# The paradox of plenty and migration patterns of resource rich countries*

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**Abstract**

How does the resource windfall of some developing economies impact their patterns of international migration? To answer this question, I develop a stylized growth model consistent with two empirical facts. I confirm using a large set of indicators that the resource curse also applies to human capital formation and I find a significant negative relationship between the abundance in natural resource of countries and their net flows of emigration. I provide a theory explaining these two facts. My modelled economy is less technologically advanced than the rest of the world but has the advantage of being abundant in natural resources. At the end of their childhood, agents face the dilemma of staying in their homeland or migrating to the more developed rest of the world. On early dates, the resource bonanza generates enough wealth effects and keeps the wages high enough so that nationals have no incentives to migrate abroad. Later however, the depletion of the resource pushes out the migration flows with increasing incentives to leave the domestic economy. These theoretical results are validated using a gravity model of migration and providing consistent evidence that the relative abundance in natural resources between source and destination countries, is a relevant determinant of bilateral migration.

*JEL classification*: F22, O11, O15, Q32.
*Keywords* : Natural resource curse; Migration; Human capital formation.

## 1 Introduction

The natural resource curse is a paradox in Development Economics that received several attention in the last two decades. It consists of the empirically grounded fact that countries and regions with an abundance of natural resources, especially point-source of non-renewable resources like minerals and fuels, have grown less rapidly and tend to have worse development outcomes than countries with smaller natural resource endowments. Following Sachs and Warner's (1995) influential work on the resource curse, sundry researchers have investigated this puzzle and it is now well known that the explanations of what is also called the paradox of plenty, range from the quality of institutions to the lack of diversification inherent with resource rich economies and their high vulnerability to external shocks.[1,2]

*Preliminary version. Some revisions are still in progress.

[1]Even if Auty (1993) was the first to use the concept of a resource curse, the most influencial work in the field belongs the one of Sachs and Warner (1995)

[2]See Auty (1993), Mehlum, Moene, and Torvik (2002), Sachs and Warner (1995), Sachs and Warner (2001), Ross (1999) and van der Ploeg (2011) for a survey on this literature.

This paper proposes a new explanation of the resource curse and use it as background to explain some singularities observed in the international migration patterns of resource rich countries. It is mainly motivated by two empirical facts uncovered using data about the decade 2000, from Barro and Lee (2013) and from the World Development Indicators of the World Bank. First, I notice a significant and robust negative relationship between schooling (enrolment and attainment) and the share of natural resource rents in the gross domestic product (GDP) of countries. This is not new evidence since Gylfason (2001) came to the same conclusion but the set of indicators and data he used is not as broad as mine. Second, I bring out a downward sloping relationship linking the net emigration rate of countries and the share of natural resource rents in their GDP. In other words, the net flux of emigration from countries across the world is significantly decreasing with their dependence on natural resources. The immediate explanation is that a greater manna from natural resource extraction leads to more opportunities for people and less incentives for them to migrate.

However, the recent trends in international migration are characterized by ever increasing waves of population movements from developing countries - especially countries rich in natural resources - to industrialized countries (OECD 2014, International Organization for Migration and Eurasylum Ltd 2014, World Bank 2015). Whether legal or clandestine, these migratory waves are indicative of a deep quest for better living standards. Besides, even if many conflicts forcing people to emigrate have political motives, there is often a rent seeking behaviour of the protagonists. The importance of understanding the mechanisms that generates the lack of economic and technological progress despite the abundance in natural resources, then appears acutely in order to face the upcoming upheavals. To the best of my knowledge, this is the first attempt that proposes a formal framework using a stylized growth model to study these questions.

The theoretical model that I propose, depicts a representative dynasty of overlapping generations living two periods in a small economy rich in natural resources but technologically less advanced than the rest of the world. I refer mainly to Gaitan and Roe (2012) to shape the supply side of the economy and to Mountford and Rapoport (2011) for the demand side. I use a Cobb-Douglas production function in the final good sector instead of the general CES specification employed in Gaitan and Roe (2012) and I drop fertility concerns - which are beyond the scope of this paper - from the optimization problem of the household in Mountford and Rapoport (2011). Another departure form the setup of Mountford and Rapoport (2011) is the utility function. In fact, I consider a quasi myopic behavior of the agents by choosing a quasi linear specification of the utility function. The latter expresses the lack of intergenerational altruism of agents and drives the resource curse on human capital as illustrated by the first empirical fact. Indeed, parents place too much focus on their own consumption at the expense of the future labor income of their offspring. Consequently, the resource bonanza is not used to finance schooling in order to sustain long run growth.

I use this framework afterwards to analyze the migration decision of agents. In line with the vast literature on international migration, the wage gap between the domestic economy and the rest of the world is the main driver of the incentives to migrate. An important novelty however is the role played by the resource manna of the domestic economy in the explanation of agents' migration decision. Two dynamics are observed. In early dates when the resource is plenty, the wages are high enough and cut the incentives to migrate abroad. Later, as the resource depletes over time, wages shrink since the rate of technological change is not high enough and this pushes out the migration flows with increasing incentives to leave the domestic economy.

These theoretical results received an empirical validation. In fact, I estimate an augmented version of the gravity model of Lewer and Van den Berg (2008), using data from the Global Bilateral Migration Database of the World Bank and from Mayer and Zignago (2011). This exercise confirms that the relative abundance in natural resources of the destination country vis-à-vis the source country, is worth including it among the determinants of migration flows.

The aim of this paper is both theoretical and empirical. The remainder is organized as follow. In Section 2, I present in more details the two stylized facts I observed in data. The theoretical model is described in Section 3 along with the theoretical results. In Section 4, I present and estimate a gravity model of international migration inspired from the one of Lewer and Van den Berg (2008) in order to validate my theory. Finally, I conclude in Section 5.

# 2 Some empirical facts

All data I use here, are from the World Development Indicator database of The World Bank except Educational Attainment data which are drawn from Barro and Lee (2013). The sample includes all countries with available data and the time period is 2000-2012. In this section, I provide the empirical evidences that motivate this research. These facts can be summarized in the following words :

**Fact 1** : Countries highly dependant on natural resources experience lower schooling on average;

**Fact 2** : Countries highly dependant on natural resources experience less emigration in net.

The sample of countries does not include countries having less than 1% share of natural resource rents in GDP since I am only concerned about countries relying significantly on natural resources. Besides, in the following I often refer to these countries as resource abundant countries because I am mostly interested by developing countries that are known as having relatively less industries and therefore rely mostly on natural resource if they have some.

## 2.1 Fact 1 : Higher dependence on natural resource, lower schooling

The scatter plots in Figure 1 below are some partial regression plots. They represent on their y-axis the residuals from the regression of the average years of schooling of adults, on the natural log of the GDP per capita of countries in my sample, for the three years 2000, 2005 and 2010. On the x-axis are represented the residuals from the regression of the share of natural resource rents in GDP against the natural log of GDP per capita.[3] The purpose is to illustrate the effect of the resource dependence on schooling, while controlling for the natural log of GDP per capita. These plots illustrate a negative relationship between countries' dependence on natural resources and the average years of schooling of their people. So, controlling for the GDP per capita, the more economies rely on natural resources, the less their people embark in long educational curriculum. This conclusion is confirmed by the high significance of the coefficients from the regression (1) presented hereafter in Table 1.

$$\text{Years of Schooling}_{it} = \alpha_{1t} + \alpha_{2t}\left(\frac{Rents}{GDP}\right)_{it} + \alpha_{3t}\ \ln(\text{GDP per capita})_{it} + \varepsilon_{it} \quad \forall t \tag{1}$$

As shown by Table 1, at a same level of GDP per capita, a country with 1% higher share of natural resource on GDP is likely to experience between 0.029 to 0.043 less years of schooling of its people. Note that I compute the Huber estimates to ensure the robustness of the estimation and that the values obtained are very close to those I get using the simple OLS estimator.[4]

[3]The average years of schooling of adults is the years of formal schooling received, on average, by adults over age 15.

[4]The Huber's estimator is an M-estimator which lowers the weight assigned to extreme values allowing for the core of the distribution to be preponderant in the estimation. For more details about the theory of Huber's estimator, see Huber (1973) and Jann (2012) for some details about its implementation, using STATA.

Figure 1: School attainment versus Resource dependence


Source: The WDI of the World Bank (rents) and Barro & Lee (Years of Schooling)

Table 1: Natural resources rents as determinant of School attainment of adults : OLS and Huber's estimates

| **Variables** | **Year 2000** | | **Year 2005** | | **Year 2010** | |
|---|---|---|---|---|---|---|
| | OLS | Huber | OLS | Huber | OLS | Huber |
| Total natural resources | -0.038*** | -0.043*** | -0.029*** | -0.030*** | -0.032*** | -0.030*** |
| rents (% of GDP) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Log(GDP per capita, | 1.372*** | 1.418*** | 1.417*** | 1.473*** | 1.389*** | 1.438*** |
| constant 2005 US$) | (0.12) | (0.11) | (0.12) | (0.10) | (0.11) | (0.10) |
| Intercept | -3.197*** | -3.575*** | -3.264*** | -3.673*** | -2.740*** | -3.167*** |
| | (0.93) | (0.89) | (0.91) | (0.82) | (0.93) | (0.94) |
| N | 100 | 100 | 105 | 105 | 106 | 106 |
| $R^2$ | 0.569 | | 0.588 | | 0.607 | |

Standard errors in parentheses
Significance levels : $*$ : 10% $**$ : 5% $***$ : 1%
Huber, 1973 : M-Regression (95% efficiency)

The same conclusion comes out when I consider school enrollment at all levels, especially at tertiary level where the relationship seems to be more pronounced than that of lower levels.[5] This is illustrated by the Figure 2 below and confirmed by a similar set of regressions to those presented in Table 1. These results and some additional plots about other education indicators are presented in more details in Appendix A.

[5] I use a broad set of indicators for education, in order to check the robustness of the conclusion of Gylfason (2001) and to keep in mind the criticisms of Stijns (2006) that the outcome may vary according to the group of countries and the indicator used to measure education.

Figure 2: Tertiary enrolment versus Resource dependence


Source: The WDI of the World Bank

Indeed, Table A1 in Appendix A reports the results of the regressions of tertiary school's participation against the resource dependence of countries and controlling for GDP per capita, confirm that even at 1% level of significance there are relevant evidence validating the negative relationship between natural resource dependence and participation to tertiary school. Moreover, as shown by Table A1 in Appendix A, at a same level of GDP per capita, an increase of 1% of the ratio of resource rents over GDP implies a decrease of about 0.3% of the rate of enrolment in tertiary school.

## 2.2 Fact 2 : Higher dependence on natural resource, lower net emigration

The intuition supporting the second empirical fact is that resource rich countries, because of the rents and the economic activities linked to the exploitation of the natural resources, provide satisfying life opportunities to their people so that their have less incentives to migrate abroad. Moreover, these countries face important inflows of migrants aiming to profit from the resource windfall. It is therefore expected that the net flux of emigration received by a country, to be decreasing with respect to its dependence on natural resources. This is illustrated by the downward slopping trends shown by the partial regression plots of Figure 3. Note that hereafter, the net emigration rate refers to the net outflows of migrants per 1,000 population of the source country, for a given year.

Figure 3: Negative relationship between net emigration and resource dependence


Source: The World Development Indicators (WDI)

In line with the methodology adopted in the previous section, I regress the net emigration rate on the explanatory variables presented above in order to confirm the significance or the relationship illustrated by Figure 3. More formally, I estimate the following regression equation, using an OLS and a Huber estimator.

$$\text{Net Emigration Rate}_{it} = \alpha_{1t} + \alpha_{2t}\left(\frac{Rents}{GDP}\right)_{it} + \alpha_{3t}\ \ln(\text{GDP per capita})_{it} + \varepsilon_{it} \quad \forall t \qquad (2)$$

The results are hereby presented in Table 2. From these results, it comes out that 1% increase of the share of resource rents in GDP leads to a decrease of the net emigration rate that is roughly between 0.2% and 0.8%.

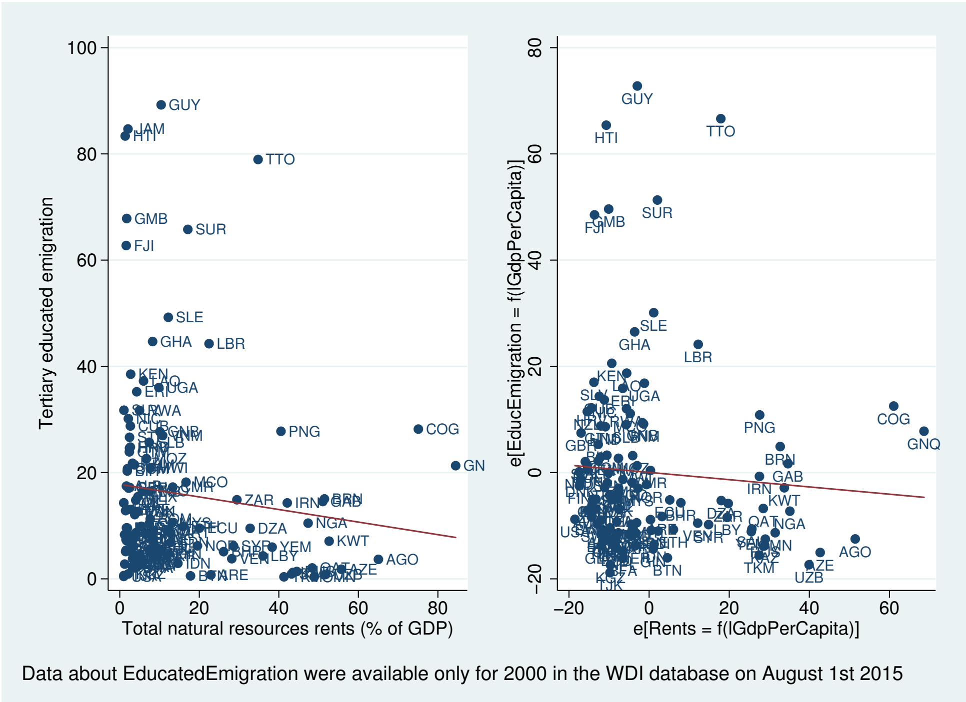
Table 2: Natural resources as determinant of net emigration : OLS and Huber's estimates

| **Variables** | **Year 2002** | | **Year 2007** | | **Year 2012** | |
|---|---|---|---|---|---|---|
| | OLS | Huber | OLS | Huber | OLS | Huber |
| Total natural resources | -0.746*** | -0.393*** | -0.832** | -0.197*** | -0.621*** | -0.162** |
| rents (% of GDP) | (0.27) | (0.14) | (0.41) | (0.08) | (0.22) | (0.08) |
| Log(GDP per capita, | -11.517*** | -5.350*** | -20.747*** | -5.147*** | -9.648*** | -4.168*** |
| constant 2005 US$) | (2.69) | (1.67) | (5.01) | (1.27) | (2.10) | (0.78) |
| Intercept | 93.086*** | 48.467*** | 163.742*** | 46.169*** | 80.184*** | 35.981*** |
| | (20.14) | (11.92) | (39.29) | (9.69) | (16.82) | (6.10) |
| N | 120 | 120 | 130 | 130 | 126 | 126 |
| $R^2$ | 0.203 | | 0.151 | | 0.194 | |

Standard errors in parentheses
Significance levels : $*$ : 10% $**$ : 5% $***$ : 1%
Huber, 1973 : M-Regression (95% efficiency)

Since the resource curse on education appears to be more effective in tertiary school, I then question whether the resource bonanza yields the same outcome for educated people. In other words, is there a specific aspect of the brain drain/gain that can be linked to the resource dependence of the source country ? To answer this question, I present if Figure **??** hereafter the partial regression plot of the emigration rate of tertiary educated people against the share of resource rent in GDP while controlling by the GDP per capita.

Figure 4: Resource dependence and brain drain/gain




Source: The World Development Indicator database of the World Bank

As unveiled by Figure 4, it seems that resource abundant countries are more likely to experience a brain gain rather than a brain drain. However, the estimated coefficients using a similar approach as previously are not significant. The regression equation that I consider has as dependent variable, the emigration rate of tertiary educated (% of total tertiary educated population). I refer to it hereby as the Educated Emigration Rate.

$$\text{Educated Emigration Rate}_{it} = \alpha_{1t} + \alpha_{2t}\left(\frac{Rents}{GDP}\right)_{it} + \alpha_{3t}\ln(\text{GDP per capita})_{it} + \varepsilon_{it} \quad \forall t \quad (3)$$

The evidence here is more mixed even if Figure 4 is consistent with the idea that the resource manna should cut incentives to migrate abroad for skilled people. Indeed, the estimation results obtained after running the regression (3), show that the coefficients corresponding to $\alpha_{2t}$ are not significantly different from 0. As a consequence, countries face different stories regarding the migration of their skilled people. While some countries, because of the presence of the resource, can provide a better living standards to their citizens, hindering by this way their willingness to emigrate, others may face political instability because of the internal struggles surrounding the control of the resource.

In the remainder of this paper, I will disregard this last aspect. In the followings, I develop a stylized growth model in order to explain the two aforementioned empirical facts.

# 3 Theory

The model depicts the dynamics of a developing economy abundant in natural resources. From now and onwards, I will consider a single natural resource and call it "Energy". My bottom line in Sections 3.1 and 3.2 is to replicate through a coherent setup, Fact 1, presented in Section 2.1. This is made by making clear how the ownership of the natural resource can influence human capital accumulation. I then use this setup in Section 3.3 to describe formally how the resource abundance of the economy influences the migration decision of nationals.

An Energy firm extracts costlessly the resource to fuel the production of a final consumption good. This production is operated by a competitive Final Good firm using labour and energy. In the demand side of the economy, the model pictures a representative dynasty of overlapping generations living two periods (young and adult). Each member of a generation, once adult, has to share its time between labor supplying and the education of its offspring. Young people inherits the level of human capital of their parents and the more they receive care from their parents, the higher level of human capital they acquire, increasing in the same way the wellness of their parents. In addition to the wage income households receive as compensation for working in the final good sector, dynasties are shareholders of the Energy firm and are paid back the profits from extraction.

Following this by-words description, I describe more formally hereafter, the functioning of my economy.

## 3.1 Setup

### 3.1.1 The Energy firm

The energy firm maximises the lifetime profit derived from supplying energy to the final good sector. It has to choose, given the market price stream $\{p_t\}_{t=0}^{+\infty}$ of the resource, an extraction path $\{E_t\}_{t=0}^{+\infty}$ such that the cumulative quantities extracted should not exceed the whole stock of the natural resource at period 0, $S_0$.

$$\max_{\{E_t\}_{t=0}^{+\infty}} \left\{ \sum_{t=0}^{+\infty} d_t p_t E_t \quad | \quad \sum_{t=0}^{+\infty} E_t \leq S_0 \quad \text{and} \quad E_t \geq 0 \, \forall t \right\} \tag{4}$$

where $d_t = \Pi_{s=0}^{t} \left[1 + r_s\right]^{-1}$ $t = 0, 1, 2, \cdots$ is the rate at which the firm discounts profits.

This set-up for the energy sector is highly simplistic. In fact, in the literature of natural resource management, it is well known that this setup inherited from Hotelling (1931) is unable to replicate the empirical dynamics of most exhaustible resources (see for instance Gaudet 2007, Livernois 2009). Besides, I assume here that extraction is costless while a more realistic assumption would allow for a marginal cost decreasing with respect to the size of the remaining stock. However, these drawbacks do not call into question the coherence of my framework, and for the sake of parsimony I will adopt it since it is able to deliver the kind of insights I are after.

Let's denote $S_t$ the remaining stock of resource at the beginning of the period $t$. Solving this problem for an optimal solution yields the following transversality condition for a maximum and the first order conditions can be stated as follow :

$$\lim_{t \to \infty} d_t p_t E_t = 0 \qquad \text{and} \qquad E_t = \begin{cases} \in [0, S_t] & \text{if } t \in \mathbb{T} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

where $\mathbb{T} \equiv \{t \in \mathbb{N} : d_t p_t = \max_\tau d_\tau p_\tau\}$.[6]

[6] I assume for analytical convenience that $\mathbb{T}$ is well defined and is not an empty set. This is equivalent to restricting my analysis to a subset of price sequences such that (4) is well defined. In fact, even if from an economic point of view, this definition may be acceptable, for an heuristic mathematical point of view, it needs to be improved. A detailed proof is provided in Appendix B

The solution is therefore of bang-bang type and I recognize the Hotteling rule which states that the producer supplies a positive amount of Energy in two consecutive time periods only if the price grows at the rate of interest. An equilibrium path in which a positive amount is supplied at each period is therefore consistent with the price $p_t$ to be growing at the rate of interest.

I will make the assumption that the interest rate $r$ is constant over time and exogenously determined. This helps providing an analytical solution of the model and is an acceptable assumption for periods of thirty years or longer. Indeed, I don't expect significant variations of the average interest rate over 30 years.[7]

### 3.1.2 The final good sector

At each period of time, labor in efficient units ($H_t$) and energy ($E_t$) are combined to produce a composite good ($Y_t$). The production function exhibits a constant return to scale Cobb-Douglas technology.

$$Y_t = A_t E_t^{\alpha} H_t^{1-\alpha}$$

with the following restrictions : $A_t > 0$, $0 < \alpha < 1$.

The parameter $A_t$ represents the technical change process that I assume to be growing at an exogenous rate $\gamma$.[8] I hypothesize that $\gamma$ is inferior to its equivalent in the rest of the world and for the realism of this hypothesis, I refer to Nelson and Phelps (1966) who argue that the rate of change of the technological parameter is an increasing function of the stock of knowledge in the economy. Since the domestic country is a developing economy, it is therefore meaningful to consider that it is less endowed in human capital than the rest of the world. Besides, because of the assumption of a Cobb-Douglas production function, it matters not whether $A_t$ is energy augmenting or labor augmenting.

Let's denote $W_t$, the average wage at time $t$. At each period of time, the Final Good firm solves the following problem :

$$\max_{E_t;H_t} Y_t - p_t E_t - W_t H_t = A_t E_t^{\alpha} H_t^{1-\alpha} - p_t E_t - W_t H_t$$

Profit maximizationof the final good sector at each period of time $t$ implies the following first order conditions :

$$\begin{cases} p_t &= \alpha A_t \left(\frac{H_t}{E_t}\right)^{1-\alpha} \\ W_t &= (1-\alpha) A_t \left(\frac{H_t}{E_t}\right)^{-\alpha} \end{cases} \quad (6) \qquad \Leftrightarrow \qquad \begin{cases} E_t &= \frac{1}{A_t}\left[\frac{\alpha}{1-\alpha}\frac{W_t}{p_t}\right]^{1-\alpha} Y_t \\ H_t &= \frac{1}{A_t}\left[\frac{\alpha}{1-\alpha}\frac{W_t}{p_t}\right]^{-\alpha} Y_t \end{cases} \quad (7)$$

### 3.1.3 The (representative) household

I consider a representative dynasty. Each generation lives 2 periods. In the first period of their life, individuals rely fully on their parents who choose on behalf of the whole household, a level of consumption ($c_t$). Taking as given the aggregate wage ($W_t$), parents also decide on the fraction of their time they are willing to devote to rearing their children ($x_t$). Children inherit the level of human capital of their parents ($h_t$) which can be raised to ($h_{t+1}$) as parents devote more time to the education of their offspring. This is a shortcut borrowed from Beine, Docquier, and Rapoport (2001) which in fact is equivalent to considering the traditional Ben-Porath human capital production function with specific parameters restriction. It also corresponds to the law of motion of the human capital variable assumed by Lucas (1988). Parents draw utility from the consumption of the final good but also from the future labor income of their children ($L_{t+1}$). I assume a quasi linear form of the utility function of the representative household.

[7]Individuals live two periods and therefore, 30 years is a reasonable actual length for a time period.

[8]i.e. $A_{t+1} = (1+\gamma)A_t \; \forall t$ and $A_0$ is given.

Overall, the problem of parents of generation $t$ is given by :

$$\max_{c_t>0;\ x_t\in[0;1]} u(c_t; L_{t+1}) = \theta c_t + (1-\theta) ln(W_{t+1}h_{t+1}) \tag{8}$$

$$\text{subject to : } \begin{cases} c_t + x_t W_t h_t \leq W_t h_t + p_t E_t \\ h_{t+1} = [1 + a x_t]\, h_t \\ h_0 > 0 \text{ is given.} \end{cases}$$

$L_{t+1} = W_{t+1}h_{t+1}$ is the wage income of the future generation indicating that parents' utility is positively related to the educational achievement of their offspring. The parameter $\theta \in [0, 1]$ in turn, represents the degree of selfishness of parents, vis-à-vis their offsprings. Through $a \in (0, \infty)$ I capture the quality of education in the country. In fact, one can easily figure out that a good education system would reinforce the outcome of parents' efforts to raise the human capital level of their children. So, the greater $a$ is, the more productive are parents' time investment to educate their progeny. I assume that $a$ is constant over time.

The optimal choice of the household at time $t$ for $x_t$ is given by :

$$x_t^* = \max\left[0; \min\left(1; \frac{1-\theta}{\theta}\frac{1}{W_t h_t} - \frac{1}{a}\right)\right]$$

From now and henceforth, I impose the following assumption which is adopted throughout the text.

**Assumption 1.**

$$\frac{1+r}{(1+a)^{1-\alpha}} < 1 + \gamma < (1+r)^{\alpha}$$

Intuitively, Assumption 1 tells that the productivity of the education system should be high enough so that it gives incentives to parents to sacrifice a positive fraction of their time to educate their children (first inequality). It also tells that the rate of technological change in the final good sector should not be too high to avoid a demand of energy which incite the Energy firm to over-extract the resource (second inequality). More formally, this assumption is a sufficient condition which ensures that the equilibrium amount of energy extracted at each period is positive. It also allows to get an interior solution for the household's problem.[9] Such interior solution which, under Assumption 1, is consistent which the equilibrium path of the economy is fully described by the following set of equations :

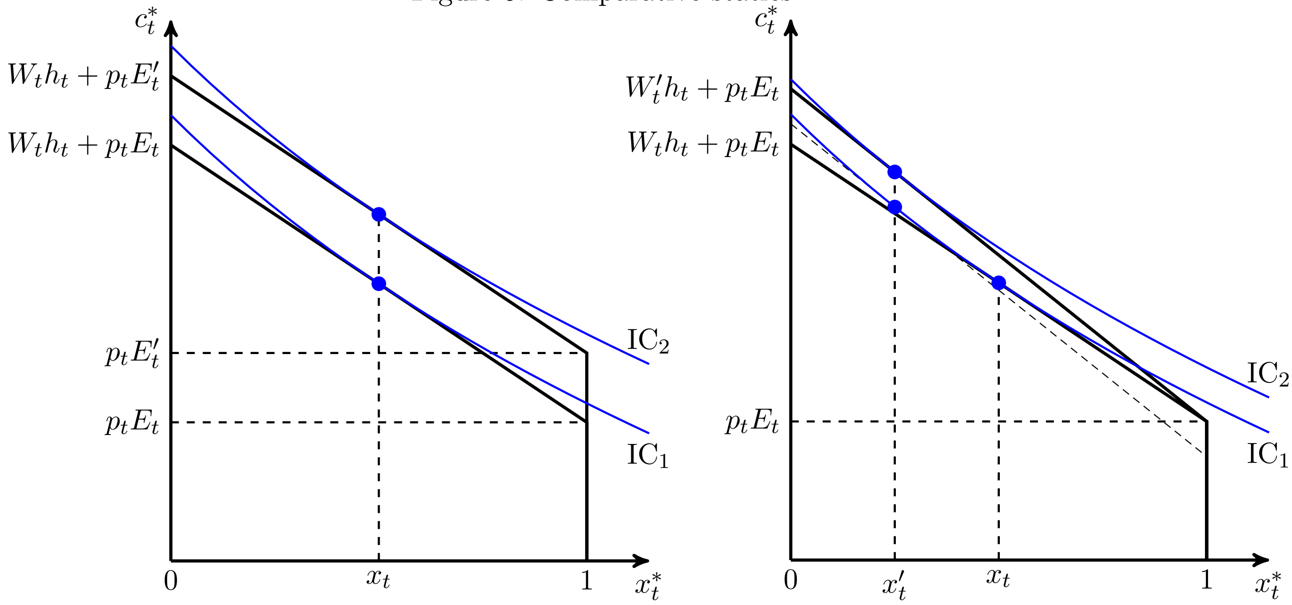
$$\begin{cases} x_t^* &= \frac{1-\theta}{\theta}\frac{1}{W_t h_t} - \frac{1}{a} \\ c_t^* &= (1+\frac{1}{a})W_t h_t + p_t E_t - \frac{1-\theta}{\theta} \\ h_{t+1}^* &= \frac{1-\theta}{\theta}\frac{a}{W_t} \end{cases} \tag{9}$$

From (9), $x_t^*$ and - as a consequence - $h_{t+1}^*$ are decreasing in $W_t$ while $c_t^*$ is increasing in $W_t$. Two effects are expected as a consequence of a change in the real wage $W_t$. First, an income effect should in principle be materialized through an increase of both consumption $c_t^*$ and $x_t^*$. Second, a substitution effect should reflect that the opportunity cost of children rearing - which is here a fraction of labor income - is increased, so that parents reduce their demand of education for their children, in favor of a higher supply of labor in order to increase their consumption. Here, given the quasi linear specification of the utility function and the fact that the numeraire is the final good, the income effect is nil as shown in Figures 5 (a) and (b).

The quasilinear preferences that induce the absence of an income effect explain also why there is no direct effect of the rents received by the household on its education decision $x_t^*$. Indeed, the revenues from the extraction of the resource are used only for the purposes of current

[9]See the characterization is the subsection 3.2.2.

Figure 5: Comparative statics




(a) Effect of an increase of $E_t$

(b) Effect of an increase of $W_t$

consumption and does not profit to the young generation. This is illustrated in Figure 5a and is at the origin of the resource curse on human capital accumulation presented below in Proposition 3.

## 3.2 Equilibrium

### 3.2.1 Definition

An equilibrium consists of paths of the quantities $\mathscr{C} \equiv \{c_t, h_{t+1}, x_t\}_{t=0}^{\infty}$ for the household ; $\mathscr{E} \equiv \{E_t^s, S_t\}_{t=0}^{\infty}$ for the Energy firm, $\mathscr{F} \equiv \{E_t^d, H_t, Y_t\}_{t=0}^{\infty}$ for the Good firm and prices $\mathscr{P} \equiv \{p_t, W_t\}_{t=0}^{\infty}$ such that given prices,

1. $\mathscr{C}$ solves the optimization problem of the household;
2. $\mathscr{E}$ solves the maximization problem of the energy firm and $\mathscr{F}$ solves the optimization problem of the final good sector and
3. and all markets clear, i.e. :

**Energy market** : $E_t^d = E_t^s = E_t \quad \forall t;$

**Final good market** : $c_t = Y_t \quad \forall t;$

**Labor market** : $H_t = (1 - x_t) h_t \quad \forall t.$

### 3.2.2 Characterization

From the problem of the household, an equilibrium path requires that $E_t > 0 \; \forall t$.[10] Then I derive from the optimization of the energy firm that any equilibrium path is consistent with a

[10] If for some date $t$, $E_t = 0$, then production in the Final Good sector equals zero and so does consumption. Besides, as a consequence, the current average wage rate is also nil and this means the extinction on the dynasty since one period earlier, the utility would be $-\infty$.

stream of the resource price following the Hotteling rule i.e. : $p_{t+1} = (1+r_t)p_t$. Using recursively this argument and sticking it into (6) yields :

$$\begin{cases} p_t &= (1+r)^t p_0 \quad \forall\ t \\ W_t &= (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}} A_t^{\frac{1}{1-\alpha}} p_0^{-\frac{\alpha}{1-\alpha}} (1+r)^{-\frac{\alpha}{1-\alpha}t} \quad \forall\ t \end{cases} \tag{10}$$

Now, recall (7) and using the final good market clearing condition, substitute $Y_t$ by $c_t^*$ in (9) to get :

$$E_t = \frac{1}{A_t}\left[\frac{\alpha}{1-\alpha}\frac{W_t}{p_t}\right]^{1-\alpha}\left[(1+\frac{1}{a})W_t h_t + p_t E_t - \frac{1-\theta}{\theta}\right]$$

Finally, rearranging this expression by making use of (10) and the solution of $h_{t+1}^*$ in (9), I end up with :

$$E_t = \begin{cases} (1+\frac{1}{a})\alpha^{\frac{1}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} p_0^{-\frac{1}{1-\alpha}} h_0 - \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta} p_0^{-1} & (t=0) \\ \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta}\left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}}(1+\gamma)^{\frac{1}{1-\alpha}} - 1\right]\frac{1}{p_0}\left(\frac{1}{1+r}\right)^t & (t \geq 1) \end{cases} \tag{11}$$

Let us recall that I have assumed earlier that the technological parameter evolves exogenously, according to $A_{t+1} = (1+\gamma)A_t\ \forall t$. Moreover, from (11), I can now formally establish how the sequence of the energy prices varies with respect to the abundance on the resource. This is the matter of the following proposition.

**Proposition 1.** *The wealthier the country is in the resource and the lower is the initial price - and more broadly, the whole sequence of prices - of Energy. More explicitly, there exist a continuously differentiable and strictly decreasing function $\varphi : \mathbb{R}_+ \to \mathbb{R}_+$ such that $p_0 = \varphi(S_0)\ \forall S_0 > 0$ with $\varphi'(S_0) < 0$ for all $S_0 > 0$.*

*Proof.* Since the objective in (4) is strictly increasing in $E_t\ \forall t$, any equilibrium path is consistent with a binding constraint. So,

$$\begin{aligned} S_0 &= \sum_{t=0}^{+\infty} E_t = E_0 + \sum_{t=1}^{+\infty} E_t \\ &= (1+\frac{1}{a})\alpha^{\frac{1}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} p_0^{-\frac{1}{1-\alpha}} h_0 - \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta} p_0^{-1} \\ &\quad + \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta}\left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}}(1+\gamma)^{\frac{1}{1-\alpha}} - 1\right]\frac{1}{p_0}\sum_{t=1}^{+\infty}\left(\frac{1}{1+r}\right)^t \\ &= (1+\frac{1}{a})\alpha^{\frac{1}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} p_0^{-\frac{1}{1-\alpha}} h_0 - \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta} p_0^{-1} \\ &\quad + \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta}\left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}}(1+\gamma)^{\frac{1}{1-\alpha}} - 1\right] p_0^{-1}\frac{1}{r} \\ &= (1+\frac{1}{a})\alpha^{\frac{1}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} p_0^{-\frac{1}{1-\alpha}} h_0 \\ &\quad + \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta}\frac{1+r}{r}\left[(1+a)(1+r)^{-\frac{1}{1-\alpha}}(1+\gamma)^{\frac{1}{1-\alpha}} - 1\right] p_0^{-1} \end{aligned} \tag{12}$$

Let us denote $\Lambda \equiv \left[(1+a)(1+r)^{-\frac{1}{1-\alpha}}(1+\gamma)^{\frac{1}{1-\alpha}} - 1\right]$. Under Assumption 1, $\Lambda > 0$. Let us also define $F : \mathbb{R}_+^2 \to \mathbb{R}$ such that :

$$F(S_0; p_0) = S_0 - (1+\frac{1}{a})\alpha^{\frac{1}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} p_0^{-\frac{1}{1-\alpha}} h_0 - \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta}\frac{1+r}{r}\left[(1+a)(1+r)^{-\frac{1}{1-\alpha}}(1+\gamma)^{\frac{1}{1-\alpha}} - 1\right] p_0^{-1}$$

$F(.;.)$ is continuously differentiable and because of (12), $F(S_0; p_0) = 0$. Besides,

$$\frac{\partial F}{\partial S_0}(S_0; p_0) = \frac{1}{1-\alpha}(1+\frac{1}{a})\alpha^{\frac{1}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} p_0^{-\frac{2-\alpha}{1-\alpha}} h_0 + \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta}\frac{1+r}{r}\Lambda p_0^{-2} > 0$$

Therefore, by the implicit function theorem, there exist a continuously differentiable function $\varphi : \mathbb{R}_+ \to \mathbb{R}_+$ such that $p_0 = \varphi(S_0)$. Moreover,

$$\varphi'(S_0) = -\frac{\frac{\partial F}{\partial p_0}(S_0; p_0)}{\frac{\partial F}{\partial S_0}(S_0; p_0)} = -\left[\frac{1}{1-\alpha}(1+\frac{1}{a})\alpha^{\frac{1}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} p_0^{-\frac{2-\alpha}{1-\alpha}} h_0 + \frac{\alpha}{1-\alpha}\frac{1-\theta}{\theta}\frac{1+r}{r}\Lambda p_0^{-2}\right]^{-1} < 0$$

Thus, this complete the proof that $p_0$ is strictly decreasing with respect to $S_0$. To extend the result to the whole sequence of Energy prices, I just have to recall that $p_t = (1+r)^t p_0 \quad \forall\, t$. $\square$

I can now rewrite (10) as :

$$W_t = (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}} A_t^{\frac{1}{1-\alpha}} \left[\varphi(S_0)\right]^{-\frac{\alpha}{1-\alpha}} (1+r)^{-\frac{\alpha}{1-\alpha}t} \tag{13}$$

Thus, this induces that $\frac{\partial W_t}{\partial S_0} > 0$. This result is not surprising. Indeed, an increase in $S_0$ is synonymous of a surplus in abundance on natural resources. Therefore, the second input's price ($W_t$) is expected to increase in order to reflect the relative scarcity of the labor input. The positive effect of the resource windfall needs however to be sustained by technological progress over time. Otherwise, real wages would decrease over time. This result is formally presented in the next proposition.

**Proposition 2.** *The resource windfall increase real wages. However, as the resource depletes over time, wages shrink unless there is significant technological change.*

*Proof.* From (13), I can write the gross growth rate of the average real wage as :

$$\frac{W_{t+1}}{W_t} = \left[\frac{A_{t+1}/A_t}{(1+r)^\alpha}\right]^{\frac{1}{1-\alpha}} = \left[\frac{(1+\gamma)}{(1+r)^\alpha}\right]^{\frac{1}{1-\alpha}}$$

Then the average real wage grows only when the technological change exceeds the interest rate. However, because of Assumption 1, $(1+r)^\alpha > (1+\gamma)$ and therefore, the equilibrium path of the model is consistent with a decreasing dynamic of real wages. $\square$

The resource constraint of the Energy firm in terms of the stock of the resource ($S_t$ at time $t$) reads : $S_t - S_{t+1} = E_t$. It follows from this equality that : $S_t = S_0 - \sum_{\tau=0}^{t-1} E_\tau = \sum_{\tau=t}^{\infty} E_\tau$ for $t \geq 1$. Finally, using (11), it is easy to see that :

$$S_{t+1} = \frac{1}{1+r} S_t \text{ and therefore } E_t = \frac{r}{1+r} S_t \quad \text{for } t \geq 1.$$

This optimal policy shows that the Energy price path does not affect extraction. This is due to the equilibrium sequence of prices that follows the Hotelling rule and given that price path, the Energy firm is indifferent between any two periods of extraction, provided that the resource constraint is respected. This policy function also establishes that the firm always extract a constant fraction ($\frac{r}{1+r}$) of the remaining stock of energy.

Overall, the expression of the other main variables of the model, as function of the parameters are the followings :

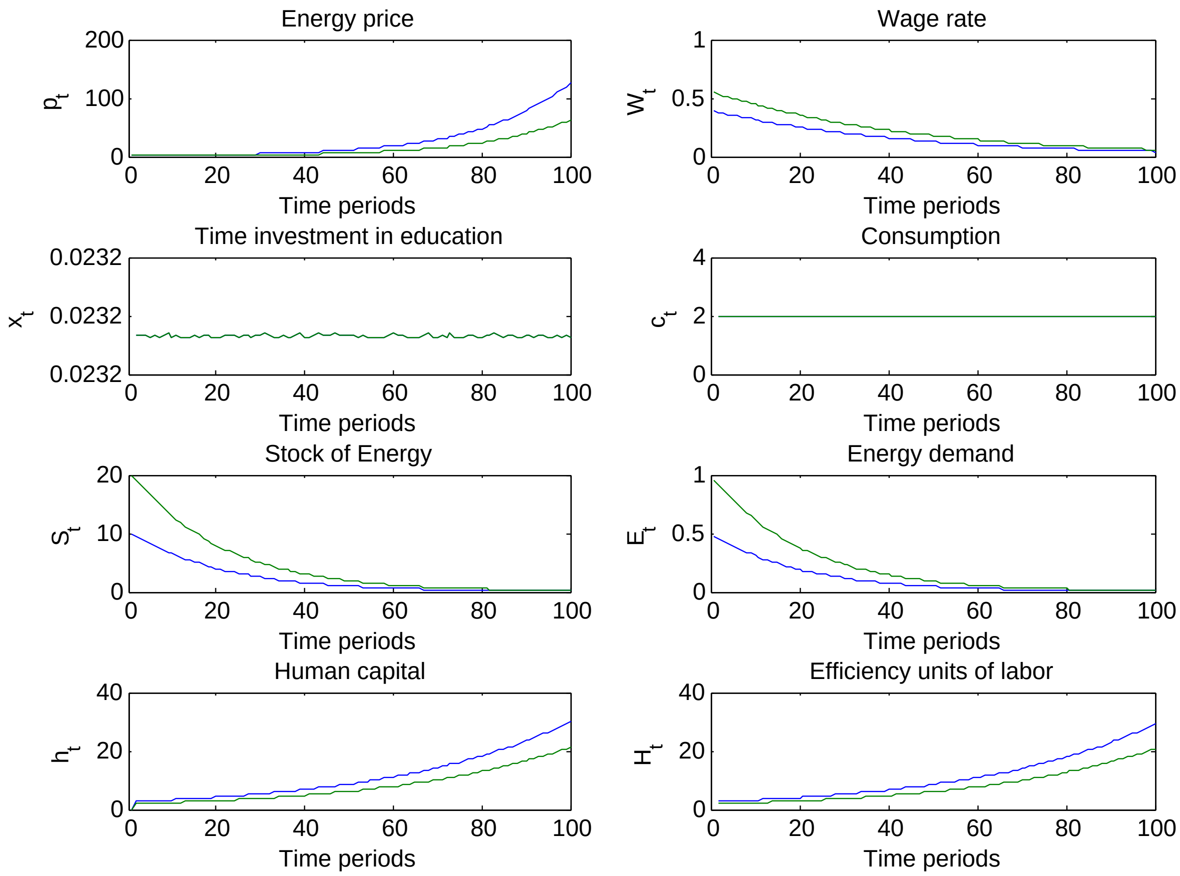
$$x_t^* = \begin{cases} \frac{1}{1-\alpha}\frac{1-\theta}{\theta}\alpha^{-\frac{\alpha}{1-\alpha}} A_0^{-\frac{1}{1-\alpha}} \left[\varphi(S_0)\right]^{\frac{\alpha}{1-\alpha}} h_0^{-1} - \frac{1}{a} & (t=0) \\ \frac{1}{a}\left[(1+r)^{\frac{\alpha}{1-\alpha}} (1+\gamma)^{-\frac{1}{1-\alpha}} - 1\right] & (t \geq 1) \end{cases} \tag{14}$$

$$c_t^* = \begin{cases} (1+\frac{1}{a})\alpha^{\frac{\alpha}{1-\alpha}} A_0^{\frac{1}{1-\alpha}} \left[\varphi(S_0)\right]^{-\frac{\alpha}{1-\alpha}} h_0 - \frac{1}{1-\alpha}\frac{1-\theta}{\theta} & (t=0) \\ \frac{1-\theta}{\theta}\left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}}\left((1+\gamma)^{\frac{1}{1-\alpha}} + \frac{\alpha}{1-\alpha}\right) - 1\right] & (t \geq 1) \end{cases} \quad (15)$$

$$h_{t+1}^* = \begin{cases} h_0 > 0 \text{ is given} & \\ a\frac{1}{1-\alpha}\frac{1-\theta}{\theta}\alpha^{-\frac{\alpha}{1-\alpha}} A_0^{-\frac{1}{1-\alpha}} \left[\varphi(S_0)\right]^{\frac{\alpha}{1-\alpha}} \left[\frac{(1+r)^\alpha}{(1+\gamma)}\right]^{\frac{1}{1-\alpha}t} & (t \geq 0) \end{cases} \quad (16)$$

I provide hereafter in Figure 6 a simulation of the time path of the main variables of the model, using calibrated parameters. I consider 2 values for the initial stock of Energy. The solid lines refer to $S_0 = 10$ while the dashed lines are about $S_0 = 20$. The initial stock of Energy determines the initial price $p_0$ which in turn determines the whole sequence of the resource price, according to (10).

Figure 6: Effects of a change in the initial stock of the resource




**Note :** I simulate here the evolution of the economy for two different values of the initial stock of Energy : $S_0 = 10$ (solid lines) and $S_0 = 20$ (dashed lines). The other parameters are $\alpha = 1/3$, $\theta = 1/2$, $a = 10$; $r = (1+3\%)^{30} - 1$; $\gamma = .001$, $A_0 = 1$ and $h_0 = 1$.

As I can see, the more abundant the resource is, the lower are its prices and the higher are wages over time. The equilibrium quantities of the inputs are negatively related to their prices. In fact, the scarcity of the resource due to a small initial endowment or its depletion over time reduces its supply and incites the household to accumulate more human capital that allows a substitution among the two inputs. This observation that the level of human capital is lower for a greater initial stock of the resource is actually a general result that is stated by the following proposition. Besides, the time investment on education is constant over time if I consider that the technological parameter evolves at a constant rate. This is the case for example if I neglect the education externalities that may be interesting to account for in such a model (see Lucas 1988). I can also notice that despite the absence of a saving asset to allow for consumption smoothness, the consumption level of the household is constant along the time span. This is mainly due to the simplicity of the model and I discuss it in the next paragraph.

**Proposition 3.** *The more the country is endowed in natural resources, the lower is the human capital level over time.*

*Proof.* Since $\varphi'(S_0) < 0$ (Proposition 1), it is straightforward from (16) that:

$$\frac{\partial h_{t+1}}{\partial S_0} = \frac{\alpha}{1-\alpha} \frac{\varphi'(S_0)}{\varphi(S_0)} h_{t+1} < 0$$

Besides, for $t \geq 1$, I can establish by making use of (11) that :

$$S_t = \sum_{\tau=t}^{\infty} E_\tau = \frac{\alpha}{1-\alpha} \frac{1-\theta}{\theta} \frac{1}{r} (1+r)^{-(t-1)} \left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}} (1+\gamma)^{\frac{1}{1-\alpha}} - 1\right] \varphi(S_0)^{-1}$$

Under Assumption 1, $\left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}} (1+\gamma)^{\frac{1}{1-\alpha}} - 1\right] > 0$ and therefore, $\frac{\partial S_t}{\partial S_0} > 0$. Finally, I can write $\frac{\partial h_{t+1}}{\partial S_0} = \frac{\partial h_{t+1}}{\partial S_t} \times \frac{\partial S_t}{\partial S_0}$ and it follows that $\frac{\partial h_{t+1}}{\partial S_t} < 0$. □

From Proposition 3, I can now argue that my framework is able to replicate the first empirical fact that states that the resource windfall influences negatively education indicators. The explanation of this results comes from the mechanisms underlined above. In fact the abundance of the resource induces a relative scarcity of the second input (labor) which prices ($W_t$) increase at all dates. This then generates a substitution effect (the expected income effect is absent because of the quasilinear utility function) which reduces the demand for education because its opportunity cost is now increased. Overall, the level of human capital achieved in the economy is lower in all periods if the resource becomes more abundant.

I need however to confess at this stage that there is a gap between the story told by the empirical facts and the findings described in Proposition 3. In fact by showing the negative relationship between education indicators and the share of natural resource rents in their GDP, I have illustrated that countries that depend heavily on resource extraction revenues are likely to see their people accumulating less human capital. Here in contrast, I have taken the derivative with respect to $S_t$ while the appropriate variable should be $\frac{p_t E_t}{Y_t}$. This shortcut is however necessary for at least two reasons. First, I can hardly imagine having real data about $S_t$ because of the diversity of the natural resource assets of countries and the challenge of their assessment and aggregation. Second, I are paying here the cost of the simplistic setup of the Energy firm. Indeed, since I consider that the extraction is made at constant marginal cost - zero actually but the outcome remains the same in the case of constant marginal cost -, I end up with a bang-bang type solution that involves that at each period the firm is indifferent on the amount of Energy to supply, and therefore the revenues from extraction $p_t E_t$ is constant over time. As I stated before, a more convenient setup would allow for a marginal cost increasing on the current extraction flow and decreasing with respect to the stock. For example, $CT(E_t, S_t) = \frac{E_t^2}{S_t}$ is a natural candidate but it fails to produce a closed-form analytical solution. For this reason, I keep the setup as it is but provide in an annex a simulation of the path of the main variables for a version of the model that embodies the aforementioned cost function in the resource extraction problem. Finally, it is an empirical observation that in many developing countries, the more a country is rich in a natural resource, the more its economy relies on the exploitation of this resource and therefore, the stock $S_t$ of the resource at time $t$ appears as a good proxy for the dependence of the country on such resource.

### 3.3 Natural resource windfall and migration

In this section, I provide a theoretical background to Fact 2 by giving the insights of how the natural resource windfall influences migration. To do so, I revisit the migration decision of the representative agent described above, to a foreign economy. I highlight the incentives that intervene as pull and push factors in this decision and link them to the stock of the resource in the domestic economy. I abstract from the impact of the migration flows on the composition of the labor force in both economies and implement a partial equilibrium exercise since I assume as given the path of the average wage rate in the foreign economy.

Households compare the value of migration to the value of staying at home. I will assign the superscript $R$ to the variables related to the rest of the world and adopt similar notations as before.

Let's consider an agent born at time $t$ who becomes adult at the beginning of the period $t+1$. Such individual compares the values of staying in his homeland and emigrating.

The value of staying in his homeland, i.e., the utility drawn from living the rest of his life in the domestic economy is given by :

$$\begin{aligned} V_{t+1} &= u\left(c^*_{t+1}; W_{t+2}h^*_{t+2}\right) \\ &= \theta c^*_{t+1} + (1-\theta)ln\left(W_{t+2}h^*_{t+2}\right) \\ &= (1-\theta)\left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}}\left(\left(\frac{A_{t+1}}{A_t}\right)^{\frac{1}{1-\alpha}} + \frac{\alpha}{1-\alpha}\right) - 1\right] + (1-\theta)ln\left[a\frac{1-\theta}{\theta}\frac{W_{t+2}}{W_{t+1}}\right] \end{aligned} \tag{17}$$

However, if the agent decides to move to the foreign country, he renounces to its share of the rents generated by the exploitation of the resource. He arrives in the foreign country having the level of human capital $h^*_{t+1}$ given by (9). He will then supply his labor force and receive a wage income proportional to the time devoted to work, the remaining time being used for children rearing activities. The agent therefore faces the following problem :

$$\max_{c^R_t>0;\ x^R_t\in[0;1]} u(c^R_t; L^R_{t+2}) = \theta c^R_{t+1} + (1-\theta)ln(W^R_{t+2}h^R_{t+2}) \tag{18}$$

$$\text{subject to :}\ \begin{cases} c^R_{t+1} \le \left(1 - x^R_{t+1}\right) W^R_{t+1}h_{t+1} \\ h^R_{t+2} = \left[1 + a^R x^R_{t+1}\right] h_{t+1} \end{cases}$$

The human capital production equation exhibits a new parameter $a^R$ that represents the quality of education in the foreign country. The assumption on the technological gap between the two countries can be expressed here through a difference in the quality of their education system : $a^R \ge a$. I remain parsimonious however by letting down this assumption which is not essential to derive the results. The solution of the optimization problem of an individual who migrates is given by :

$$\begin{cases} x^{R*}_{t+1} &= \frac{1-\theta}{\theta}\frac{1}{W^R_{t+1}h_{t+1}} - \frac{1}{a^R} \\ c^{R*}_{t+1} &= (1+\frac{1}{a^R})W^R_{t+1}h_{t+1} - \frac{1-\theta}{\theta} \\ h^{R*}_{t+2} &= \frac{1-\theta}{\theta}\frac{a^R}{W^R_{t+1}} \end{cases} \tag{19}$$

From (19),I can now express the value of the migration as follow :

$$
\begin{aligned}
V_{t+1}^{R} &= u\left(c_{t+1}^{R*}; W_{t+2}^{R}h_{t+2}^{R*}\right) \\
&= \theta c_{t+1}^{R*} + (1-\theta)ln\left[W_{t+2}^{R}h_{t+2}^{R*}\right] \\
&= \theta\left[(1+\tfrac{1}{a^R})W_{t+1}^{R}h_{t+1}^{*} - \tfrac{1-\theta}{\theta}\right] + (1-\theta)ln\left[W_{t+2}^{R}\tfrac{1-\theta}{\theta}\tfrac{a^R}{W_{t+1}^{R}}\right] \\
&= a(1+\tfrac{1}{a^R})(1-\theta)\tfrac{W_{t+1}^{R}}{W_t} - (1-\theta) + (1-\theta)ln\left[a^R\,\tfrac{1-\theta}{\theta}\,\tfrac{W_{t+2}^{R}}{W_{t+1}^{R}}\right]
\end{aligned}
\tag{20}
$$

Led to this stage, I can now describe more explicitly how the abundance in natural resource of the domestic economy, influences the representative agent's migration decision. This result is established in Proposition 4 hereafter. To simplify the presentation, let's assume that the foreign economy is evolving along a balanced growth path i. e. there is a constant $g_W^R$ such that $W_{t+1}^R = g_W^R W_t^R\,\forall t$. Besides, from Proposition 3, it comes out that the domestic economy also evolves along a balanced growth path and the gross rate of growth of the domestic average wage is given by $g_W = (1+\gamma)^{\frac{1}{1-\alpha}}\,(1+r)^{-\frac{\alpha}{1-\alpha}}\,\forall t$. The technological gap in favour of the foreign economy then involves that $g_W^R > g_W$. In addition to these shortcuts that are made to increase the transparency of the argumentation, I introduce the following restriction on the parameters.

**Assumption 2.**

$$
\Omega \equiv (1+a)\left[g_W + \frac{\alpha}{1-\alpha}(1+r)^{-\frac{\alpha}{1-\alpha}}\right] - ln\left[\frac{a^R}{a}\,\frac{g_W^R}{g_W}\right] > 0 \tag{21}
$$

This assumption imposes the reasonable condition that initially (at $t=0$) the individual is willing to stay in the more familiar environment of his homeland. It enables us to focus on the more relevant part of the parameter space (See the proof of Proposition 4 for more comprehensive understanding.).

**Proposition 4.** *Under Assumption 2, if the resource bonanza is sufficiently important at the beginning (i.e. if $S_0$ is sufficiently high), then two dynamics are observed :*

1. *In early date, the abundance of the resource generates enough wealth effects that cut or even hinder incentives to migrate;*
2. *Later, as the resource depletes over time, the wage gap in favour of the rest of the world, drives incentives to migrate abroad.*

*Proof.* Let's denote $\Phi \equiv a(1+\frac{1}{a^R})(1-\theta)g_W^R W_0^R\,\frac{A_0^{-\frac{1}{1-\alpha}}}{1-\alpha}\alpha^{-\frac{\alpha}{1-\alpha}}$ . From (17), (20) and making use of (13) I get :

$$
\begin{aligned}
V_{t+1}^{R} - V_{t+1} &= a(1+\tfrac{1}{a^R})(1-\theta)\tfrac{W_{t+1}^{R}}{W_t} - (1-\theta) + (1-\theta)ln\left[a^R\,\tfrac{1-\theta}{\theta}\,\tfrac{W_{t+2}^{R}}{W_{t+1}^{R}}\right] \\
&\quad -(1-\theta)\left[(1+a)(1+r)^{-\frac{\alpha}{1-\alpha}}\left((1+\gamma)^{\frac{1}{1-\alpha}} + \tfrac{\alpha}{1-\alpha}\right) - 1\right] - (1-\theta)ln\left[a\tfrac{1-\theta}{\theta}(1+r)^{-\frac{\alpha}{1-\alpha}}\right] \\
&= a(1+\tfrac{1}{a^R})(1-\theta)g_W^R\,\tfrac{W_0^R}{W_0}\,\left(\tfrac{g_W^R}{g_W}\right)^t \\
&\quad -(1-\theta)(1+a)\left[g_W + \tfrac{\alpha}{1-\alpha}(1+r)^{-\frac{\alpha}{1-\alpha}}\right] + (1-\theta)ln\left[\tfrac{a^R}{a}\,\tfrac{g_W^R}{g_W}\right] \\
&= a(1+\tfrac{1}{a^R})(1-\theta)g_W^R W_0^R\,\tfrac{A_0^{-\frac{1}{1-\alpha}}}{1-\alpha}\alpha^{-\frac{\alpha}{1-\alpha}}\left[\varphi(S_0)\right]^{\frac{\alpha}{1-\alpha}}\,\left(\tfrac{g_W^R}{g_W}\right)^t - (1-\theta)\Omega \\
&= \Phi\left[\varphi(S_0)\right]^{\frac{\alpha}{1-\alpha}}\,\left(\tfrac{g_W^R}{g_W}\right)^t - (1-\theta)\Omega
\end{aligned}
$$

My hypothesis that the domestic economy is initially sufficiently endowed in natural resource can now be explicitly written down as :

$$S_0 > \varphi^{-1}\left[\left((1-\theta)\frac{\Omega}{\Phi}\right)^{\frac{1}{\alpha}-1}\right]$$

where $\varphi^{-1}$ is the reciprocal of $\varphi$. Let's recall in fact that since $\varphi$ is continuous and strictly monotone, then it is a bijective function.

Under this restriction, jointly with the Assumption 2 and given that $g_W^R > g_W$ as a consequence of the technological gap in favour of the foreign economy, I can conclude that :

$$V_1^R - V_1 < 0 \qquad \text{and} \qquad \lim_{t\to\infty}\left(V_{t+1}^R - V_{t+1}\right) = +\infty$$

Finally I can make use of a similar argument to the one provided by the intermediate value theoremto conclude that :

$$\exists t_0 \in \mathbb{N}/\forall t \in \mathbb{N}, t < t_0 \Leftrightarrow V_{t+1}^R - V_{t+1} < 0.$$[11]

Said in words, all along the period before $t_0$, the abundance of the natural resource is such that the utility drawn from living in homeland outweighs what is derived from migration. The agent then has no incentives to migrate abroad. However, from $t_0$ and onwards, the technological gap take precedence over the resource windfall and the agent is better off if he moves to the foreign economy. □

Once again, I have made the analysis with respect to the stock of the resource while the empirical evidence Fact 2 that I aimed to replicate here is about the resource dependence of countries. However, the same argument as before hold since for a developing country, it is not surprising that natural resource wealth often goes with a high dependence on the revenues from the extraction of such resources. The lesson I have to learn here is that even in a typical developing country facing a resource curse, agents react to the constraints imposed by the depletion of the resource by accumulating other type of assets in order to overcome the challenges involve by the increasing scarcity of the resource. However, the more is the resource bonanza, and further is delayed such reaction.

The depletion of the resource then goes with a reduction of the dependence of the country *vis-à-vis* the resource and as the resource is exhausted, citizens face significant welfare lost by staying in the domestic economy and receive increasing incentives to migrate abroad.

My policy recommendation therefore in such context is to promote an increasing national-level budget allocation to critical services such as health and education. In my model, the parameter that capture the quality of social services is $a$. As one can notice it, both the gross domestic product of the modelled economy ($Y_t$) and the level of human capital in the economy ($h_t$) are strictly increasing with respect to $a$. In contrast, the time investment in education of parents is decreasing with respect $a$. This is to show that if an important share of the revenues for extraction is used to finance an improvement of social services, this will have a positive effect on growth and on human capital accumulation but parents will not necessarily need to invest more of their time, rearing their children. The net effect on the difference in welfare ($V_{t+1}^R - V_{t+1}$) is however ambiguous since an improvement of the quality of the social services may pull or instead push migration flows.

[11] Actually since $t$ is a discrete variable, I cannot apply directly the intermediate value theorem (IVT). However, I can first consider the continuous version of $V_{t+1}^R - V_{t+1}$ define on $\mathbb{R}$. I denote it $W(\tau)$. Therefore, $W(\tau) = V_{\tau+1}^R - V_{\tau+1}$ for $\tau \in \mathbb{N}$. It easy to show that $W(.)$ is continuous and strictly increasing w.r.t. $\tau$. I can therefore apply the IVT to conclude that : $\exists \tau_0 \in \mathbb{R}/W(\tau) = 0$. Now I can define $t_0 \equiv [\tau_0]$, the integer part of $\tau_0$.

# 4 Empirical validation : a gravity model of migration

In this section, I aim to provide an empirical validation to the conclusions drawn from the theoretical model developed in Sections 3 and 3.3. To do so, I augment the immigration gravity model developed by Lewer and Van den Berg (2008) by including the share of resource rents on national wealth among the determinants of migration flows.

## 4.1 Background: the gravity model of immigration of Lewer and Van den Berg

Lewer and Van den Berg (2008) have adapted the traditional gravity of trade to the concern of migration given the similarities of the determinants of these two economic realities. Like international trade models, they suggest that immigration is driven by some attractive forces (difference in income per capita which stand for the difference in wages as suggested by labour market models of immigration on the one side and population size of source and destination countries on the other side) and curbed by some cost factors mainly correlated to geographical remoteness (distance and contiguity). Other factors such as ethnicity/language, history and past episodes of migration could also play significant role and are for this reason used as control variables. Overall, Lewer *et al.* proposed the following gravity equation of immigration as baseline :

$$\begin{aligned} \mathrm{imm}_{ij} &= a_0 + a_1(\mathrm{pop}_i \times \mathrm{pop}_j) + a_2 \left(\mathrm{rely}_{ij}\right) + a_3 \left(\mathrm{dist}_{ij}\right) + a_4 \left(\mathrm{stock}_{ij}\right) \\ &\quad + a_5 \left(\mathrm{LANG}_{ij}\right) + a_6 \left(\mathrm{CONT}_{ij}\right) + a_7 \left(\mathrm{LINK}_{ij}\right) + u_{ij} \end{aligned} \tag{22}$$

where $\mathrm{pop}_i \times \mathrm{pop}_j$ is the natural log of the product of the populations of source and destination countries, $\mathrm{rely}_{ij}$ is the ratio of destination to source country per capita income, $\mathrm{dist}_{ij}$ is the natural log of the distance between the two countries, $\mathrm{stock}_{ij}$ is the number of source country natives already living in the destination country, and $\mathrm{LANG}_{ij}$, $\mathrm{CONT}_{ij}$ and $\mathrm{LINK}_{ij}$ are dummy variables for pairs of countries that share a common language, a contiguous border and colonial links. Hereafter, I will augment this baseline gravity equation with the explanatory variables that are relevant to test my theory.

## 4.2 Data and methodology

The main change I introduce into the framework of Lewer and Van den Berg (Equation (22)) is that I incorporate the log of the ratio of destination to source country's natural resource rents ($\mathrm{rRents}_{ij}$) among the explanatory variables.[12] I also replace the variable $\mathrm{stock}_{ij}$ by the percentage of migrants in the destination country to account for past episodes of migration since I don't have the bilateral corresponding variable. Overall, I posit the following gravity equation :

$$\begin{aligned} \mathrm{mig}_{ij} &= a_0 + a_1(\mathrm{pop}_i \times \mathrm{pop}_j) + a_2 \left(\mathrm{rIncome}_{ij}\right) + a_3 \left(\mathrm{dist}_{ij}\right) + a_4 \left(\mathrm{stock}_j\right) \\ &\quad + a_5 \left(\mathrm{LANG}_{ij}\right) + a_6 \left(\mathrm{CONT}_{ij}\right) + a_7 \left(\mathrm{LINK}_{ij}\right) \\ &\quad a_8 \left(\mathrm{rRents}_{ij}\right) + u_{ij} \end{aligned} \tag{23}$$

The dependant variable $\mathrm{mig}_{ij}$ is the log of the flows of migrants who moved from country $i$ to country $j$ in 2000.[13] The estimation is made using four different estimators for the sake

[12] As it must be clearly understood now, I aim to demonstrate that the difference in resource abundance can meaningfully be considered as a driver of migration flows. Somehow, this is in line with the major gold rushes that took place in the XIX$^{th}$ century in Australia, New Zealand, Brazil, Canada, South Africa, and the United States. More recently, countries and regions that have had important discovery of oil deposits also faced important inflows of populations and was then incited to adopt restrictive immigration policies (Qatar, Gabon, Angola, Alberta in Canada, etc.)

[13] Except for the Poisson Pseudo-Maximum Likelihood estimator which requires to introduce the variable in level rather than in logarithms.

of consistency. Mainly [but not only] because of the presence of many zeros in the matrix of bilateral migration, the selection model of Heckman (Heckman), the Poisson Pseudo-Maximum Likelihood (PPML) and the Zero Inflated Negative Binomial (ZINB) estimators are of particular relevance. I however start by the Scaled OLS estimation which is known as the simplest option in such context even if it has no theoretical foundation and may lead to biased estimations. I will discuss in more details, the strengths and weaknesses of each of these estimators, in light of the estimation results.

Different data sources are put together to allow this exercise. I use the Global Bilateral Migration Database of the World Bank for the dependant variable $\text{mig}_{ij}$. This database provide for five time periods, the complete worldwide bilateral flows of migrants for each couple of country disaggregated by gender.[14] For the purpose of the estimations, I will focus solely on the more recent time period and the total flow of migrants. The variables population ($\text{pop}_i \times \text{pop}_j$), GDP per capita ($\text{rIncome}_{ij}$) and resource rents ($\text{rRents}_{ij}$) are computed using data from the World Development Indicators of the World Bank whilst the geographic and ethnic variables such as $\text{dist}_{ij}$, $\text{LANG}_{ij}$, $\text{CONT}_{ij}$ and $\text{LINK}_{ij}$ are originated from the dyadic GeoDist database of Mayer and Zignago (2011).

### 4.3 Estimation results and discussions

Similarly to gravity models of trade, the estimation of the coefficients of the model (23) means dealing with two major issues that make the traditional OLS estimator (column (1) of Table 3), inconsistent.

One the one side, the log-linearisation of the genuine form of the gravity equation is inherent with getting an error term which is highly likely to become correlated with the regressors (Helpman, Melitz, and Rubinstein 2008, Silva and Tenreyro 2006). It is therefore important to test the hypothesis of homoskedasticity of the error term. To overcome this issue in this context, I start first by running successively the Breusch-Pagan / Cook-Weisberg test for heteroskedasticity, the White's general test for heteroskedasticity and the LM test. All of these tests yield the conclusion that the null hypothesis of constant variance of the error terms could not be accepted even at 10% degree of significance level. An appropriate alternative approach would therefore be the use of the Weighted Least Squares estimator. However, the second issue I face makes this option inappropriate. Indeed, on the other side, since the logarithm of zero is not defined, the elimination of migration flows when zeros are not randomly distributed may leads to sample selection bias. In fact, in my dataset, the dependant variable is missing for 45.70% of the observations (log of zero).

The simplest solution to challenge these two concerns is the one adopted by Lewer and Van den Berg (2008). I consist in including the zeros by considering instead by adding 1 to the dependant variable before taking the log. The intuition is that for small values of $y$, $ln(1+y) \approx y$ while for greater values, $ln(1+y) \approx ln(y)$. The estimation can later be made by using robust method *à la* White for instance. The problem here is the lack of theoretical foundation to this approach even if there is striking empirical regularity that consistent estimates can often be approximated by dividing the OLS estimates by the proportion of nonlimit observations in the sample (Gómez-Herrera (2013) citing Wang and Winters).[15] This option is applied in column (2) of Table 3.

An alternative solution is the selection model of Heckman. As noted by Linders (2006), this approach is preferred theoretically and econometrically when an appropriate over-identifying

[14] 1960, 1970, 1980, 1990 and 2000

[15] Wang, Z.K. & Winters, L.A., (1992). "The Trading Potential of Eastern Europe," Discussion Papers 92-21, Department of Economics, University of Birmingham.

variable is chosen. Formally, the specification of the heckman model in this context would be is as follow :

$$\begin{cases} (23) \text{ if } \mathrm{mig}_{ij} \text{ is observed} & : \text{Regression equation} \\ \mathrm{mig}_{ij} \text{ is observed only if } \mathrm{mig}^*_{ij} = X'_{ij}\beta + v_{ij} > 0 & : \text{Selection equation} \end{cases} \tag{24}$$

$$\text{where} \begin{pmatrix} u_{ij} \\ v_{ij} \end{pmatrix} \rightsquigarrow \mathcal{N}\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}; \begin{pmatrix} \sigma_u^2 & \rho\sigma_u \\ \rho\sigma_u & 1 \end{pmatrix}\right]$$

$\mathrm{mig}^*_{ij}$ is a latent (unobserved) variable describing the background incentives to migrate and an agent takes the decision to migrate only when this variable exceeds a certain threshold normalize here to zero. The parameter $\rho$ in turn, informs whether sample selection represent an important issue in the dataset or not. Moreover, the model is just identified if the set of regressors in $X_{ij}$ is the same as in (23) and Heckman recommands adding an over-identifying variable to the Selection equation in order to get stable and robust results. These variable must be one that influences the decision of migration but not its intensity. Following Helpman, Melitz, and Rubinstein (2008), common language ($\mathrm{LANG}_{ij}$) is used as excluded variable since this variable is expected to affect the decision to migrate but not its intensity which is captured here by the size of migration flows. The results of the estimation are reported in column (3) and (4) of Table 3.

Another simple way to deal with these problems is proposed by Silva and Tenreyro (2006) present a simple way of dealing with this problem. They showed that if the gravity model contains the correct set of explanatory variables, the Poisson pseudo-maximum likelihood (PPML) estimator provides consistent estimates of the original non linear model. It is exactly equivalent to running a type of non linear least squares on the original equation. Since I am dealing with a pseudo-maximum likelihood estimator, it is not necessary that the data be in fact distributed as Poisson. So although Poisson is more commonly used as an estimator for count data models, it is appropriate to apply it far more generally to non linear models such as gravity. I present the results of the PPLM estimation in column (5) of Table 3.

Burger, van Oort, and Linders (2009) pointed out that an important condition of the Poisson model is that it assumes equidispersion i.e. the variance of the dependant variable should roughly be equal to its mean. They emphasized that overdispersion combined with an excess zeros may lead to inconsistency of the PPLM estimator. They proposed in turn to use the Zero-Inflated Negative Binomial as alternative when these problems emerge. In the current context, the variance of the dependant variable is 27 071 times its mean and zeros represent 45.70% of the observations. This is the main motivation of the ZINB estimation reported in column (6) and (7) of Table 3 presented hereafter.

Table 3: Estimation Results

| | Simple OLS | Scaled OLS | Heckman Outcome | Heckman Selection | PPML | ZINB Outcome | ZINB Inflate |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Log(Pop$_i$×Pop$_j$) | 0.589*** | 0.520*** | 0.367*** | 0.215*** | 0.736*** | 0.145*** | -0.016 |
| | (0.01) | (0.01) | (0.01) | (0.00) | (0.03) | (0.00) | (0.05) |
| Log(ratio of GDP per capita) | 0.075*** | 0.128*** | 0.021** | 0.040*** | 0.105*** | 0.015*** | -0.103** |
| | (0.01) | (0.01) | (0.01) | (0.00) | (0.03) | (0.00) | (0.05) |
| Log(ratio of resource rents) | 0.042*** | 0.010*** | 0.051*** | -0.005*** | 0.108*** | 0.013*** | 0.068*** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.02) | (0.00) | (0.02) |
| Log(distance to largest cities) | -1.110*** | -0.894*** | -0.843*** | -0.291*** | -0.612*** | -0.259*** | 0.322*** |
| | (0.02) | (0.02) | (0.03) | (0.01) | (0.10) | (0.01) | (0.12) |
| Contiguity dummy | 2.209*** | 3.420*** | 2.243*** | 0.724*** | 1.662*** | 0.154*** | -21.668 |
| | (0.11) | (0.11) | (0.13) | (0.13) | (0.32) | (0.02) | (30537.28) |
| Common language dummy | 1.090*** | 1.304*** | | 0.570*** | 0.850*** | 0.236*** | -0.156 |
| | (0.05) | (0.04) | | (0.03) | (0.14) | (0.01) | (0.27) |
| Colonial relationship dummy | 2.329*** | 3.230*** | 2.140*** | 1.339*** | 1.461*** | 0.306*** | -3.553 |
| | (0.13) | (0.13) | (0.18) | (0.14) | (0.19) | (0.02) | (8.05) |
| Log(Share of migrants in Pop$_j$) | 0.588*** | 0.398*** | 0.507*** | 0.099*** | 0.828*** | 0.146*** | 0.301*** |
| | (0.01) | (0.01) | (0.02) | (0.01) | (0.07) | (0.00) | (0.11) |
| Intercept | -6.217*** | -6.711*** | -0.067 | -4.197*** | -13.182*** | -1.309*** | -6.848*** |
| | (0.31) | (0.25) | (0.42) | (0.17) | (1.52) | (0.07) | (1.70) |
| N | 15 960 | 27 556 | 27 556 | | 27 556 | 15 960 | |
| R-squared | 0.437 | 0.420 | | | 0.403 | | |
| F-statistic: F( 8, N-K-1) | 1549.43 | 2489.51 | | | | | |
| p value | 0.0000 | 0.0000 | | | | | |
| Wald-statistic : chi2(7) | | | 3084.39 | | | | |
| p value | | | 0.0000 | | | | |
| LR-statistic : chi2(8) | | | | | | 8065.63 | |
| p value | | | | | | 0.0000 | |

Standard errors in parentheses
Significance levels : * : 10% ** : 5% *** : 1%

Unsurprisingly, most of the variables are highly significant since they are well known as relevant explanatory variables of gravity models. Besides, the Wald test indicates that the model explains much of the variation in the dependant variable. The important novelty here is the ratio of natural resource rents of destination to origin country which is also highly significant and has the expected sign. Hence, the difference in resource of countries also deserve to be considered as a determinant of international migration.

# 5 Conclusion

Understanding the background mechanisms driving migrants flows is undoubtedly of primary interest in our time of ever increasing waves of migrants, usually from developing countries to more developed ones. To describe such mechanisms, research on migration often focuses on wage (or income) gap between countries and other gravitational forces such as geographical, historical and cultural remoteness/proximity among source and destination countries.

In this paper, I show theoretically and confirm empirically that the relative dependence of a country on natural resources may play a significant role on the intensity and the direction of migration flows it faces. Indeed, I develop an overlapping generations model in which agents live two periods to show that a resource curse is likely to be observed on human capital accumulation if the representative agent have a utility function that exhibits a lack of intergenerational altruism. Later, I establish that even if the technological gap between home and destination countries further takes the precedent, the endowment on natural resources of an economy exerts an attractive force on migration flows. These theoretical findings are supported by the empirical results. The gravity model of migration that I estimate, reinforces the main stylized fact that motivates this research. Indeed, I clearly identify the difference in natural resource rents of countries as a relevant determinant of bilateral migration flows.

The model proposed in this paper is a simple, flexible and transparent framework in which several other aspects of the influence of resource wealth on migration patterns can be studied. This is in fact a result of my objective to provide an easily accessible framework to derive my findings. However, the sake of parsimony that I have, involves some drawbacks. Among these weaknesses, I can list the absence of uncertainty in the model. Indeed, on the supply side of the economy, I assume that prices and the technological parameters are deterministic while in fact a more reasonable hypothesis would allow for some stochastic terms. In the same line, the market structures adopted here are very simplistic. This is particularly effective for the resource management problem that also abstracts for some complex governance and institutional issues that are often problematic in some developing countries. Finally, in the assessment of the migration decision, I neglect the barriers and visas restrictions that may have an important impact on the migrant's decision. All these aforementioned flaws remain promising areas of research that deserve to be explored.

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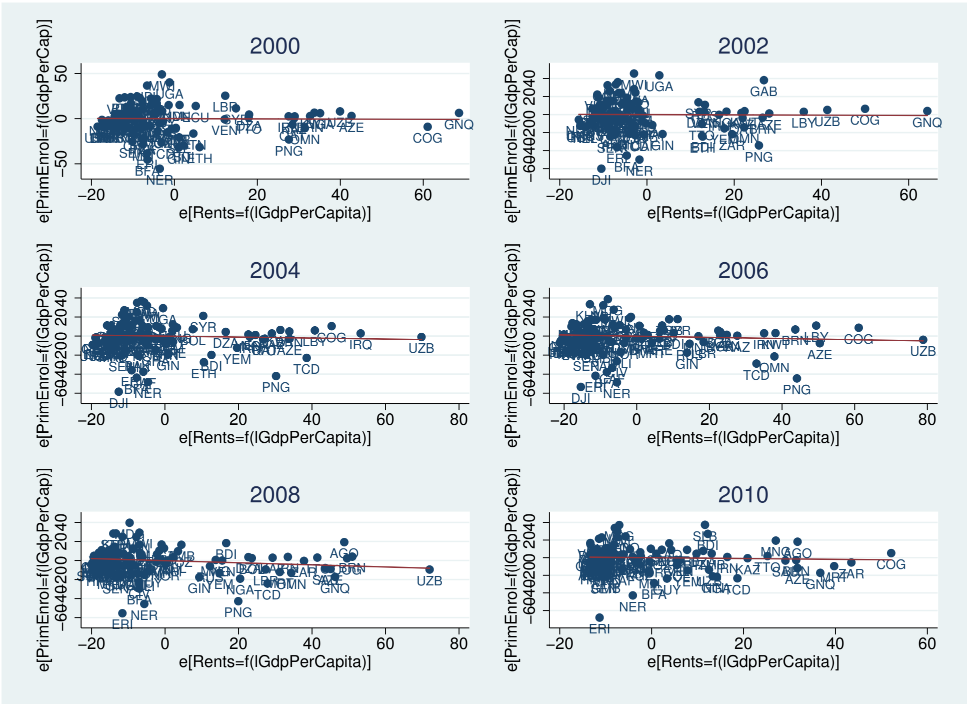
# Appendix A More on the empirical facts

In general, the education indicators show a negative relationship with the resource dependence of the countries and the relationship is more effective as I consider higher level of schooling.

In primary school, there no relationship since the slope of the regression lines are very close to 0. This is what I show through Figure A1. Moreover, the regression of the rate of enrolment in primary school against the share of natural resource rents in GDP and the log of the GDP per capita shows no significant coefficients for all years from 2000 to 2012. This lead to the conclusion that there is no link between primary school participation and resource dependence of countries.

Figure A1: Primary School Enrolment versus Resource dependence

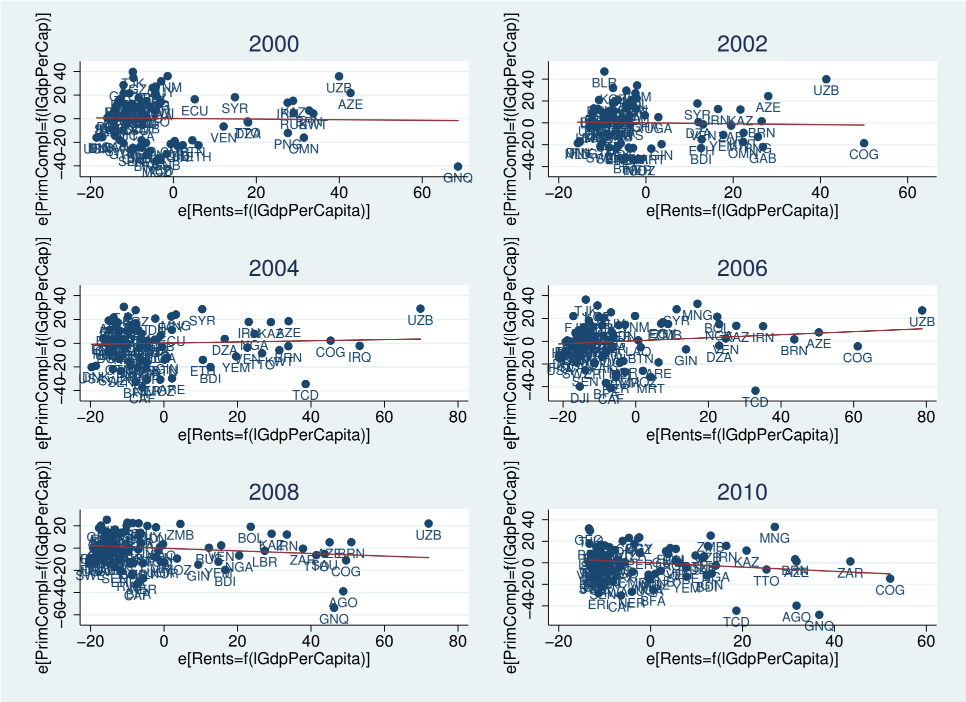



Source: The WDI of the World Bank (rents) and Barro & Lee (Years of Schooling)

The completion rate of primary school also seems to be independent from the resource dependence of the country. This is shown by the partial regression plots of Figure A2. Besides, the regression of the completion rate of primary school against the share of natural resource rents in GDP and the log of the GDP per capita shows no significant coefficients for all years from 2000 to 2012 but 2009 and 2010. In these two years, the share of natural resource rents in GDP influences negatively the completion rate of primary school.

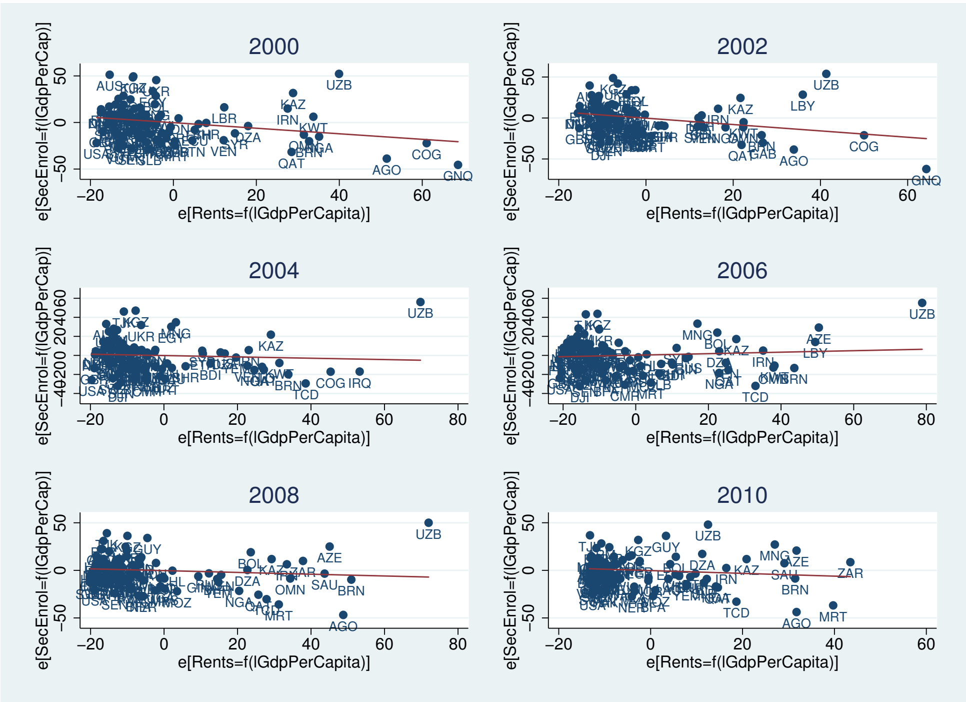
In secondary school however, the upward sloping relationship between schooling and resource dependence shows up for most of the years, except for 2006 where the slope is non negative but significantly not non nil (see Figure A3).

Figure A2: Primary School completion rate versus Resource dependence




Source: The WDI of the World Bank (rents)

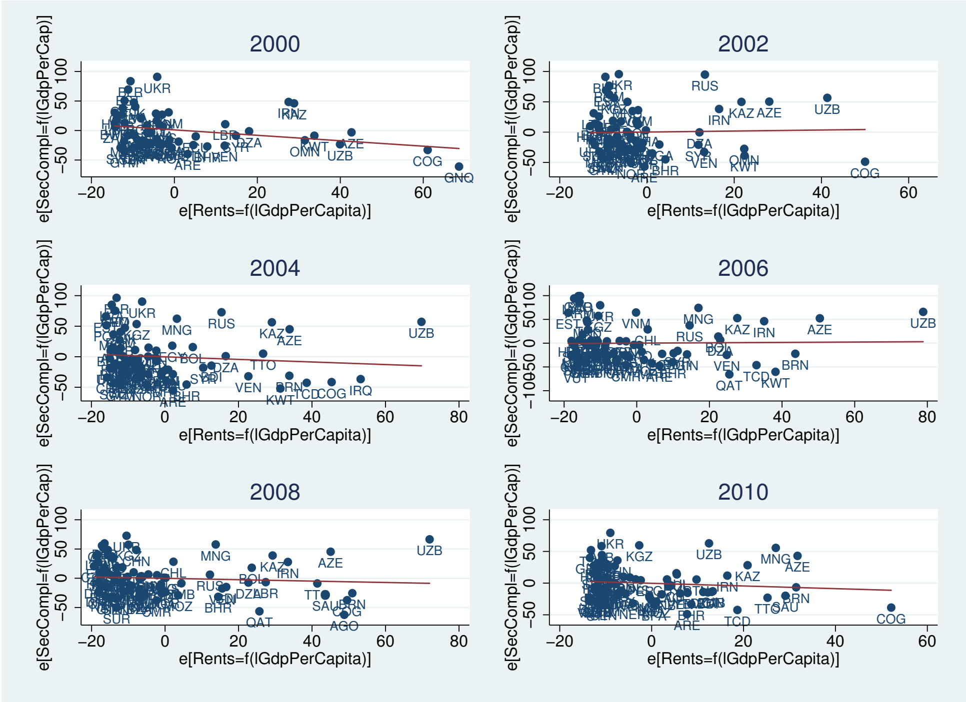
Figure A3: Secondary School Enrolment versus Resource dependence




Source: The WDI of the World Bank (rents) and Barro & Lee (Years of Schooling)

The graphs in Figure A4 correspond to the completion rate of Secondary School and provide similar conclusion as before.

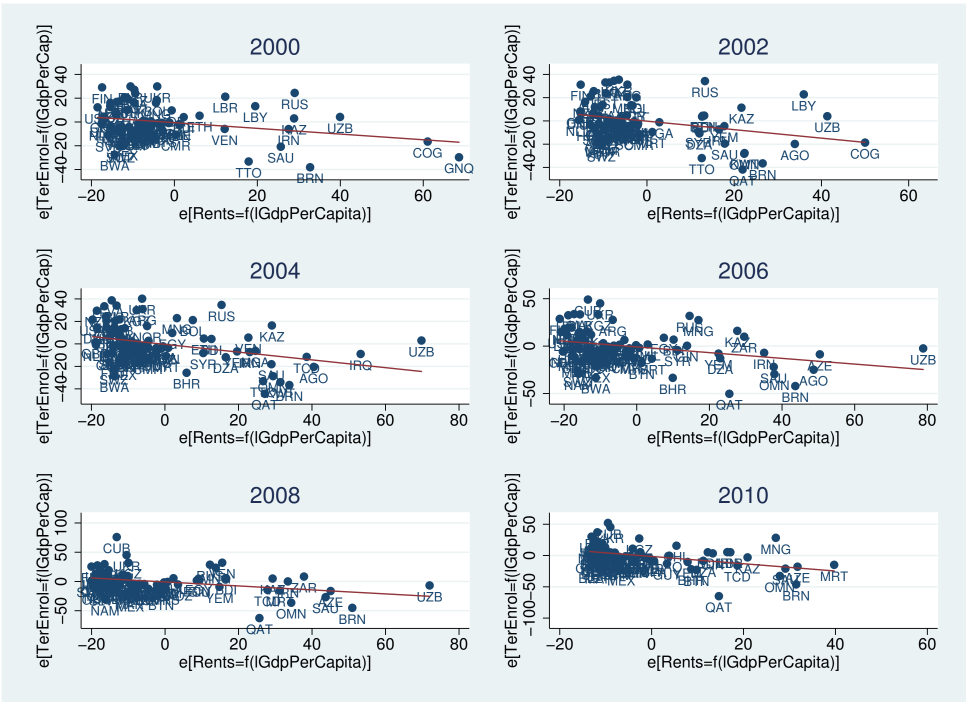
Figure A4: Secondary School completion rate versus Resource dependence




Source: The WDI of the World Bank (rents) and Barro & Lee (Years of Schooling)

In tertiary school, the result is more sharp. Indeed, the enrolment rate in tertiary school decrease significantly with the resource dependence of countries.

Figure A5: Tertiary School Enrolment versus Resource dependence




Source: The WDI of the World Bank (rents) and Barro & Lee (Years of Schooling)

Besides, Table A1 hereafter reveals that at a same level of GDP per capita, an increase of 1% of the ratio of resource rents over GDP implies a decrease of about 0.3% of the rate of enrolment in tertiary school.

Table A1: Natural resources as determinant of tertiary schooling : OLS and Huber's estimates

| **Variables** | **Year 2000** | | **Year 2005** | | **Year 2010** | |
|---|---|---|---|---|---|---|
| | OLS | Huber | OLS | Huber | OLS | Huber |
| Total Natural resources | -0.241** | -0.232** | -0.341*** | -0.338*** | -0.584*** | -0.532*** |
| rents (% of GDP) | (0.09) | (0.10) | (0.09) | (0.09) | (0.14) | (0.15) |
| Log(GDP per capita, | 10.681*** | 11.025*** | 12.526*** | 13.044*** | 12.552*** | 13.331*** |
| constant 2005 US$) | (0.95) | (0.79) | (1.12) | (1.00) | (1.16) | (0.99) |
| Intercept | -54.260*** | -57.397*** | -64.105*** | -68.744*** | -56.995*** | -64.278*** |
| | (7.28) | (5.74) | (8.74) | (7.29) | (9.54) | (7.88) |
| N | 82.000 | 82.000 | 88.000 | 88.000 | 84.000 | 84.000 |
| $R^2$ | 0.619 | | 0.609 | | 0.639 | |

Standard errors in parentheses

Significance levels : $*$ : 10% $**$ : 5% $***$ : 1%

Huber, 1973 : M-Regression (95% efficiency)

## Appendix B Detailed solution of the energy firm's problem

I provide hereafter, the formal proof of the optimal choice of the Energy firm in partial equilibrium.

*Proof.* The Lagrangian associated to the problem (4) is :

$$\begin{aligned}\mathfrak{L}(E_t, \lambda_t, \mu) &= \sum_{t=0}^{+\infty} d_t p_t E_t - \mu \left[\sum_{t=0}^{+\infty} E_t - S_0\right] + \sum_{t=0}^{+\infty} d_t \lambda_t E_t \\ &= \sum_{t=0}^{+\infty} d_t (p_t + \lambda_t) E_t - \mu \left[\sum_{t=0}^{+\infty} E_t - S_0\right]\end{aligned}$$

Any solution of (4) must satisfies the Kuhn-Tucker conditions :

$$\frac{\partial \mathfrak{L}(E_t, \lambda_t, \mu)}{\partial E_t} = d_t(p_t + \lambda_t) - \mu = 0 \, \forall t \tag{25a}$$

$$\tag{25b}$$

$$\mu \left[\sum_{t=0}^{+\infty} E_t - S_0\right] = 0 \tag{25c}$$

$$\sum_{t=0}^{+\infty} E_t \leq S_0 \tag{25d}$$

$$\mu \geq 0 \tag{25e}$$

$$\tag{25f}$$

$$\lambda_t E_t = 0 \text{ for } t = 0, 1, 2, \cdots, \infty \tag{25g}$$

$$-E_t \leq 0 \text{ for } t = 0, 1, 2, \cdots, \infty \tag{25h}$$

$$\lambda_t \geq 0 \text{ for } t = 0, 1, 2, \cdots, \infty \tag{25i}$$

Since the objective function in (4) is stricly increasing in each $E_t$ for $t = 0, 1, 2, \cdots, \infty$, it is obvious that the optimum is consistent which the exhaustion of the resource. Therefore, the complementary slackness conditions associated to the Lagrange multiplier $\mu$ involve $\mu \geq 0$ and a binding constraint (25d).

Let's denote in line with the text, $\mathbb{T} \equiv \{t \in \mathbb{N} : d_t p_t = \max_\tau d_\tau p_\tau\}$ and make the implicit assumption that $\mathbb{T}$ is well defined and not empty. Without loss of generality I can also assume that $0 \in \mathbb{T}$. I am going to show that an optimal choice of the firm requires to supply a positive amount of energy only on time periods in $\mathbb{T}$.

Indeed, from (25a) and for all $t = 0, 1, 2, \cdots, \infty$, I can write :

$$d_0(p_0 + \lambda_0) = \mu = d_t(p_t + \lambda_t)$$

Since $d_0 = 1$, from the assumption that $0 \in \mathbb{T}$ and for $t \notin \mathbb{T}$, I obtain :

$$p_0 - d_t p_t = d_t \lambda_t - \lambda_0 > 0 \;\Rightarrow\; d_t \lambda_t > \lambda_0 \geq 0 \;\Rightarrow\; \lambda_t > 0 \;\Rightarrow\; E_t = 0.$$

□

# Appendix C Detailed results of the estimations of the gravity model of migration

The database includes 183 countries, listed in the table below.

Table C2: List of countries included in the sample

| | | | |
|---|---|---|---|
| Afghanistan | Dominican Republic | Liberia | Seychelles |
| Albania | Ecuador | Libya | Sierra Leone |
| Algeria | Egypt, Arab Rep. | Lithuania | Singapore |
| Angola | El Salvador | Luxembourg | Slovak Republic |
| Antigua and Barbuda | Equatorial Guinea | Macedonia, FYR | Slovenia |
| Argentina | Eritrea | Madagascar | Solomon Islands |
| Armenia | Estonia | Malawi | Somalia |
| Australia | Ethiopia | Malaysia | South Africa |
| Austria | Fiji | Maldives | Spain |
| Azerbaijan | Finland | Mali | Sri Lanka |
| Bahamas, The | France | Malta | St. Kitts and Nevis |
| Bahrain | Gabon | Marshall Islands | St. Lucia |
| Bangladesh | Gambia, The | Mauritania | St. Vincent and the Grenadine |
| Barbados | Georgia | Mauritius | Sudan |
| Belarus | Germany | Mexico | Suriname |
| Belgium | Ghana | Micronesia, Fed. Sts. | Swaziland |
| Belize | Greece | Moldova | Sweden |
| Benin | Grenada | Mongolia | Switzerland |
| Bhutan | Guatemala | Morocco | Syrian Arab Republic |
| Bolivia | Guinea | Mozambique | Tajikistan |
| Bosnia and Herzegovina | Guinea-Bissau | Myanmar | Tanzania |
| Botswana | Guyana | Namibia | Thailand |
| Brazil | Haiti | Nepal | Togo |
| Brunei Darussalam | Honduras | Netherlands | Tonga |
| Bulgaria | Hungary | New Zealand | Trinidad and Tobago |
| Burkina Faso | Iceland | Nicaragua | Tunisia |
| Burundi | India | Niger | Turkey |
| Cambodia | Indonesia | Nigeria | Turkmenistan |
| Cameroon | Iran, Islamic Rep. | Norway | Tuvalu |
| Canada | Iraq | Oman | Uganda |
| Cape Verde | Ireland | Pakistan | Ukraine |
| Central African Republic | Israel | Palau | United Arab Emirates |
| Chad | Italy | Panama | United Kingdom |
| Chile | Jamaica | Papua New Guinea | United States |
| China | Japan | Paraguay | Uruguay |
| Colombia | Jordan | Peru | Uzbekistan |
| Comoros | Kazakhstan | Philippines | Vanuatu |
| Congo, Rep. | Kenya | Poland | Venezuela, RB |
| Costa Rica | Kiribati | Portugal | Vietnam |
| Cote d'Ivoire | Korea, Dem. Rep. | Qatar | Yemen, Rep. |
| Croatia | Korea, Rep. | Russian Federation | Zambia |
| Cuba | Kuwait | Rwanda | Zimbabwe |
| Cyprus | Kyrgyz Republic | Samoa | |
| Czech Republic | Lao PDR | San Marino | |
| Denmark | Latvia | Sao Tome and Principe | |
| Djibouti | Lebanon | Saudi Arabia | |
| Dominica | Lesotho | Senegal | |