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 a country’s GDP appreciates the real exchange rate by 14% within 10 years following the discovery. The appreciation is driven by the prices of non-tradable goods, which is in line with the ‘traditional’ theory of exchange rates. Our finding provides direct evidence on the appreciation channel central to the theories on the ‘Dutch disease’ and the ‘Balassa-Samuelson effect’.

Keywords: Real exchange rates, natural resource discoveries, Dutch disease, oil
JEL-codes: F31, F41, Q33

1 Introduction

Standard theory predicts that economies adjust to windfalls or productivity shocks in the traded sector through an inter-sectoral reallocation of labor and an appreciation of the real exchange rate (Corden and Neary, 1982; Neary, 1988). Despite the theory’s near canonical status, no direct empirical evidence exists that has identified and quantified

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the appreciation channel across countries. The difficulty lies largely in poor data quality and endogenous measures of resource or productivity shocks. 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 (Horn, 2011; Arezki, Ramey and Sheng, 2016). By using bilateral data we obtain a vast increase in the statistical variation available for inference. Our exercise provides the first direct evidence on the appreciation channel that is a central ingredient in the theories of the ‘Dutch disease’ and the ‘Balassa-Samuelson effect’.

We find that a country with the median discovery in our sample, or 10% of a country’s GDP, experiences an appreciation of the real exchange rate of approximately 2% 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 5% (relative to the US) in order to match this degree of appreciation. Similarly, Berka, Devereux and Engel (2014) find that productivity in the traded sector would have to increase by 10% to generate a similar increase in the real exchange rate. The effect we find is thus quantitatively large.

Using bilateral real exchange rates allow us to focus on variation at the country-pair-year level. We estimate a difference-in-differences model by comparing the growth rate of the bilateral real exchange rate in years around a giant discovery to years further away, as well as to the growth rate of the real exchange rate in countries without resource discoveries. The combination of growth rates and inclusion of country-pair fixed-effects controls for country-pair specific levels and trends in the bilateral exchange rates. This allows us to take into account differences in growth paths across countries, which theoretically lead to a real appreciation in favour of the faster growing country (i.e. the

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1 Earlier empirical work on resource shocks examined the contraction of the manufacturing sector (Allcott and Keniston, 2014; Ismail, 2010) and non-resource trade (Harding and Venables, 2016) as well as the appreciation of real exchange rate (Cashin, Cespedes and Sahay, 2004; Chen and Rogoff, 2003; Bjornland and Thorsrud, 2016; Kuralbayeva and Stefanski, 2013) in response to changes in natural resource exports, commodity prices or oil-sector employment. This work however relies either on endogenous measures of resource wealth or on time-variation common to all countries or districts.

2 The median discovery of 10% of GDP translates to an appreciation of 1.8 percent with our estimates. Rogoff (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. \( 0.366 \times \ln(1.05) = 0.018 \). Berka, Devereux and Engel (2014) 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 \( 0.18 \times 0.1 = 0.018 \). To match the effects on the real exchange rate from a discovery of 100% of GDP, according to the empirical results of these authors, the corresponding increases in GDP per capita and traded sector productivity would have to be as large as 47% and 78%, respectively.

3 The bilateral real exchange rate has been used by Betts and Kehoe (2006; 2008) and Engel (1999). Imbs et al. (2005) use the bilateral real exchange rate against the US at the sector level. Much of the remaining literature focuses on real effective exchange rates - trade-weighted averages of bilateral real exchange rates (Cashin, Cespedes and Sahay, 2004; Chen and Rogoff, 2003). Note that we estimate the effect of giant discoveries on the real effective exchange rate in Appendix A and find a similar appreciation as with the bilateral real exchange rates.
Balassa-Samuelson effect). Since giant discoveries are difficult to anticipate, the timing of the discoveries can be treated as plausibly exogenous (Lei and Michaels, 2014; Arezki, Ramey and Sheng, 2015). In contrast, more common measures of endowments such as resource wealth or exports are seen as endogenous\footnote{Brunnschweiler and Bulte (2008) and van der Ploeg and Poelhekke (2010) discuss this endogeneity in the context of the resource curse. Cust and Harding (2013) focus on the quality of institutions as a source of endogeneity.}. The giant discovery data have three additional benefits. First, discoveries are large, and therefore distinguishable from the many other shocks affecting real exchange rates. Second, a discovery is a de-facto news shock, which allows us to capture forward-looking behaviour. Third, giant discoveries are country-specific and hence provide variation both within and across countries.

Our contribution is three-fold. First, by identifying the effect of large resource discoveries on adjustments in the real exchange rate we provide direct evidence for the appreciation channel of the Dutch-Disease effect. 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). Second, we show that the appreciation is gradual rather than immediate as suggested by standard theories (Arezki, Ramey and Sheng, 2016; van der Ploeg and Venables, 2013), implying that prices do not adjust instantaneously to new information. 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 tradable-good prices are anchored internationally while prices of non-tradable goods are allowed to adjust to local conditions.

2 Empirics

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 services\footnote{Services are defined as the sum of transportation, storage, communication, wholesale, retail, restaurants, hotels and other services.} (S):

\[
Y = \underbrace{A + C + S}_{\text{Non-Resource Economy}} + \underbrace{M}_{\text{Mfg. Mining and Utilities}} + \underbrace{MU}_{\text{Non Res. Non-Mfg. Non-resource non-manufacturing sector}}.
\]


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

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 (NT).\footnote{Altering sectoral specification by moving agriculture to the traded sector or considering only services as the non-traded sector does not affect our results.}
**Exchange Rate:** 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). We use IMF’s national currency-US exchange rate to transform the indices into comparable units. The transformed indices are used to construct bilateral real exchange rates $RER_t^{ij}$ between country $i$ and $j$ in period $t$. We decompose the real exchange rate into its tradable ($RERT_t^{ij}$) and non-tradable component ($RERN_t^{ij}$) following Engel (1999) as well as Betts and Kehoe (2006; 2008):

$$
\frac{p_{i,t}}{p_{j,t}} \equiv \left( \frac{p_{i,t}^T}{p_{j,t}^T} \right) \times \left( \frac{p_{i,t}/p_{i,t}^T}{p_{j,t}/p_{j,t}^T} \right)
$$

(2)

Here, $p_{i,t}$ and $p_{j,t}^T$ refer to the aggregate and traded-sector price indices in country $i$ and time $t$. Our sample covers $N = 172$ countries over the period 1970-2013. Since we do not want to double-count 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. 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. In Table 1 we provide descriptive statistics for all the country-pair observations including the US in the denominator. Note that the mean of the tradable component is positive ($grert_{iUS}^t$) while the mean of the non tradable component is negative ($grern_{iUS}^t$). This is consistent with the US experiencing a faster growth in the tradable sector relative to other countries (Balassa-Samuelson effect). Also note that the tradable component is nearly twice as volatile as the non-tradable component.

<table>
<thead>
<tr>
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<th>mean</th>
<th>sd</th>
<th>max</th>
<th>min</th>
</tr>
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<tbody>
<tr>
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<td>0.20</td>
<td>6.01</td>
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<tr>
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<td>6.04</td>
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<td>$grern_{iUS}^t$</td>
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<td>0.12</td>
<td>2.30</td>
<td>-2.33</td>
</tr>
</tbody>
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Change in RER for all country pair observations with the US in the denominator

Table 1: Descriptive Statistics

**Giant Oil and Gas Discoveries** We use information on the net present values of giant oil and gas discoveries relative to GDP in country $i$ and period $t$, $d_i^t$, from Arezki, Ramey and Sheng (2016). The raw data on discoveries contain information on the timing, the location and the estimated total ultimately recoverable amount of oil and gas (Horn, 2011). Arezki, Ramey and Sheng (2016) use this information to calculate discovery specific gross revenues using an approximated oil production profile and country specific
(a) Oil price and number of giant oil and gas discoveries. Number of discoveries is uncorrelated with the real price of oil (correlation coefficient below 0.02 and a p-value of 0.9).

(b) Size of giant oil and gas discoveries. 100 indicates that a discovery made in period t has a net present value that is equivalent to the GDP of the country in period t.

Figure 1: Giant oil and gas discoveries.
interests rate to discount future revenues. Figure 1a 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. This adds confidence to our identifying assumption that the timing of discoveries is exogenous. Figure 1b presents the net present values of the discoveries relative to nominal GDP at the date of discovery. Between 1970 and 2013, 302 giant discoveries had been made in 56 countries, with an average and median size of 67% and 10% of GDP, respectively.

**Bilateral Measure of Discoveries** We use $\delta_i^t = 1 + d_i^t$ as a simple monotonic transformation of the discovery measure $d$ above and define a bilateral measure of discoveries:

$$ D_{ij}^t \equiv \log \left( \frac{\delta_i^t}{\delta_j^t} \right). $$ (3)

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

**Estimation Strategy** We estimate some variations of the following specification:

$$ y_{ij}^t = \sum_{k=-5}^{10} \beta_k D_{ij}^{t-k} + \eta_{ij}^t + \rho_t + \varepsilon_{ij}^t $$ (4)

Our LHS variable $y_{ij}^t$ is a placeholder for $grer_{ij}^t$, $grert_{ij}^t$ and $grern_{ij}^t$ (as defined in Table 1 for the US as country $j$). Country-pair and time fixed effects are represented by $\eta_{ij}^t$ and $\rho_t$ respectively. The country-pair-specific error, $\varepsilon_{ij}^t$, is allowed to arbitrarily correlate with errors of other bilateral pairs containing either country $i$ or country $j$ (two-way clustering). The $\beta_k$ terms represent the semi-elasticities 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, $\Omega_k = \sum_{j=0}^{k} \beta_j$, and use these to construct 90%-confidence bands.

**Identification** Equation 4 is a difference-in-differences specification where we compare the growth rates of the bilateral real exchange rate in the years around a giant discovery with the growth rates further away and in countries without discoveries. Country-pair

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7See Arezki, Ramey and Sheng (2016) for more information.
fixed effects account for country-pair specific trends in the real exchange rate (Balassa-Samuelson effect), while year fixed effects account for global shocks. The timing of individual discoveries is at the core of our identification strategy and we follow Lei and Michaels (2014) and Arezki, Ramey and Sheng (2016) in arguing that it is plausibly exogenous due to the uncertainty surrounding explorations. Since 1965, only 2% of all wells drilled resulted in giant oil or gas discoveries (Toews and Vezina, 2016). Hence, countries are unlikely to get lucky in the first place. More importantly, the relationship between exploration drilling and the occurrence of giant discoveries is not deterministic. Exploration does not guarantee giant discoveries, not even in the long run. Consequently, predicting the exact timing of a giant oil discovery is impossible, even for the operating companies.

3 Results

Main Results: The main results are displayed in the three charts of Figure 2. All three charts depict the cumulative impulse response $\Omega_{t \in [0,10]}$ to a giant discovery. The first chart presents the cumulative response of the real exchange rate to a giant discovery. The second and third charts decompose the effect on the real exchange rate into the effect on the tradable and the non-tradable component, respectively. In chart 2 we observe that giant discoveries do not seem to affect the tradable goods component of the real exchange rate. The cumulative response fluctuates around zero and remains insignificant. In chart 3 we see that giant discoveries positively affect the non-tradable goods component of the real exchange rate. The size of the average discovery in our data is 67% of GDP, which leads to the real exchange rate appreciating by 10%. A country getting particularly lucky with a discovery that is equal to its GDP (90th percentile of discoveries), experiences an appreciation of the real exchange rate by 14%.

Comparing chart 1 and chart 3 suggests that the appreciation of the real exchange rate following a giant discovery is mainly driven by the non-tradable goods component of the real exchange rate. However, the cumulative effect on the real exchange rate is measured imprecisely and remains insignificant at the 10% level.

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8 Anecdotal evidence suggests that large discoveries are made within three metres of where other companies were searching years ago (Kavanagh, 2013).

9 Symmetrically, we present the cumulative estimates by adding up the $\beta$’s of the leads $\Omega_{t \in [0,-5]}$.

10 As seen in chart 1 and 3 of figure 2, $\Omega_{10} = \sum_{j=0}^{10} \beta_j = 0.2$, i.e. $0.2 \times \log(1 + 0.67) = 0.10$. 

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Robustness: We show that our results are very robust in a number of exercises in online Appendix A. First, 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 4 with the artificial data is symmetric and centred at zero, indicating that our econometric model is unlikely to produce spurious results. Second, 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. Third, we control for cumulated past discoveries to account for potential path-dependence in discoveries. Fourth, we drop the top and the bottom 1% of the dependent variable to account for outliers. Fifth, to ensure that our results are not sensitive to specific sector classifications we use alternative definitions of tradable and non-tradable goods. Sixth, following Betts and Kehoe (2008), we use producer prices as alternative price measures. Finally, we also estimate the effect of oil discoveries on unilateral real effective exchange rates and find that the appreciation is quantitatively almost identical to our baseline. In Appendix B we demonstrate that our results are qualitatively and quantitatively consistent with a ‘traditional’ small-open-economy model (calibrated to the experience of Canada), where real exchange rates move only due to changes in non-traded good prices. In addition to illuminating the potential channels at play, the model exercise strengthens our confidence in our empirical results.

Conclusion: We find robust evidence for an appreciation of the real exchange rate in response to a large oil or gas discovery. A discovery which has the size of a country’s GDP causes the real exchange rate to appreciate by approximately 14% within 10 years. Consistent with traditional theories on exchange rates we find that the appreciation is almost exclusively driven by an appreciation of prices in the non-tradable sector. We thus provide the first, direct evidence of the key appreciation channel central to both the ‘Dutch-Disease’ and the ‘Balassa-Samuelson’ literature.
Figure 2: Cumulative effect of large oil and gas discoveries on the real exchange rate and its tradable and non-tradable components.

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the sum of year-to-year growth effects for the years $t$ to $t+k$. The cumulative effect is calculated by adding up $\beta_k$’s which are estimated in equation 4: $\Omega_k = \sum_{j=0}^{k} \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\beta_k$’s of the leads: $\Omega_{-k} = \sum_{j=-k}^{0} \beta_j$. 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.
References


Appendix on Empirical Robustness

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 4 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 $\beta_k$'s. Figure A.1 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.2, 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, this increases the comparability between ‘treated’ and ‘controls’. The results are presented in Figure A.3.

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 4. Figure A.4 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.5.

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.6 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 then presented in Figure A.7.
**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 times 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.8. 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 more noisy, but quantitatively in line with our main result (see Figure A.9).
Figure A.1: 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 4 and add up the estimated $\beta$'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. Results are briefly described under Robustness in section 3 of the main text.
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. **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 $\beta_k$’s which are estimated in equation $4$: $\Omega_k = \sum_{j=0}^k \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\beta_k$’s of the leads: $\Omega_{-k} = \sum_{j=0}^{-k} \beta_j$. 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. Results are briefly described under Robustness in section 3 of the main text.
Figure A.3: 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 $\beta_k$'s which are estimated in equation 4: $\Omega_k = \sum_{j=0}^{k} \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\beta_k$'s of the leads: $\Omega_{-k} = \sum_{j=-k}^{0} \beta_j$. 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. Results are briefly described under Robustness in section 3 of the main text.
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. *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 \( \beta_k \)'s which are estimated in equation 4: \( \Omega_k = \sum_{j=0}^{k} \beta_j \). Symmetrically, we present the cumulative estimates by adding up the \( \beta_k \)'s of the leads: \( \Omega_{-k} = \sum_{j=-k}^{0} \beta_j \). 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. Results are briefly described under Robustness in section 3 of the main text.
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. **Drop top and bottom 1% of the distribution to account for outliers.**

![Graph showing cumulative effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components.](image)

**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 $\beta_k$’s which are estimated in equation 4: $\Omega_k = \sum_{j=0}^{k} \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\beta_k$’s of the leads: $\Omega_{-k} = \sum_{j=0}^{k} \beta_{-j}$. 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. Results are briefly described under Robustness in section [3] of the main text.
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. 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 $\beta_k$'s which are estimated in equation 4: $\Omega_k = \sum_{j=0}^{k} \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\beta_k$'s of the leads: $\Omega_{-k} = \sum_{j=0}^{-k} \beta_j$. 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. Results are briefly described under Robustness in section [3] of the main text.
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. Agricultural goods are redefined as being tradable.

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the the sum of year-to-year growth effects for the years $t$ to $t+k$. The cumulative effect is calculated by adding up $\beta_k$’s which are estimated in equation $\Omega_k = \sum_{j=0}^{k} \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\beta_k$’s of the leads: $\Omega_{-k} = \sum_{j=-k}^{0} \beta_j$. 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. Results are briefly described under Robustness in section 3 of the main text.
Figure A.8: Effect of large oil and gas discoveries on the growth of the real exchange rate and its tradable and non-tradable components. Information on producer prices is used to decompose changes in the real exchange into its tradable and its non-tradable component.

Notes: All results are estimated using OLS and include country-pair fixed effects and year fixed effects. The LHS variable is either the change in the logged real exchange rate between two countries, the change in the tradable or the change in the non-tradable component of the logged real exchange rate. The blue solid line is the sum of year-to-year growth effects for the years $t$ to $t+k$. The cumulative effect is calculated by adding up $\beta_k$’s which are estimated in equation 4: $\Omega_k = \sum_{j=0}^{k} \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\hat{\beta}_k$’s of the leads: $\hat{\Omega}_k = \sum_{j=-k}^{0} \hat{\beta}_j$. 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. Results are briefly described under Robustness in section 3 of the main text.
Figure A.9: Effect of large oil and gas discoveries on the growth of the real effective exchange rate.

Notes: Results are estimated using OLS and include country fixed effects and year fixed effects. The LHS variable is the change in the logged real effective 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 $\beta_k$'s which are estimated in a specification analog to equation 4: $\Omega_k = \sum_{j=0}^{k} \beta_j$. Symmetrically, we present the cumulative estimates by adding up the $\beta_k$'s of the leads: $\Omega_{-k} = \sum_{j=0}^{-k} \beta_j$. The dashed lines represent the 90% confidence intervals. Errors are clustered on the country level. Results are briefly described under Robustness in section 3 of the main text.
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 and its traded and non-trade components 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:

$$\max_{b_{t+1}, c^T_t, c^N_t} \sum_{t=0}^{\infty} \beta^t (\gamma \log c^T_t + (1 - \gamma) \log c^N_t)$$

(5)

$$p^T_t c^T_t + p^N_t c^N_t \leq w_t + r^T_t + r^N_t + f_t$$

$$f_t \equiv R_t p^T_t b_t - p^T_t b_{t+1} + p^O_t e^O_t$$

$$b_{t+1} \geq -B$$ and $$b_0$$, 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, $c^N_t$. 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, $p^N_t$, is determined locally. The agent also chooses holdings of foreign bonds, $b_{t+1}$.\[11\] 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 $r^N_t$. He is also endowed with an exogenous windfall of (tradable) natural resources, $e^O_t$, which he sells for an internationally set (and exogenous) price $p^O_t$ as well as a stock of (risk-free) international bonds, $b_t$, held from the previous period.\[12\]

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, $p^O_t e^O_t$. 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, $p^O_t e^O_t$, can change in a

\[11\]Negative values of $b_t$ represent debt. To rule out the possibility of Ponzi schemes, debt is bounded from below by some large number, $B$.

\[12\]We assume that all uncertainty with respect to $p^O_t e^O_t$ is resolved in period zero. Hence from period zero onwards the agent knows the entire future path of windfall revenue.
This directly influence the current-period \( f_t \) but also indirectly influence 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 \((L^s_t)\) and sector-specific capital \((K^s_t)\) rented from the household.\(^{13}\) The profit maximization problem of the sector \( s = T, N \) firm is given by:

\[
\max_{L^s_t, K^s_t} p^s_t Y^s_t - w_t L^s_t - r^s_t K^s_t \quad \text{s.t. } Y^s_t = A^s_t (L^s_t)^{1-\alpha} (K^s_t)^\alpha,
\]

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

**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, \( R_t \):

\[
R_t = R^* + \phi \left( e^{\frac{b_t - \bar{b}}{\lambda t}} - 1 \right).
\]

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.\(^{15}\) 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 dependance on initial conditions and equilibrium dynamics that can posses a random walk component. Finally, following convention, we assume that

\(^{13}\)Due to changes in either prices or quantities of natural resources.

\(^{14}\)To 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)).

\(^{15}\)We 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.
the household does not internalize the costs of borrowing.\footnote{Allowing 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 $p^m_t m_t = f_t$. Also, markets clear so that $c^T_t = Y^T_t + m_t$, $c^N_t = Y^N_t$, $L^T_t + L^N_t = 1$, $K^T_t = 1$ and $K^N_t = 1$.

**Competitive Equilibrium** For any $R^*$ and $\{p^T_t, p^O_t\}_{t=0}^{\infty}$, a competitive equilibrium of the model is defined as a set of prices $\{p^T_t, p^N_t, w_t, r^T_t, r^N_t, R_t\}_{t=0}^{\infty}$ as well as a set of allocations $\{c^T_t, c^N_t, b_t, L^T_t, L^N_t, m_t, K^T_t, K^N_t\}_{t=0}^{\infty}$ 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 $\tilde{c}^N_t \equiv c^N_t/A^N_t$. The first order conditions of the household give us the Euler equation that (indirectly) pins down bond holdings:

$$\frac{g^T_t \tilde{c}^T_{t+1}}{\tilde{c}^T_t} = \beta R_{t+1}. \quad (8)$$

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. $\lim_{t \to \infty} p^O_t / p^O_t A^O_t = 0$, the Euler equation implies that $\lim_{t \to \infty} \tilde{b}_t = \tilde{b}$.\footnote{To see this, notice from equation (7) and equation (8) that in the limit $g^T = \beta(R^* + \phi(e^\tilde{b} - \tilde{b}) - 1)$. The fact that $R^* = g^T/\beta$ then implies that $\tilde{b}_t = \tilde{b}$ in the limit.}

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:

$$\frac{p^N_t}{p^T_t} = \frac{1 - \gamma}{\gamma} \frac{c^T_t}{c^N_t} = \frac{1 - \gamma}{\gamma} \frac{Y^T_t + \frac{f^T_t}{Y^T_t}}{Y^N_t}.$$  

(9)

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

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

(10)

Applying the implicit function theorem to equations (9) and (10) respectively, we can show that $\frac{dp_t^N/p_t^T}{dL_t^T} < 0$ and $\frac{df_t}{df_t} < 0$. Putting these two inequalities together implies that $\frac{dp_t^N/p_t^T}{df_t} > 0$. Thus, an inflow of foreign revenue results in higher relative prices. Intuitively, notice from equation 9, that higher $f_t$ acts like an increase in the productive capacity of the traded goods sector which increases the relative ‘abundance’ of traded goods relative to non-traded goods and hence drives an increase in non-traded good prices.\(^{18}\) Finally, we can derive the aggregate price index of the economy, $p_t$, as:

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

(11)

Given that the price of traded goods is fixed internationally, equation (11) implies that aggregate prices change only in response to changes in relative prices. It then follows that an increase in foreign revenue will result in a higher aggregate price level: $\frac{dp_t}{df_t} > 0$.

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.\(^{19}\) 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).

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.\(^{20}\) Since we assume

\(^{18}\)Inflows of foreign revenue therefore act in a similar fashion to the Balassa-Samuelson effect where higher productivity growth in the traded sector leads to a relative abundance of traded goods and a rise of non-traded good prices (Neary, 1988).

\(^{19}\)The specific country choice is largely irrelevant for our purposes and other advanced, small open economies like Belgium or the Netherlands give very similar results.

\(^{20}\)We calculate HP-smoothed constant-price sectoral value-added per worker using value added data
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 $A_{T1970} = A_{N1970} = 1$ and we define sectoral productivity in our model as:

$$A_s^N_t = g_{Nt}^{t-1970} \quad \text{and} \quad A_s^T_t = g_{Tt}^{t-1970}. \quad (12)$$

Given the above normalization and since the country is assumed to be on a balanced growth path, the initial endowment of bonds $b_0 = \bar{b}$ 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%.

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 $\beta$ to match the average real interest rate in Canada between 1970-2010 of approximately 5%, which implies $\beta = 0.97$.

The weight in the preferences on the traded-sector consumption good, $\gamma$, influences the employment share in the traded sector via equation $[10]$. As such, we choose $\gamma = 0.153$ from UN (2014) and employment data from Series D266-289 and D290-317 in STATCAN (2016b) and Table 282-0008 from STATCAN (2016a).

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Table B.1: Calibrated parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_0^N/A_0^T$</td>
<td>1</td>
<td>Normalization</td>
</tr>
<tr>
<td>$A_s^T_t$</td>
<td>$A_s^T_t = (g_s)^{t-1970}$</td>
<td>Constant, exogenous sectoral productivity growth in sector $s = T, N.$</td>
</tr>
<tr>
<td>$g_T - 1$</td>
<td>0.02</td>
<td>Annualized average growth rate of HP-smooothed traded sector productivity in Canada, 1970-2010.</td>
</tr>
<tr>
<td>$g_N - 1$</td>
<td>0.007</td>
<td>Annualized average growth rate of HP-smooothed non-traded sector productivity in Canada, 1970-2010.</td>
</tr>
<tr>
<td>$1 - \alpha$</td>
<td>0.67</td>
<td>Labor share in each sector.</td>
</tr>
<tr>
<td>$b_0 = \bar{b}$</td>
<td>$-0.9$</td>
<td>Average consolidated Public Sector Debt to GDP ratio in Canada, 1970-2010</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.97</td>
<td>Average real interest rate in Canada, 1970-2010.</td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.08</td>
<td>Elasticity of risk premium, van der Ploeg and Venables (2011)</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.153</td>
<td>Average employment share in traded sector, 1970-2010.</td>
</tr>
<tr>
<td>$a$</td>
<td>0.28</td>
<td>NPV of resource discovery is 100% of time zero GDP. (Only in oil rich country.)</td>
</tr>
</tbody>
</table>

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\(^{21}\)For 1970 - 2008 these data are constructed using information from STATCAN (2016a) 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).

\(^{22}\)The real interest rate is calculated by subtracting the average growth rate of nominal traded good prices, $p_{r,t}$, 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 $R^* = 8.1\% - 3.5\% \approx 5\%.$
We choose $\phi$ 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 $p_t^O e_t^O = 0^{23}$. 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 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

\[\text{(a) Resource export revenues (} p_t^O e_t^O \text{) as a percentage of GDP in both countries.}\]

\[\text{(b) Total foreign revenues (} f_t \text{) as a percentage of GDP.}\]

Figure B.1: Simulation Results showing resource export revenue and total foreign revenue as a fraction of GDP. In the above $P= \text{Non-Resource Economy}$; $R= \text{Resource Economy}$.

to match the average share of employment in the traded goods sector in Canada between 1970 and 2010 of approximately 16.7%.

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

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\[\text{23 notice that since the price of natural resources is exogenous, we cannot disentangle it from the changes in quantities. For our purposes, this does not make a difference, and we can simply assume without loss of generality that the price of resources is fixed to unity, over the period and that changes in resource revenues all stem from changes in } e_t^O.\]
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 100% of GDP.\footnote{Five years is the average time after a discovery that production starts after a giant resource discovery in Arezki, Ramey and Sheng (2015).} 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.\footnote{We make these assumption to attempt to replicate the production patterns used in Arezki, Ramey and Sheng (2015) as best as we can. In their paper the production profile starts of as a plateau - whose length depends on the size of field - and then exponentially declines at a constant depletion rate. Both the depletion rate and the length of the plateau depend on ultimately recoverable reserves which are not made available by Arezki, Ramey and Sheng (2015) and hence cannot be replicated exactly. However, we have tried different specifications of the resource production function such as having a constant level of resource output, having an exponentially declining level of resource output, or having some combination of the two. Importantly, there is no qualitative difference in our results and only a very limited quantitative difference.} This gives rise to the following production profile in the oil rich country:

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

(13)

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:

\[
d_0 = \left( \frac{\sum_{j=5}^{29} p_j^O e_j^O}{(1 + R_j)^j} \right) / GDP_0.
\]  

(14)

We set $a = 0.28$ in equation (13) so that $d_0 = 1$ - i.e. the net present value of the discovery at time zero is 100% of time zero GDP.

The results for this exercise are shown in Figures B.1 and B.2. Figure B.1a 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 10% 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 B.1b 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 (resulting in positive 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. \cite{26} 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 B.2a shows the relative prices of non-traded to traded goods in both economies whilst Figure B.2b 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 6%. After ten years, the price of non-traded goods is approximately 17% 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.

\footnote{The increase and reduction of borrowing referred to here is relative to that of country 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:

$$\frac{p_i}{p_j} \equiv \left(\frac{p_i^T}{p_j^T}\right)_{RERT} \times \left(\frac{p_i}{p_i^T}\right)_{RERN} \times \left(\frac{p_j}{p_j^T}\right)_{RERN}$$

All terms are the same as in the main body of the paper. Figure B.3 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 4.7% in period zero followed by a slow appreciation of approximately 15% 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. In addition to illuminating the potential channels at play, this model exercise, based on a simple ‘traditional model’ of the real exchange rate, strengthens our confidence in our empirical results.

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27 Notice 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.