Commodity Prices, Innovation and Growth: Is All That Glitters Gold?

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Abstract

Commodity price shocks can have substantial effects on the real side of an economy. A large expansion on the value of exports of a commodity generates a real appreciation of the domestic currency, which in turn stimulates a reallocation of resources between productive sectors in the economy. If knowledge spillovers between sectors are asymmetric and the main knowledge producing sector is potentially the most affected by the commodity price shocks we shall observe negative effects on aggregate innovation rates and hence over the growth rate of the economy. In this paper we quantitatively assess the effects that these shocks have on innovation and growth. We develop a small open economy model that has different productive sectors based on Mendoza (1995), in conjunction with a Schumpeterian-type model in those sectors (Aghion, Akcigit, and Howitt, 2013). Our findings suggest that (1) there is an important reallocation of resources between productive sectors, (2) knowledge spillovers are asymmetric and knowledge creation is driven mainly by the tradable non-commodity sector, and (3) positive commodity price shocks generate negative effects on the aggregate growth rate of the economy. These results suggest that positive commodity price shocks may increase the wealth of the economy but at the cost of lower growth in the medium run.

1 Introduction

Dutch diseases are episodes in which a rapid expansion of the exports of a commodity generates a real appreciation of the domestic currency, causing adverse effects on the tradable sector. These are usually originated by extractive commodity sectors that expand suddenly due to discoveries of natural reserves or increases in the international price of the commodity. The real appreciation increases the demand for non-tradable goods and leads to a reallocation of labor from the tradable to the non-tradable sector, generating a de-industralization process. Examples of such are the natural gas discoveries in the Netherlands during the 1950's, Chile's copper boom since the 1990's, or the present oil situation of Venezuela, where the booming commodity sector has reallocated labor from the industrial (tradable) sector, towards the commodity and services (non-tradable) sector. We present evidence using cross-country data, that shows the existence of the dutch disease symptoms described above, driven by increases in international fuel prices during the last two decades. In particular, there has been a real exchange rate appreciation and a labor reallocation from the tradable to the non-tradable and commodity sectors after an increase in fuel prices on the sample of countries for which fuel exports represent more than 20% of total exports.

In the present paper, we argue that this labor reallocation has adverse effects on growth, due to existing spillovers in the innovation processes between sectors. This idea of spillovers on the innovation process refers to the fact that many innovations necessarily rely on past innovations to occur, somehow "standing on the shoulders of giants". Using data on patent citations, we argue that innovations in the non-tradable and commodity sectors rely on the innovations of the tradable sector in a stronger way that how the tradable sector innovations rely on the innovations of the rest of the economy. That is, there is a bigger spillover of knowledge from the tradable sector towards the commodity and non-tradable sectors, than the other way around. On one hand, almost half of the patents in the non-tradable sector cite patents in the tradable sector, and almost 20% of the patents in the commodity sector cite patents in the tradable sector. On the other hand, less than 20% of the patents in the tradable sector cite patents in the other two sectors. In this sense, the labor reallocation between sectors caused by a Dutch disease will cause a slowdown in the growth rate of the economy, which is typically inefficient since agents do not internalize the externalities of the innovation processes.

The purpose of the paper is to analyze the effects of a dutch disease in a small open economy, by considering an equilibrium business cycle model composed by households and three productive sectors: services sector (non-tradable), commodity sector and industry sector (tradables). We assess the effects of labor reallocation on the growth rate of the economy by incorporating Schumpeterian-type growth in each of the sectors (Aghion and Howitt, 1992; Aghion, Akcigit, and Howitt, 2013). Innovation in each sector depends on its profitability, which depends on the relative price of the good that is produced by it. Thus, a fall in the price of one good will cause a reallocation of resources towards the other sectors and innovation to fall in that specific sector. Given that there are spillovers from the innovation in this sector towards the innovation process of the rest of the economy, the overall growth rate falls.

On the empirical section we show the existence of symptoms of a Dutch disease in a cross-country panel set of data to argue that international commodity prices do cause real exchange rate appreciation and reallocation of labor within sectors. However, due to lack of cross-country data on innovation, we calibrate the model with data from Canada. The reason for doing this is that Canada is a country that faced the symptoms of a Dutch disease and is the only country from which we have data on patent applications, which will proxy for the innovation processes in each of the sectors. The advantage of calibrating the benchmark model to an economy where there exists a Dutch disease is that we will be able to shed light on aspects such as how the intensity of the dutch disease can affect innovation and growth, and the total inefficiencies and welfare losses due to the disease as compared to the social planner's decision. Moreover, we will be able to perform a wide range of policy experiments regarding fiscal policies, such as structural balance fiscal rules, that aim at reducing the damaging effects of the disease by subsidizing innovation, for example.

Although the Dutch disease phenomenon has been common along history, it has not been deeply studied in the literature. In particular, there has been no study that relates the labor reallocation of the Dutch disease with inefficiencies in the innovation process due to the knowledge spillovers between sectors, nor there has been a quantitative assessment of the effects of such inefficiency on the growth of the economy. Corden and Neary (1982) is the first to describe a model of dutch disease in a static environment, while Krugman (1987), Sachs and Warner (2001) and Torvik (2001) present evidence and more developed models. In more recent terms, Peretto and Valente (2011) and Peretto (2012) study the long-run effects of a Dutch disease phenomenon by combining endogenous growth models and open economies, but only from a theoretical point of view. Also, Ferraro and Peretto (2015) study the the effect of commodity price movements in the long run growth. We believe that our work makes a contribution to this literature by addressing the inefficiency due to knowledge spillovers in the innovation process both from a theoretical and from a quantitative point of view. Also, study the effects on growth when the economy deviates from its balanced growth path, unlike the work of Ferraro and Peretto (2015), for example.

The paper is organized as follows. Section 2 presents the empirical part in which we describe the data we use for the study of the commodity price effects and knowledge spillovers, 3 presents the model we will use for our simulations while section 4 presents the solution and calibration to it. Lastly, in section 5 we present our simulation results and section 6 concludes.

2 Empirical Section

Our empirical section consists of two parts. On the first part, we argue that positive shocks in fuel prices generate real exchange rate appreciations and labor re-allocations from the tradable, non-commodity sector (tradable sector from hereon) in the economy, towards the non-tradable sectors. We use cross-country evidence to support this hypothesis using data on labor, real exchange rates and commodity prices. On the second part, we argue that there are more innovation spillovers from the tradable sector towards the non-tradable and commodity sectors, than the other way round. To support this hypothesis, we use data on patent data and citations for each sector, and find that the percentage of patents from the non-tradable and commodity sectors that cite patents from the tradable sector is significantly higher than the percentage of patents from the tradable sector that cite inventions on the rest of the economy. This suggests that patents (which proxy for innovation in each specific sector) in the non-tradable and commodity sectors strongly depend on the inventions of the tradable sector, whereas the link in the opposite direction is much weaker.

This suggests that a fall in the innovation rate of the tradable sector would cause a stronger fall in overall innovation, than a fall in innovation on the non-tradable and commodity sectors. Therefore, we argue that when there is a positive commodity price shock, the labor reallocation caused between sectors harms the overall growth rate in the economy. The competitive equilibrium does not take into account this innovation spillover between sectors, so the equilibrium is inefficient.

2.1 Cross-country Data on Commodity Prices

For the labor shares per productive sector, we were initially using the World Bank's database with data on economic variables. However, after analyzing in detail the labor variables and comparing them with the original source (International Labor Organization statistics), we found out that these variables were misconstructed, since they were using different sources and industrial classifications (ISIC 1 - ISIC 4) for different periods. Thus, there were countries that had sudden jumps in the labor employed on each sector. To perform the empirical exercises presented in the next section, we had to construct again the database using the data from the International Labor Organization, which has yearly data on labor for each country, for each sector of the different industrial classifications (agriculture, mining, construction, etc.), from different sources. We took the earliest data for each country and, when the source or industrial classification changed, we used the growth rates of the sectors that are exactly comparable between classifications, and estimated the labor allocations. Although there is data for many countries and years, there is not much data for African countries, and for many of the oil-exporting countries (such as Iran, Iraq, Bahrain, etc.). Moreover, for the countries that are in the database, there is not data for every year so we do not have a balanced panel.

The data for the real exchange rate comes from the Bank for International Settlements, which has a database with cross-country nominal and real CPI-based exchange rates. For many countries there is data from 1980, and for some others there is data only since 1994. The real exchange rate has 2010 as base (2010=100) and is defined such that an increase in the real exchange rate is interpreted as a real appreciation of the country. However, since we want to interpret the real exchange rate as it is common in the emerging economies, we transformed our variable to be: $1/RER$. In this way, a decrease in the variable is interpreted as a real appreciation of the country.

To measure the change in fuel prices, we used a fuel price index constructed by the International Monetary Fund. This fuel price index is constructed based on the prices of crude oil (petroleum), natural gas and coal prices. There is data for this index since 1992.

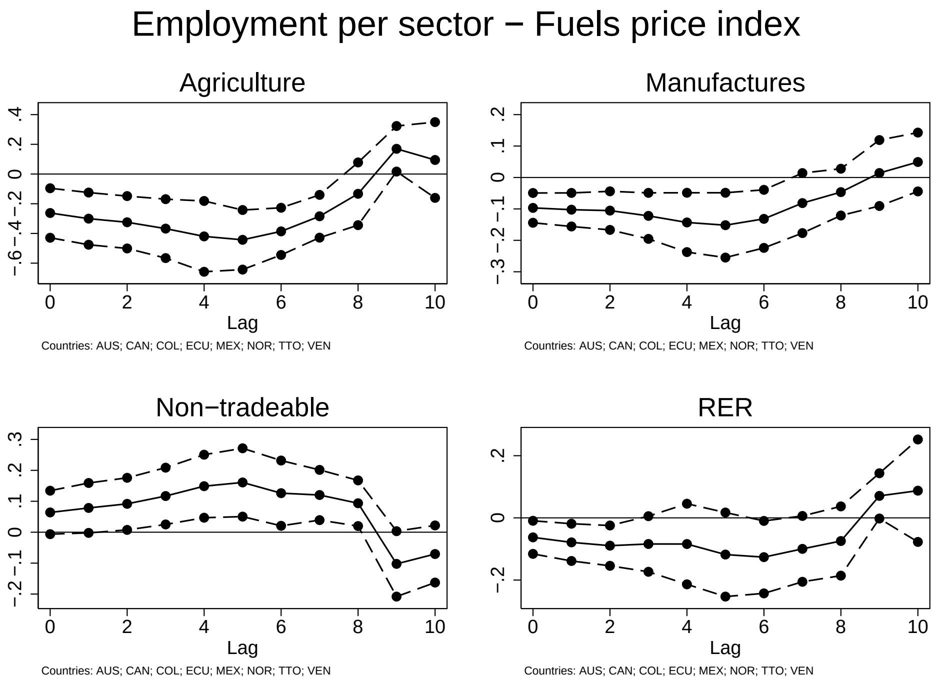
Given that we want to analyze the effect of a change in the fuels' price over the labor shares per sector and real exchange rate for countries that are highly dependent on commodity exports, we chose the countries for which fuel exports were at least 20% of total exports for at least one year in the sample. For this purpose, we use a variable from the World Bank's database which indicates the percentage of fuel exports over total exports for each country every year. Since we only have data for the fuels' price index from 1992, the data on labor shares goes only until 2008 and there is not information on labor shares for many countries. Our final sample includes Australia, Canada, Colombia, Ecuador, Mexico, Norway, Trinidad and Tobago and Venezuela from 1992 to 2008, with some missing years for some countries.

2.1.1 Commodity Prices and Labor Reallocation

To support our hypothesis, we estimate the effect of an increase in the price of fuel commodities on the labor share in the tradable sectors of the economy, non-tradable sectors and on the real exchange rate. The correlations were computed by estimating the following regression:

$$\log\left(y_{i,t}\right) = \beta_0 + \beta_1 \log\left(P^{com}_{i,t-j}\right) + \eta_i + \epsilon_{i,t}, \quad j \in \{0, \cdots, 10\}$$

where $y_{i,t}$ is the: (1) labor share in agriculture, (2) labor share in manufactures, (3) labor share in non-tradable sector (defined as labor in a) electricity, gas and water supply, b) construction and c) transport, storage and communications) and (4) the real exchange rate. As independent variable, $P^{com}_{i,t-j}$, we use a fuel price index (based on crude oil, natural gas and coal prices). The variable η_i is a country fixed effect, and $\epsilon_{i,t}$ is a normally distributed error term. We do not include time fixed effects, since the independent variable varies across time but is constant across countries, so the time fixed effects would create perfect collinearity. For our estimations, we use robust standard errors which, on this panel setting, are equivalent to clustering by country. The coefficient of interest in each of the regressions is β_1, which can be interpreted as the percentage increase in the dependent variable after a 1% increase in the independent variable. The results of the regressions with the fuels' price index as the explanatory variable are shown in Table 5. The following figures illustrate the coefficients for each of the regressions, with the 95% confidence interval.



The above figure strongly suggests that an increase in the price of fuels generates an appreciation of the real exchange rate and a reallocation of labor across sectors, moving from the tradable sectors (agriculture and manufactures) to the non-tradable sector. Moreover, these effects seem to last for at least six years after the price shock, increasing during the first years and then attenuating until they disappear.

On average, a 1% increase in the fuel price index generates an immediate fall in the labor share of agriculture of around 0.3%, a fall in the labor share of manufactures of 0.1% an increase in the labor share of non-tradables of around 0.06%, and a real exchange rate appreciation of 0.06%. The effect on the labor reallocation is increasing during the first five years, after which the labor share of agriculture falls by 0.44%, the labor share of manufactures falls by 0.15% and the labor share of services rises by 0.16%. Later, the correlation of a price increase and the labor reallocation diminishes until it disappears on the eighth year. In contrast, the effect on the real exchange rate appreciation statistically diminishes on the third year after the shock.

This empirical exercise suggests that there is an effect of the prices of commodities on labor reallocation between sectors in the economy, in countries that are very dependent on commodity exports. The following section presents evidence on knowledge spillovers on the innovation process.

2.2 Patent and Citations Data

For the second part, we use the NBER Patents database and information from Compustat. The patent data comes from the NBER patent database, which contains US patent information from 1976 to 2006.[1] The database contains information about patents, citations, assignees, among others. We focus on patents and citations. The second component is information from Compustat.[2] We consider firms in North America (US and Canada) for the maximum amount of years available. We then merge the two databases. The key variable to use in the merge is the `gvkey`, the Compustat ID.[3] We keep all observations for which we have matches.

2.2.1 Asymmetric Knowledge Spillovers

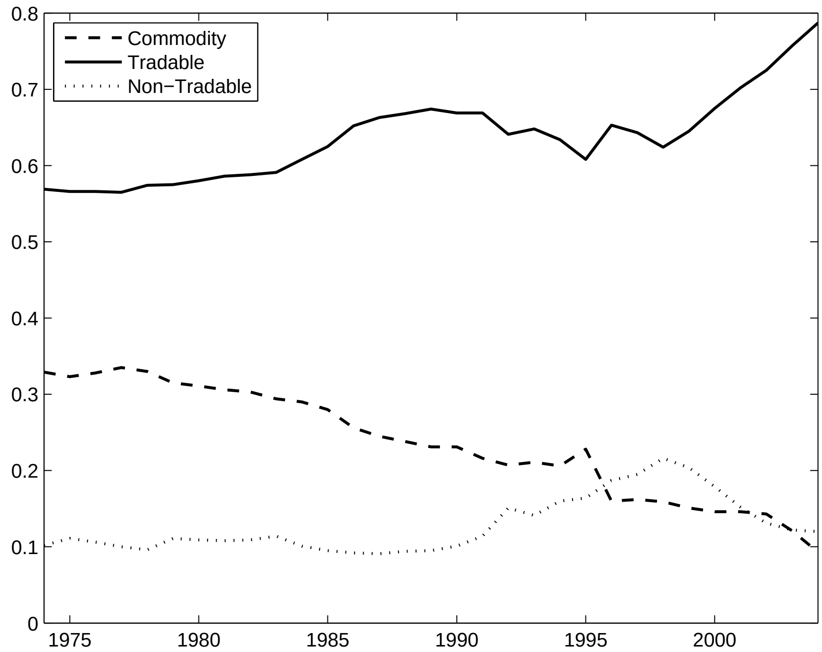
We separate the patent information by productive sectors: (i) commodity sector, (ii) tradable sector and (iii) non-tradable sector. For this we use the categorization made by Forbes (2002), which uses SIC codes. We obtain a total of 5,092,817 matches for patents. Figure 1 illustrates the number of patent applications per sector (we focus on applications because they are closest to the date of the invention):

[1]The information is available at https://sites.google.com/site/patentdataproject/Home.

[2]The information is available at https://wrds-web.wharton.upenn.edu.

[3]There is a bridge available that links patent assignee number with a gvkey code in the NBER Patent database.

Figure 1: Share of Patent Applications by Sector



It should be noted that the tradable sector accounted for around 60% of the total innovation in the economy during the last four decades. Thus, growth in the economy could be strongly linked with innovation in the tradable sector.

Table 1 describes the distribution of citations by productive sectors:

Table 1: Citations by Productive Sectors

		Citing patents			
		Commodity	Tradable	Non-Tradable	Total
Cited patents	Commodity	654,692	198,415	17,447	870,554
	Tradable	156,495	2,658,189	427,356	3,242,040
	Non-Tradable	15,234	542,686	422,303	980,223
	Total	826,421	3,399,290	867,106	5,092,817

Notice that patents can be cited and can cite other patents. Hence, we include the two aspects in our analysis. The next Table summarizes information regarding how the cited and citing patents are distributed according to the different productive sectors:

Table 2: Distribution of Citing and Cited Patents by Productive Sectors

	Total Citing Patents (%)	Total Cited Patents (%)
Commodity	16.2%	17.1%
Tradable	66.7%	63.7%
Non-Tradable	17.0%	19.2%

We can see that there is a small asymmetry between the cited and the citing patents. For the case of the former, we observe that 63.7% of the cited patents are from the tradable sector, while 17.1% and 19.2% are from the commodity and the non-tradable sector, respectively. Regarding the citing patents, 66.7% are from the tradable sector while 16.2% and 17% are from the commodity and non-tradable sector respectively. We can see that in terms of citations, from a cited and citing point of view, the tradable sector appears to be much more active than the other two sectors in terms of patenting.

Knowledge spillovers may be proxied by the structure of citations between productive sectors. Table 3 presents the data on the number of patents per sector that cite patents on each sector:

Table 3: Distribution of Citations by Productive Sectors, Citing Patents

	Commodity	Tradable	Non-Tradable
Cite Commodity	79.2%	5.8%	2.0%
Cite Tradable	18.9%	78.2%	49.3%
Non-Tradable	1.8%	16.0%	48.7%

We observe that citing patents from the commodity sector mainly cite patents from the same sector, in roughly 79% of the occasions, followed by cites made to the tradable sector, which occurs in approximately 19% of the cases. Citing patents from the tradable sector tend to cite the same sector in nearly 78% of the case and, to a much lower extent, the non-tradable sector, in 16% of the cases. Finally, citing patents from the non-tradable sector cite in roughly the same amount patents from the tradable and non tradable sectors, in 49% of the occassions each.

As a way to conclude we see from the analysis presented above the following two facts, related with growth and diffusion of knowledge. First, regarding growth of knowledge, most of the patenting is done in the tradable sector. This is independent of whether we look at cited (64% of total) or citing patents (67% of total). The ratio of citations of the commodity and the non-tradable sectors to the tradable sector are equal to 26.8% and 30.2% for the cited patents case, respectively, and equal to 24.3% and 25.5% for the citing patents case, respectively. This suggests that if patenting is a proxy for innovation, most of the innovation is done in the tradable sector and hence would suggest that it would be the main force driving the increase in knowledge.

Second, we see that citing patterns are asymmetric which implies that so is the diffusion of knowledge. The tradable sector tends to cite itself when we look at cited or citing patents, and in a much lower extent, to cite the non-tradable sector. For the commodity sector we see that it also tends to cite itself and to cite the tradable sector with a much lower intensity. Finally, the non-tradable sector tends to cite in roughly an equal magnitude patents from the tradable and non-tradable sector. All these interactions suggest that the tradable sector plays a major role in the diffusion of knowledge in the economy.

3 The Model

Our base model follows closely Schmitt-Grohé and Uribe (2015), which builds on the multi-sector model developed by Mendoza (1995).[4] We consider three base productive sectors in the economy: commodities, tradable and non-tradable goods. A composite tradable good sector is also present and its production process uses as inputs commodities and tradable goods. In addition, a final

[4]This is not the same model we presented in the term paper presentation. Based on comments that we received on that occasion we introduced modifications. However, we were not completely certain about the existence of a balanced growth path in the modified framework. Given, we decided to develop a simpler model which is the one presented in this section. The initial model is presented in the Appendix.

good producing sector uses as inputs the non-tradable good and the composite tradable good. The problem of the households is relatively standard except for the fact that they must choose how many hours of labor they will supply to each of the base productive sectors. For simplification purposes our model does not include capital but it could be modified in order to add it to the productive processes.

The new feature that our model incorporates is the fact that the base productive sectors need intermediate goods in their production processes. These intermediate goods are produced by monopolists, which can be replaced with some probability by new entrants that innovate. Thus, by including innovation in the model we are allowing for creative destruction to take place. We model this component in a similar fashion as in Aghion, Akcigit, and Howitt (2013) (which follows the spirit of Aghion and Howitt, 1992) but we extend it to a multiple productive sector framework. Hence, productivity growth in this model will be endogenously determined and will be driven by the entrants in each of the base productive sectors.

The next subsections describe the components of our model.

3.1 Households

Households maximize the following lifetime utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\left[C_t - A_t \left(\frac{(L_t^c)_c^{\omega}}{\omega_c} + \frac{(L_t^x)^{\omega_x}}{\omega_x} + \frac{(L_t^n)^{\omega_n}}{\omega_n}\right)\right]^{1-\sigma} - 1}{1-\sigma}$$

subject to:

$$C_t + P_t^u B_{t+1} = P_t^u B_t (1 + r_t^*) + W_t^c L_t^c + W_t^x L_t^x + W_t^n L_t^n + \Pi$$

where C_t corresponds to consumption of the final good of the economy, L_t^i to the labor supply provided to the productive sector i of the economy (to be specified below), A_t corresponds to the productivity of the economy, B_{t+1} denotes the stock of bonds the household will choose for next period, P_t^u is the relative price of the composite tradable good as a function of the final good, W_t^i denotes the wage the household receives for supplying labor every period to sector i and Π denotes the profits obtained from production, which we will specify below.

3.2 Productive Sectors

There are 5 productive sectors in the economy. The first one is the final good sector and the second one is the composite tradable good sector. The other 3 correspond to the commodity, tradable and non-tradable sectors.

3.2.1 Final Good Sector

The final good producer behaves competitively and uses as inputs a tradable composite good and non-tradable goods. The problem of the final good producer can be represented by:

$$\max_{D_t^u, D_t^n} \Pi_t^f = [\mu_f (A_t D_t^u)^{\gamma_f} + (1-\mu_f)(A_t D_t^n)^{\gamma_f}]^{\frac{1}{\gamma_f}} - P_t^u D_t^u - P_t^n D_t^n$$

where D_t^u and D_t^n correspond to the amounts of tradable composite and and non-tradable goods demanded for the production of the final good, respectively, and A_t is a productivity parameter. P_t^u and P_t^n are the relative prices of the goods used in the production process.

3.2.2 Tradable Composite, Commodity, Tradable and Non-Tradable Good Producing Sectors

The tradable composite good is produced by using the commodity and the tradable good. The problem that the producer faces is given by:

$$\max_{D_t^c, D_t^x} \Pi_t^u = P_t^u \left[\mu_u (A_t D_t^c)^{\gamma_u} + (1-\mu_u)(A_t D_t^x)^{\gamma_u}\right]^{\frac{1}{\gamma_u}} - P_t^c D_t^c - P_t^x D_t^x$$

The commodity, tradable and non-tradable good producing sectors use as inputs labor and intermediate goods, which are sector-specific. For the case of the tradable sector, the problem of the tradable good producer is given by:

$$\max_{L_t^x, M_t^x} \Pi_t^x = A_t^{1-\alpha}(L_t^x)^{1-\alpha}(M_t^x)^{\alpha} - W_t L_t^x - Q_t^x M_t^x$$

where the production technology is given by $Y_t^x = A_t^{1-\alpha}(L_t^x)^{1-\alpha}(M_t^x)^{\alpha}$.

The intermediate good is produced by a monopolist. Her problem is given by:

$$\max_{M_t^x} \tilde{\Pi}_t^x = Q_t^x(M_t)M_t - M_t$$

The intermediate good producer uses the final good to produce the good.

The other sectors have a similar structure except for the prices they face.

3.2.3 Productivity and Entrants

In this model productivity evolves according to the following structure:

$$A_t = \begin{cases} A_{t-1} & \text{with probability} \quad 1-\kappa \\ \theta A_{t-1} & \text{with probability} \quad \kappa \end{cases}$$

where $\theta > 1$. Notice that the growth rate of the economy will be given by

$$\begin{aligned} A_t &= A_{t-1}(1-\kappa) + \theta\kappa A_{t-1} \\ A_t - A_{t-1} &= \kappa A_{t-1}(\theta - 1) \\ g &= \frac{A_t - A_{t-1}}{A_{t-1}} = \kappa(\theta - 1) \end{aligned}$$

In our model, κ is a function of all the R&D expenditure in the economy.

Monopolists can be replaced by potential entrants. Potential entrants can hire R_t^i workers to try to innovate and replace the monopolist in sector i . If they are successful, they replace the monopolist with probability $\kappa(R_1, R_2, R_3)$. Hence, the problem that a potential entrant faces in the tradable intermediate good sector is

$$\max_{R_t^x} \kappa(R_t^c, R_t^x, R_t^n)\tilde{\Pi}_t^x - W_t R_t^x$$

A candidate function for $\kappa(\cdot)$ is $\kappa(R_t^c, R_t^x, R_t^n) = (R_t^c)^{\nu_c}(R_t^x)^{\nu_x}(R_t^n)^{\nu_n}$.

4 Model Solution and Calibration

In this section we characterize the solution to our model by computing how steady state allocation and prices will be determined. We also present our calibration strategy.

4.1 Households

Before proceeding it is important to note that it is necessary to transform the variables of the model to efficiency units, given that the economy is growing. All variables in efficiency units will be denotes by lower cases (i.e. $x_t = \frac{X_t}{A_t}$).

Let $\beta\lambda_t$ be the Lagrange multiplier of the budget constraint. Then, the first order conditions of the household's problem yield the following equalities:[5]

[5] We are assuming an interior solution. Given the structure and parametrization that we will choose this will hold in equilibrium.

$$
\begin{aligned}
\left[C_t - A_t\left(\frac{(L_t^c)_c^{\omega}}{\omega_c} + \frac{(L_t^x)^{\omega_x}}{\omega_x} + \frac{(L_t^n)^{\omega_n}}{\omega_n}\right)\right]^{-\sigma} &= \lambda_t \\
\mathbb{E}_t\left[\frac{\beta\lambda_{t+1}(1+r_{t+1}^*)P_{t+1}^x}{\lambda_t P_t^x}\right] &= 1 \\
\left[C_t - A_t\left(\frac{(L_t^c)_c^{\omega}}{\omega_c} + \frac{(L_t^x)^{\omega_x}}{\omega_x} + \frac{(L_t^n)^{\omega_n}}{\omega_n}\right)\right]^{-\sigma} A_t(L_t^c)^{\omega_c-1} &= W_t^c\lambda_t \\
\left[C_t - A_t\left(\frac{(L_t^c)_c^{\omega}}{\omega_c} + \frac{(L_t^x)^{\omega_x}}{\omega_x} + \frac{(L_t^n)^{\omega_n}}{\omega_n}\right)\right]^{-\sigma} A_t(L_t^x)^{\omega_x-1} &= W_t^x\lambda_t \\
\left[C_t - A_t\left(\frac{(L_t^c)_c^{\omega}}{\omega_c} + \frac{(L_t^x)^{\omega_x}}{\omega_x} + \frac{(L_t^n)^{\omega_n}}{\omega_n}\right)\right]^{-\sigma} A_t(L_t^n)^{\omega_n-1} &= W_t^n\lambda_t
\end{aligned}
$$

From which we obtain the Euler equation (note that $A_t = (1+g)^t$):

$$
\mathbb{E}_t\left[\frac{\beta(1+r_{t+1}^*)}{(1+g)^{\sigma}}\left(\frac{c_{t+1} - \left(\frac{(L_{t+1}^c)_c^{\omega}}{\omega_c} + \frac{(L_{t+1}^x)^{\omega_x}}{\omega_x} + \frac{(L_{t+1}^n)^{\omega_n}}{\omega_n}\right)}{c_t - \left(\frac{(L_t^c)_c^{\omega}}{\omega_c} + \frac{(L_t^x)^{\omega_x}}{\omega_x} + \frac{(L_t^n)^{\omega_n}}{\omega_n}\right)}\right)^{-\sigma}\frac{P_{t+1}^x}{P_t^x}\right] = 1
$$

And the labor supply equations:

$$
\begin{aligned}
L_t^c &= (w_t^c)^{\omega_c-1} \\
L_t^x &= (w_t^x)^{\omega_x-1} \\
L_t^n &= (w_t^n)^{\omega_n-1}
\end{aligned}
$$

4.2 Productive Sectors

The final good producer problem yields the following first order conditions:

$$
\begin{aligned}
A_t\mu_f\left[\mu_f(A_tD_t^u)^{\gamma_f} + (1-\mu_f)(A_tD_t^n)^{\gamma_f}\right]^{\frac{1}{\gamma_f}-1}(D_t^u)^{\gamma_f-1} &= P_t^u \\
A_t(1-\mu_f)\left[\mu_f(A_tD_t^u)^{\gamma_f} + (1-\mu_f)(A_tD_t^n)^{\gamma_f}\right]^{\frac{1}{\gamma_f}-1}(D_t^n)^{\gamma_f-1} &= P_t^n
\end{aligned}
$$

Which in turn imply:

$$\frac{\mu_f}{1-\mu_f}\left(\frac{d_t^u}{d_t^n}\right)^{\gamma_f - 1} = \frac{P_t^u}{P_t^n}$$

The first order conditions of the problem that the producer of the tradable composite good faces imply the following optimality condition:

$$\frac{\mu_u}{1-\mu_u}\left(\frac{d_t^c}{d_t^x}\right)^{\gamma_u - 1} = \frac{P_t^c}{P_t^x}$$

For the case of the commodity producing sector (other sectors are practically identical) the first order conditions yield:

$$\frac{(1-\alpha)P_t^c Y_t^c}{L_t^c} = W_t^c$$
$$\frac{\alpha P_t^c Y_t^c}{M_t^c} = Q_t^c$$

Thus, the demand that the monopolist faces is $M_t^c = \frac{\alpha P_t^c Y_t^c}{Q_t^c}$ and her problem yields the following first order condition:

$$M_t^c = \alpha^2 P_t^c Y_t^c$$

which implies that the equilibrium price will be $Q_t^c = \frac{1}{\alpha}$ and equilibrium profits will be $\tilde{\Pi}_t^c = (1-\alpha)\alpha P_t^c Y_t^c$.

The same structure applies for the other sectors.

Regarding potential entrants, the first order condition for a potential entrant to the commodity sector is given by:

$$\kappa'(R_t^c, R_t^x, R_t^n)\tilde{\Pi}_t^c = W_t^c$$

Replacing the candidate function we obtain the demand for workers:

$$R_t^c(R_t^x, R_t^n) = \left[\frac{\tilde{\Pi}_t^c \nu_c (R_t^x)^{\nu_x} (R_t^n)^{\nu_n}}{W_t^c}\right]^{\frac{1}{1-\nu_c}}$$

For all sectors we have that:

$$R_t^c(R_t^x, R_t^n) = \left[\frac{\tilde{\Pi}_t^c \nu_c (R_t^x)^{\nu_x} (R_t^n)^{\nu_n}}{W_t}\right]^{\frac{1}{1-\nu_c}}$$

$$R_t^x(R_t^c, R_t^n) = \left[\frac{\tilde{\Pi}_t^x \nu_x (R_t^c)^{\nu_c} (R_t^n)^{\nu_n}}{W_t}\right]^{\frac{1}{1-\nu_x}}$$

$$R_t^n(R_t^c, R_t^x) = \left[\frac{\tilde{\Pi}_t^n \nu_n (R_t^c)^{\nu_c} (R_t^x)^{\nu_x}}{W_t}\right]^{\frac{1}{1-\nu_n}}$$

The system of equations is highly nonlinear. Let $\Omega_t^i = \left[\frac{\tilde{\Pi}_t^i \nu_i}{W_t^i}\right]^{\frac{1}{1-\nu_i}}$ for $i = c, x, n$. By applying logs on both sides we can write the system as:

$$\underbrace{\begin{bmatrix} \ln R_t^c \\ \ln R_t^x \\ \ln R_t^n \end{bmatrix}}_{Z_t} = \underbrace{\begin{bmatrix} \ln \Omega_t^c \\ \ln \Omega_t^x \\ \ln \Omega_t^n \end{bmatrix}}_{H_t} + \underbrace{\begin{bmatrix} 0 & \frac{\nu_x}{1-\nu_c} & \frac{\nu_n}{1-\nu_c} \\ \frac{\nu_c}{1-\nu_x} & 0 & \frac{\nu_n}{1-\nu_x} \\ \frac{\nu_c}{1-\nu_n} & \frac{\nu_x}{1-\nu_n} & 0 \end{bmatrix}}_{\nu} \underbrace{\begin{bmatrix} \ln R_t^c \\ \ln R_t^x \\ \ln R_t^n \end{bmatrix}}_{Z_t}$$

Which implies that $Z_t = (I - \nu)^{-1} H_t$. Notice that H_t is a function of wages and profits. Let R_t^c, R_t^x, R_t^n denote the solutions of the systems of equations, which are given by:

$$R_t^c = (\Omega_t^n)^{\frac{\nu_n(1-\nu_n)}{1-\nu_c-\nu_x-\nu_x}} (\Omega_t^x)^{\frac{\nu_x(1-\nu_x)}{1-\nu_c-\nu_x-\nu_x}} (\Omega_t^c)^{\frac{(1-\nu_n-\nu_x)(1-\nu_c)}{1-\nu_c-\nu_x-\nu_x}}$$

$$R_t^x = (\Omega_t^n)^{\frac{\nu_n(1-\nu_n)}{1-\nu_c-\nu_x-\nu_x}} (\Omega_t^c)^{\frac{\nu_c(1-\nu_c)}{1-\nu_c-\nu_x-\nu_x}} (\Omega_t^x)^{\frac{(1-\nu_c-\nu_n)(1-\nu_x)}{1-\nu_c-\nu_x-\nu_x}}$$

$$R_t^n = (\Omega_t^x)^{\frac{\nu_x(1-\nu_x)}{1-\nu_c-\nu_x-\nu_x}} (\Omega_t^c)^{\frac{\nu_c(1-\nu_c)}{1-\nu_c-\nu_x-\nu_x}} (\Omega_t^n)^{\frac{(1-\nu_c-\nu_x)(1-\nu_n)}{1-\nu_c-\nu_x-\nu_x}}$$

Replacing the definition of Ω^i:

$$R_t^c(y_t^c, y_t^x, y_t^n) = \left(\frac{(1-\alpha)\alpha\nu_n P_t^n y_t^n}{w_t^n}\right)^{\frac{\nu_n}{1-\nu_c-\nu_x-\nu_x}} \left(\frac{(1-\alpha)\alpha\nu_x P_t^x y_t^x}{w_t^x}\right)^{\frac{\nu_x}{1-\nu_c-\nu_x-\nu_x}} \left(\frac{(1-\alpha)\alpha\nu_c P_t^c y_t^c}{w_t^c}\right)^{\frac{(1-\nu_n-\nu_x)}{1-\nu_c-\nu_x-\nu_x}}$$

$$R_t^x(y_t^c, y_t^x, y_t^n) = \left(\frac{(1-\alpha)\alpha\nu_n P_t^n y_t^n}{w_t^n}\right)^{\frac{\nu_n}{1-\nu_c-\nu_x-\nu_x}} \left(\frac{(1-\alpha)\alpha\nu_c P_t^c y_t^c}{w_t^c}\right)^{\frac{\nu_c}{1-\nu_c-\nu_x-\nu_x}} \left(\frac{(1-\alpha)\alpha\nu_x P_t^x y_t^x}{w_t^x}\right)^{\frac{(1-\nu_c-\nu_n)}{1-\nu_c-\nu_x-\nu_x}}$$

$$R_t^n(y_t^c, y_t^x, y_t^n) = \left(\frac{(1-\alpha)\alpha\nu_x P_t^x y_t^x}{w_t^x}\right)^{\frac{\nu_x}{1-\nu_c-\nu_x-\nu_x}} \left(\frac{(1-\alpha)\alpha\nu_c P_t^c y_t^c}{w_t^c}\right)^{\frac{\nu_c}{1-\nu_c-\nu_x-\nu_x}} \left(\frac{(1-\alpha)\alpha\nu_n P_t^n y_t^n}{w_t^n}\right)^{\frac{(1-\nu_c-\nu_x)}{1-\nu_c-\nu_x-\nu_x}}$$

For the case of the commodity sector, we know that $L_t^c = \frac{(1-\alpha)P_t^c y_t^c}{w_t^c}$ and that $m_t^c = \alpha^2 P_t^c y_t^c$. Replacing in the production function we have that

$$y_t^c = \left(\frac{(1-\alpha)P_t^c y_t^c}{w_t^c}\right)^{1-\alpha} \left(\alpha^2 P_t^c y_t^c\right)^{\alpha}$$

from which we can obtain the equilibrium wage for the sector:

$$w_t^c = (1-\alpha)(\alpha^2)^{\frac{\alpha}{1-\alpha}} (P_t^c)^{\frac{1}{1-\alpha}}$$

The same structure applies for the other sectors. Imposing the labor market clearing condition we can compute the output produced by each sector, which is given by the solution to the following system of equations:

$$\begin{aligned}
\left((1-\alpha)(\alpha^2)^{\frac{\alpha}{1-\alpha}} (P_t^c)^{\frac{1}{1-\alpha}}\right)^{\omega_c - 1} &= \frac{y_t^c}{(P_t^c \alpha^2)^{\frac{\alpha}{1-\alpha}}} + R_t^c(y_t^c, y_t^x, y_t^n) \\
\left((1-\alpha)(\alpha^2)^{\frac{\alpha}{1-\alpha}} (P_t^x)^{\frac{1}{1-\alpha}}\right)^{\omega_x - 1} &= \frac{y_t^x}{(P_t^x \alpha^2)^{\frac{\alpha}{1-\alpha}}} + R_t^x(y_t^c, y_t^x, y_t^n) \\
\left((1-\alpha)(\alpha^2)^{\frac{\alpha}{1-\alpha}} (P_t^n)^{\frac{1}{1-\alpha}}\right)^{\omega_n - 1} &= \frac{y_t^n}{(P_t^n \alpha^2)^{\frac{\alpha}{1-\alpha}}} + R_t^n(y_t^c, y_t^x, y_t^n)
\end{aligned}$$

By solving this system of equations we can find the solution to y_t^c, y_t^x, y_t^n.

By market clearing conditions we must have that the demand for non-tradable goods must be equal to their supply, so $d_t^n = y_t^n$. Given this, from the first order condition of the final good producer we can pin down d_t^u:

$$d_t^u = \left(\frac{P_t^u (1-\mu_f)}{P_t^n \mu_f} \right)^{\frac{1}{\gamma-1}} d_t^n$$

Also, using the production function of the final good producer and the first order condition of the composite tradable good producer problem, we can pin down d_t^x and d_t^c. Replacing the optimality relationship for d_t^c as a function of d_t^x in the production function we obtain:

$$d_t^x = \frac{d_t^u}{\left(\mu_u \left(\frac{(1-\mu_u)P_t^c}{\mu_u P_t^x} \right)^{\frac{\gamma_u}{\gamma_u - 1}} + 1 - \mu_u \right)^{\frac{1}{\gamma_u}}}$$

From which we can also obtain d_t^c. Household consumption and bond positions can be obtained from the Euler equation and the market clearing conditions.[6]

We calibrate the parameters of our model in order to fit data from Canada. As presented in section 2, among different kind of commodities we see that it is the price of fuel the one that generates important effects on the economy. We focus on Canada because fuel commodities represent a large share of its exports (Chen and Rogoff, 2003) and also because it is seen as a small open economy, due to its high financial integration and lack of capital controls (Mendoza, 1991).

For the calibration of the parameters of our model, we follow Schmitt-Grohé and Uribe (2015) given that the production side is very similar. Although Canada does not appear explicitly in Schmitt-Grohé and Uribe (2015), there are other small open economies that resemble Canada. Thus, we adopt their parametrization.[7] The calibration of the new sector was performed as follows. The long run growth of Canada according to statistics from the FRED database is approximately 1.018%. This pins down the growth rate of our model in steady state. This is, $g = 0.018$. Recall

[6] At this stage of the paper we are not focused on matching bond positions in the steady state. However, we could introduce capital to the model and follow the approaches of Schmitt-Grohé and Uribe (2003) and Uribe and Yue (2006), for example, to pin down these variables.

[7] We would like to calibrate the full model specifically to the case of Canada in a future draft.

that $g = z(\theta - 1)$, so we have two parameters and only one value. However, z is the average entry rate in the economy in our model. This is because when there is a successful innovation there is an automatic replacement of the incumbents. According to Ciobanu and Wang (2012), the average yearly entry rate of firms in Canada between 2000 and 2008 is close to 10.8%. However, they also document that the roughly 3.3 percentage points of the entry rate correspond to short-lived firms. Hence, we pick a conservative entry rate for the economy of 7%. This implies that $z = 0.07$ in steady state from which we can deduce that $\theta = 1.2565$.

The calibration of the parameters in the R&D expenditure function combines what was presented in section 2 and the entry rate of the economy. We use as inputs the patents by sectors, according to information from Compustat and the NBER Patent Database. The average distribution of patents across sectors is 23.5% the commodity sector, 64.6% the tradable sector and the rest to the non-tradable sector. Given this we have that $\nu_c = 0.37\nu_x$ and $\nu_n = 0.2\nu_x$. Thus, given the functional form of the R&D function and the fact that $z = 0.07$ in equilibrium, we have that $\nu_x = 0.2734$, $\nu_n = 0.0550$ and $\nu_c = 0.1011$. Note that this calibration is also a function of the equilibrium production quantities, which determine R_t^c, R_t^x and R_t^n.

The structure we assume for the commodity price process is the following:

$$
\begin{aligned}
\ln(P_t^c) &= \rho^c \ln(P_{t-1}^c) + (1 - \rho^c)\ln(\overline{P}_{t-1}^c) + \epsilon_t^c \\
\ln(\overline{P}_t^c) &= \varphi^c \ln(\overline{P}_{t-1}^c) + \eta_t^c
\end{aligned}
$$

We assume that the commodity price is affected by its own past realizations (P_t^c) and also by changes in its long run mean ($\overline{P}_t^c$). To calibrate these parameters we use commodity price information from the database presented in Jacks (2013). We focus on the real price of petroleum between 1860 and 2013 and we identify that an average cycle lasts nearly 25 years (this is, starting from the trend, it takes roughly 25 years to go back to the trend). Given that we need to set two parameters with one time series we choose a parametrization of $\rho^c = 0.5$ and $\varphi^c = 0.85$. We set the steady state values of the four prices of the economy to unity.

Table 4 summarizes the values of the parameters in our model:

Table 4: Summary of Parameters

Parameter	Value
α	0.33
ω_c	1.455
ω_x	1.455
ω_n	1.455
σ	2
μ_f	0.436
μ_u	0.102
γ_f	0.5
γ_u	0.5
ρ^c	0.5
φ^c	0.85
z	0.07
r^*	0.04

Finally, we assume a particular structure to relate tradable and commodity prices outside the balanced growth path. We assume that $P_t^c = (P_t^x)^{-1}$. The purpose of imposing this constraint is related to the commodity currency literature (Chen and Rogoff, 2003). In general, countries whose exports are composed to a large extent by commodities face changes in their real exchange rates, which affect the profitability of other sectors in the economy. At this stage of our paper we could not generate endogenously this response but we plan to include new features to do so in the future.

5 Simulation Results

In this section we present the result of our simulations. One of the main purposes of this paper is to show that commodity price shocks may affect short and medium run growth. Hence, we analyze the response of the economy to a shock in the price of the commodity good. In particular, we study the effect of a 10% increase in the long run mean of the commodity price process (the $\overline{P}^c$ component).

Before proceeding it is important to mention that we define net exports as functions of the variables presented in the previous section. Specifically, we define $nx_t^i = P_t^i(y_t^i - d_t^i)$ for $i = c, x$. Given that the total output of the goods in the economy may differ from the domestic demand for the goods, it is important to have the definition of net exports in mind.

The solution method for our simulations is perturbation (first order approximation) because we are interested in analyzing the behavior around the balanced growth path.

Figures 2 and 3 present the response of the main variables in the economy to the commodity price shock (all variables are presented in deviations with respect to their steady state):

Figure 2: Responses to a 10% shock in the Commodity Price Long Run Mean

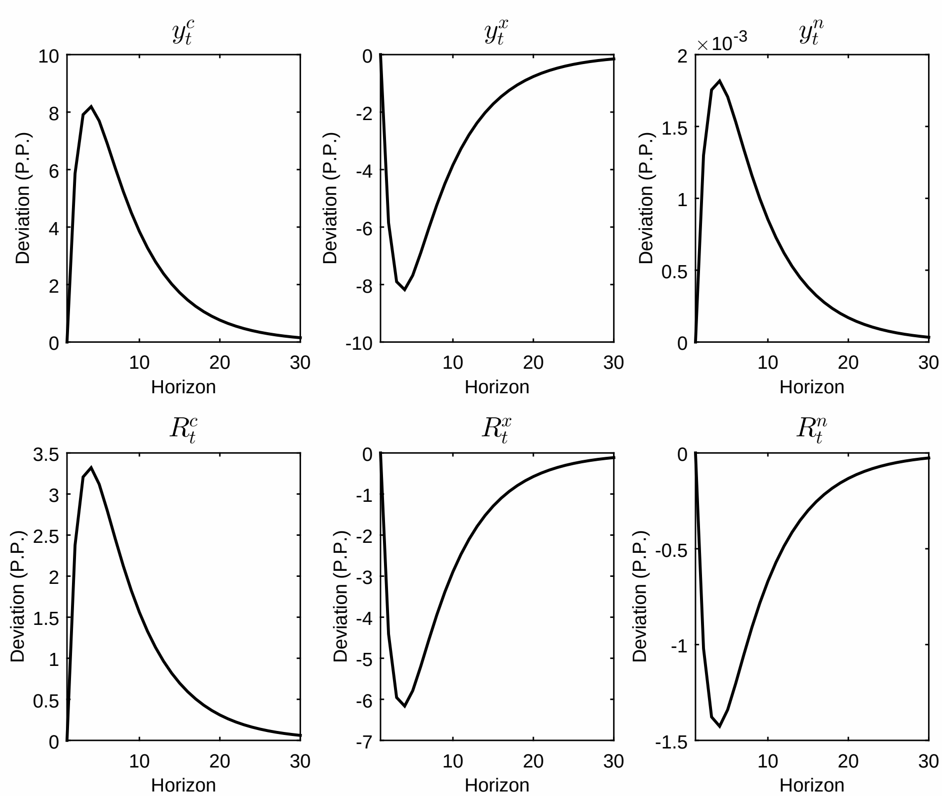
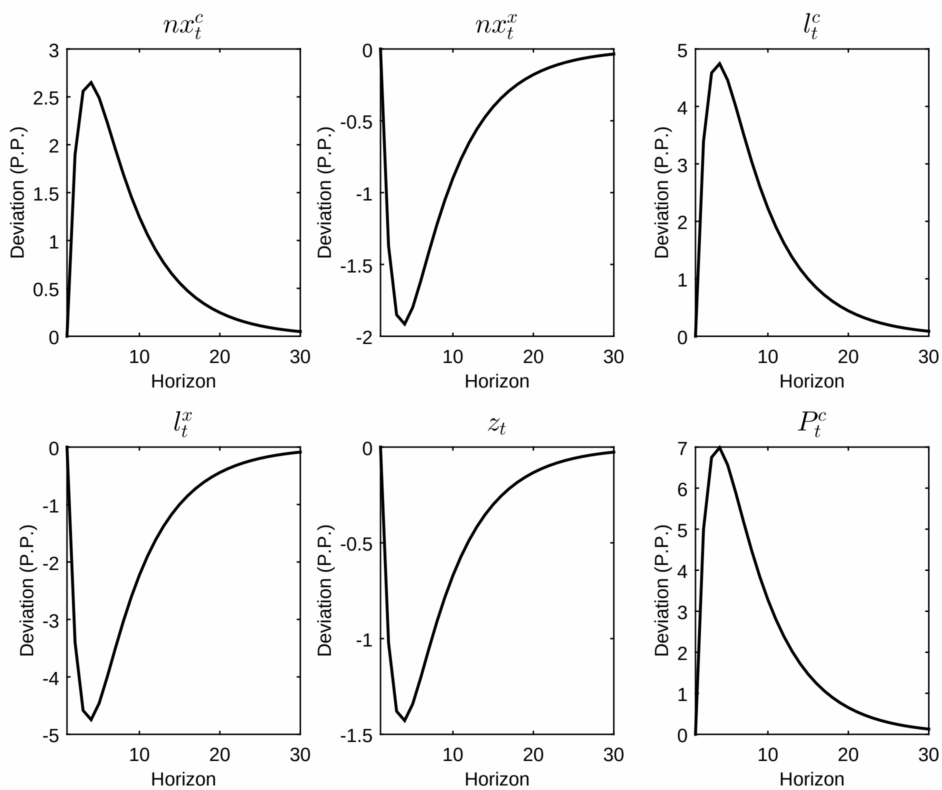


Figure 3: Responses to a 10% shock in the Commodity Price Long Run Mean (Continued)



We observe from Figure 2 that the commodity price shock reduces output in the tradable sector while increasing it in the commodity and non-tradable sectors. The number of resources invested in research increase in the commodity sector, by roughly 3%, but decrease in the tradable and non-tradable sectors by 6% and 1.5% respectively. Notice that even though output in the non-tradable sector increased we have that the profitability of the sector is not as high as in the commodity sector. The non-linearities of our model allow for rich dynamics.

Figure 3 shows the responses of the net exports of both sectors. We observe that the additional production of the commodity good is not absorbed by the domestic demand, leading to an increase of net exports of roughly 2.5%. For the case of the tradable sector we see that net exports decrease in around 2%, driven mainly by the reduction in the domestic production of the good. We can also see that, given that wages are tightly related to prices of goods, labor supply responses are quite different: labor supply increases for the case of the commodity sector and decreases for the tradable sector.

We can observe that z, the aggregate innovation rate of the economy, declines by 1.5% at the trough of response. This illustrates the fact that even though the profitability of the commodity sector increases, it is not sufficient to increase the overall innovation rate of the economy. Lastly, we observe a relatively long response in the price of the commodity good when the long run mean is shocked. The response almost completely dies out after nearly 30 periods.

We can use the response of the innovation rate to compute the forgone growth of the economy due to the commodity price shock. Given the response of z_t we can compute the growth rate of the economy outside the balanced growth path. Once we have computed the growth rates we can compare them to a situation in which the economy was always on its balanced growth path. By doing so, at a horizon of 29 years (which would be equivalent to a "cycle") we find that the 10% long-run mean commodity price shock generated a loss of output in the balanced growth path of nearly 1.6%. This result implies that commodity price shocks can indeed affect growth rates in the economy in a framework in which there are externalities in the innovation process. This opens an opportunity for policy: it may be possible to create contingent taxes that mitigate the commodity price shock and reduces growth losses and distorsions in the economy. Notice, however, that the effects of the commodity price shock result to be modest: the economy loses almost one year of growth in a horizon of 29 years. This opens space for a valid question: is a policy necessary in this context? The magnitude of the shock may not necessarily be in line with what we observe in reality, which are much larger shocks, and also we have that the functional form that defines aggregate innovation has strong complementarities. By considering larger shocks and a different functional form we may be able to obtain stronger effects on growth losses which may open a space for a clear necessity of policy intervention in the economy.

6 Conclusions and Future Work

The effects on the real side of the economy of a Dutch disease episode can be substantial. A strong expansion of the exports of a commodity generates a real appreciation of the domestic currency, generating a reallocation of resources between productive sectors in the economy. Specifically, a real appreciation leads to a reallocation of labor from the tradable to the commodity and the non-tradable good sectors, generating a de-industralization process.

In this paper we study the potentially negative consequences of Dutch disease episodes on growth. The reallocation of resources generated by commodity price shocks may channel resources from sectors that are the core of innovation to others that are not. In particular, the asymmetric knowledge spillovers that exist between productive sectors and resource reallocation may generate negative externalities on the innovation rate of the economy.

Using cross-country data we find evidence of Dutch disease episodes, driven by increases in international fuel prices during the last two decades. More specifically, there has been a real exchange rate appreciation and a labor reallocation from the tradable to the non-tradable and commodity sectors after an increase in fuel prices. Also, using data on patent citations, we find that innovations in the non-tradable and commodity sectors rely on the innovations of the tradable sector in a stronger way that how the tradable sector innovations rely on the innovations of the rest of the economy. This implies that asymmetric knowledge spillovers are a fact. Additionally, we find that the tradable sector leads by far the creation of knowledge in the economy, which in turn is theoretically the most affected sector when a Dutch disease episode occurs.

In order to quantitatively assess the consequences of a commodity price shock we develop a small open economy model composed by households and productive sectors, among which we can find commodity, tradable and non-tradable good sectors, following Mendoza (1995). To introduce growth, we incorporate a Schumpeterian component to the model, following Aghion and Howitt (1992) and Aghion, Akcigit, and Howitt (2013). Innovation is possible in the main productive sectors of the economy but the likelihood of innovation differs between them, as evidence suggests. Thus, aggregate innovation and hence the growth rate of the economy will be affected whenever a commodity price shock occurs. Our findings suggest that the growth rate indeed falls and can account for growth losses of roughly 1 year in a horizon of 29. This opens space for potential policy intervention as externalities generate growth losses in the medium run.

As future work we would like to explore many interesting avenues. The first one would be to focus on the Canadian case, as it appears to fit well the evidence that we have found. This would imply to narrow the focus of the patent study and of the calibration of the model. A second avenue is to continue developing the model we have presented. Adding capital and frictions would certainly help to match Canadian data and would certainly generate richer dynamics, allowing us to assess the fit of our model. Continuing in this point, we would also try to merge the model presented in the body of the paper with the one presented in the Appendix, as the latter presents interesting features, specially in the innovation side. Finally, we believe that there is substantive space for the introduction of policies in this context. Given that commodity price shocks generate negative externalities, we would like to introduce a government that could apply a contingent tax on the commodity price, in order to mitigate the harmful effects of the price shock on the growth rate of the economy.

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Appendix

In this section we present the description of our initial model, which is modified with respect to the one presented in the Term Paper Presentation according to the feedback that we received. This model combines features of a small open economy along with endogenous growth theory. We extend the framework presented in Ates and Saffie (2014) by allowing for a multi-sector productive structure of the economy. Specifically, we introduce commodity, tradable and non-tradable good sectors in line with Mendoza (1995), and we allow for a richer innovation structure in line with the findings presented in section 2.

We did not present this model in the main body of the paper because we are not certain about whether a balanced growth path is sustainable. We describe the model and show where the potential problem arises.

The Initial Model

Productive Sectors

There are 3 productive sectors in the economy: commodities, tradables and non tradables. The three productive sectors use intermediate goods in their production process. For the case of the tradable sector we have that total output is given by:

$$\ln Y_t^x = \alpha_x \int_0^1 \ln M_{j,t}^x dj$$

where $M_{j,t}^x$ is the amount of intermediate good j that the final producer uses in period t. The problem that the final good producer of the tradable sector faces is then:

$$\max_{\{[M_j]_0^1, K_t\}} P_t^x Y_t^x - \int_0^1 M_{j,t}^x P_{j,t}^x dj$$

where $P_{j,t}^x$ corresponds to the price of intermediate good j at period t and P_t^x is the price of the final good, the tradable good. First order conditions yield:

$$M_{j,t}: \quad \frac{P_t^x \alpha Y_t^x}{M_{j,t}} = P_{j,t}^x \Rightarrow M_{j,t} = \frac{P_t^x \alpha_x Y_t^x}{P_{j,t}^x}$$

We assume that in the intermediate good sector firms face Bertrand monopolistic competition in each product line. They produce according to the production function:

$$M_{j,t}^x = q_{j,t}^x L_{j,t}^x$$

where $q_{j,t}^x$ denotes the efficiency of labor. The leader faces the lowest marginal cost and charges the marginal cost of its follower. Assume that the efficiency of labor of its follower is denoted by $\tilde{q}_{j,t}^x$. Then, the price that the leader will charge is given by:

$$P_{j,t}^x = \frac{W_t}{\tilde{q}_{j,t}^x}$$

where W_t is the wage rate in period t. Efficiency evolves according to the following process:

$$q_{j,t}^x = (1 + \theta^c I^c)^{\nu_1^x} \left(1 + \theta^x I_j^x\right)^{\nu_2^x} (1 + \theta^n I^n)^{1-\nu_1^x-\nu_2^x} q_{j,t-1}^x$$

where I_j^x is an indicator function that takes the value of 1 if product line j receives an entrant, which replaces the current leader. This happens with probability ϕ_x. θ^x is the step size, which denotes how large are the "jumps" in productivity whenever there is successful innovation. I^c and I^n denote indicator functions that are equal to one if there is innovation in product lines in the commodity and non-tradable sectors, which happens with probabilities ϕ_c and ϕ_n, respectively.[8] Notice that

$$q_{j,t}^x = (1 + \theta^x)^{\nu_2^x} \Omega^x \tilde{q}_{j,t}$$

where $\Omega^x = \phi_c \phi_n (1 + \theta^c)^{\nu_1^x} (1 + \theta^n)^{1-\nu_1^x-\nu_2^x} + \phi_c(1 - \phi_n)(1 + \theta^c)^{\nu_1^x} + (1 - \phi_c)\phi_n (1 + \theta^n)^{1-\nu_1^x-\nu_2^x} +$

[8] Given that the problem for all product lines is symmetric we do not need to specify a particular product line.

$(1-\phi_c)(1-\phi_n)$

The profits of the intermediate good producer are then given by:

$$
\begin{aligned}
& M^x_{j,t}\left(P^x_{j,t}-\frac{W_t}{q^x_{j,t}}\right) \\
&= M^x_{j,t}\left(\frac{W_t}{\tilde{q}^x_{j,t}}-\frac{W_t}{q^x_{j,t}}\right) \\
&= M^x_{j,t}\left(\frac{W_t(1+\theta^x)^{\nu^x_2}\Omega^x}{q^x_{j,t}}-\frac{W_t}{q^x_{j,t}}\right) \\
&= M^x_{j,t}\left(\frac{W_t((1+\theta^x)^{\nu^x_2}\Omega^x-1)}{q^x_{j,t}}\right) \\
&= \frac{P^x_t\alpha_x Y^x_t}{P^x_{j,t}}\left(\frac{W_t((1+\theta^x)^{\nu^x_2}\Omega^x-1)}{q^x_{j,t}}\right) \\
&= \frac{P^x_t\alpha_x Y^x_t q^x_{j,t}}{W_t(1+\theta^x)^{\nu^x_2}\Omega^x}\left(\frac{W_t((1+\theta^x)^{\nu^x_2}\Omega^x-1)}{q^x_{j,t}}\right) \\
&= \frac{P^x_t\alpha_x Y^x_t\left((1+\theta^x)^{\nu^x_2}\Omega^x-1\right)}{(1+\theta^x)^{\nu^x_2}\Omega^x}
\end{aligned}
$$

Notice also that $M^x_{j,t}=q^x_{j,t}L^x_{j,t}$. Replacing in the production function we have:

$$\ln Y^x_t=\alpha_x\int_0^1 \ln q^x_{j,t}+\alpha_x\int_0^1 \ln L^x_{j,t}$$

Which implies that

$$Y^x_t = A^{x\,\alpha_x}_t L^{x\,\alpha_x}_t$$

where $\ln A^x_t=\int_0^1 \ln q^x_{j,t}$ and $\ln L^x_t=\int_0^1 \ln L^x_{j,t}$. Notice that A^x_t would represent TFP for the tradable sector. Notice also that the growth of the TFP in this sector is given by:

$$\ln\left(\frac{A_t^x}{A_{t-1}^x}\right) = \int_0^1 \ln\left(\frac{\left(1+\theta^x I_j^x\right)^{\nu_2^x}\Omega^x q_{j,t-1}^x}{q_{j,t-1}^x}\right) dj$$

$$= \nu_2^x \phi_x \ln(1+\theta^x) + \ln\left(\Omega^x\right)$$

Hence, the growth rate is:

$$1 + g^x = (1+\theta^x)^{\phi_x \nu_2^x}\Omega^x$$

The value of a patent is given by $V_x = \frac{\pi}{1-\beta(1-\phi_x)}$. Entrants must hire ψ_x units of workers in order to produce one unit of innovation. If succesful, an entrant innovates over a random product line. By free entry we have that:

$$V_x = W\psi_x$$

which implies that

$$\phi_x = \frac{\pi}{W\psi_x\beta} - \frac{1-\beta}{\beta}$$

We observe that the entry rate is increasing in the profits of the sector, and decreasing in startup costs. We can think of the same structure for the remaining sectors.

Finally, let the total output of the economy be defined by a Cobb-Douglas aggregator:

$$Y_t = (Y_t^x)^{\beta_x}(Y_t^c)^{\beta_c}(Y_t^n)^{1-\beta_x-\beta_c}$$

Rearranging terms we have:

$$Y_t = A_t L_t$$

where $A_t \equiv \underbrace{(A_t^x)^{\alpha_x \beta_x}(A_t^c)^{\alpha_c \beta_c}(A_t^n)^{\alpha_n(1-\beta_x-\beta_c)}}_{\text{TFP}}$ and $L_t \equiv (L_t^x)^{\alpha_x \beta_x}(L_t^c)^{\alpha_c \beta_c}(L_t^n)^{\alpha_n(1-\beta_x-\beta_c)}$.

The price of commodities P^c and tradable goods P^x are given for this economy. They are also expressed relative to non tradable goods. The tradable and commodity prices follow an AR(1) process of the form:

$$
\begin{aligned}
\ln(P_t^x) &= \rho^x \ln(P_{t-1}^x) + \epsilon_t^x \\
\ln(P_t^c) &= \rho^c \ln(P_{t-1}^c) + (1-\rho^c)\ln(\overline{P}_{t-1}^c) + \epsilon_t^c \\
\ln(\overline{P}_t^c) &= \varphi^c \ln(\overline{P}_{t-1}^c) + \eta_t^c
\end{aligned}
$$

Households

Households consume the last two and have a lifetime utility of the form

$$U = \sum_{t=0}^{\infty} \beta^t \mathbb{E}_0 \left(\frac{C_t^{1-\sigma} - 1}{1-\sigma} \right)$$

where they choose consumption, C. C_t is a consumption CES aggregation of the two different types of goods in the economy:

$$C_t = (\lambda X_t^{\gamma} + (1-\lambda) N_t^{\gamma})^{\frac{1}{\gamma}}$$

where X corresponds to the amount of the tradable good that is consumed and N to the amount of the non tradable good that is consumed.

The household's budget constraint is given by:

$$P_t^x X_t + N_t + B_{t+1} \leq W_t L_t + (1+r^*) B_t + \Pi_t$$

where Π_t represents all profits that household earn as owners of final and intermediate good producing firms.

The time constraint that the household faces is given by:

$$L_t^x + L_t^c + L_t^n + \psi_x\phi_x + \psi_c\phi_c + \psi_n\phi_n = L_t$$

Solving The Model

In order to solve the model we need to transform it to efficiency units.

Final Good Producer

Recall that the optimality condition with respect to intermediate good j was:

$$M_{j,t} = \frac{P_t^x \alpha_x Y_t^x}{P_{j,t}^x}$$

Replacing $M_{j,t}^x = q_{j,t}^x L_{j,t}^x$ we have that

$$L_{j,t}^x = \frac{P_t^x \alpha_x Y_t^x}{P_{j,t}^x q_{j,t}^x}$$

Recall that $P_{j,t}^x = \frac{W_t(1+\theta^x)^{\nu_2^x}\Omega^x}{q_{j,t}^x}$. Thus,

$$L_{j,t}^x = \frac{P_t^x \alpha_x Y_t^x}{W_t(1+\theta^x)^{\nu_2^x}\Omega^x}$$

Integrating we have that the total labor demand from sector x is given by:

$$L_t^x = \frac{P_t^x \alpha_x Y_t^x}{W_t(1+\theta^x)^{\nu_2^x}\Omega^x}$$

Notice also that profits for the final good producer are given by:

$$\Pi_t^x = (1-\alpha_x)P_t^x Y_t^x$$

We need to transform the model to efficiency units now. The production function of the final good producer is given by:

$$Y_t^x = (A_t^x)^{\alpha_x}(L_t^x)^{\alpha_x}$$

Dividing by A_t we have

$$\tilde{Y}_t^x = \frac{(A_t^x)^{\alpha_x}}{A_t}(L_t^x)^{\alpha_x}$$

The problem here is that $\frac{(A_t^x)^{\alpha_x}}{A_t}$ may not be stationary. This is due to the fact that at this stage we cannot assure that the ratio will grow at a constant rate. If that is not the case, the model cannot sustain a balanced growth path.

Table 5: Effect of a change in fuels' price index over labor shares and RER

	Lag										
VARIABLES	0	1	2	3	4	5	6	7	8	9	10
Agriculture	-0.262***	-0.300***	-0.325***	-0.367***	-0.420***	-0.443***	-0.386***	-0.284***	-0.133	0.170**	0.0947
	(0.0723)	(0.0762)	(0.0765)	(0.0860)	(0.103)	(0.0870)	(0.0689)	(0.0624)	(0.0916)	(0.0665)	(0.108)
Constant	2.925***	3.043***	3.105***	3.231***	3.378***	3.438***	3.214***	2.837***	2.291***	1.185***	1.208**
	(0.288)	(0.298)	(0.294)	(0.325)	(0.384)	(0.319)	(0.251)	(0.225)	(0.328)	(0.236)	(0.382)
Observations	138	130	122	114	105	98	90	82	75	66	54
R-squared	0.436	0.432	0.400	0.379	0.337	0.276	0.210	0.117	0.026	0.022	0.009
Number of countries	9	9	9	9	9	9	9	9	9	9	8
Manufactures	-0.0967***	-0.102***	-0.105***	-0.122***	-0.143***	-0.152***	-0.132**	-0.0814*	-0.0466	0.0142	0.0493
	(0.0205)	(0.0231)	(0.0266)	(0.0317)	(0.0409)	(0.0447)	(0.0400)	(0.0414)	(0.0323)	(0.0455)	(0.0396)
Constant	3.030***	3.042***	3.042***	3.097***	3.165***	3.185***	3.098***	2.901***	2.764***	2.540***	2.451***
	(0.0820)	(0.0906)	(0.102)	(0.120)	(0.152)	(0.164)	(0.146)	(0.149)	(0.116)	(0.161)	(0.140)
Observations	138	130	122	114	105	98	90	82	75	66	54
R-squared	0.394	0.352	0.315	0.290	0.257	0.189	0.136	0.054	0.017	0.001	0.016
Number of countries	9	9	9	9	9	9	9	9	9	9	8
Non-tradable	0.0640*	0.0785*	0.0918**	0.117**	0.149***	0.161***	0.126**	0.120***	0.0937**	-0.102*	-0.0705
	(0.0305)	(0.0350)	(0.0365)	(0.0398)	(0.0442)	(0.0479)	(0.0458)	(0.0352)	(0.0320)	(0.0459)	(0.0391)
Constant	2.399***	2.347***	2.301***	2.212***	2.105***	2.070***	2.206***	2.233***	2.334***	3.038***	2.955***
	(0.122)	(0.137)	(0.140)	(0.150)	(0.164)	(0.176)	(0.167)	(0.127)	(0.115)	(0.163)	(0.139)
Observations	138	130	122	114	105	98	90	82	75	66	54
R-squared	0.229	0.243	0.242	0.261	0.278	0.239	0.152	0.137	0.078	0.045	0.023
Number of countries	9	9	9	9	9	9	9	9	9	9	8
Real Exchange Rate	-0.0626**	-0.0787**	-0.0894**	-0.0839*	-0.0840	-0.118*	-0.126**	-0.0997*	-0.0744	0.0708*	0.0875
	(0.0231)	(0.0260)	(0.0281)	(0.0388)	(0.0562)	(0.0586)	(0.0505)	(0.0459)	(0.0483)	(0.0316)	(0.0697)
Constant	-4.174***	-4.119***	-4.086***	-4.116***	-4.127***	-4.012***	-3.988***	-4.088***	-4.186***	-4.710***	-4.765***
	(0.0920)	(0.102)	(0.108)	(0.147)	(0.209)	(0.215)	(0.184)	(0.166)	(0.173)	(0.112)	(0.247)
Observations	153	144	135	126	117	108	99	90	81	72	56
R-squared	0.082	0.101	0.102	0.063	0.039	0.057	0.055	0.033	0.017	0.008	0.018
Number of countries	9	9	9	9	9	9	9	9	9	9	8

Robust standard errors in parentheses
*** $p < 0.01$, ** $p<0.05$, * $p<0.1$