

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 a resource boom on prices. We find that a giant discovery with the value of 10% of a country's GDP appreciates the real exchange rate by 1.5% within 10 years following the discovery. Importantly, a significant part of the appreciation occurs before production starts and the appreciation is driven by the non-traded component of the real exchange rate. Moreover, we show that labor reallocates from the traded goods sector to the non-traded goods sector leading to changes in labor productivity in the respective sectors. Our findings provide direct evidence on the channels central to the theories of the Dutch disease and the Balassa-Samuelson effect.

Keywords: Real exchange rates, natural resource discoveries, Dutch disease, oil, Balassa-Samuelson effect

JEL-codes: F31, F41, Q33

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1 Introduction

The Dutch disease theory and the Balassa-Samuelson hypothesis predict that a key mechanism through which economies adjust to windfalls or productivity shocks in the traded sector is an appreciation of the real exchange rate (Corden and Neary, 1982; Corden, 1984; Eastwood and Venables, 1982; Balassa, 1964; Samuelson, 1964). Despite the near canonical status of these theories, poor data quality and endogenous measures of resource or productivity shocks have made it challenging to provide robust empirical evidence on the appreciation channel across countries.

In this paper, we estimate the appreciation channel by combining bilateral real exchange rate data with information on giant oil and gas discoveries. By exploiting the uncertainty in the timing of resource discoveries, we overcome the endogeneity problem. By using bilateral data, we obtain a vast increase in the statistical variation available for inference.¹ Our exercise provides direct evidence on the appreciation channel for a wide set of countries. This complements Berka, Devereux and Engel (2018) and Chinn and Johnston (1996), who study eurozone countries and 14 OECD-countries, respectively.

We find that a country with the median discovery in our sample, 10% of a country's GDP, experiences an appreciation of the real exchange rate of approximately 1.5% over the first ten years following a discovery. By comparison, Rogoff (1996) finds that GDP per capita in a country would have to increase by 4% (relative to the US) in order to match this degree of appreciation. Berka, Devereux and Engel (2018) find that productivity in the traded sector would have to increase by 9% to generate a similar increase in the real exchange rate.² The effect we find is thus quantitatively large.

Economies also adjust to windfalls or traded-sector productivity shocks through the reallocation of labor across sectors. By focusing on a subsample of 23 OECD countries, we also provide direct evidence on the labor-reallocation channel and the associated changes in sectoral labor productivity. Following a giant discovery with the value of 10% of GDP, the employment share in the traded goods sector drops by 0.5 percentage points. Labor productivity increases by 1.8% in the traded sector, and decreases by 0.3% in the non-traded sector. To match these effects, the ratio of natural resources exports to GDP would have to increase by approximately 14-30%, using the estimates of Kuralbayeva and Stefanski (2013).³ Again, our estimates are economically large and in line with previous results.

¹The bilateral real exchange rate has been used by Betts and Kehoe (2006, 2008), Engel (1999) as well as Imbs et al. (2005). Much of the remaining literature focuses on real *effective* exchange rates - trade-weighted averages of bilateral real exchange rates (Cashin, Céspedes and Sahay, 2004; Chen and Rogoff, 2003).

²Rogoff (1996) estimates that a country's price level relative to the U.S. increases 0.366 percent as the country's GDP per capita increases one percent relative to the U.S. ($0.366 \times 0.04 \approx 0.015$). Berka, Devereux and Engel (2018) estimate that a one percent increase in the productivity of the traded goods sector leads to a 0.18 percent appreciation of the real exchange rate ($0.18 \times 0.09 \approx 0.015$).

³Kuralbayeva and Stefanski (2013) estimate that as a country's resource-export share rises by one percent, manufacturing employment share decreases by 0.0169 percentage points ($0.0169 \times 30 \approx 0.5$), traded-sector labor productivity rises by 0.097 percent ($0.097 \times 19 = 1.8$) and non-traded-sector labor productivity falls

Our contribution is three-fold. First, the use of bilateral real exchange rates and unanticipated large resource discoveries allows for better identification of real exchange rate appreciation that follows such discoveries, a mechanism which is central in Dutch disease theories. More generally, we provide evidence for the Balassa-Samuelson effect if we interpret a large discovery as a productivity shock to the tradable sector (Neary, 1988).⁴

Second, focusing on the timing of the discovery allows us to remain agnostic about when the effects on the real exchange rate, labour reallocation and sectoral productivity occur. Arezki, Ramey and Sheng (2017) and van der Ploeg and Venables (2013) point out that resource discoveries may have effects before production starts as agents borrow in anticipation of higher, future resource income. Engel and West (2005) find that expectation of higher future GDP can lead to nominal exchange rate appreciation. Our estimates show that appreciation and sector-reallocation starts soon after the discoveries are made and before production begins, but that there is nonetheless a gradual build-up to the full effect. We emphasize this anticipation effect by constructing and calibrating a standard, dynamic, small-open-economy model. The model reproduces both the magnitudes and the paths of the real-exchange rate, labor reallocation and sectoral productivity over the first ten years following a discovery but, possibly due to a lack of modelled frictions, it predicts a somewhat more rapid initial response to discoveries than what we find in the data.

Third, we show that the appreciation is nearly exclusively driven by the non-tradable component of the real exchange rate. This provides strong evidence in favour of the traditional theory of real exchange rates, where prices of tradable goods are anchored internationally while prices of non-tradable goods are allowed to adjust to local conditions.⁵

by 0.02 percent ($0.021 \times 14 = 0.3$).

⁴Many other papers have explored this mechanism in the context of the Balassa-Samuelson literature and found that this hypothesis does best in explaining real exchange rates in the longer run (Chong, Jordà and Taylor, 2012; Lothian and Taylor, 2008; Tica and Družić, 2006; Chinn and Johnston, 1996). For a review of this literature see Taylor and Taylor (2004). Focusing on the variation in natural resource wealth, a variety of papers have examined Dutch disease predictions empirically by exploring the effects on employment and wages of traded and non-traded sectors (Ismail, 2010; Kuralbayeva and Stefanski, 2013; Smith, 2014), non-resource trade (Harding and Venables, 2016) as well as movements in real exchange rates (Cashin, Cespedes and Sahay, 2004; Chen and Rogoff, 2003; Bjornland and Thorsrud, 2016). These studies, however, either use endogenous resource measures or do not fully exploit the available cross-country variation for identification and provide quantitatively and qualitatively diverging results. There is also a literature exploiting the within country spatial variation and the reallocation of labor within a country (Allcott and Keniston, 2014; Beine, Coulombe and Vermeulen, 2014; Aragón, Rud and Toews, 2018). While these papers typically improve on the empirical identification and the data quality, their results have little to add to the discussion on real exchange rate movements and traded-sector employment on the country level.

⁵Traditional theories of the real-exchange rate go back to Cassel (1918) and Pigou (1923). More recently papers by Rebelo and Vegh (1995), Stockman and Tesar (1995) or de Cordoba and Kehoe (2000) examine how sectoral productivity, demand or trade shocks can cause changes to non-traded goods prices which then drive fluctuations in real exchange rates.

2 Real Exchange Rates

The appreciation of the real exchange rate is at the core of Dutch-Disease theories and is often considered to be responsible for the deterioration of the tradable goods sector, i.e. manufacturing. In this section we identify and quantify the cumulative effect of giant discoveries on the real exchange rate and its tradable and non-tradable goods component.

Structure: Consider an economy which consists of mining and utilities, manufacturing as well as a non-resource non-manufacturing sector defined as the sum of agriculture (A), construction (C) and services⁶ (S):

$$(1) \quad \text{Total Economy} = \underbrace{\overbrace{A + C + S}^{\text{Non-Resource Economy}}}_{\text{Non Res. Non-Mfg. (N)}} + \underbrace{M}_{\text{Mfg. (T)}} + \underbrace{MU}_{\text{Mining and Utilities}} .$$

Throughout this paper we focus on the non-resource economy only. We treat the manufacturing sector as the traded-goods sector (T) and the non-resource non-manufacturing sector as the non-traded good sector (N).⁷

Exchange Rates: We construct sector-specific price indices using data on one digit ISIC v.3 current and constant sectoral value-added in national currency units from the UN (2014). The IMF's national currency-US exchange rate is used to transform the indices into comparable units. The transformed indices are then used to construct bilateral real exchange rates $REER_t^{ij}$ between country i and j in period t . Following Engel (1999) as well as Betts and Kehoe (2008, 2006), we decompose these as:

$$(2) \quad \underbrace{\frac{p_{i,t}}{p_{j,t}}}_{REER_t^{ij}} \equiv \underbrace{\left(\frac{p_{i,t}^T}{p_{j,t}^T}\right)}_{REER_t^{ij}} \times \underbrace{\left(\frac{p_{i,t}/p_{i,t}^T}{p_{j,t}/p_{j,t}^T}\right)}_{REER_t^{ij}}$$

Here, $p_{i,t}$ and $p_{i,t}^T$ refer to the aggregate and traded-sector price indices in country i and time t . The first term on the right hand side is the bilateral real exchange rate of traded goods, $REER_t^{ij}$. It measures any deviations from the law-of-one-price or differences in the composition of baskets of traded goods across countries. The second term in the above is a ratio of internal relative prices, denoted by $REER_t^{ij}$. As is emphasized by Betts and Kehoe

⁶Services are defined as the sum of transportation, storage, communication, wholesale, retail, restaurants, hotels and other services.

⁷Altering the sectoral specification by moving agriculture to the traded sector or considering only services as the non-traded sector does not affect our results.

(2008), we could write this as:

$$(3) \quad RERN_t^{ij} = \frac{p_{i,t}(p_{i,t}^T, p_{i,t}^N)/p_{i,t}^T}{p_{j,t}(p_{j,t}^T, p_{j,t}^N)/p_{j,t}^T}$$

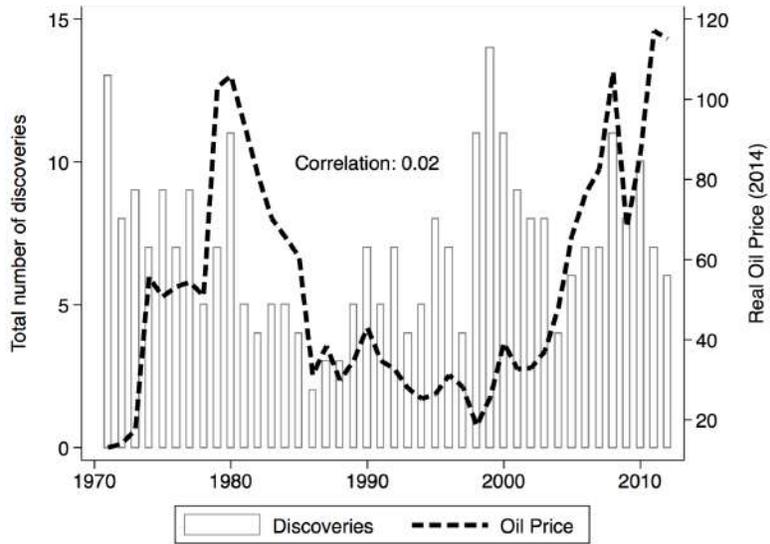
where $p_{i,t}^N$ is a price index for non-traded goods in country i , and we make explicit the dependence of $p_{i,t}$ on the indices of both traded and non-traded goods. The functional form of $RERN_t^{ij}$ however depends on how statistical offices in each country construct aggregate price indices.⁸ To circumvent the need to assume a functional form or to measure the prices of non-traded goods, we follow Betts and Kehoe (2008) and use the equational form in (2) to calculate $RERN_t^{ij}$. Thus, we can decompose the real exchange rate into the tradable and non-tradable components just from data on traded goods price indices and aggregate price indices. Our sample covers $N = 172$ countries over the period 1970-2013. Not double-counting country pairs, the number of unique observations per year is $\frac{N^2-N}{2} = 14,706$. Using all available information gives us 12,536 unique country pairs and a total of 383,934 observations. See Table A.1 in the Appendix for a snapshot of the data.

Giant Oil and Gas Discoveries: Information on the timing of individual giant oil and gas discoveries, as provided by Horn (2011), is essential for our study for two reasons. First, we need the timing of discoveries since we are interested in understanding Dutch Disease dynamics and what happens to outcome variables between a discovery and the start of production. Second, the difficulty in anticipating discoveries places the timing of these discoveries at the center of our identification strategy. We follow Lei and Michaels (2014) and Arezki, Ramey and Sheng (2017) in arguing that discoveries are plausibly exogenous due to the uncertainty surrounding exploration and future technology developments, once we control for country and year fixed effects and previous discoveries.⁹ Countries and exploration companies are unlikely to make such discoveries, as only about 2% of the exploration wells in a global data set starting in 1965 turned into giant discoveries (Toews and Vezina, 2017). Consequently, predicting the exact timing of a giant oil discovery is difficult, even for the operating companies. Figure 1(a) presents the relationship between the real price of oil and the total number of giant discoveries. Note that the number of discoveries is uncorrelated with the real price of oil, with a correlation coefficient below 0.02 and a p-value of 0.9, increasing the confidence in our identification strategy.

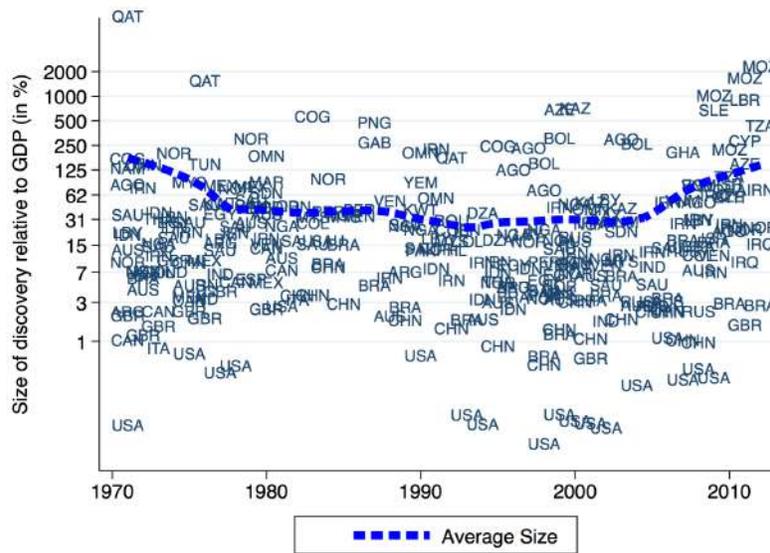
Our main measure of treatment is the net present values of giant oil and gas discoveries relative to GDP in country i and period t , d_t^i , which we received from Arezki, Ramey and

⁸For example, if we were to assume that $p_{i,t}(p_{i,t}^T, p_{i,t}^N) = (p_{i,t}^T)^{\gamma_i} (p_{i,t}^N)^{1-\gamma_i}$, then $RERN_t^{ij}$ is an explicit function of relative internal prices, $RERN_t^{ij} = \frac{(p_{i,t}^N/p_{i,t}^T)^{1-\gamma_i}}{(p_{j,t}^N/p_{j,t}^T)^{1-\gamma_j}}$.

⁹In contrast, more common measures of endowments such as resource wealth or exports are seen as endogenous. Brunnschweiler and Bulte (2008) and van der Ploeg and Poelhekke (2010) discuss this endogeneity in the context of the resource curse. Cust and Harding (forthcoming) focus on the quality of institutions as a source of endogeneity.



(a) Oil price and number of giant oil and gas discoveries.



(b) Size of giant discoveries relative to a country's period t GDP (%).

Figure 1: Overview of giant oil and gas discoveries.

Sheng (2017). The raw data on discoveries contains information on the timing, the location and the estimated total ultimately recoverable amount of oil and gas (Horn, 2011). To calculate the net present value of each discovery at the date of discovery, Arezki, Ramey and Sheng (2017) combine the data from Horn (2011) with a generic approximated oil production profile, the nominal oil price at the date of discovery and a country specific interests rate to discount future revenues. They normalize the resulting value on nominal GDP measured at the date of discovery.¹⁰ The calculated values are presented in Figure 1(b). 302 giant discoveries were made in 56 countries between 1970 and 2013. The average and median size of discoveries is 67% and 10% of GDP, respectively.

We use $\delta_t^i = 1 + d_t^i$ as a simple monotonic transformation of the discovery measure d above and define a bilateral measure of discoveries:

$$(4) \quad D_t^{ij} \equiv \log \left(\frac{\delta_t^i}{\delta_t^j} \right).$$

D is robust to zeros in the denominator and symmetric in that a discovery in country i and country j have the same quantitative impact, but opposite signs: $\frac{\partial D_t^{ij}}{\partial \log(\delta_t^i)} = -\frac{\partial D_t^{ij}}{\partial \log(\delta_t^j)} = 1$.

Estimation Strategy: We estimate the following specification:

$$(5) \quad gX_t^{ij} = \sum_{k=-5}^{10} \beta_k D_{t-k}^{ij} + \eta^{ij} + \rho_t + \varepsilon_t^{ij}$$

Our dependent variable is the growth in the bilateral real exchange rate which we define as the change in the natural log of the real exchange rate and its components: $gX_t^{ij} \equiv \log(X_t^{ij}) - \log(X_{t-1}^{ij})$, where $X = RER, RERT, RERN$. Country-pair and time fixed effects are represented by η^{ij} and ρ_t respectively. The latter capture global shocks. Since our dependent variables are growth rates, country-pair fixed effects capture trends in relative prices between the two countries. Thus, we study the impact of giant discoveries on deviations from country-pair specific trends. The β_k terms represent the year-to-year growth effect of discoveries k periods after the discovery. We are interested in the cumulative effect of a discovery on the real exchange rate k periods after a discovery in period t , which is the sum of the 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, $\Omega_k = \sum_{j=1}^k \beta_j$, and use these to construct 95% and 90%-confidence bands. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$.¹¹ The country-pair specific

¹⁰See equation 11 in Arezki, Ramey and Sheng (2017) for the exact formula of the measure we use.

¹¹Note that this allows us to test for diverging pre-trends between the treatment and the control group before the discovery. Diverging pre-trends would indicate that we should be careful with the causal interpretation of our results. However, as will be shown throughout the paper, the pre-trend development of all outcomes in countries which are about to have a discovery is statically indistinguishable from the

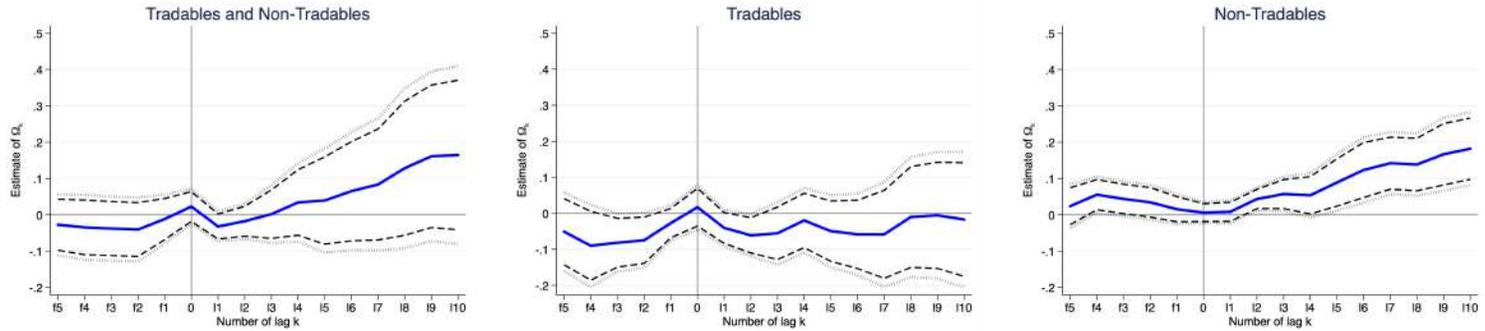
error, ε_t^{ij} , is allowed to arbitrarily correlate with errors of other bilateral pairs containing either country i or country j (two-way clustering).

Results: The main results are displayed in the 3 charts of Figure 2. The solid lines show the cumulative impulse response $\Omega_{t \in [1,10]}$ to a giant discovery, while the dashed and the dotted lines indicate 90% and 95% confidence intervals. The first chart depicts the cumulative response of the real exchange rate to a giant discovery. In the second and third charts we decompose the effect on the real exchange rate into the effect on the tradable and the non-tradable component, respectively. First of all, note that in the periods before the discoveries, indicated by the vertical line, there is no apparent and statistically significant difference in price changes in the countries which are about to be treated relative to the control group. This is important since the implicit assumption allowing us to interpret our results as causal is that prices in the treated and control group follow a similar trend in the absence of a discovery. In case of the prices of tradable goods we do not observe any significant divergence in prices following a discovery. Thus, we conclude that consistent with standard economic theory, prices of tradable goods remain unaffected by country specific shocks. On the other hand, the third chart shows that discoveries positively affect the non-tradable goods component of the real exchange rate. The results imply that 10 years after a median-sized discovery (10% of GDP) the non-tradable goods component of the real exchange rate increases by 1.7%.¹² Also note that the prices of non-tradable goods component start increasing immediately following the discovery and are already significantly higher in the treated group by the time production typically starts, 4-6 years following the discovery (Arezki, Ramey and Sheng, 2017). This is in line with the idea that forward-looking agents may borrow and spend in anticipation of a higher future resource income before production starts, i.g. Dutch Disease dynamics.

Consistent with the discussion above we find that the real exchange rate starts appreciating following a discovery. And while the cumulative effect on the real exchange rate is measured imprecisely we find that the exchange rate appreciates by 1.6% within 10 years following a median-sized discovery. The magnitude of the real exchange rate appreciation is nearly identical to the appreciation of the non-tradable goods component of the real exchange rate. By comparing the three charts, it is apparent that the appreciation of the real exchange rate is entirely driven by its non-tradable goods component. Note that the large confidence interval originates in the imprecise estimation of the effect on the prices of tradable goods. This is consistent with the well documented results that most of the variance in the bilateral exchange rates is attributable to fluctuations in the real exchange rate of traded goods (Engel, 1999).

pre-trend developments in the control group.

¹²From chart 3 of Figure 2, $\Omega_{10} = \sum_{j=1}^{10} \beta_j = 0.18$. The impact of a median discovery is thus $0.017 \approx 0.18 \times \log\left(\frac{1+0.1}{1}\right)$.



Notes: All results 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 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 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed and the dotted lines represent the 90% and the 95% confidence intervals. To calculate the 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.

Figure 2: Cumulative effect of large discoveries on the real exchange for all countries.

Robustness: In Appendix A we present a battery of robustness tests for our main results. First, we reproduce Figure 2 by adjusting our measure to taxation. In particular, we use tax data from Wood MacKenzie to estimate country specific government takes to adjust the measure provided to us by Arezki, Ramey and Sheng (2017) in attempt to control for differences in the proportion of the value of discoveries that accrue to government. The results are slightly larger but do not differ significantly from our baseline result as shown in Figure A.1. Second, instead of using the GDP adjusted measure of discoveries we reproduce our main results using time dummies. This allows us to address potential endogeneity concerns and measurement issues with the discovery measure by focusing exclusively on the timing of discoveries. The results are presented in Figure A.2 for the full sample and for the OECD subsample defined in the next section. Third, to examine whether our results are spurious, we conduct a randomisation test by randomly reallocating discoveries across countries and time. The distribution of point estimates from re-estimating equation 5 with the artificial data is symmetric and centred at zero, indicating that our econometric model is unlikely to produce spurious results (see Figure A.3). Fourth, we show that the results are robust to changing the treatment and control group by varying the number of lags and by reducing the sample to countries which had at least one giant discovery since 1970 (see Figure A.4 and Figure A.5). Fifth, in Figure A.6 we control for cumulated past discoveries to account for potential path-dependence in discoveries. Sixth, we drop the top and the bottom 1% of the dependent variable to account for outliers (see Figure A.7). Seventh, to ensure that our results are not sensitive to specific sector classifications, we use alternative definitions of tradable and non-tradable goods and present the results in Figure A.8 and Figure A.9. In all the robustness tests presented in Figures A.1-A.9, the results remain unaffected. Eighth, following Betts and Kehoe (2008), we use producer prices as alternative price measures. The results are presented in Figure A.10. Note that while the results are quantitatively similar, the appreciation of the real exchange rate is now also significant at the 10%. Finally, we also estimate the effect of oil discoveries on unilateral real effective exchange rates confirming our results (see Figure A.11).

3 Labor Reallocation and Productivity

Economies adjust to resource windfalls not only through price changes, but also through the reallocation of factors across sectors. In this section we identify and quantify the effect of giant discoveries on the reallocation of labor as well as the associated changes in labor productivity for a subsample of countries.

OECD sample: To explore the reallocation channel we focus on countries which were OECD members by 1973.¹³ We restrict our analysis to these countries since our identification

¹³The sample consists of the following OECD countries: Australia, Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway,

strategy relies on time-series variation which requires comparable, high quality data going back to the beginning of our sample. Countries in this sample had the capacity and an explicit agenda to collect comparable sector level data as early as 1970 (den Butter, 2007). Finally, it is important to emphasise that approximately 25% of the 302 giant discoveries between 1970 and 2013 were made by 9 countries in this sample leaving us with enough variation for identification.

Employment Data: We obtain sectoral employment data for 1970-2013 from the ILOSTAT online database,¹⁴ which is based on population censuses, national labor force surveys as well as official estimates. We use this data to compute employment shares of the traded and non-traded sector in each country. Using all available information gives us data on 23 countries up to 43 years and a total of 878 observations.

Productivity Data: We construct data on sectoral labor productivity for 1970-2013. We obtain one digit ISIC v.3 sectoral value-added data from the UN in constant (2005) US dollars. Following the procedure outlined in Kuralbayeva and Stefanski (2013), we convert this into constant (2005) international (or PPP) dollars using country-sector specific price-level data from the World Bank’s 2005 International Comparison Program (ICP). Finally, we calculate value added per worker in constant (2005) international dollars in the traded and non-traded sectors by combining this data with the employment data described above. Using all available information gives us 878 observations. See Table A.2 in the Appendix for descriptive statistics.

Estimation Strategy: As before, our identification strategy relies on the timing of giant discoveries and we emphasise the exogeneity of the timing by providing 5 year long pre-trends. However, whereas before our focus was on price difference across countries over time, here we focus on sector level differences within the same country and, thus, we estimate the following specification:

$$(6) \quad gX_t^i = \sum_{k=-5}^{10} \beta_k \log(\delta)_{t-k}^i + \eta^i + \rho_t + T_t^i + \varepsilon_t^i.$$

Here our LHS variable, gX_t^i , is a placeholder for the employment share changes in the tradable sector, labor productivity growth in the tradable sector or labor productivity growth in the non-tradable goods sector in country i .¹⁵ Our measure of discoveries is now the unilateral, monotonic transformation of the discovery measure d - discussed in the previous section. Country fixed effects and time fixed effects are captured by η^i and ρ_t respectively.

Portugal, Spain, Sweden, Switzerland, Turkey, UK and USA.

¹⁴We combine the ISIC revision 2 and 3 of the employment data.

¹⁵We normalize labor productivity in the tradable and non-tradable sectors by average labor productivity within the same country and period to account for country level changes in labor productivity.

In our preferred specification we also add a country specific linear trend, T_i , to capture the systematic evolution of sectoral employment and productivity associated with structural transformation (see for example Herrendorf, Rogerson and Valentinyi (2014) or Lagakos and Waugh (2013)).¹⁶ As before, the β_k terms represent the semi-elasticities of discoveries k periods away from the discovery which we add up according to the following formula $\Omega_k = \sum_{j=1}^k \beta_j$ for the lags and according to the following formula $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$ for the leads. The country-specific error is ε_t^i and standard-errors are clustered on the country level.

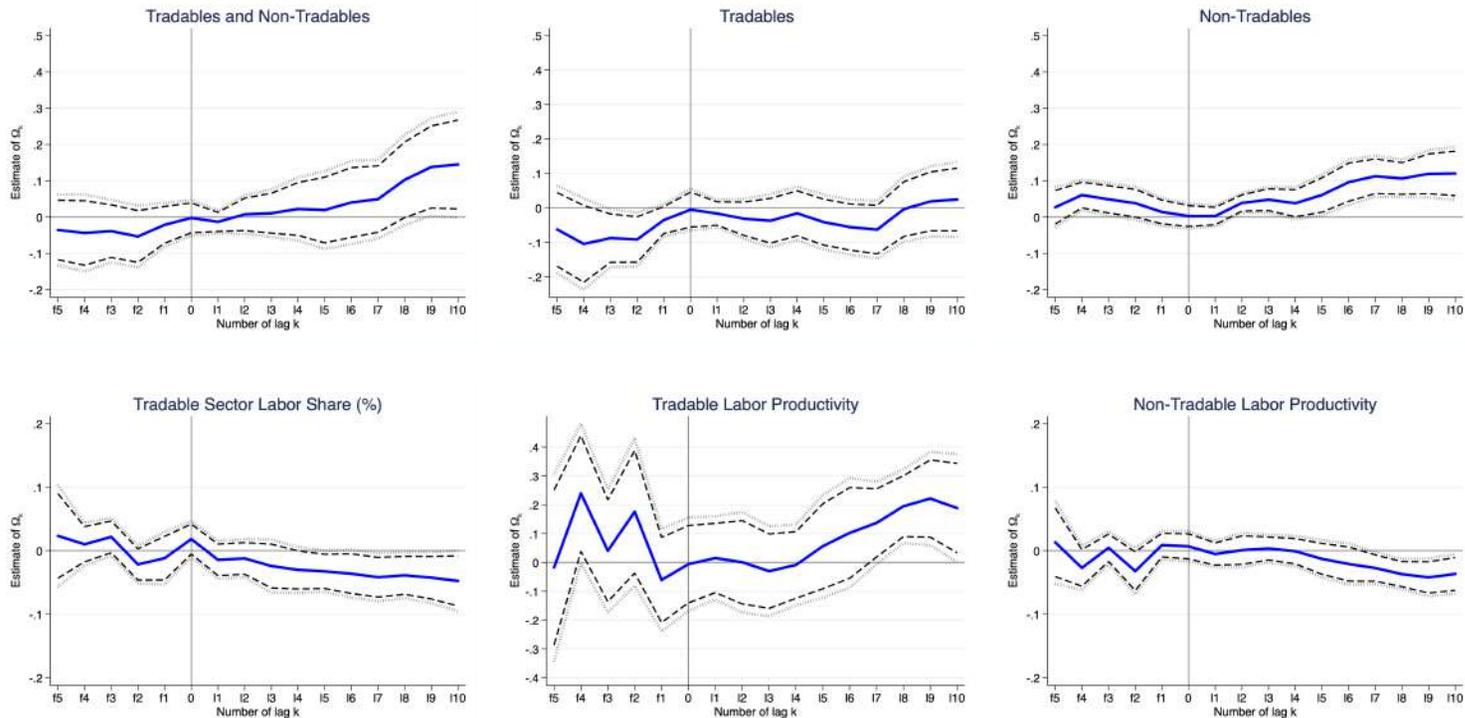
Results: The results are presented in Figure 3. The first row emphasizes that our previous findings with respect to the bilateral real exchange rates remain quantitatively and qualitatively unchanged in this particular sub-sample: a discovery with the value of 10% of a country’s GDP leads to a 1.5% appreciation of the real exchange rate.¹⁷ Furthermore, unlike in the full sample, the result on the real exchange rate is significant at the 5%.

Next, we turn to the estimation of employment and productivity effects of giant oil and gas discoveries. At the core of Dutch Disease theories is the idea that an increase in income leads to higher spending and a reallocation of labor from the traded to the non-traded sector. In the first chart of the second row we provide evidence for the presence of this mechanism by exploring the effect on the employment share in the traded sector (see equation 1 for the definition). Changes in employment shares before the discovery do not differ significantly between the treated group and the control group. But following the discovery, labor shares in the tradable goods sector decreases relative to the control group. In particular, a median discovery decreases the employment share in the traded sector by 0.45 percentage points. Since the average country employs 14% of its labor force in the traded sector, our results suggest that employment drops by 4% following a median discovery in the first 10 year following a discovery. Also note that by the time production typically starts approximately 5 years following the discovery, more than 50% of the 10-year cumulative effect has already occurred. This, once again, indicates that Dutch Disease dynamics begin to operate well before production starts. We also report the effect of discoveries on labor productivity in the respective sectors in the two bottom right charts. We focus on labor productivity both because models of Dutch disease offer stark predictions with respect to this measure (see Kuralbayeva and Stefanski (2013) or the model in Appendix B) but also because - lacking sufficiently high quality wage data going back to 1970 - under minimal assumptions these measures can be interpreted as constant-price sectoral wages.¹⁸ A median discovery increases labor productivity in the traded sector by 1.8% and decreases it in the non-traded sector by 0.3%.

¹⁶See Figure A.12 in the Appendix for the results without the trend.

¹⁷The estimation consists of all bilateral combinations of countries which includes at least one of the 23 OECD countries.

¹⁸According to standard theory wages, measured in units of sectoral output, are equal to a worker’s marginal productivity and - under a Cobb-Douglas production function - are also proportional to average labor productivity (output per worker). See the illustrative example in Appendix B for details.



Notes: Results are based on the subsample of OECD countries defined in the text. The LHS variable in the *first row* 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. All results include country-pair fixed effects and year fixed effects. The LHS variable in the *second row* is either the change in the traded sector labor share, changes in traded sector labor productivity or changes in the non-traded sector labor productivity. All results include country fixed effects, year fixed effects and a country specific linear trend (Please see the Figure A.12 in the Appendix for the results without the trend.). The blue solid line is the sum of year-to-year growth effects for the years t to $t+k$. The cumulative effect is calculated by adding β_k 's which are estimated in equation 6: $\Omega_k = \sum_{j=0}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed and the dotted lines represent the 90% and the 95% confidence intervals. To calculate the confidence intervals we employ a two-way clustering in the *first row*. This allows the errors to correlate arbitrarily with errors of other bilateral pairs containing one of the countries within the pair. We cluster the standard errors on the country level in the *second row*.

Figure 3: Cumulative effect of large discoveries on the real exchange, labor shares and productivities in OECD subsample.

Responses	RER	RERT	RERN	Mfg. Emp Sh.	Mfg. Prod.	Non-Mfg. Prod.
Data (Full)	1.6%	-0.1%	1.7%	-	-	-
Data (OECD)	1.5%	0.3%	1.2%	-0.45pp	1.8%	-0.3%
Model	1.4%	0%	1.4%	-0.68pp	1.4%	-0.3%

Note: The model estimates are well within the 90% confidence bounds of our estimates.

Table 1: Summary of responses to giant resource discovery (equivalent to 10% of GDP) after 10 years.

Finally, to address potential endogeneity and measurement concerns related to our measurement of discoveries, we reproduce the results by replacing our discovery measure with time dummies. Results are qualitatively similar and are presented in Figure A.13.

4 Theory

To put our estimates in perspective we summarise the empirical results of the previous section in rows 1 and 2 of Table 1 and compare them to the theoretical predictions of a calibrated model in the bottom row. These theoretical results are based on a simple, small-open-economy model calibrated to the experience of Canada - arguably a small, open and resource-rich country. The model, presented in Appendix B, is designed to capture the main mechanisms of the original model by Corden and Neary (1982). The real exchange rate is entirely driven by changes in the prices of non-tradable goods, labor can move freely to equalise the marginal revenue products across sectors and capital is sector-specific. In contrast to the original model we allow for forward looking behaviour and borrowing to capture Dutch Disease dynamics which have been emphasised by van der Ploeg and Venables (2013). In that setting, a discovery may trigger an increase in spending long before production starts. Intuitively, agents expecting future windfalls borrow from abroad to smooth consumption and hence increase their spending on tradable and non-tradable goods. Whilst higher demand for tradable goods can be satiated by imports from abroad, more workers must be employed in the non-tradable sector to meet the higher demand for locally produced non-tradable goods. In order for this to happen, prices of non-tradable goods rise, increasing the wages in the non-tradable sector and pulling workers out of the tradable sector into the non-tradable sector. The reallocation of workers in the presence of a fixed factor leads to lower labor productivity in the non-traded sector and higher labor productivity in the traded sector. Notice that the response to the discovery in our model is not instantaneous, since there is a debt-elastic interest rate that increases with borrowing. This prevents agents from perfectly smoothing expected future revenues. We find that our empirical estimates match the predictions of the model very well, except that the instantaneous adjustments at the time of discovery are more muted in the data than in the model.

5 Conclusion

We provide robust evidence for an appreciation of the real exchange rate in response to a large oil or gas discovery. A discovery equivalent in value to 10% of a country's GDP causes the real exchange rate to appreciate by 1.5% within 10 years. Consistent with traditional theories of exchange rates, we find that the appreciation is almost exclusively driven by the non-traded component of the real exchange rate. We also provide evidence for the reallocation of labor from the traded to the non-traded sector. In particular, we find that following a median discovery, half a percentage point of the total labor force reallocates from the tradable to the non-tradable goods sector within 10 years. Finally, we show evidence on changes in sectoral labor productivity associated with this reallocation. Following a median discovery, labor productivity rises by 1.8% in the traded sector and decreases by 0.3% in the non-traded sector. Importantly, the empirical findings match very well with the predictions of a standard, small-open-economy model of exchange rates. This paper thus provides the first direct evidence of the key appreciation and reallocation channels central to both the Dutch disease and the Balassa-Samuelson literature, in the framework of a quasi-natural experiment.

References

- Allcott, Hunt and Daniel Keniston. 2014. Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America. Technical report National Bureau of Economic Research.
- Aragón, Fernando M, Juan Pablo Rud and Gerhard Toews. 2018. “Resource shocks, employment, and gender: evidence from the collapse of the UK coal industry.” *Labour Economics* 52:54–67.
- Arezki, Rabah, Valerie A Ramey and Liugang Sheng. 2017. “News shocks in open economies: Evidence from giant oil discoveries.” *The quarterly journal of economics* 132(1):103–155.
- Balassa, Bela. 1964. “The purchasing-power parity doctrine: a reappraisal.” *The Journal of Political Economy* pp. 584–596.
- Beine, Michel, Serge Coulombe and Wessel N Vermeulen. 2014. “Dutch disease and the mitigation effect of migration: evidence from Canadian provinces.” *The Economic Journal* 125(589):1574–1615.
- Berka, Martin, Michael B. Devereux and Charles Engel. 2018. “Real Exchange Rates and Sectoral Productivity in the Eurozone.” *American Economic Review* 108(6):1543–81.
URL: <http://www.aeaweb.org/articles?id=10.1257/aer.20151045>
- Betts, Caroline M. and Timothy J. Kehoe. 2006. “U.S. Real Exchange Rate Fluctuations and Relative Price Fluctuations.” *Journal of Monetary Economics* 53(7):1297–1326.
- Betts, Caroline M. and Timothy J. Kehoe. 2008. “Real Exchange Rate Movements and the Relative Price of Non-traded Goods.” *NBER Working Paper* (14437).
- Bjornland, Hilde C. and Leif A. Thorsrud. 2016. “Boom or Gloom? Examining the Dutch Disease in Two-speed Economies.” *The Economic Journal* .
- BOC. 2016. “Government of Canada marketable bonds - average yields - over 10 years.” http://www.bankofcanada.ca/wp-content/uploads/2010/09/selected_historical_v122487.pdf/.
- Brunnschweiler, Christa N and Erwin H Bulte. 2008. “The resource curse revisited and revised: A tale of paradoxes and red herrings.” *Journal of environmental economics and management* 55(3):248–264.
- Cashin, Paul, Luis F. Céspedes and Ratna Sahay. 2004. “Commodity currencies and the real exchange rate.” *Journal of Development Economics* 75(1):239 – 268.
- Cassel, G. 1918. “Abnormal deviations in international exchanges.” *Economic Journal* 28.

- Chen, Yu-Chin and Kenneth Rogoff. 2003. “Commodity currencies.” *Journal of International Economics* 60(1):133 – 160.
- Chinn, Menzie and Louis Johnston. 1996. Real Exchange Rate Levels, Productivity and Demand Shocks: Evidence from a Panel of 14 Countries. Working Paper 5709 National Bureau of Economic Research.
URL: <http://www.nber.org/papers/w5709>
- Chong, Yanping, Òscar Jordà and Alan M Taylor. 2012. “The Harrod–Balassa–Samuelson Hypothesis: Real Exchange Rates And Their Long-Run Equilibrium.” *International Economic Review* 53(2):609–634.
- Corden, W Max and J Peter Neary. 1982. “Booming Sector and De-Industrialisation in a Small Open Economy.” *The Economic Journal* 92:825–48.
- Corden, Warner Max. 1984. “Booming sector and Dutch disease economics: survey and consolidation.” *oxford economic Papers* 36(3):359–380.
- Cust, James and Torfinn Harding. forthcoming. “Institutions and the Location of Oil Exploration.” *Journal of the European Economic Association* .
- de Cordoba, Gonzalo Fernandez and Timothy J. Kehoe. 2000. “Capital flows and real exchange rate fluctuations following Spain’s entry into the European Community.” *Journal of International Economics* 51(1):49 – 78.
URL: <http://www.sciencedirect.com/science/article/pii/S0022199699000379>
- den Butter, Frank AG. 2007. “National accounts and indicators.” *Measurement in Economics: A Handbook* p. 189.
- Eastwood, Robert K and Anthony J Venables. 1982. “The macroeconomic implications of a resource discovery in an open economy.” *The Economic Journal* 92(366):285–299.
- Engel, Charles. 1999. “Accounting for US Real Exchange Rate Changes.” *Journal of Political Economy* 107(3).
- Engel, Charles and Kenneth D. West. 2005. “Exchange Rates and Fundamentals.” *Journal of Political Economy* 113(3):485–517.
URL: <https://doi.org/10.1086/429137>
- Harding, Torfinn and Anthony J Venables. 2016. “The Implications of Natural Resource Exports for Nonresource Trade.” *IMF Economic Review* 64(2):268–302.
- Herrendorf, Berthold, Richard Rogerson and Akos Valentinyi. 2014. Chapter 6 - Growth and Structural Transformation. In *Handbook of Economic Growth*, ed. Philippe Aghion and Steven N. Durlauf. Vol. 2 of *Handbook of Economic Growth* Elsevier pp. 855 – 941.
URL: <http://www.sciencedirect.com/science/article/pii/B9780444535405000069>

- Horn, Mike Myron K. 2011. "Giant Oil and Gas Fields of the World." <http://www.datapages.com/>. Accessed: 2015-03-03.
- Hsiang, Solomon M and Amir S Jina. 2014. The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones. Technical report National Bureau of Economic Research.
- Imbs, Jean, Haroon Mumtaz, Morten O. Ravn and H el ene Rey. 2005. "PPP Strikes Back: Aggregation And the Real Exchange Rate." *The Quarterly Journal of Economics* 120(1):1.
- IMF. 2016. "Government Financial Statistics."
- Ismail, Kareem. 2010. The Structural Manifestation of the Dutch Disease'; The Case of Oil Exporting Countries. IMF Working Papers 10/103 International Monetary Fund.
- Kuralbayeva, Karlygash and Radoslaw Stefanski. 2013. "Windfalls, Structural Transformation and Specialization." *Journal of International Economics* 90:273–301.
- Lagakos, David and Michael E. Waugh. 2013. "Selection, Agriculture, and Cross-Country Productivity Differences." *American Economic Review* 103(2):948–80.
URL: <http://www.aeaweb.org/articles?id=10.1257/aer.103.2.948>
- Lei, Yu-Hsiang and Guy Michaels. 2014. "Do giant oilfield discoveries fuel internal armed conflicts?" *Journal of Development Economics* 110(C):139–157.
- Lothian, James R and Mark P Taylor. 2008. "Real exchange rates over the past two centuries: how important is the Harrod-Balassa-Samuelson effect?" *The Economic Journal* 118(532):1742–1763.
- Neary, Peter. 1988. "Determinants of the Equilibrium Real Exchange Rate." *American Economic Review* 78(1):210–15.
- Pigou, A. 1923. "The foreign exchanges." *Quarterly Journal of Economics* 37:52–74.
- Rebelo, Sergio and Carlos A. Vegh. 1995. *Real Effects of Exchange-Rate-Based Stabilization: An Analysis of Competing Theories*. MIT Press pp. 125–188.
URL: <http://www.nber.org/chapters/c11018>
- Rogoff, Kenneth. 1996. "The Purchasing Power Parity Puzzle." *Journal of Economic Literature* 34(2):647–668.
- Samuelson, Paul A. 1964. "Theoretical Notes on Trade Problems." *The Review of Economics and Statistics* 46(2):145–154.
URL: <http://www.jstor.org/stable/1928178>
- Schmitt-Grohe, Stephanie and Martin Uribe. 2003. "Closing small open economy models." *Journal of International Economics* 61:163–185.

- Smith, Brock. 2014. Dutch disease and the oil and boom and bust. Technical report Oxford Centre for the Analysis of Resource Rich Economies, University of Oxford.
- STATCAN. 2016a. *Canadian Socioeconomic Database from Statistics Canada*. Statistics Canada.
- STATCAN. 2016b. *Historical Statistics of Canada*. Statistics Canada.
- Stefanski, Radoslaw and Gerhard Toews. 2018. What's in a wedge? Misallocation and taxation in the oil industry. WorkingPaper 1804 University of St Andrews.
- Stockman, Alan C. and Linda L. Tesar. 1995. "Tastes and Technology in a Two-Country Model of the Business Cycle: Explaining International Comovements." *The American Economic Review* 85(1):168–185.
URL: <http://www.jstor.org/stable/2118002>
- Taylor, Alan M. and Mark P. Taylor. 2004. "The Purchasing Power Parity Debate." *The Journal of Economic Perspectives* 18(4):135–158.
URL: <http://www.jstor.org/stable/3216796>
- Tica, Josip and Ivo Družić. 2006. "The Harrod-Balassa-Samuelson effect: a survey of empirical evidence." *EFZG working paper series* (07):1–38.
- Toews, Gerhard and Pierre-Louis Vezina. 2017. Resource discoveries and FDI bonanzas: An illustration from Mozambique. Working Paper 199 OxCarre.
- UN. 2014. *National Accounts Statistics database*.
- van der Ploeg, Frederick and Anthony J. Venables. 2011. "Harnessing Windfall Revenues: Optimal Policies for Resource-Rich Developing Economies." *The Economic Journal* 121(551):1–30.
- van der Ploeg, Frederick and Anthony J. Venables. 2013. "Absorbing a windfall of foreign exchange: Dutch disease dynamics." *Journal of Development Economics* 103:229–243.
- van der Ploeg, Frederick and Steven Poelhekke. 2010. "The pungent smell of *red herrings*: Subsoil assets, rents, volatility and the resource curse." *Journal of Environmental Economics and Management* 60(1):44–55.

A For Online Publication: Appendix on Empirical Robustness

Descriptives In Table A.1 we provide descriptive statistics for all the country -pair observations including the US in the denominator. In Table A.2 we provide the descriptive statics of the labor data for the sub-sample of 23 OECD countries.

Taxation A significant share of the expected revenues is received by the operating oil companies and, thus, might not necessarily be spent locally. To account for this we use data from Wood Mackenzie to calculate the country specific average government take, the share of profits collected by governments, and use it to adjust our discovery measures. See Stefanski and Toews (2018) for details on the construction of government take. The results are presented in Figure A.1.

Time Dummy As an alternative to the measure provided to us by Arezki, Ramey and Sheng (2017) we use time dummies, indicating the year of the discovery. This strategy ensures that the identifying variation is insulated to the timing of discoveries and reduces potential bias related to measurement error and omitted variables. The results are presented in Figure A.2 for the effects on the exchange rate and in Figure A.13 for the effects on labor shares and productivities and are in line with our main results. The dummy measure in the bilateral specification is coded as 1 if $D_t^{ij} > 0$ and -1 if $D_t^{ij} < 0$.

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 randomly reassign the value of the treatment variable across the whole sample. Second, we repeatedly re-estimate equation 5 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 A.3 displays the distribution of the generated point estimates of the cumulative effect after 10 years. The distribution is centred around zero, as expected for a well-specified model. 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.

Redefining treatment and control groups We re-estimate our baseline specification with different lag structures. The results are presented in Figure A.4, where the adjustment in the lag structure is self explanatory. We also re-estimate our main specifications by focusing on countries which have at least one giant discovery in the last 50 years. Arguably,

variable	mean	sd	max	min
$grer_t^{iUS} = \log(RED_t^{iUS}) - \log(RED_{t-1}^{iUS})$	0.00	0.20	6.01	-5.84
$grert_t^{iUS} = \log(RED_t^{iUS}) - \log(RED_{t-1}^{iUS})$	0.01	0.23	6.04	-5.71
$grern_t^{iUS} = \log(RED_t^{iUS}) - \log(RED_{t-1}^{iUS})$	-0.01	0.12	2.30	-2.33

Note: All country-pair observations with the US in the denominator (43 years, 164 countries).

Table A.1: Descriptive Statistics: Exchange Rate

variable	mean	sd	max	min
$\log(\text{Labor force})_t^i - \log(\text{Labor force})_{t-1}^i$	0.01	0.01	0.10	-0.09
$\log(\text{T Emp. Sh.})_t^i - \log(\text{T Emp. Sh.})_{t-1}^i$	-0.00	0.01	0.03	-0.03
$\log(\text{T Prod.})_t^i - \log(\text{T Prod.})_{t-1}^i$	0.01	0.04	0.23	-0.19
$\log(\text{N Prod.})_t^i - \log(\text{N Prod.})_{t-1}^i$	0.00	0.00	0.25	-0.06

Note: Labor statistics for countries joining the OECD by 1973 (43 year, 23 countries).

Table A.2: Descriptive Statistics: Labor

this increases the comparability between ‘treated’ and ‘controls’. The results are presented in Figure A.5.

Alternative specification We 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 $t - 1$, $\hat{D}_{t-1}^{ij} = \sum_{k=0}^{t-1} D_k^{ij}$, and add it as a control to equation 5. Figure A.6 shows the results.

Outliers We drop 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 A.7.

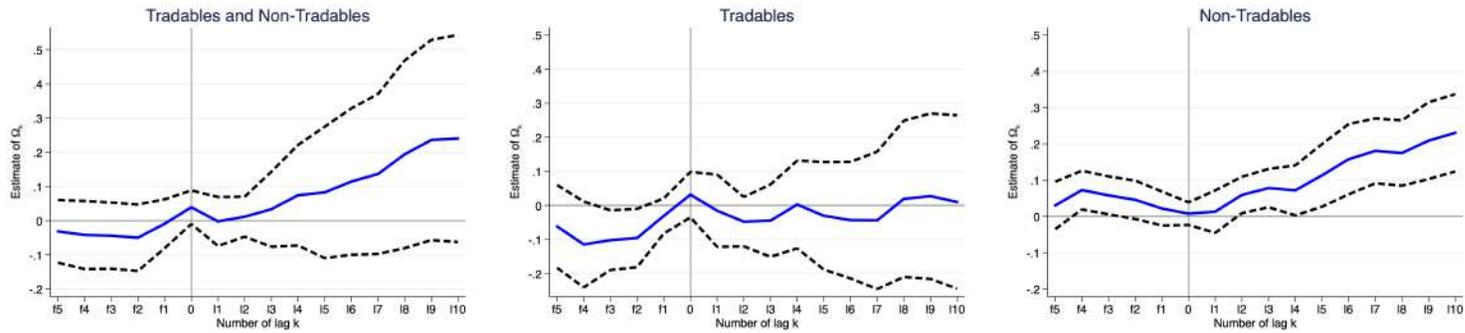
Alternative economic structures The manufacturing sector is considered tradable, as is standard in the literature, and all other non-resource sectors are considered to be non-tradable in our baseline specification. We conduct two robustness tests in which we deviate from this definition. In Figure A.8 we present the results from estimating our baseline specification where we exclude the agricultural and the construction sector from the non-tradable sector. Alternatively, we treat the agricultural sector as tradable and the results from estimating our baseline specification are presented in Figure A.9.

Alternative data We have chosen the UNCTAD data for our baseline specification because it has the largest coverage in the time and the cross sectional 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 re-estimate our model by employing producer prices. Using their data reduces the number of countries and years in our sample to 50 and 26, respectively. With 26 time periods we cannot employ as many leads and lags as in our baseline specification. We reduce the number of leads to 2 and the number of lags to 6. The results are displayed in Figure [A.10](#). In contrast to our baseline specification, we find that now also the effect on the total real exchange rate is statistically significant. The magnitudes remain in line with our baseline specification.

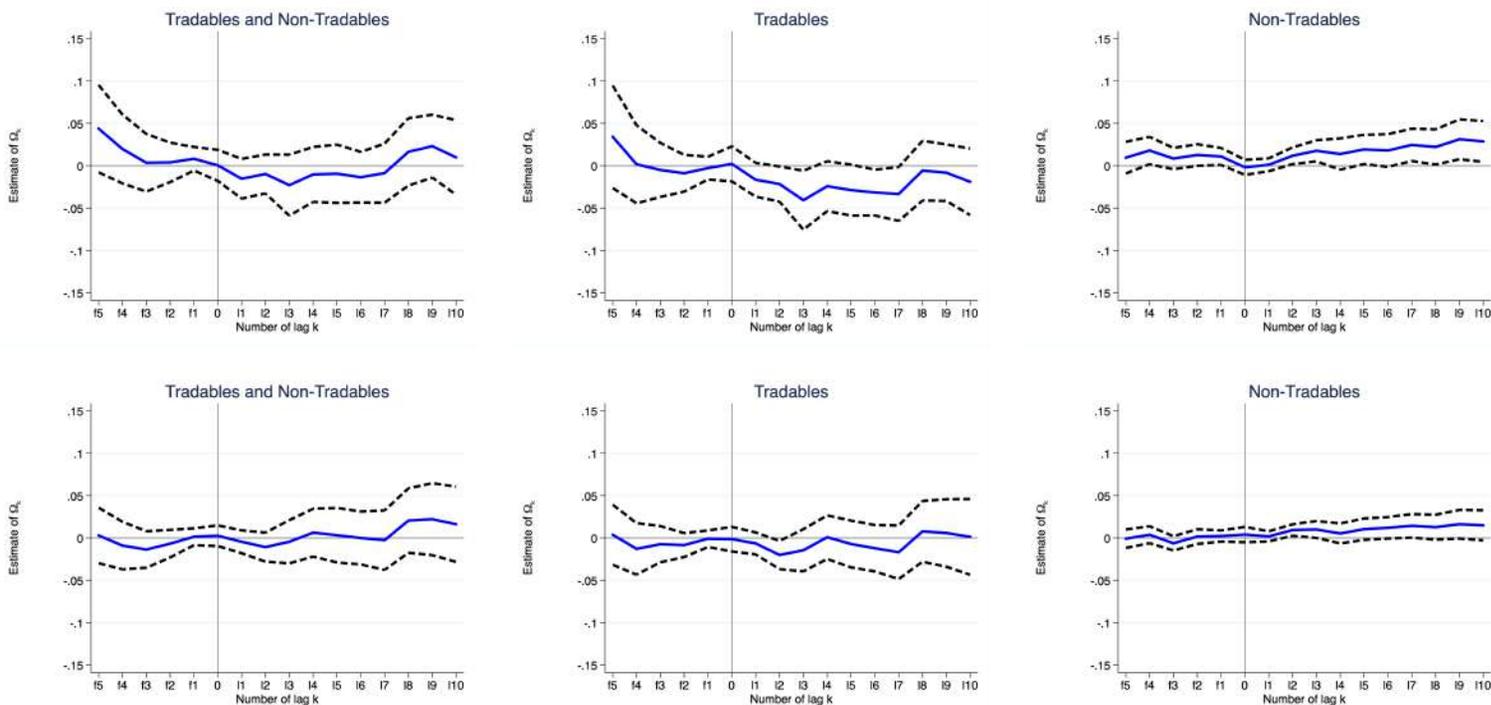
Real Effective Exchange Rate Our bilateral real exchange rates imply equal and stable weights across all potential trading partners and changes are entirely driven by changing prices. To account for the varying importance of trading partners in the determination of the real exchange rate, we estimate the unilateral version of our main specification using the real effective exchange rate as our LHS variable. The real effective exchange rate is widely used due to its simplicity and its implications on purchasing power, however it is also dependent on the choice of trade-weights and does not allow us to account for country-pair-specific characteristics. For the estimation we use a publicly available data set provided by [Bruegel](#) covering 142 countries and at least 33 years. The estimate of the cumulative effect on the real effective exchange rate is larger and statistically significant on the 10% level (see Figure [A.11](#)). In the second row of the same Figure we reproduce the results using a time dummy on the RHS instead of our baseline measure.

Figure A.1: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Discovery measures are adjusted for country specific average taxation.**



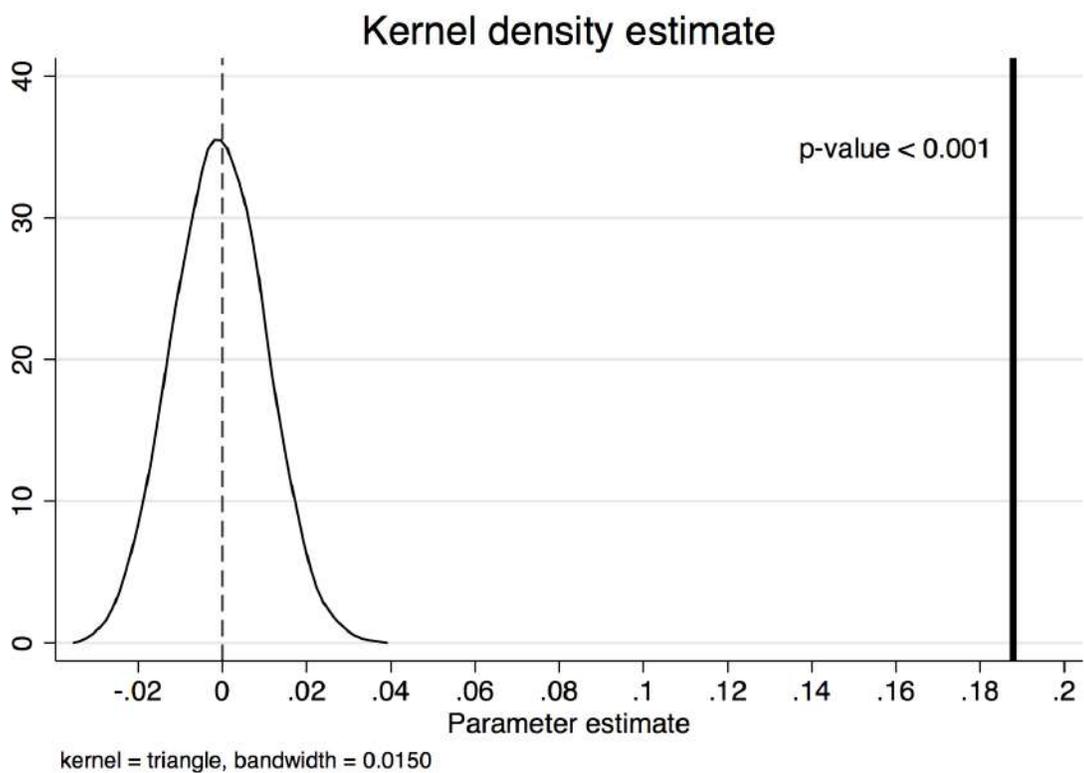
Notes: Results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding β_k 's which are estimated in equation 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent 90% confidence intervals. To calculate the 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.

Figure A.2: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Discovery measures are replace by time dummies indicating the year of the discovery.**



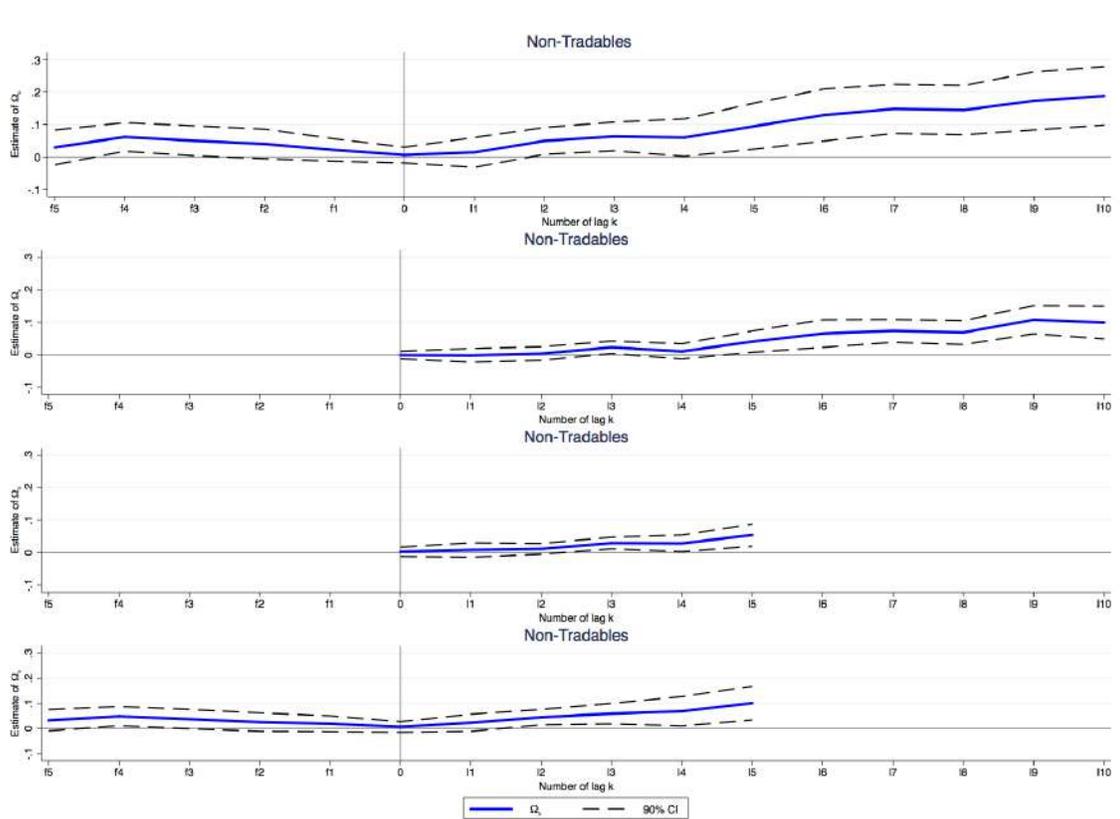
Notes: Results are estimated using OLS and include country-pair fixed effects and year fixed effects. In the *first row* we present the results for the full sample and in the second row we present the results for the OECD subsample. The LHS variable is either the change in the logged real exchange rate 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 sum of year-to-year growth effects for the years t to $t + k$. The cumulative effect is calculated by adding β_k 's which are estimated in equation 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

Figure A.3: Distribution of point estimates for the cumulative effect on the changes in the logged real exchange rate of the non-tradable goods.



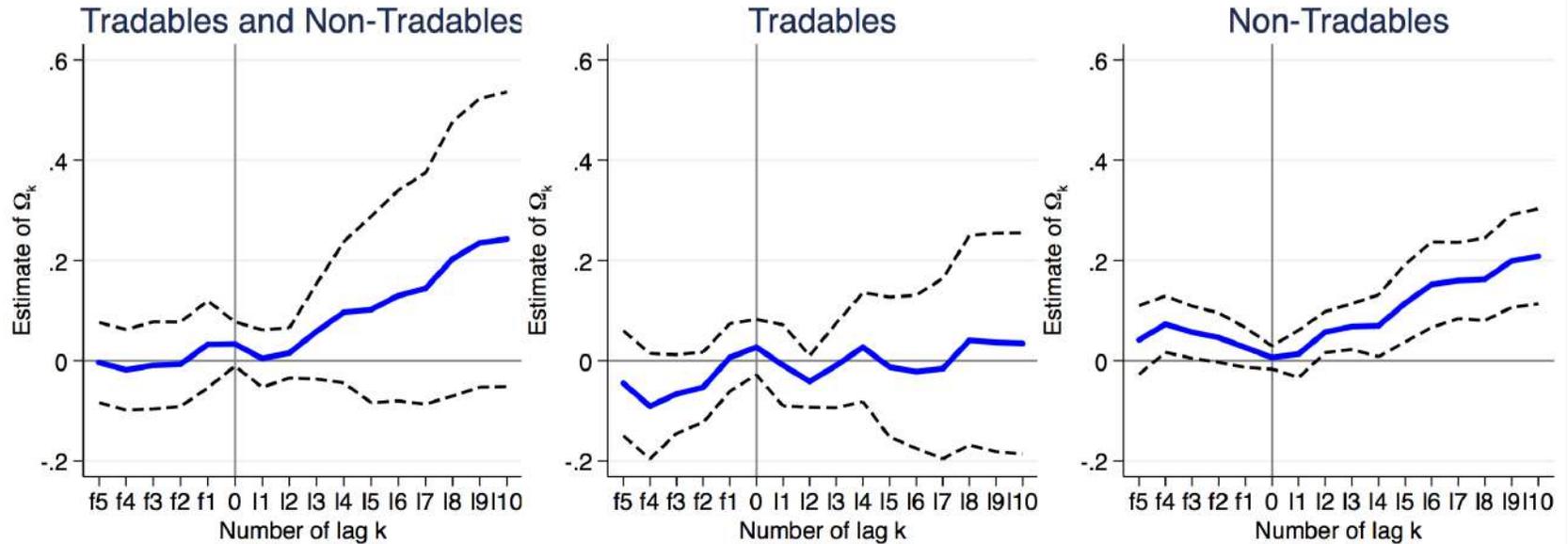
Notes: The distribution is constructed by re-estimating equation 5 and add up the estimated β 's up to 10 years following a discovery. Cumulative coefficient from the estimate using real data is shown as vertical lines with the p-value.

Figure A.4: 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.**



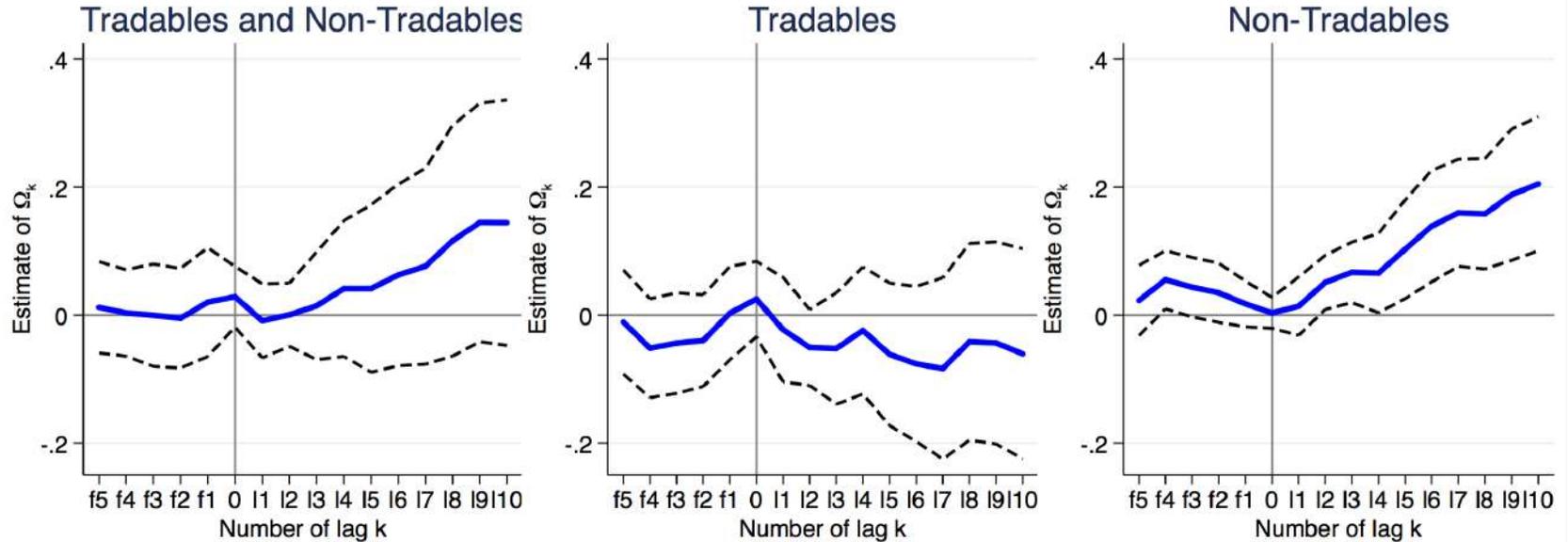
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is change in the logged real exchange rate of non-tradable goods. The blue solid line is the sum of year-to-year growth effects for the years t to $t+k$. The cumulative effect is calculated by adding up β_k 's which are estimated in equation 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

Figure A.5: 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.**



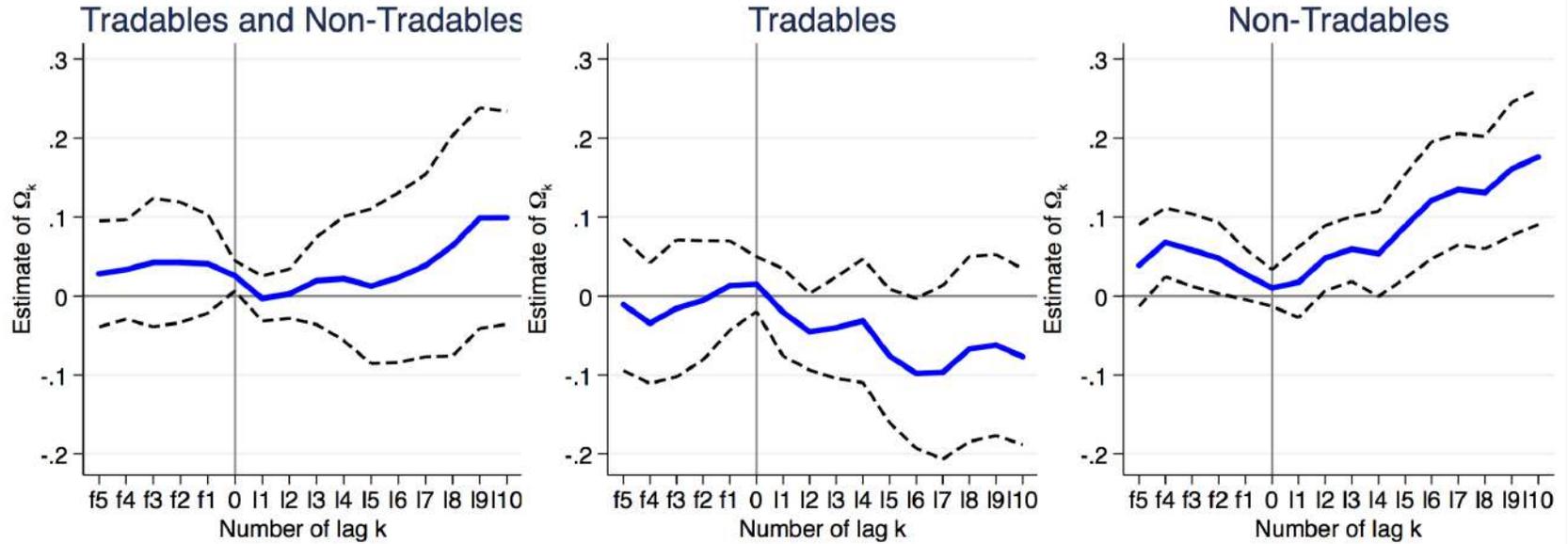
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the 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 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

Figure A.6: 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.**



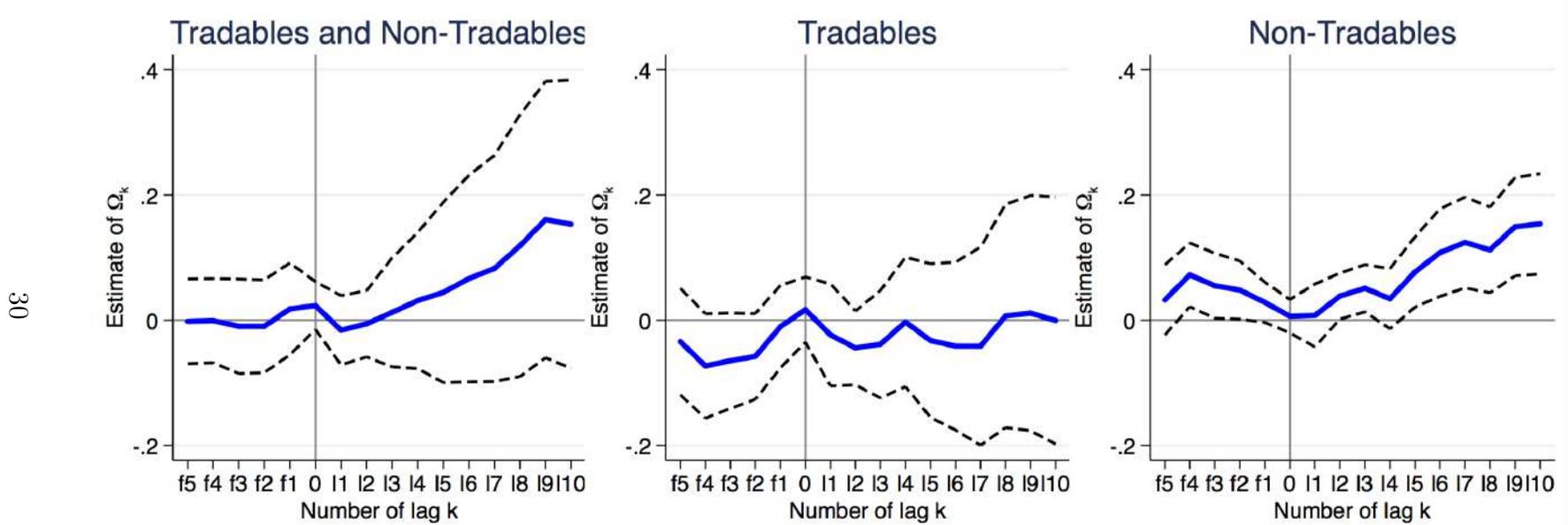
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the real exchange rate. The blue solid line is the 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 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

Figure A.7: 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.**



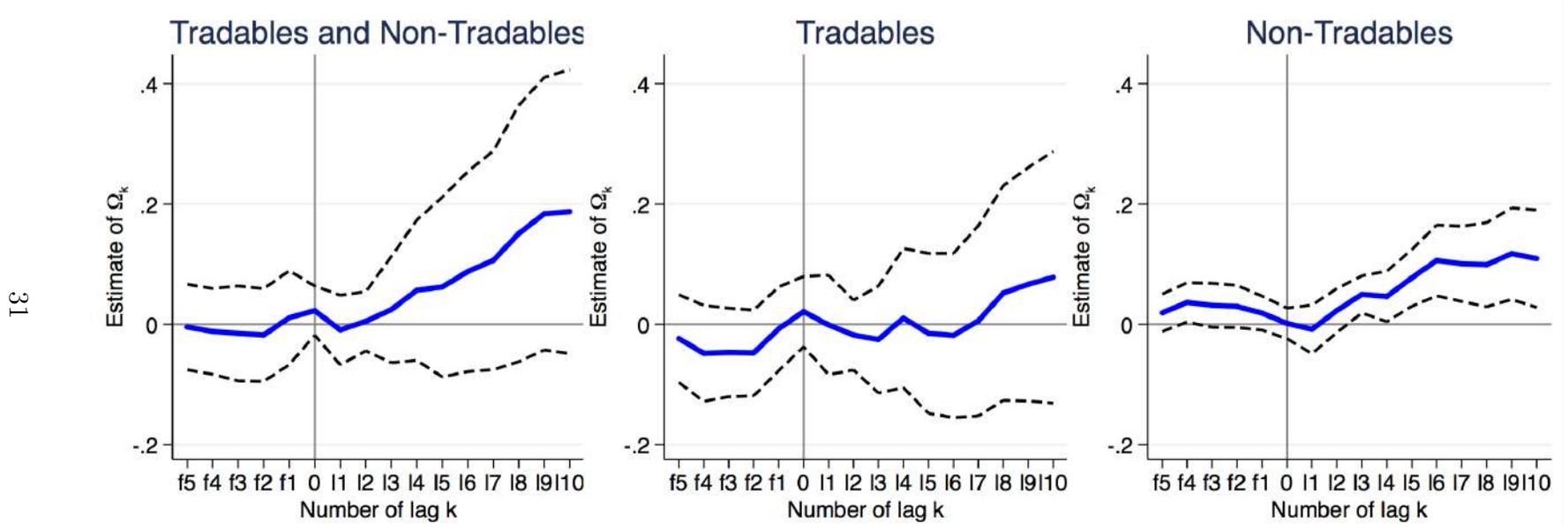
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the 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 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

Figure A.8: 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 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 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

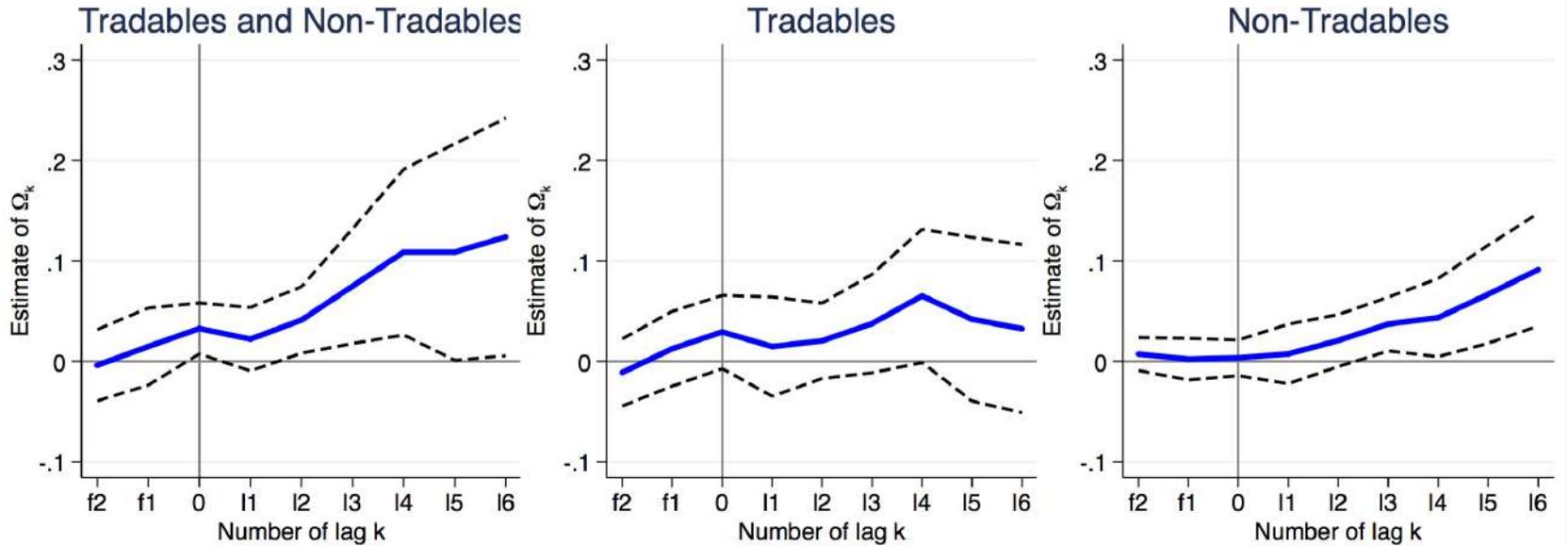
Figure A.9: Cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Agricultural goods are redefined as being tradable.**



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 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 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

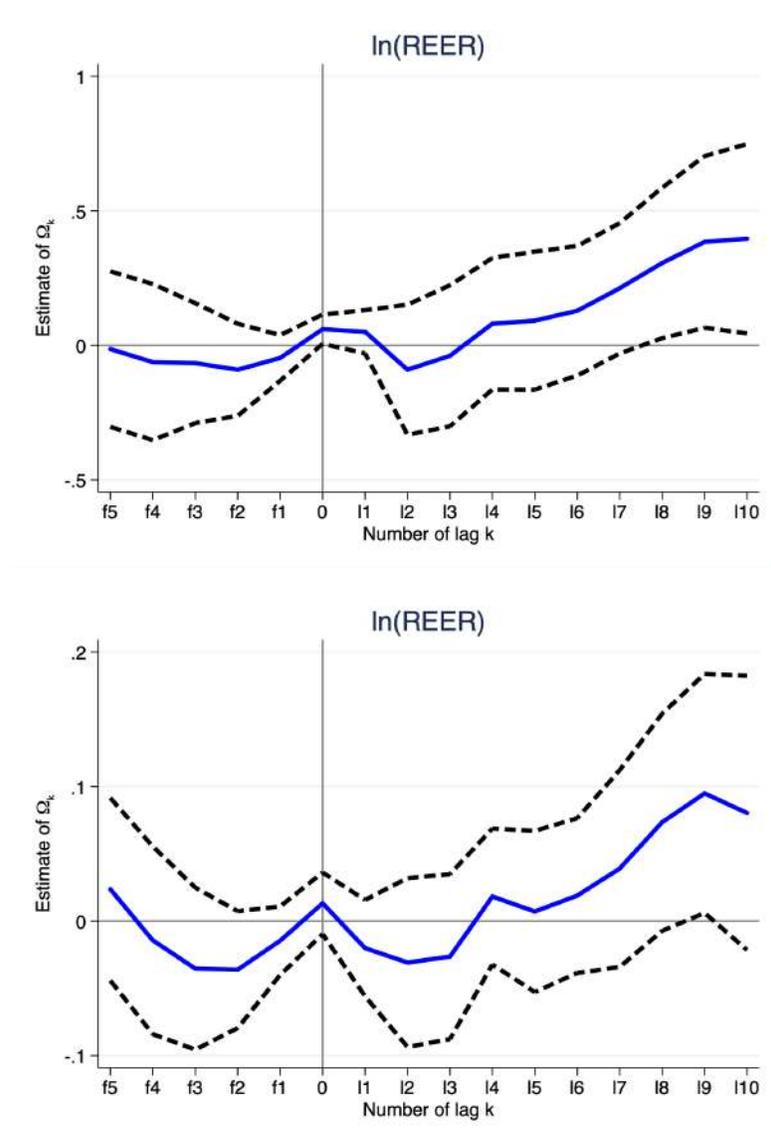
Figure A.10: Effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. **Information on producer prices is used to decompose changes in the real exchange into its tradable and its non-tradable component.**

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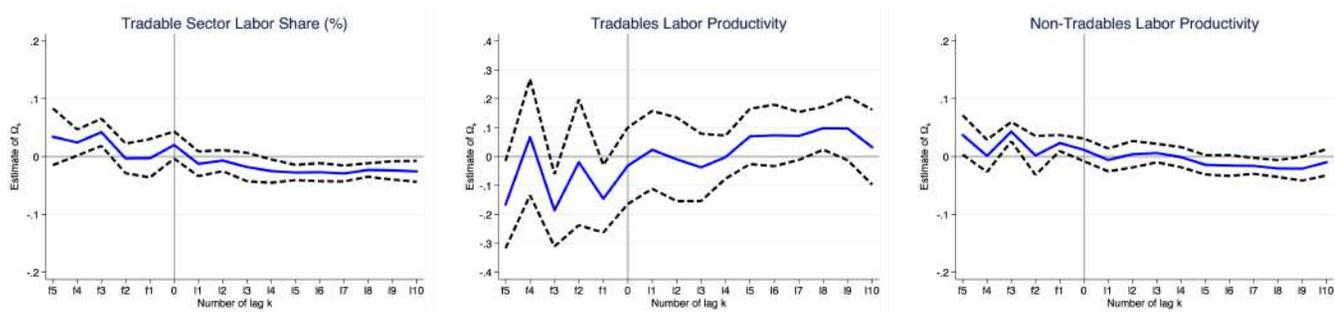
Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the 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 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. To calculate the 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.

Figure A.11: Effect of large oil and gas discoveries on the growth of the real effective exchange rate.



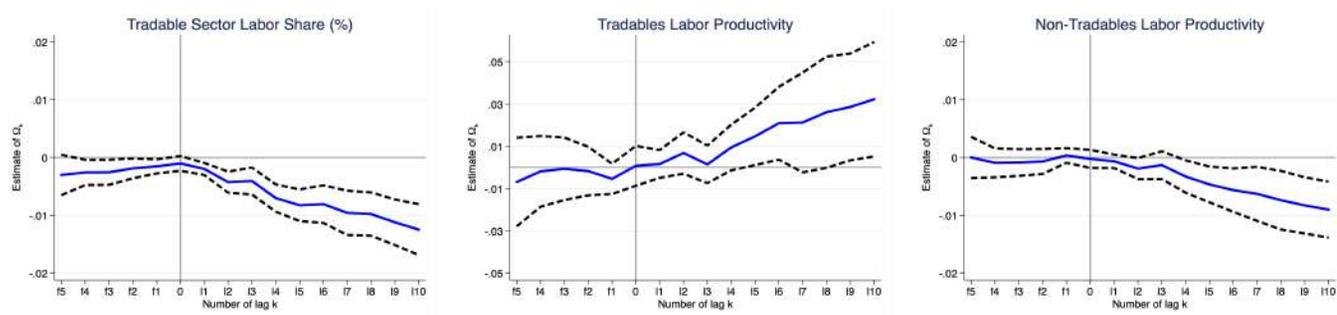
Notes: Data on the real effective exchange rate from [Bruegel](#). Results are estimated using OLS and include country fixed effects, year fixed effects and country specific linear trends. The LHS variable is the change in the logged real effective exchange rate. In the *second row* we use a dummy on the RHS to indicate the timing of the discovery instead of our baseline measure. The blue solid line is 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 a specification analog to equation 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. Errors are clustered on the country level.

Figure A.12: Cumulative effect of large discoveries on labor shares and labor productivities in OECD countries **without a linear trend**.



Notes: Results are estimated using OLS and include country fixed effects and year fixed effects. The LHS variable is either the change in the traded sector labor share, changes in traded sector labor productivity or changes in the non-traded sector labor productivity. In the *first row* we use a dummy on the RHS to indicate the timing of the discovery. In the *second row* we eliminate the country specific linear trend. The blue solid line is the sum of year-to-year growth effects for the years t to $t+k$. The cumulative effect is calculated by adding β_k 's which are estimated in equation 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. We cluster the standard errors on the country level.

Figure A.13: Cumulative effect of large discoveries on labor shares and labor productivities in OECD countries **with a dummy indicating the timing of the discovery**.



Notes: Results are estimated using OLS and include country fixed effects and year fixed effects. The LHS variable is either the change in the traded sector labor share, changes in traded sector labor productivity or changes in the non-traded sector labor productivity. In the *first row* we use a dummy on the RHS to indicate the timing of the discovery. In the *second row* we eliminate the country specific linear trend. The blue solid line is the sum of year-to-year growth effects for the years t to $t+k$. The cumulative effect is calculated by adding β_k 's which are estimated in equation 5: $\Omega_k = \sum_{j=1}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the β_k 's of the leads: $\Omega_{-k} = \sum_{j=-1}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. We cluster the standard errors on the country level.

B For Online Publication: Appendix Describing Model

We set out a simple model to illustrate how inflows of foreign revenue affect a country's real exchange rate. We calibrate the model to the experience of Canada and compare the implications of the model to our empirical findings. We find that the quantitative and qualitative predictions of the model track the evolution of the real-exchange rate, its traded and non-trade components as well as employment and sectoral productivity very closely, although the model predicts a somewhat higher initial response to an oil shock than is observed in the data.

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

$$(7) \quad \max_{b_{t+1}, c_t^T, c_t^N} \sum_{t=0}^{\infty} \beta^t (\gamma \log c_t^T + (1 - \gamma) \log c_t^N)$$

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

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

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

Utility takes a 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 goods, c_t^N . The price of traded goods, p_t^T , is taken as the numeraire, is exogenous and is pinned down on international markets. The price of non-traded goods, p_t^N , is determined locally. The agent also chooses holdings of foreign bonds, b_{t+1} .¹⁹ Purchasing a foreign bond in period $t - 1$, yields R_t units of the traded good in 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 an exogenous windfall of (tradable) natural resources, e_t^O , which he sells for an internationally set (and exogenous) price p_t^O as well as a stock of (risk-free) international bonds, b_t , held from the previous period.²⁰

For expositional ease, we split the budget constraint to emphasize an agent's (net) foreign revenue, f_t . This term captures the inflows of revenue 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, $p_t^O e_t^O$. In this paper we are interested in measuring how a change in an agent's foreign revenue, f_t , drives prices and real exchange rates. Importantly, a change in f_t can occur for one of two reasons. First, the size of the windfall, $p_t^O e_t^O$, can change in a given period.²¹

¹⁹Negative values of b_t represent debt. To rule out the possibility of Ponzi schemes, debt is bounded from below by some large number, B .

²⁰We assume that all uncertainty with respect to $p_t^O e_t^O$ is resolved in period zero. Hence from period zero onwards the agent knows the entire future path of windfall revenue.

²¹Due to changes in either prices or quantities of natural resources.

This directly influences the current-period f_t but also indirectly influences future values of f_t through changes in savings decisions. Second, the agent could learn of a natural resource discovery whose production would come online at some known, future date. Anticipating this additional source of revenue, the agent would adjust his current bond holdings to smooth future revenue over time.

Firms There are two representative, competitive firms producing traded (T) and non-traded (N) goods using labor (L_t^s) and sector-specific capital (K_t^s) rented from the household.²² The profit maximization problem of the sector $s = T, N$ firm is given by:

$$(8) \quad \max_{L_t^s, K_t^s} p_t^s Y_t^s - w_t L_t^s - r_t^s K_t^s \quad \text{s.t.} \quad Y_t^s = A_t^s (L_t^s)^{1-\alpha} (K_t^s)^\alpha,$$

Production functions, Y_t^s , take a Cobb-Douglas form and we assume $0 < \alpha < 1$. Sector-specific productivity at time t is denoted by A_t^s . For simplicity we assume that productivities grow at constant, exogenous, sector-specific rates: $g_s \equiv A_{t+1}^s / A_t^s - 1$.

Interest Rates We follow Schmitt-Grohe and Uribe (2003) as well as van der Ploeg and Venables (2011) by introducing a debt-elastic interest rate, R_t :

$$(9) \quad R_t = R^* + \phi \left(e^{\bar{b} - \frac{b_t}{A_t^T}} - 1 \right).$$

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 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.²³ The debt-elastic interest rate is both a realistic and a technically convenient assumption. It is eminently plausible that the probability of default increases with higher debt levels (especially in poorer country, where many giant resource discoveries take place) which can contribute to higher interest rates. The assumption also eliminates the steady state's dependence on initial conditions and equilibrium dynamics that can possess a random walk component. Finally, following convention, we assume that the household does not internalize the costs of borrowing.²⁴

²²To keep the model as simple as possible and to focus on the mechanism of interest, we do not include natural resources as an input. We also assume sector-specific (or fixed) capital as a reduced-form method of introducing decreasing returns to scale in production. 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)).

²³We show below that this 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.

²⁴Allowing households to internalize these costs has very little quantitative and qualitative impact.

Market Clearing Trade is not necessarily balanced, period-by-period, as both foreign debt and oil exports can be used to pay for imports of traded goods, m_t . It follows that $p_t^T m_t = f_t$. Also, 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 $K_t^N = 1$.

Competitive Equilibrium For any R^* and $\{p_t^T, p_t^O\}_{t=0}^\infty$, a competitive equilibrium of the model is defined as a set of prices $\{p_t^T, p_t^N, w_t, r_t^T, r_t^N, R_t\}_{t=0}^\infty$ as well as a set of 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.

Solution From the household and firms' problems, we can derive an Euler Equation that describes the evolution of bond holdings as well as two equations describing the evolution of employment and prices. Together, these equations pin down the solution to the problem.

First, to derive an Euler Equation it is helpful to de-trend variables. In particular, given productivity growth rates, we define variables that are constant in the long run: $\tilde{b}_t \equiv b_t/A_t^T$, $\tilde{c}_t^T \equiv c_t^T/A_t^T$ and $\tilde{c}_t^N \equiv c_t^N/A_t^N$. The first order conditions of the household give us the Euler equation that (indirectly) pins down bond holdings:

$$(10) \quad \frac{g_T \tilde{c}_{t+1}^T}{\tilde{c}_t^T} = \beta R_{t+1}.$$

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 in the long run oil revenues are vanishingly small i.e. $\lim_{t \rightarrow \infty} \frac{p_t^O e_t^O}{A_t^T p_t^T} = 0$, the Euler equation implies that $\lim_{t \rightarrow \infty} \tilde{b}_t = \bar{b}$.²⁵

Second, we focus on the remaining two equations which help illustrate how foreign revenue affects prices. From the consumer's first order conditions and the market clearing conditions, we derive a relationship between relative prices and relative quantities:

$$(11) \quad \frac{p_t^N}{p_t^T} = \frac{1 - \gamma}{\gamma} \frac{c_t^T}{c_t^N} = \frac{1 - \gamma}{\gamma} \frac{Y_t^T + \frac{f_t}{p_T}}{Y_t^N}.$$

Combining the above equation with the first order conditions of firms, gives an implicit expression for traded sector employment:

$$(12) \quad A_t^T (L_t^T)^{-\alpha} (1 - L_t^T) = \frac{1 - \gamma}{\gamma} \left(A_t^T (L_t^T)^{1-\alpha} + \frac{f_t}{p_T} \right).$$

²⁵To see this, notice from equation (9) and equation (10) that in the limit $g_T = \beta(R^* + \phi(e^{\bar{b}-\tilde{b}_t} - 1))$. The fact that $R^* = g_T/\beta$ then implies that $\tilde{b}_t = \bar{b}$ in the limit.

market clearing in the labor market). The black lines in Figure B.1, plot these wage offers in each sector as a function of employment in the non-traded sector, L_t^N . The marginal revenue products of each sector declines with higher levels of employment due to diminishing marginal products in production and fixed capital. In equilibrium the wages paid by each sector equate as workers move to the higher paying sector. The intersection of the the two curves at w_t^* pins down the equilibrium level of employment in the non-traded sector, L_t^{N*} (and implicitly in the traded sector as $L_t^{T*} = 1 - L_t^{N*}$).

After a discovery of oil, there is an increase in foreign revenue, f_t , which - as argued above - increases the price of the non-traded good to \bar{p}_t^N . At this higher price, the marginal revenue product of the non-traded sector rises for every level of employment to $\overline{MRP}_t^N = \bar{p}_t^N(1 - \alpha)A_t^N(L_t^N)^{-\alpha}(K_t^N)^\alpha$, plotted in red in the Figure. Since the price of traded goods is fixed internationally, the wage offers in that sector remain unchanged. Higher wage offers in the non-traded sector, attract more workers away from the traded sector, increasing non-traded sector employment to \bar{L}_t^{N*} and resulting in a new higher, equilibrium wage of \bar{w}_t^* .

As the size of employment in each sector changes, so does the sector's labor productivity. As more workers flow into the non-traded sector there is now less capital available per worker and hence the average productivity of each worker in the sector falls as does the wage in terms of non-traded good prices: $\bar{w}_t/\bar{p}_t^N = \overline{MRP}_t^N/\bar{p}_t^N = (1 - \alpha)\frac{Y_t^N}{L_t^N}$. In contrast, as employment in the traded sector shrinks, there is now more capital available per worker and hence the average productivity of each worker in the sector rises as does the wage in terms of traded good prices: $\bar{w}_t/\bar{p}_t^T = \overline{MRP}_t^T/\bar{p}_t^T = (1 - \alpha)\frac{Y_t^T}{L_t^T}$.

Next, we calibrate the above model and use it to measure the predicted increase in relative and aggregate prices in response to a giant resource discovery and the subsequent foreign revenue inflow.

Calibration Like Schmitt-Grohe and Uribe (2003) we calibrate our model to match a number of features of a typical small, open economy: Canada.²⁷ For the purpose of the calibration, we assume that Canada is on a balanced growth path and has zero endowments of oil so that it exhibits constant interest rates as well as a constant growth rate of sectoral output, consumption and bond holdings.

We divide the economy into traded and non-traded sectors as in the main body of the paper. 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).

²⁷The specific country choice is largely irrelevant for our purposes and other advanced, small open economies like Belgium or the Netherlands give very similar results.

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 $s = T, N$.
$g_T - 1$	0.02	Annualized average growth rate of HP-smoothed traded sector productivity in Canada, 1970-2010.
$g_N - 1$	0.007	Annualized average growth rate of HP-smoothed non-traded sector productivity in Canada, 1970-2010.
$1 - \alpha$	0.67	Labor share in each sector.
$b_0 = \bar{b}$	-0.9	Average consolidated Public Sector Debt to GDP ratio in Canada, 1970-2010
β	0.97	Average real interest rate in Canada, 1970-2010.
ϕ	0.08	Elasticity of risk premium, van der Ploeg and Venables (2011)
γ	0.153	Average employment share in traded sector, 1970-2010.
a	0.028	NPV of resource discovery is 10% of time zero GDP. (Only in oil rich country.)

Table B.1: Calibrated parameters

We find that the average annual labor productivity growth rate between 1970 and 2010 was 2% in the traded sector and 0.7% in the non-traded sector.²⁸ 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. Letting $g_T \equiv 1 + 0.02$ and $g_N \equiv 1 + 0.007$, we normalize $A_{1970}^T = A_{1970}^N = 1$ and we define sectoral productivity in our model as:

$$(14) \quad A_t^N = g_N^{t-1970} \text{ and } A_t^T = g_T^{t-1970}.$$

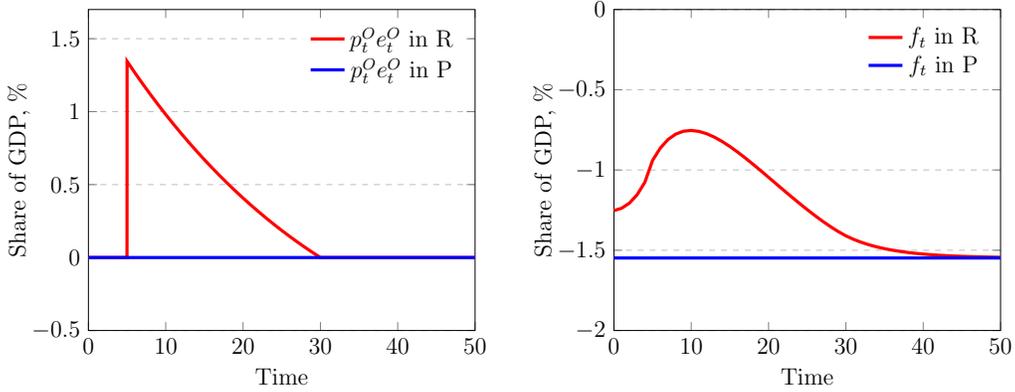
Given the above normalization and since the country is assumed to be on a balanced growth path, the initial endowment of bonds b_0 must equal the parameter that determines the balanced growth path level of bond holdings, \bar{b} . We choose these parameters to match the 1970-2010 average of the ratio between Federal government debt and nominal GDP of approximately, 49%.²⁹

Since Canada 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 Canada between 1970-2010 of approximately 5%, which implies $\beta = 0.97$.³⁰

²⁸We calculate HP-smoothed constant-price sectoral value-added per worker using value added data from UN (2014) and employment data from Series D266-289 and D290-317 in STATCAN (2016*b*) and Table 282-0008 from STATCAN (2016*a*).

²⁹For 1970 - 2008 these data are constructed using information from STATCAN (2016*a*) in Tables 385-0010 and 380-0500. We then extend this data to 2010 using information on GDP from UN (2014) and information on the Stock Position of Liabilities of the Central Government from IMF (2016).

³⁰The real interest rate is calculated by subtracting the average growth rate of nominal traded good prices,



(a) Resource export revenues ($p_t^O e_t^O$) as a percentage of GDP in both countries. (b) Total foreign revenues (f_t) as a percentage of GDP.

Figure B.2: Simulation Results showing resource export revenue and total foreign revenue as a fraction of GDP. In the above P= Non-Resource Economy; R= Resource Economy.

The weight in the preferences on the traded-sector consumption good, γ , influences the employment share in the traded sector via equation (12). As such, we choose $\gamma = 0.153$ to match the average share of employment in the traded goods sector in Canada between 1970 and 2010 of approximately 16.7%.

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 $\phi = 0.082$ so that the model matches a 1.94% increase in period zero interest rate from the steady state interest rate ($R^* = 5\%$) if the Canadian economy were to start with an initial debt that would be 1% higher than the steady state level of debt i.e. $b'_0 = b_0 \times 1.01 = -0.91$.

Finally, we assume in the baseline calibration that our country is on a balanced growth path and has no oil production. As such, we simply set $p_t^O e_t^O = 0$.³¹ We shall refer to this baseline country as the oil poor country and denote it by P . All calibrated parameters are summarized in Table B.1.

Quantitative Exercise Given the calibration, we perform a quantitative exercise that helps isolate and gauge the impact of a resource discovery on prices and bilateral real

$p_{T,t}$, between 1970 and 2010 (approximately 3.5% per year from UN (2014)) from the average annual nominal interest rate during the period (approximately 8.1% per year) obtained from the Bank Of Canada (BOC, 2016). Thus, the implicit real interest rate is approximately $R^* = 8.1\% - 3.5\% \approx 5\%$.

³¹Notice 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 .

exchange rates. To do this we consider two nearly identical economies. We assume that both economies are described by the above model and share all parameters from the above calibration with the exception of their resource endowments. The first economy is simply our baseline country P , which has no natural resources ($p_t^O e_t^O = 0$). The second economy, country R , is assumed to have a natural resource discovery in period zero that starts production five years after the discovery, lasts 25 years and has a net present value of 10% of GDP.³² 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.³³ This gives rise to the following production profile in the oil rich country:

$$(15) \quad p_t^O e_t^O = \begin{cases} a(1 - \frac{t-5}{25}), & \text{for } 5 \leq t \leq 29 \\ 0, & \text{otherwise} \end{cases}$$

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:

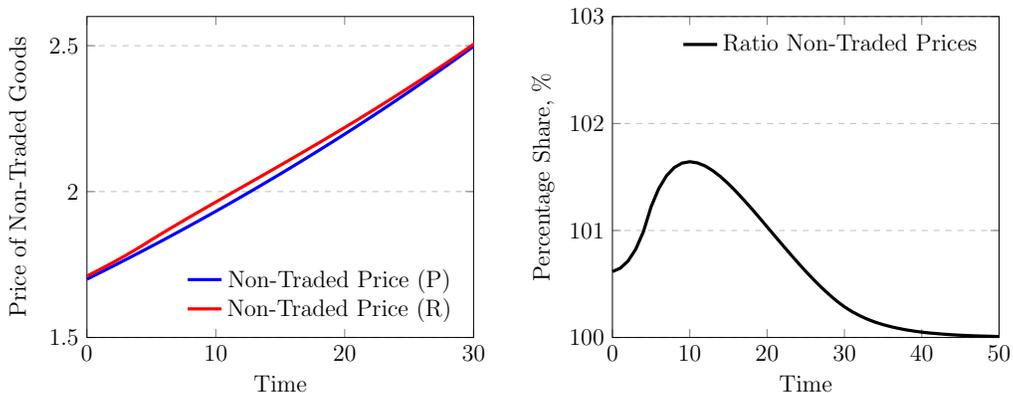
$$(16) \quad \bar{d}_0 = \left(\sum_{j=5}^{29} \frac{p_j^O e_j^O}{(1 + R_j)^j} \right) / GDP_0^i.$$

We set $a = 0.028$ in equation (15) so that $\bar{d}_0 = 0.1$ - i.e. the net present value of the discovery at time zero is 10% of time zero GDP.

The results for this exercise are shown in Figures B.2 and B.3. Figure 2(a) shows each country's revenue from resource exports relative to GDP. Country P 's revenue are zero as the country is not endowed with natural resources. In country R , resource export revenue jump in period 5 (when production starts) to roughly 1.3% of GDP and then slowly decline to 0% of GDP 25 years later. In the previous section we saw that it is (net) total foreign revenue (i.e. f_t) that ultimately generates price differences between these two economies. As such, Figure 2(b) shows each country's total foreign revenue relative to GDP. Country P consumers pay a constant 1.5% of GDP in interest for their steady-state debt holdings. Since country P has no natural resources (and is on a balanced growth path) this is the full extent of the country's total foreign revenue. In country R however, debt is also used to smooth the country's resource revenue over time in anticipation of the start of resource production. Before production begins, country R households increase borrowing from abroad

³²Five years is the average time after a discovery that production starts after a giant resource discovery in Arezki, Ramey and Sheng (2017).

³³We make these assumption to attempt to replicate the production patterns used in Arezki, Ramey and Sheng (2017) 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 (2017) 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) Relative price of traded to non-traded goods. (b) Ratio of relative non-traded goods price in country R to P .

Figure B.3: Simulation results showing changes in relative prices of non-traded goods. In the above P = Non-Resource Economy; R = Resource Economy.

(resulting in less negative net inflows of foreign revenue) to smooth consumption before resource production comes online. After resource production begins, the household reduces its borrowing to pay back the initial increase in borrowing and to spread the benefits of the discovery over time.³⁴ As we get further away from the start of resource production, the foreign revenue of country R approaches that of country P as net bond holdings in country R approach the steady-state bond holdings of country P .

Next, we examine the evolution of relative prices. Figure 3(a) shows the relative prices of non-traded to traded goods in both economies whilst Figure 3(b) shows the resulting ratio of these relative prices. First, observe that in country P - which is on a balanced growth path - relative prices grow at a constant rate of approximately 1.2% per year. This increase is due to the classic Balassa-Samuelson effect driven by faster productivity growth in the traded sector. In the Canadian data, the corresponding growth rate is approximately 1% 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 revenue, f_t . When consumers learn of the discovery, they borrow more in order to smooth their consumption path. This additional revenue is largely spent on importing foreign goods. As foreign, traded goods become more abundant, the price of *non-traded* goods rises by approximately 0.6%. After ten years, the price of non-traded goods is approximately 1.7% higher than if no resources had been discovered. As resource production winds down, relative prices return to what they would have been had no resource discovery taken place.

³⁴The increase and reduction of borrowing referred to here is relative to that of country P .

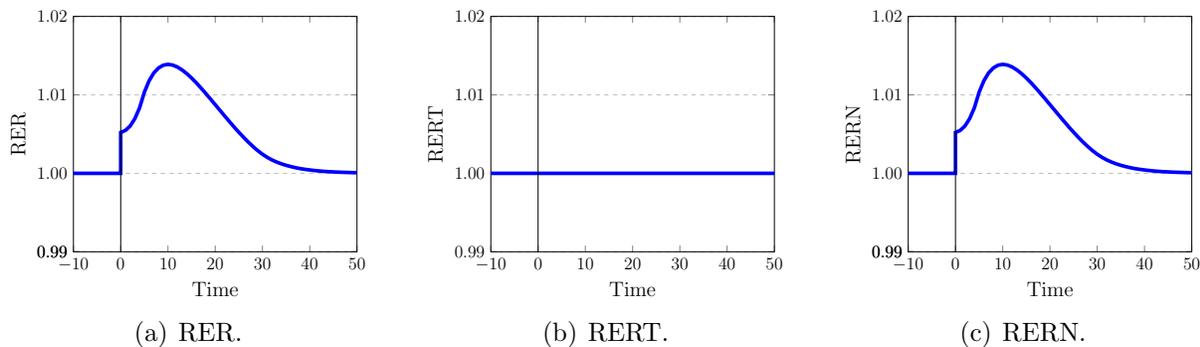


Figure B.4: Decomposition of RER into $RERT$ and $RERN$ according to equation (17) for countries R and P .

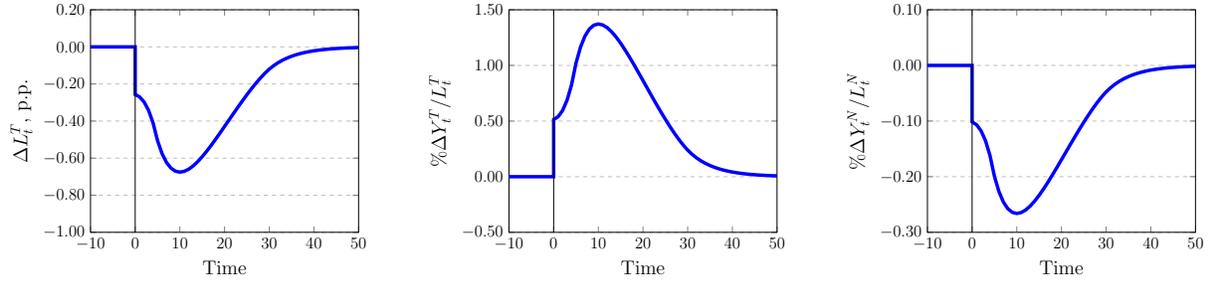
Real Exchange Rates In order to compare our results to the data, we construct a bilateral real exchange rate (RER) in the model for countries i and j and decompose it into its traded and non-traded components as follows:

$$(17) \quad \underbrace{\frac{p_i}{p_j}}_{RER} \equiv \underbrace{\left(\frac{p_i^T}{p_j^T}\right)}_{RERT} \times \underbrace{\left(\frac{p_i/p_i^T}{p_j/p_j^T}\right)}_{RERN}$$

All terms are the same as in the main body of the paper. Figure B.4 plots this decomposition for the resource rich and resource poor countries (assuming that $i = R$ and $j = P$). Since $RERT = 1$, changes in the real exchange rate, RER , will stem entirely from changes in internal relative prices as captured by $RERN$. The model predicts an initial jump in RER of 0.5% in period zero followed by a slow appreciation of approximately 1.4% after 10 periods driven by the profile of foreign revenue flowing into country R . The results of our model closely resemble our empirical results in Figure 2 both quantitatively and qualitatively. ³⁵

Employment and Productivity Figure B.5 shows the percentage point change in the traded-sector employment share as well as the percentage change in sectoral labor productivities in country R relative to country P . Employment share in the traded sector in country R shrinks by approximately 0.68 percentage points 10 years after the discovery relative to employment in the traded sector in country P . Since capital is sector-specific, the shrinking employment in the traded-sector translates into more capital per worker and a higher traded-sector labor productivity which rises 1.4% in country R relative to labor productivity in country P , 10 years after the discovery. Similarly, the higher employment in the non-traded sector coupled with sector-specific capital stocks results in a 0.3% lower

³⁵Notice however, that our model predicts a strong jump in RER and $RERN$ in period zero (at news of the discovery). Whilst the point estimate in our data does not suggest such a jump, due to the uncertainty bounds, we cannot statistically exclude the possibility of such a jump.



(a) Percentage point change in T sector employment shares. (b) Percentage change in T sector labor productivity. (c) Percentage change in NT sector labor productivity.

Figure B.5: Changes in sectoral employment and productivity in the resource economy relative to the non-resource economy.

non-traded sector productivity in country R relative to country P .³⁶ Along the dimensions of employment and productivity, our model results closely resemble our empirical findings in the bottom row of Figure 3 both quantitatively and qualitatively. Thus, in addition to illuminating the potential channels at play, the exercises in the above two paragraphs that are based on a very simple traditional model of the real exchange rates and sectoral reallocation, serve to strengthen our confidence in our empirical results.

³⁶The asymmetric size in the response of the labor productivity in each sector has to do with that sector's initial size. Since the traded sector is relatively small, a decline in the employment of that sector by some fixed quantity of workers will have a larger effect on the traded sector than the corresponding increase by the same number of workers in the much larger non-traded sector.