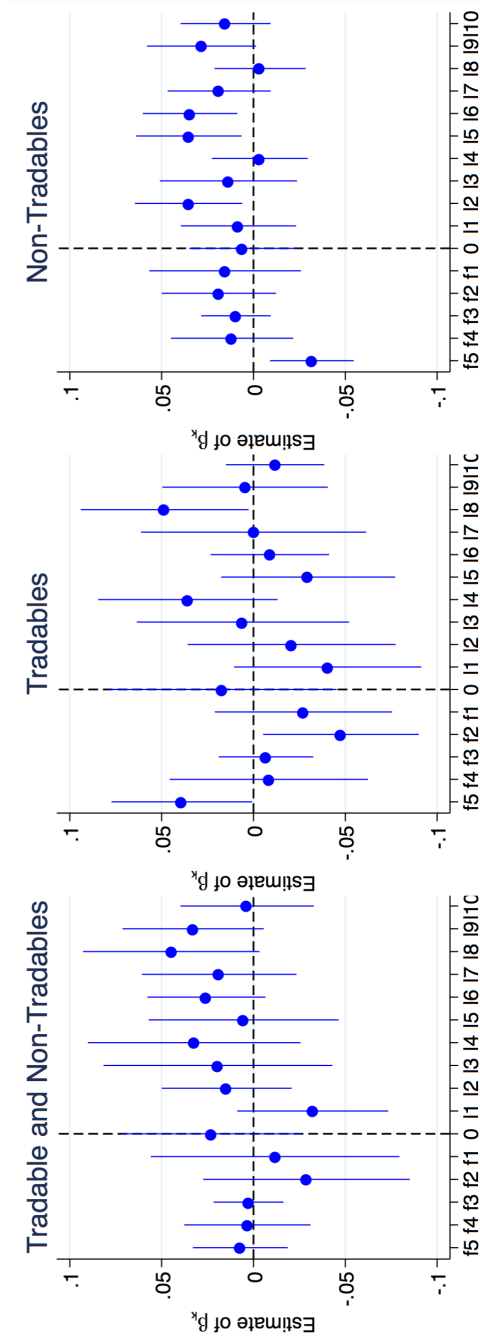
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding up β_k's which are estimated in equation 18: $\Omega_k = \sum_{j=0}^{k} \beta_j$. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.

Figure 14: Distribution of point estimates for the cumulative effect on the changes in the logged real exchange rate of the non-tradable goods.

Notes: The distribution is constructed by re-estimating equation 18 and add up the estimated β's up to 10 years following a discovery. Cumulative coefficient from the estimate using real data is shown as vertical lines with the p-value.

Figure 15: Marginal effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable and the change in the non-tradable component of the logged real exchange rate respectively. The blue solid dots indicate the point estimates of β_k's from equation 18. The blue solid lines indicate the 95% confidence intervals. We employ a two-way clustering which allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair.