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RESEARCH ARTICLE

The effects of migration and pollution on cognitive skills in Caribbean economies: a theoretical analysis

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Abstract

This work examines the interaction between demographic features and environmental constraints in Caribbean small island developing states. Specifically, it aims to clarify human capital dynamics when migration and environmental quality matter. To do so, two main ingredients are introduced in an overlapping generations model: countries may benefit from migration through a *brain gain* or remittances, and production emits pollution that hinders the accumulation of human capital. Two cases emerge from the analysis. In the first case, an environmental policy is sufficient to correct the externality, and migration should stay at a relatively low level. In the second case, if pollution emissions are high relative to the effectiveness of environmental policy, migration leads to an increase in per capita output and human capital. This only happens if the emigration rate is already high, because it leads to a reduction in demographic pressure on the environment.

Keywords: pollution; development; migration; Caribbean islands

JEL classification: Q01; Q56; F24; J24

1. Introduction

At the Earth Summit held in Rio de Janeiro in 1992, Small Island Developing States (SIDSs) were defined 'as a special case both for environment and development' issues because they share common economic, social and environmental vulnerabilities. Due to the small size of their economies, their remoteness and their scarce natural resources, increasing the human capital might be crucial to managing those vulnerabilities.

Among SIDSs, Caribbean islands exhibit a high level of emigration and, specifically, skilled emigration (ECLAC, 2017; ECLAC, 2018).[1] According to the literature, migration may improve economic growth through *brain gain* – i.e., an increase in the average

[1]There are 16 countries in this group: Antigua and Barbuda, the Bahamas, Barbados, Belize, Cuba, Dominica, the Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint-Kitts and Nevis, Saint-Lucia, Saint Vincent and the Grenadines, Suriname and Trinidad and Tobago. Guyana and Suriname are not islands but continental countries that share SIDS vulnerabilities.

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human capital in the sending economy – because the emigration opportunity creates incentives to invest in education in the sending countries. However, a brain gain occurs if the emigration is not too high and if the initial human capital is low (Stark *et al.*, 1997; Beine *et al.*, 2011; Docquier and Rapoport, 2012; Docquier *et al.*, 2012; Hatton, 2014). Moreover, the possibility for an economy to drive the full potential from its population's human capital is not solely defined by investments in education. In fact, human capital can also be impacted by local pollution.

Several studies have highlighted the link between exposure to local pollutants – such as metals, pesticides or persistent organic pollutants (POPs) – and the reduction of cognitive skills (Power *et al.*, 2016; Pujol *et al.*, 2016; Lett *et al.*, 2017). Moreover, small islands are characterized by scarcity of land and the proximity between areas with different uses. If pollutants are released untreated, there is a higher probability of contamination of water sources or soil in residential areas. Besides, because of the high population density in inhabited areas, the share of the domestic population impacted by a local pollutant can be larger than in other countries. Local pollutants in Caribbean islands may originate from different sources such as waste, wastewater or agricultural pollution. As in many developing countries, this results from inadequate environmental policies for waste management or wastewater, combined with inefficient governance (Barton *et al.*, 2008; Mohee *et al.*, 2015). Moreover, the agricultural use of pesticides and fertilizers was considered the main local pollution source between 1980 and 2000; many pesticides are highly persistent in the ecosystems, and stocks of obsolete substances were not dealt with until 2017 (Rawlins *et al.*, 1998).[2]

This work arises from the observation that there is no model that includes migration, fertility and education choices while dealing with the effects of pollution on human capital accumulation. However, considering migration when studying the link between human capital and pollution is necessary for Caribbean SIDSs because they may suffer from both *brain drain* and environmental issues. The aim of this work is to address this gap in the literature and to answer the following questions. In this context, what are the effects of an environmental policy? Is a brain gain still possible when cognitive skills are undermined by local pollution, and if so, under which conditions?

To do so, an overlapping generations (OLG) model is developed. In this economy, production is responsible for pollution emissions, and the efficiency of human capital accumulation depends on exposure to pollution (whether a flow or a stock) during childhood. The model incorporates intergenerational choices and solidarity into the analysis, as well as their impacts on production, the environment and population dynamics. An environmental tax is thus tested, and special focus is given to the evolution of human capital level, physical capital stock and consumption per capita.

In this paper, individuals care about their adult and old age consumption, knowing that the latter can be funded through savings or intergenerational transfers from their children. The environment impacts the economy through an externality and consequently has no effect on households' savings, fertility and education decisions. In addition to the usual intertemporal tradeoff between adult and old age consumption, there are two tradeoffs to fund consumption during the retirement period. The first is between savings and intergenerational transfers. Migration increases gains from human capital, which results in a substitution from savings to investments in children to receive more transfers. This is not detrimental to the capital stock if the increases in human

[2] For more information, see http://www.fao.org/americas/noticias/ver/en/c/1068631/.

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capital or in the number of savers (or the labor force) are large enough to compensate for the reduction in savings (as a percentage of income). This is more likely if the second tradeoff, that is between education and fertility, leans in favor of education. The fertility choice depends on migration and on the cost of raising children, which includes an overcrowding effect linked to the active population size (de la Croix and Gosseries, 2012; de la Croix and Gobbi, 2017). When the cost of children increases, parents have an incentive to decrease their fertility at the benefit of education.

At the aggregate level, migration has a positive effect on the population size if the increase in fertility induced by migration is higher than the loss due to departures. At this point, it is as if the economy is not affected by pollution, and the relationship between population size and migration is described by an inverted U-shaped curve. However, for the rest of the analysis, two cases emerge. In the first case, it is possible to cancel out the environmental externality through an environmental policy consisting of a tax on pollution emissions and publicly funded maintenance. In the long run, the economy can reach a balanced growth path (BGP), where production, human capital and physical capital grow at the same rate while the pollution stock is null. In this case, the relationship between economic growth and the emigration rate (or remittances) is described by an inverted U-shaped curve. This is due to the combination of the increase (reduction) in human capital, population and capital stock when migration is low (high). On this green growth path, the economy displays the same dynamics and characteristics as economies unaffected by environmental degradation (as in Ait Benhamou and Cassin, 2020).

In the second case, depending on the pollution intensity and the efficiency of cleaning expenses, environmental degradation is too large to be completely nullified by environmental policy. In this case, which is much more intricate, the aggregate variables display different dynamics and, instead of a BGP, there is a steady state. This is explained by the pollution stock, which hampers human capital accumulation until the economy reaches equilibrium. Second, the stability of the steady-state values is related primarily to the environmental damage function in the human capital dynamics. This function must be convex to observe a stable equilibrium. Third, in the presence of the environmental externality, the relationships between, on the one hand, the emigration rate and, on the other hand, production per capita, human capital and/or per capita utility are described by U-shaped curves. Indeed, if migration is low, an increasing rate of emigration leads to an increased population size and pollution stock. This decreases average human capital until a threshold at which the reduction of the population allows gains in human capital. The effects of remittances – or domestic transfers – are more ambiguous because they do not directly reduce the population size. When this parameter is large, it leads to a decrease in adult income – that benefits retirees – which can result in a reduction in fertility. This is increased by its negative effect on physical capital stock due to the substitution between savings and investments in children.

Therefore, the main contribution of this paper is to provide a brain gain analysis with environmental issues and endogenous fertility. It appears that in countries such as the Caribbean SIDSs, depending on the environmental features of the territory, migration effects can be completely different.

The remainder of this paper is structured as follows. Section 2 presents some facts on the Caribbean region. Sections 3 and 4 describe the model and the equilibrium, respectively. Section 5 is a discussion on the long-run effects of migration and the environment. Finally, section 6 draws conclusions and defines a roadmap for future research.

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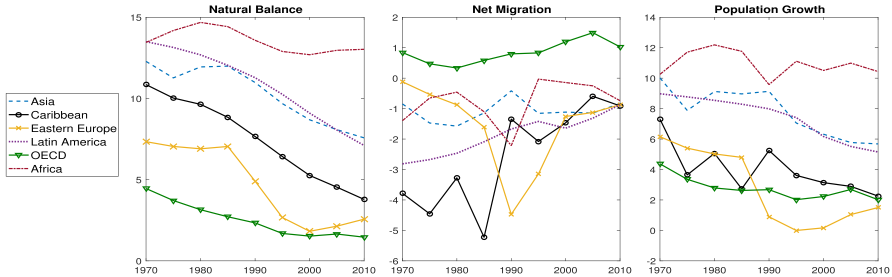

NB: Changes are given over a 5-year period.
Source: Author, based on the WDI

Figure 1. Demographic features by region (% of population).

2. Stylized facts and evidence

The first highlight of this article is the importance of migration in Caribbean SIDSs. Using data from the World Bank's World Development Indicators (WDI), figure 1 plots the natural balance, migration balance, and population growth as a percentage of the population within five years in Africa, Asia, the Caribbean, Latin America and Eastern Europe as well as countries of the Organisation for Economic Co-operation and Development (OECD). The United Nations Statistics Division (UNSD) releases migration flow data defined as the net change in the migrant stock between years 1 and 5. For the Caribbean group, the extent of migration flows is the highest among emerging economies in our country sample.[3] Figure 1 shows that the emigration flows have decreased strongly since 1990 for Caribbean countries. However, the size of the diaspora compared to the domestic population remains significant. Figure 2 represents the average of the share of nationals living in a foreign country between 2000 and 2015 by region. It is defined as the ratio of the diaspora over the sum of the diaspora and the domestic population. On average, between 2000 and 2015, more than 20 per cent of the persons born in the Caribbean were living in another country. Two-thirds of Caribbean migrants live in the U.S. (ECLAC, 2017), with the rest living in European or other Caribbean countries. The majority of migrants tend to be young and at a productive age.[4]

Strong links between the diaspora and their family in the domestic area remain (Thomas-Hope, 2002). This leads to important remittances – i.e., transfers between the diaspora and their family in the domestic area (ECLAC, 2017; ECLAC, 2018). Figure 3 displays a comparison of the percentage of received personal remittances relative to GDP across regional groups for the period 2000–2015. It shows that, among developing regions, the median personal remittances received appear to be higher in the Caribbean countries (4.38 per cent of GDP); except for Eastern Europe and Central Asia since the implementation of the Schengen area at the end of the 1990s.

[3] Middle East and North African countries are not represented because their demographic features exhibit strong volatility due to conflicts. In the 1970s, due to the immigration policies in the receiving countries, Caribbean emigration was especially high. Eastern Europe also exhibits strong migration features since the implementation of the Schengen Area.

[4] This is not the case for those from Cuba, who are on average over 45 years old.

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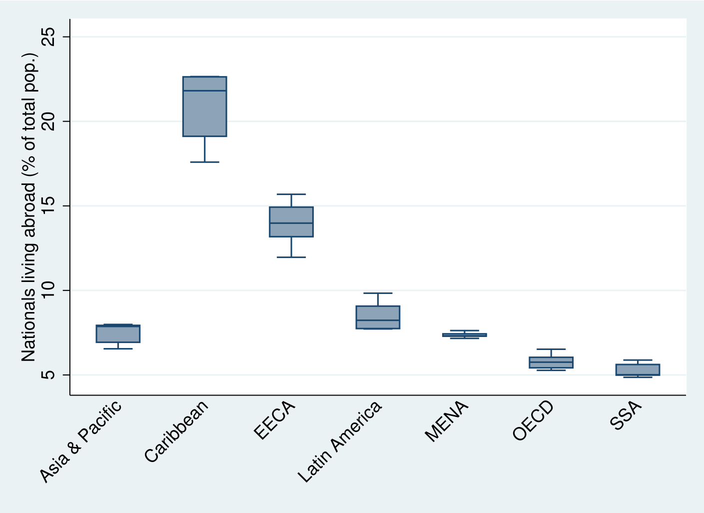

Figure 2. Average of nationals living abroad (% of total population, 2000–2015).
Legend: **EECA**: Eastern Europe and Central Asia, **MENA**: Middle East and North Africa, **SSA**: Sub-Saharan Africa.
Source: Author, based on the UNSD migration dataset and the WDI.

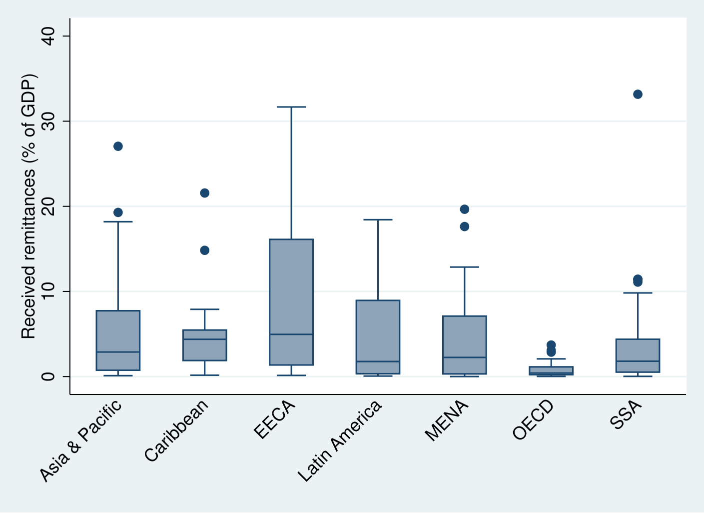

Figure 3. Received personal remittances (% of GDP, 2000–2015).
Legend: **EECA**: Eastern Europe and Central Asia, **MENA**: Middle East and North Africa, **SSA**: Sub-Saharan Africa.
Source: Author, based on the UNSD migration dataset and the WDI.

Second, it is important to describe the epidemiological studies that justify the introduction of an externality on human capital. Pollution is one of the determinants of health, particularly for children, who are much more vulnerable because of their behavior

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and developing systems (Gordon *et al.*, 2004). This leads to a potential loss of cognitive skills in a degraded environment (for a meta-analysis of the subject, see Power *et al.*, 2016). Specifically, Pujol *et al.* (2016) finds that urban air pollution affects the brain maturation of children under 12 years old, and Lett *et al.* (2017) finds that children more exposed to industrial pollutants have math scores that are 1.63 points lower than their less exposed peers. Moreover, there is strong consensus on the effect of air pollution on the occurrence of asthma and on health in general (among others, Liu *et al.*, 2017; Marcotte, 2017; Rosa *et al.*, 2017). Additionally, while the effect of pesticides on health is more difficult to measure, it is clearly negative, and many studies call for studying their effects (among others, Lai, 2017; Lammoglia *et al.*, 2017). In summary, pollution may have important consequences for human capital accumulation through two main channels: the direct degradation of cognitive skills and a decrease in school attendance.

3. The model

This section describes the OLG model – with discrete time indexed by $t = 0, 1, 2, \ldots, +\infty$ – used to analyze the economic development in SIDSs with pollution, migration and intergenerational transfers.[5]

3.1. Production and the environment

The production of the composite good is carried out by a representative firm. As in Varvarigos (2013), the output is produced according to constant returns to scale technology. The firm combines units of efficient work, $L_t h_t$ – where h_t is the human capital per worker – and capital stock, K_t:

$$Y_t = AK_t^{\alpha} \left(L_t h_t\right)^{1-\alpha}, \tag{1}$$

where $A > 0$ is the technology level and $\alpha \in (0, 1)$ is the share of capital in production.

During the production process, the firm emits pollution, which induces a negative impact on human capital accumulation. To correct this externality, the government implements a tax $\tau \in (0, 1)$ on production. Tax revenue is used to fund pollution emissions reduction, m_t, with $m_t = \xi \tau Y_t$ and $\xi \in]0, 1]$ representing the efficiency of abatement expenditures. The firm's profit is:

$$\Pi_t = A(1-\tau)K_t^{\alpha} \left(L_t h_t\right)^{1-\alpha} - w_t h_t L_t - R_t K_t. \tag{2}$$

For simplicity, capital is assumed to fully depreciate in one period. Denoting the wage for one unit of efficient labor by w_t and the return factor of capital by $R_t \equiv 1 + r_t$, with r_t being the interest rate, factor prices are:

$$w_t = A(1-\alpha)(1-\tau)K_t^{\alpha} \left(L_t h_t\right)^{-\alpha}, \tag{3}$$

$$R_t = A\alpha(1-\tau)K_t^{\alpha-1} \left(L_t h_t\right)^{1-\alpha}. \tag{4}$$

The production sector generates a pollution flow with respect to $\Omega \in]0; 1]$, the pollution intensity of production. The dynamics of the pollution stock, given in equation (5),

[5] OLG models are convenient for studying intergenerational transfers – as in Thibault (2008) or Del Rey and Lopez-Garcia (2016) – and human capital dynamics.

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also depend on $a \in]0; 1]$, the natural absorption rate of pollution.

$$Z_{t+1} = \Omega Y_t - m_t + (1-a)Z_t = (\Omega - \xi\tau)AK_t^{\alpha}\,(L_t h_t)^{1-\alpha} + (1-a)Z_t. \qquad (5)$$

Any local pollution such as pesticides, metals or POPs in soil or freshwater could be considered in equation (5). Here, if $a = 1$, the model describes a pollution flow. If $a = 0$, all emissions of pollution remain in the environment and the only sustainable way of dealing with the pollution is to completely abate emissions. Abatement efforts could include water treatment, waste processing or changes in technology to reduce emissions.

3.2. Household behavior

In this economy, there are three generations: children, adults and retirees. At each period t, adults choose their number of children n_t, depending on the cost of fertility. As in de la Croix and Gosseries (2012), raising children requires a fraction $\sigma N_t^{\delta} n_t$ of income, where $0 < \delta < 1$ captures the overcrowding effect: the larger the population, the more costly fertility is.[6] This assumption is in line with empirical evidence described in works such as de la Croix and Gobbi (2017) or Sibly *et al.* (2002).

The emigration rate is denoted by $\rho \in [0, 1[$. Migration implies that only $(1-\rho)n_t N_t$ children stay in the domestic country as adults. The other $\rho n_t N_t$ children migrate to countries where wages are greater. The evolution of the size of the adult generation (or the labor force) is represented by:

$$N_{t+1} = n_t N_t (1-\rho). \qquad (6)$$

Adults born in $t-1$ care about their adult and old age consumption levels, denoted by c_t and d_{t+1}, respectively. Agents' preferences are represented by the following utility function, according to the psychological discount factor β:

$$U(c_t, d_{t+1}) = \ln(c_t) + \beta \ln(d_{t+1}). \qquad (7)$$

When they are children, individuals are reared by their parents and receive an education to acquire a human capital level h_t. Adults in the domestic country supply one inelastic unit of labor to earn a wage w_t per unit of human capital h_t. A fraction γ of their revenue is transferred to their parents. The rest of their income is devoted to consumption c_t, savings s_t and children's education $n_t e_t$. Adults in foreign countries can claim higher wages, which are assumed to be proportional to the domestic wage, such that $w_t^F \equiv \varepsilon w_t$, where $\varepsilon > 1$ denotes the net gain from migration. The parameter ε can be interpreted as the increase in income that can be obtained in the receiving country over the income in the domestic area, from which the costs associated with migration are subtracted. Migrants also transfer a share γ of their revenue to their parents. Thus, parents receive remittances from their children abroad and intergenerational transfers from children in the domestic area. The budget constraint in the first period is given by:

$$c_t + s_t + n_t e_t = w_t h_t (1 - \gamma - \sigma n_t N_t^{\delta}). \qquad (8)$$

Human capital per child h_{t+1} depends on education expenditures per child $e_t > 0$ (null values would bring the stock of human capital to 0), the parents' human capital

[6] In de la Croix and Gosseries (2012), the cost of rearing children σ is defined as a combination of parameters for available land, T, the fertility productivity factor, λ, and weight of land in the cost of children, $\delta : \sigma \equiv 1/\lambda T^{\delta}$. Here, this expression is simplified by directly using σ.

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h_t and the pollution level, which affects the efficiency of human capital accumulation $\theta(Z_t)$. This function is defined for positive or null real values of Z_t and decreases with the pollution stock, such that $\theta'(Z_t) < 0$. Therefore, a polluted environment deteriorates the children's ability to accumulate human capital, regardless of whether it comes from their parents' human capital or investments in education. The children's human capital h_{t+1} is written as:

$$h_{t+1} = \theta(Z_t) h_t^{1-\mu} e_t^{\mu}, \tag{9}$$

where $0 < \mu < 1$ represents the efficiency of education.

When they are old, agents only consume their savings remunerated at the return factor R_{t+1} and the intergenerational transfers sent by their children, wherever the children live. The budget constraint in the second period is written as:

$$d_{t+1} = s_t R_{t+1} + n_t \gamma (1-\rho) w_{t+1} h_{t+1} + n_t \gamma \rho \varepsilon w_{t+1} h_{t+1}. \tag{10}$$

Hence, individuals face a first tradeoff between adult versus old age consumption. Second, they choose between savings or children's transfers to fund their consumption when old. Finally, they decide whether to increase education or fertility to raise the amount of intergenerational transfers received. Here, $\gamma(1-\rho+\rho\varepsilon) w_{t+1} h_{t+1}$ is the share of children's income received by parents. In the rest of the paper, the share of the children's income transferred is denoted by $\Lambda_h = \gamma(1-\rho+\rho\varepsilon)$. It is increased by ε, ρ and γ, which are the net gain from migration, the emigration rate and the intergenerational transfer rate, respectively. The consumer program is summarized by:

$$\max_{c_t, s_t, e_t, n_t} U(c_t, d_{t+1}) = \ln(c_t) + \beta \ln(d_{t+1})$$

$$\text{s.t.} \quad c_t + s_t + n_t e_t = w_t h_t (1 - \gamma - \sigma n_t N_t^{\delta})$$

$$d_{t+1} = s_t R_{t+1} + n_t \Lambda_h w_{t+1} h_{t+1}$$

$$h_{t+1} = \theta(Z_t) h_t^{1-\mu} e_t^{\mu}.$$

To solve this model, constraints are substituted into the utility function, which leads to the first-order condition (FOC) of the household's problem. The FOC with respect to s_t shows the consumption tradeoff over the life cycle (equation (11)). It depends on the psychological discount factor, β, and the return factor on savings, R_{t+1}. The two other FOCs of the household's problem with respect to education and fertility – equations (12) and (13) – suggest that the remuneration from intergenerational transfers and savings should be equal in equilibrium.

$$\frac{1}{c_t} = \frac{\beta R_{t+1}}{d_{t+1}} \tag{11}$$

$$\frac{1}{c_t} = \frac{\beta \mu \Lambda_h w_{t+1} h_{t+1}}{e_t d_{t+1}} \tag{12}$$

$$\frac{1}{c_t} = \frac{1}{\sigma N_t^{\delta} w_t h_t + e_t} \frac{\beta \Lambda_h w_{t+1} h_{t+1}}{d_{t+1}}. \tag{13}$$

Combining (12) and (13) yields a first no-arbitrage condition. It ensures that the household is indifferent between education and fertility by equating the opportunity

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costs of education and fertility. It directly determines the level of education expenditures:

$$\frac{\mu\Lambda_h w_{t+1}h_{t+1}}{e_t} = \frac{\Lambda_h w_{t+1}h_{t+1}}{\sigma N_t^{\delta} w_t h_t + e_t} \tag{14}$$

$$e_t^{\star} = \frac{\mu\sigma N_t^{\delta}}{1-\mu} w_t h_t. \tag{15}$$

Education choice depends solely on adult income, the cost of raising children and the efficiency of education. Moreover, the adult population increases the congestion effect, which results in higher costs of fertility. Thus, the larger the income and/or the adult population size, the higher the education expenditures are.

Another no-arbitrage condition is obtained thanks to equations (11) and (13). It equates the returns from savings R_{t+1} and future intergenerational transfers relative to the cost of children. Thus, the condition ensures that the household is indifferent between investments in children and savings. Moreover, when combined with the optimal education choice, this gives rise to a relationship essentially between equilibrium input prices at $t+1$:

$$R_{t+1} = \frac{\Lambda_h w_{t+1}h_{t+1}}{\sigma N_t^{\delta} w_t h_t + e_t} \tag{16}$$

$$R_{t+1} = \frac{(1-\mu)\Lambda_h}{\sigma} \frac{w_{t+1}h_{t+1}}{w_t h_t N_t^{\delta}}. \tag{17}$$

Rewriting the adult's budget constraint according to the optimal choice of education summarizes the investments in children – i.e., fertility and human capital – in one term: $n_t(\sigma w_t h_t N_t^{\delta}/(1-\mu))$. This term represents a part of the adults' investments in their old age consumption. In other words, it is the adult available income that is not consumed in the first period. It is denoted by x_t in equation (19):

$$w_t h_t(1-\gamma) = c_t + s_t + n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu} \tag{18}$$

$$x_t = s_t + n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu}. \tag{19}$$

The next step is to solve the intertemporal optimization problem of the household. To do so, expression (17) and the budget constraints are introduced in the FOC with respect to the savings (equation (11)) to obtain a new expression for $x_t \equiv (\beta(1-\gamma)/(1+\beta))w_t h_t$ (equation (20)). It also leads directly to an expression for adult consumption:

$$\beta R_{t+1}c_t = d_{t+1} \Leftrightarrow \frac{\beta(1-\gamma)}{1+\beta} w_t h_t = s_t + n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu} \tag{20}$$

$$\Leftrightarrow c_t = \frac{1-\gamma}{1+\beta} w_t h_t. \tag{21}$$

Equations (20) and (21) depict the tradeoff between adult consumption and investments in old age consumption, i.e., between c_t and x_t. As expected, the discount

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factor, β, has a positive (negative) effect on x_t (c_t). Second, both variables are negatively affected by the intergenerational transfer rate, γ, which generates a negative income effect. Nevertheless, γ has an ambiguous effect on old age consumption, d_{t+1}, and since higher transfers can be received when old, this lowers the burden on investing when an adult.

From the two expressions for x_t, it is possible to obtain the initial relationship between savings and investments in intergenerational transfers:

$$s_t = w_t h_t \left(\frac{\beta(1-\gamma)}{1+\beta} - n_t \frac{\sigma N_t^{\delta}}{1-\mu} \right). \tag{22}$$

At this point, the tradeoff between fertility and savings is not solved. It is necessary to obtain an additional equation between savings and fertility. To do so, note that the representative household has perfect foresight regarding future returns from investment (de la Croix and Michel, 2002). As a result, the optimal choices of the households simultaneously solve their intertemporal income optimization problem and the market clearing conditions (MCCs), given in the following equations:

$$K_{t+1} = s_t N_t \tag{23}$$

$$L_{t+1} = N_{t+1} = n_t N_t (1-\rho) \tag{24}$$

$$h_{t+1} = \theta(Z_t) e_t^{\mu} h_t^{1-\mu}. \tag{25}$$

Combining the input prices, w_{t+1} and R_{t+1} (given by equations (3) and (4)) and the MCCs in equality (17) yields the following equation:

$$s_t = n_t \left[\frac{1-\alpha}{\alpha} \frac{(1-\mu)\Lambda_h}{(1-\rho)\sigma w_t h_t N_t^{\delta}} \right]^{-1}. \tag{26}$$

Finally, solving the system defined by equations (22) and (26) leads to the household's optimal choices:

$$s_t^{\star} = \frac{\beta\alpha(1-\rho)(1-\gamma)}{(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} w_t h_t, \tag{27}$$

$$n_t^{\star} = \frac{\beta\Lambda_h(1-\gamma)(1-\alpha)(1-\mu)}{\sigma(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} N_t^{-\delta}. \tag{28}$$

A comparative static analysis of household choices, given by equations (15), (27) and (28), is conducted with respect to migration-related parameters.[7] First, for the tradeoff between savings and investments in children to fund old age consumption – i.e., s_t versus $n_t(\sigma w_t h_t N_t^{\delta}/(1-\mu))$ – savings are negatively correlated with Λ_h, the share of children's income received by parents. Thus, increases in the net gain from migration, ε, the emigration rate ρ and/or the intergenerational transfer, γ, increase children's investments at the expense of savings. For γ, this is aggravated by the negative income effect that comes from the term $(1-\gamma)$, as described earlier.

Second, the tradeoff between fertility and education – i.e., n_t and e_t – depends on the incentives to invest in education and, on the other hand, on migration. As noted above,

[7] Derivative expressions are given in online appendix A.

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households choose to invest in education expenditures if the efficiency of education and the child-rearing costs, measured by μ and σN_t^{δ}, respectively, are higher. Through the overcrowding effect, migration may change the latter term. Specifically, n_t is positively correlated with ρ and ε, while the impact of γ depends on the interaction between the share of the children's income received Λ_h and the negative income effect induced by $(1-\gamma)$. This interaction is captured by the condition below:

$$\frac{\partial n_t}{\partial \gamma} > 0 \Leftrightarrow \frac{\gamma}{1-\gamma} < \frac{\alpha(1-\rho)}{\Lambda_h(1-\alpha)}.$$

If migration leads to a strong increase in population size, fertility decreases to the benefit of education expenditures because of the overcrowding effect. Therefore, migration can affect education through its impact on fertility. To clarify this mechanism, it is necessary to first study the population dynamics and labor market.

Finally, as households do not take into account the environmental externality, their optimal choices cannot reflect the dynamics of human capital. Therefore, agents will invest in education, fertility or capital in the same way as in a situation without the externality.[8]

4. Equilibrium

The MCCs for capital and labor are given by equations (23) to (25), respectively. The values of the household's optimal choices $s_t^\star$, $n_t^\star$ and $e_t^\star$ are given in equations (27), (28) and (15). The wage and the return factor on capital correspond to (3) and (4), respectively. Using all these previous findings, the intertemporal equilibrium can be deduced.

Proposition 1: *Given the initial conditions $K_0 > 0$, $N_0 > 0$, $h_0 > 0$, and $Z \geq 0$, the intertemporal equilibrium is the sequence (K_t, N_t and h_t) that satisfies the following system $t \geq 0$:*

$$\begin{aligned} K_{t+1} &= \Psi \alpha A(1-\tau)(1-\rho)K_t^{\alpha} N_t^{1-\alpha} h_t^{1-\alpha} \\ N_{t+1} &= \Psi \Lambda_h (1-\rho)\frac{(1-\mu)}{\sigma} N_t^{1-\delta} \\ h_{t+1} &= \theta(Z_t)\left[\frac{\sigma \mu A(1-\alpha)(1-\tau)}{1-\mu}\right]^{\mu} K_t^{\alpha\mu} N_t^{\mu(\delta-\alpha)} h_t^{1-\alpha\mu} \\ Z_{t+1} &= (\Omega - \xi\tau)AK_t^{\alpha}(N_t h_t)^{1-\alpha} + (1-\alpha)Z_t, \end{aligned} \tag{29}$$

where $\Psi = \frac{\beta(1-\alpha)(1-\gamma)}{(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}$.

Two cases arise from the analysis of the environmental problem. The first case is if the pollution emissions can be completely abated and thus maintained at 0 in the long run. The second case appears if the pollution emissions cannot be completely abated.

[8]If the environment is introduced into the utility function with private environmental maintenance (as in Mariani *et al.*, 2010, for instance), the household's choices can change, even if parents are not aware of the environmental externality on their children's ability.

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4.1. Case 1: equilibrium with the total abatement of pollution emissions

This case emerges only if the efficiency of the abatement effort is high enough and/or if the pollution intensity of production is low enough to have $\xi\tau = \Omega$. With a long-term zero pollution stock, $\bar{\theta} = \theta(0)$ denotes the efficiency of human capital accumulation. In that case, the ratio of capital to efficient units of labor k_t can be defined as:

$$k_{t+1} \equiv \frac{K_{t+1}}{N_{t+1}h_{t+1}} = \left(\frac{A\sigma(1-\tau)}{1-\mu}\right)^{1-\mu} \frac{\alpha}{\bar{\theta}\Lambda_h[\mu(1-\alpha)]^{\mu}} k_t^{\alpha(1-\mu)} N_t^{\delta(1-\mu)}. \tag{30}$$

The growth factors of the stocks of physical capital, human capital per capita and the adult population are denoted by g_t^K, g_t^h and g_t^N, respectively.

$$g_t^K = \frac{K_{t+1}}{K_t} = \Psi\alpha A(1-\tau)(1-\rho)k_t^{\alpha-1} \tag{31}$$

$$g_t^h = \frac{h_{t+1}}{h_t} = \bar{\theta}\left[\frac{\mu A\sigma(1-\alpha)(1-\tau)}{1-\mu}\right]^{\mu} k_t^{\alpha\mu} N_t^{\mu\delta} \tag{32}$$

$$g_t^N = \frac{N_{t+1}}{N_t} = \Psi\Lambda_h(1-\rho)\frac{(1-\mu)}{\sigma}N_t^{-\delta}. \tag{33}$$

Equation (30) depicts the labor force growth rate, which depends solely on the economy's structural parameters and on population size. Consequently, population dynamics affect both human and physical capital stocks; however, the reverse is not true. The growth rate of the population is directly given by $n_t^*(1-\rho)$, and in the long run $n^* = 1/(1-\rho)$. It is possible to decrease the adult generation size until $N^\star$ is reached. This is the case if the initial population size is larger than $N^\star$, the steady-state value of the labor force:

$$N^\star = \left[\Psi(1-\rho)\Lambda_h\frac{(1-\mu)}{\sigma}\right]^{1/\delta}. \tag{34}$$

All the parameters that have a positive effect on n_t, except for ρ, have a positive effect on $N^\star$. The ambiguous effect of the emigration rate is due to its positive (negative) impact on the number of children (adults). It depends on the following condition:

$$\frac{\partial N^\star}{\partial\rho} > 0 \Leftrightarrow \frac{1-\rho}{1-\rho+\rho\varepsilon} > \sqrt{\frac{\gamma(1-\alpha)}{\alpha(\varepsilon-1)}}. \tag{35}$$

Proposition 2: *Due to the constant returns to scale for human and physical capital, the economy reaches a balanced growth path (BGP), where the system satisfies Proposition 1, and the stock of physical and efficient units of labor grows at the same constant rate $g_{BGP} = g^K = g^h$. Therefore, the long-term ratio of capital per unit of efficient labor is constant: $k_t \equiv K_t/L_t h_t = k_{BGP}$. The values of k and g in the unique locally stable equilibrium are:*

$$k_{BGP} = \left[\frac{\alpha[\Psi A(1-\rho)(1-\tau)]^{1-\mu}}{\bar{\theta}[\mu\Lambda_h(1-\alpha)]^{\mu}}\right]^{1/(1-\alpha(1-\mu))} \tag{36}$$

$$g_{BGP} = \left[[\bar{\theta}[\mu\Lambda_h(1-\alpha)]^{\mu}]^{1-\alpha}[\Psi\alpha^{\alpha}A(1-\rho)(1-\tau)]^{\mu}\right]^{1/(1-\alpha(1-\mu))}. \tag{37}$$

Proof of Proposition 2: See online appendix B.1. □

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Proposition 3: *On the BGP, there is a negative correlation between k_{BGP} and the efficiency of human capital accumulation, $\bar{\theta}$, the tax rate τ, and the share of children's income transferred to parents, Λ_h – given that Λ_h is positively correlated with the emigration rate, ρ, the intergenerational transfers, γ, and the net gain from migration, ε. The technology factor, A, and the cost of raising children, σ, have a positive effect on k_{BGP}.*

The positive effects of A and σ on the long-term ratio of capital per unit of efficient labor, k_{BGP}, result from the increase in production and from the decrease in the number of children due to the extra cost – i.e., the decrease in the size of the next generation. The negative impact of the other parameters on this ratio is due to the increase in the number of units of efficient labor in the economy – with respect to ε, $\bar{\theta}$, γ and ρ. Finally, while the effect of pollution is completely canceled out, the economic cost of this operation leads to a reduction in the capital stock per efficient unit of labor with respect to τ.

Proposition 4: *On the BGP, economic growth, g_{BGP}, is positively impacted by the technology factor, A, the psychological discount factor, β, the efficiency of human capital accumulation, $\bar{\theta}$, and the net gain from migration, ε. The tax rate has a negative effect on economic growth, while the effects of the intergenerational transfer rate, γ, and the emigration rate, ρ, depend on the conditions below:*

$$\frac{\partial g_{BGP}}{\partial \rho} > 0 \Leftrightarrow \frac{1-\rho}{1-\rho+\rho\varepsilon} > \frac{[\varepsilon-(1-\alpha)(\varepsilon-1)(1-\rho)]}{\alpha(\varepsilon-1)(1-\rho)} \tag{38}$$

$$\frac{\partial g_{BGP}}{\partial \gamma} > 0 \Leftrightarrow \frac{1-\alpha}{\alpha}\frac{1-(1-\alpha)(1-\gamma)}{(1-\alpha)(1-\rho)-\gamma} > \frac{(1-\rho)}{\Lambda_h}. \tag{39}$$

First, note that the long-term growth factor directly gives the growth in production per worker and thus in production per capita because of the constant population size. In that case, the growth factor of the production per capita can be directly translated into the growth in utility, which depends strongly on consumption (see online appendix B.3 for details).

On the one hand, some effects are easy to describe. For k_{BGP}, the tax rate represents the cost for the economy to cope with environmental degradation. Therefore, the higher pollution emissions are, the higher the tax rate and the lower the growth rate. Increases in the technological factor, A, and in the efficiency of human capital accumulation, $\bar{\theta}$, lead to a more efficient economy. Increases in the psychological discount factor, β, result in higher investments in the future and subsequently in an increase in economic growth. Moreover, an increase in the net gain from migration, ε, enhances the income of the old age generation and per capita production growth.

On the other hand, the effects of the emigration rate, ρ, and of the intergenerational transfer rate, γ, are quite intricate. Conditions are obtained for the sign of the derivatives of the growth factor on the BGP with respect to the emigration rate and the intergenerational transfer (see online appendix B.2 for details); however, they are difficult to interpret. This is explained by the opposite effects that are observed on household choices and on aggregate variables.

First, the emigration rate, ρ, creates an incentive to have more children through the increase in the gains from migration. However, because there are more adults who leave the territory in the next period, it can lead to a decrease in the number of units of efficient labor. As the population size increases, education expenditures can increase because of

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the congestion effect, which is reinforced by the substitution effect between investments in children and savings that occurs when the emigration rate increases. In that context, higher migration can lead to an increase in human capital and thus to an increase in income, which is directly given by $w_t h_t$. Therefore, the effect of the emigration rate on the capital stock is threefold. By increasing the number of children, there is a rise in child-rearing expenditures and thus a decrease in savings, which is the substitution effect, on the intensive margin. In addition, the extensive margin also affects the capital stock. Migration can lead to a decrease (an increase) in the adult population size, which induces a reduction (a rise) in the capital stock because of the smaller (larger) number of contributors. Finally, there is a migration effect on education expenditures and thus on human capital dynamics and income. In a wealthier economy, even if the share of the income devoted to savings is reduced, the capital stock might be larger, therefore the relationship between migration and economic growth depends on the combination of those three effects.

Second, the intergenerational transfer rate, γ, reduces fertility because of the negative income effect described above, but only when γ is very high. For low values, γ should lead to an increase in investment in children. Therefore, while the mechanisms are different, their impacts through the net gains from migration are the same as those of ρ. If small, it leads to a rise in the units of efficient labor, and if high, savings are low, and the population size and human capital may decline.

In conclusion, three main intuitions can be derived from this first case. If the environmental externality can be completely canceled out, the economy can reach a BGP where there is green growth. The higher the externality, the lower economic growth will be. Second, there is a strong tradeoff between intergenerational transfers and savings because migration enhances the net gain from the children's transfers. In that context, positive impacts from migration on the capital stock and the economy are possible, but only if there is a gain in human capital and in the labor force. Consequently, and this is the last intuition, it is possible to have an emigration rate that has a negative impact on the economic growth of these countries because of the combined effects on capital stock and on units of efficient labor stock. However, due to the complexity of the conditions obtained for the emigration rate and the intergenerational transfers, it is difficult to capture the respective magnitudes of these different effects. This could be clarified by a numerical analysis of two Caribbean islands: Barbados and Jamaica.

Ait Benhamou and Cassin (2020) conduct similar analyses on five Caribbean islands using a model without environmental degradation or endogenous fertility. Their parameters calibrated to study migration can be used directly in the present work, except for the fertility cost, σ, and the congestion parameter δ (see online appendix C for the detailed calibration method and the parameters values). Barbados and Jamaica have been selected for this analysis because they present very different features. Indeed, Jamaica relies heavily on migration ($\rho = 0.49$) because both the gain from migration, ε, and the intergenerational transfer rates are high ($\varepsilon = 6.58$ and $\gamma = 0.2$). In comparison, those values are lower in Barbados, $\rho = 0.37$, $\varepsilon = 1.91$ and $\gamma = 0.12$. Moreover, for this illustration, the environmental parameters are set to completely nullify the externality caused by production, Ω, the natural absorption rate, a, the efficiency of the environmental policy, ξ, and the tax rate, τ, and are thus set to 0.2, 0.5, 0.8 and 0.25, respectively.

Figure 4 displays economic growth according to the emigration rate and the share of income transferred to the parents for Barbados and Jamaica.[9] The relationship between

[9]The other parameters are not studied because they are not strongly related to migration features.

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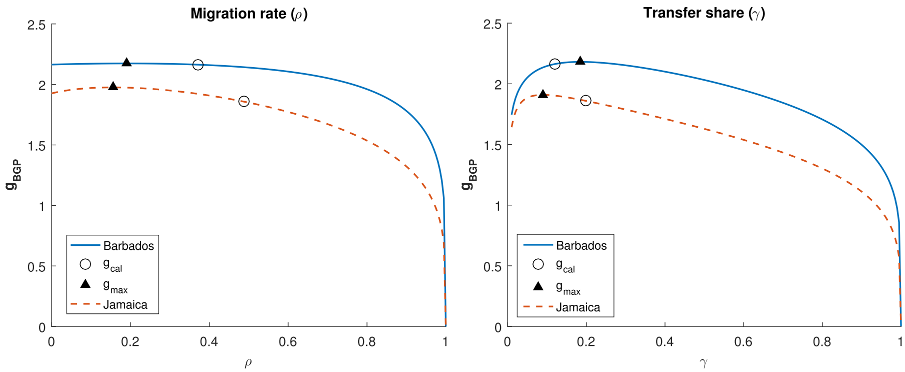

Figure 4. BGP values of the growth factor (g_{BGP}) according to parameters ρ and γ.

economic growth and migration or remittances is described by inverted U-shaped curves. This result is in line with the literature, which holds that migration should not be overly large to prevent the depletion of productive capital stocks. In Jamaica, high migration levels lead to a strong substitution effect, and both observed parameters γ and ρ (represented by circles) are higher than their optimal level (depicted by the triangles). Barbados is not strongly impacted by migration – the curve on the left is relatively flat – because the net gain from migration is small, and thus even with a relatively high level of migration, the loss in terms of economic growth is small. This means that the negative outcomes from the migration rate, in particular, the reduction in savings, are higher if the country relies heavily on migration through higher remittances or higher gains from migration. In contrast, if the development stage of the sending country is close to those of the receiving economies, migration may not lead to a brain gain, but it does not have a negative impact on economic growth.

4.2. Case 2: equilibrium with partial abatement of pollution

The next step of the analysis is to compute the steady state of the economy if pollution is not completely abated, thus if $Z^\star > 0$.

Proposition 5: *A steady state (SS) is an equilibrium satisfying Proposition 1 and where* $N_t = N^\star$, $K_t = K^\star$, $h_t = h^\star$ *and* $Z_t = Z^\star$ *are constant:*

$$N^\star = \left[\frac{(1-\mu)(1-\rho)\Lambda_h}{\sigma}\Psi\right]^{1/\delta} \tag{40}$$

$$K^\star = \alpha(1-\alpha)(1-\tau)\Psi(1-\rho)\frac{a\theta^{-1}(\chi)}{\Omega-\xi\tau}$$

$$h^\star = \frac{a\theta^{-1}(\chi)}{(\Omega-\xi\tau)A}\left[\alpha A(1-\tau)\right]^{-\alpha/(1-\alpha)}\left[\frac{\sigma}{\Lambda_h(1-\mu)}\right]^{1/\delta} \times (\Psi(1-\rho))^{-(1-\alpha(1-\delta))/\delta(1-\alpha)} \tag{41}$$

$$Z^\star = \theta^{-1}(\chi), \tag{42}$$

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where $\chi = [\mu\Lambda_h(1-\alpha)]^{-\mu}[\Psi A\alpha^{\alpha}(1-\tau)(1-\rho)]^{-\mu/(1-\alpha)}$ *is the efficiency of human capital accumulation in the steady state and* $\theta^{-1}(.)$ *is the inverse function of* $\theta(Z_t)$.

Proof of Proposition 5: See online appendix D.1. □

The model is a four-dimensional problem, and it is quite difficult to study the stability of the equilibrium. Instead, the rest of this section offers some insights into the mechanisms that might affect the dynamics of the model. In the previous case, when the population size converges to its steady-state value, human and physical capital grow at the same rate (see online appendix B.1). Here, the pollution stock prevents human capital from increasing in the long run. Therefore, the focus of this discussion is on the determinants of the pollution dynamics: the damage function, $\theta(Z_t)$, the natural absorption rate, a, and the pollution intensity, Ω.

The numerical analysis is conducted with Barbados' parameters; however, the robustness test results for Jamaica are displayed in online appendix D.2 (see table A2). Two functions for $\theta(Z_t)$ that respect the conditions given in the model (see section 3) are tested. This means that those functions are defined for positive or null values of Z_t and their first derivatives with respect to Z_t are negative. The two functions tested are $\theta_1(Z_t) = \bar{\theta}/(1+Z_t)$ and $\theta_2(Z_t) = \bar{\theta}/(1+Z_t^2)$.

In figure 5, the dynamics of production (Y_t), the capital stock (K_t), the pollution stock (Z_t) and human capital (h_t) are displayed. The plain line represents the benchmark economy with $\theta_1(Z_t)$, while the dashed line displays the results for $\theta_2(Z_t)$. The first specification results in a stable equilibrium with damped oscillations, while the second exhibits regular oscillations around the steady state. It appears that the second function is concave for some values of Z_t, which leads to an unstable equilibrium (see online appendix D.2 for details). A sufficient assumption to ensure the stability of the equilibrium should be that $\theta'(Z_t) < 0$ and $\theta''(Z_t) \geq 0$. Moreover, it is clear that the initial pollution stock might affect the stability of the equilibrium. In the rest of the article, the results are computed with the function $\theta_1(Z_t)$ and, for simplicity, the subscript is removed.

Second, supplementary analyses of the stability have been conducted for pollution intensity, Ω, and the natural absorption of pollution, a (see online appendix D.2 for the details). Those parameters seems to impact the amplitude of the oscillations, the time necessary to reach the equilibrium, and steady-state values of production, human capital and physical capital stock. However, they do not impact the steady-state values of the pollution stock nor the stability of the equilibrium. In the presence of pollution emissions, human capital cannot increase without leading to a rise in pollution. Due to the externality, this leads to an abrupt decrease in human capital and the capital stock (because of income loss). With the loss of productive capital, production is lessened, which thus reduces the pollution stock. When pollution is low, another cycle begins, with human capital accumulation, growing production and physical capital. However, increases – for all variables – are slower because future human capital depends on past values of human capital. Consequently, the economy reaches a steady state with damped oscillations. In the steady state, the increase in human capital that would normally occur is exactly compensated by the reduction in abilities due to pollution. This cyclical convergence has also been found by Varvarigos (2013) with similar mechanisms. The level where this equilibrium exists depends on χ, the efficiency of human capital accumulation on the steady state. Before the steady state is reached, a high Ω, or a low a, accelerates the accumulation of the pollution stock. This results in a larger cycle amplitude. However, the steady-state

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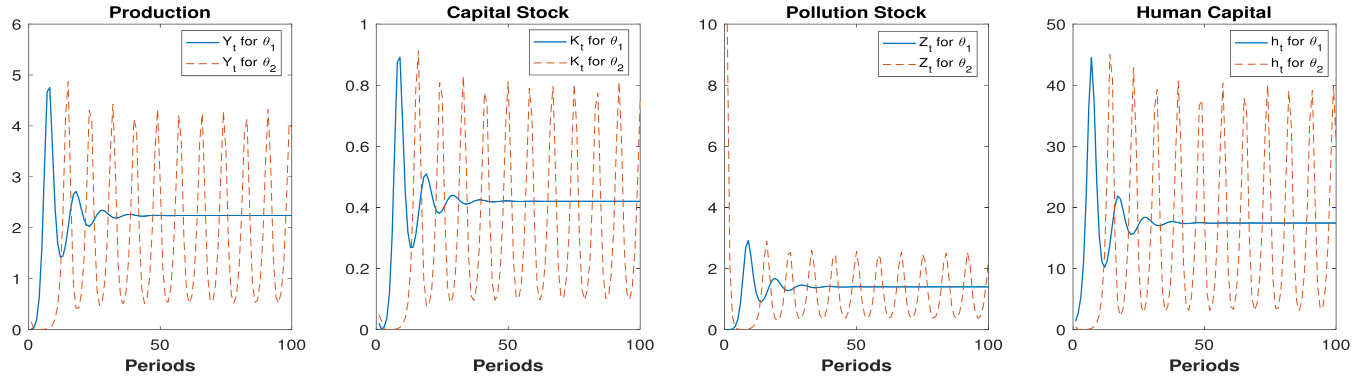

Figure 5. The effect of $\theta(Z_t)$ on the stability of the steady state.

pollution stock is reached when the marginal increase in human capital is exactly compensated by the marginal loss due to the reduction in cognitive skills. Consequently, the long-term pollution stock depends only on parameters in χ.

5. Discussion on migration and the environment

If pollution emissions cannot be completely abated, intricate interactions between the environmental and demographic dynamics appear. This section describes these interactions in the long run, thanks to the comparison between the two cases described earlier. Using comparative statistics and numerical simulations, the discussion is conducted in two steps with a first part on the environmental dimension and a second one on the impact of migration.

A large part of the discussions is derived from the numerical simulations on Barbados and Jamaica because of the complexity of the expressions obtained from the analytical exercise (see online appendix D.3 for details). However, the conclusions from the simulations are highly consistent with changes in the parameters. Besides, the aim of this work is not to scrutinize the values of the parameters but rather to depict the impacts of their variations on the economies described by this model and to show that regardless of which country is considered, the qualitative results remain the same for the migration effects. Finally, in the steady state, the dynamics of the population size are considered to be equivalent to the adult generation size.[10] Therefore, in the rest of this work, population size and adult generation size present exactly the same features, and the two terms can be used interchangeably to describe the population.

5.1. The environment and public policy

Proposition 6: *In the steady state, the pollution intensity, Ω, has a negative effect on the stock of physical capital and human capital, while the absorption rate, a, has a positive effect on them. The tax reduces the pollution stock, while it has a positive effect on $K^\star$ and $h^\star$ under the following conditions:*

$$\frac{\partial K^\star}{\partial \tau} > 0 \Leftrightarrow \zeta_\tau < \frac{\tau}{1-\tau}\left[\frac{\xi-\Omega}{\Omega-\xi\tau}\right]$$

$$\frac{\partial h^\star}{\partial \tau} > 0 \Leftrightarrow \zeta_\tau < \frac{\tau}{1-\tau}\left[\frac{\xi(1-\tau)-\alpha(\xi-\Omega)}{(\Omega-\xi\tau)(1-\alpha)}\right],$$

where $\zeta_\tau = (\partial\theta^{-1}(\chi)/\partial\tau)(\tau/\theta^{-1}(\chi))$ is the elasticity of steady-state pollution with respect to the tax rate, τ.

First, in the present work, the households' choices are totally independent of the level of pollution or the environmental tax. Here, only the human and physical capital stocks are negatively (positively) impacted by the pollution stock, $\theta^{-1}(\chi)$ (the efficiency of human capital, χ).

As noted above, the pollution stock in the steady state is directly given by the value of χ and not by the environmental features of the pollution dynamics. However, the pollution intensity of production, Ω, strongly impacts the transitional dynamics of the pollution stock and thus the accumulation of both human and physical capital. If Ω is

[10] There are $N^\star$ adults or retirees, while before migration, there are $N^\star/(1-\rho)$ children.

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high, the efficiency of human capital accumulation is lessened in the first stages of development, which means that the human capital level that can be attained in the steady state is also lower, even if the value of $\theta(Z^{\star})$ remains the same. Due to the loss of income that occurs with the decline in human capital, the capital stock will be lessened in the long run. In this context, a change in the tax rate, τ, affects steady-state pollution through the long-run level of human capital accumulation, χ. This could entail an improvement in both human and physical capital, depending on the conditions linked to the pollution intensity. To demonstrate this effect, two numerical illustrations are proposed. For both simulations, figures display steady-state values for production, production per worker, human capital, the capital stock, the labor force, the pollution stock, total utility and utility per capita of the residents according to the tax level, with $\tau \in (0, 1)$. Note that values of production or utility per adult will display exactly the same features as production (or utility) per active individual or production (or utility) per capita because those three population sizes are strictly proportional. Second, utility per capita is defined as the utility that can be obtained through adult and old age consumption. These definitions are maintained for all the numerical simulations presented in this work.

In the first simulation, illustrated by figure 6, it is possible to overcome completely the environmental externality. The figures depict asymptotes when $\xi\tau$ approaches Ω, which can be attributed to the fact that the economy can reach a BGP in that case, when $\tau\xi = \Omega$. The second simulation, shown in figure 7, depicts a context of high emissions with $\Omega = 0.6$. In that case, while it is possible to observe an increase in production, production per capita and human capital, the environmental policy fails to improve utility per capita. One explanation is that the effects of the environmental policy on the externality are too small to overcome the economic loss due to the tax. Therefore, while the economic results are improved in terms of production, the substantial tax prevents an increase in utility. Note that the criteria to define whether emissions are high depend mostly on the efficiency of the maintenance effort. If this parameter is small, even a low level of emissions will be too large and generate the same results.

Finally, note that these effects are highly consistent across different values of the parameters concerning migration – i.e., γ, ρ, ε – as well as for different values of environmental features or parameters that control the overcrowding effect.

5.2. The impact of migration

The next step of the analysis is to study the interplay between the demographic characteristics of the Caribbean SIDSs and environmental degradation in the context of high environmental vulnerabilities. Specifically, the aim is to study the conditions under which a potential brain gain appears in countries where environmental degradation can be large or environmental policy inefficient due to natural or institutional vulnerabilities. To achieve this aim, the focus is on two parameters: the emigration rate, ρ, and the intergenerational transfer rate, γ.[11] In the numerical simulations, the intensity of pollution emissions, the absorption rate, the efficiency of the maintenance effort, and the tax rate are set to $\theta = 0.6$ and $a = \xi = \tau = 0.5$, respectively.

The effect of the emigration rate, ρ

[11] ε gives the relative position in terms of GDP of the domestic economy compared to the migrant-receiving countries.

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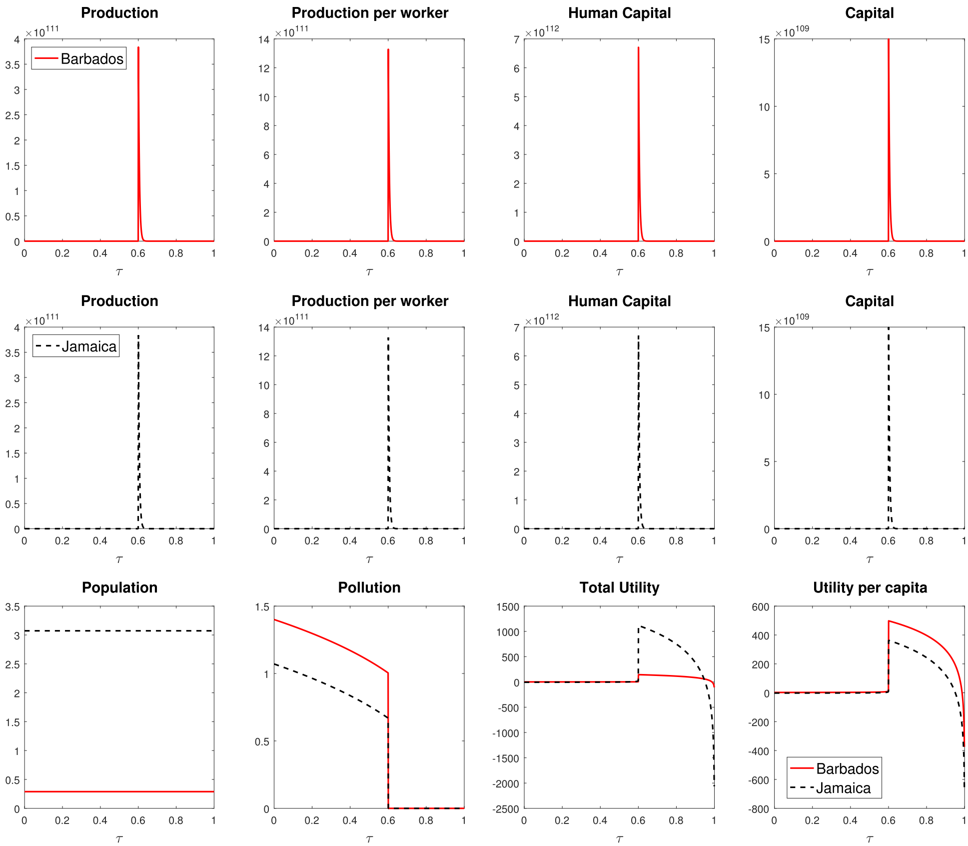

Figure 6. The effect of the environmental tax rate τ for $\Omega = 0.4$, $\xi = 0.5$, $a = 0.5$.

Proposition 7: *The steady-state values of the population size, pollution stock, physical capital and human capital are positively correlated with the emigration rate, ρ, under the following conditions:*

$$\frac{\partial N^\star}{\partial \rho} > 0 \Leftrightarrow \frac{1-\rho}{1-\rho+\rho\varepsilon} > \left[\frac{\gamma(1-\alpha)}{\alpha(\varepsilon-1)}\right]^{1/2}$$

$$\frac{\partial Z^\star}{\partial \rho} > 0 \Leftrightarrow \frac{(1-\rho)(\varepsilon-1)}{\Lambda_h} > \frac{1}{[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)]}$$

$$\frac{\partial K^\star}{\partial \rho} > 0 \Leftrightarrow \zeta_\rho > \frac{\rho}{1-\rho}\left[\frac{\gamma\varepsilon(1-\alpha)}{\alpha(1-\rho)+\Lambda_h(1-\alpha)}\right]$$

$$\frac{\partial h^\star}{\partial \rho} > 0 \Leftrightarrow \zeta_\rho > \left[\frac{\rho(\varepsilon-1)}{\delta(1-\rho+\rho\varepsilon)} - \frac{\rho\gamma\varepsilon(1-\alpha(1-\delta))}{\delta(1-\rho)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right],$$

where $\zeta_\rho = (\partial\theta^{-1}(\chi)/\partial\rho)(\rho/\theta^{-1}(\chi))$ is the elasticity of the steady-state pollution stock with respect to the emigration rate, ρ.

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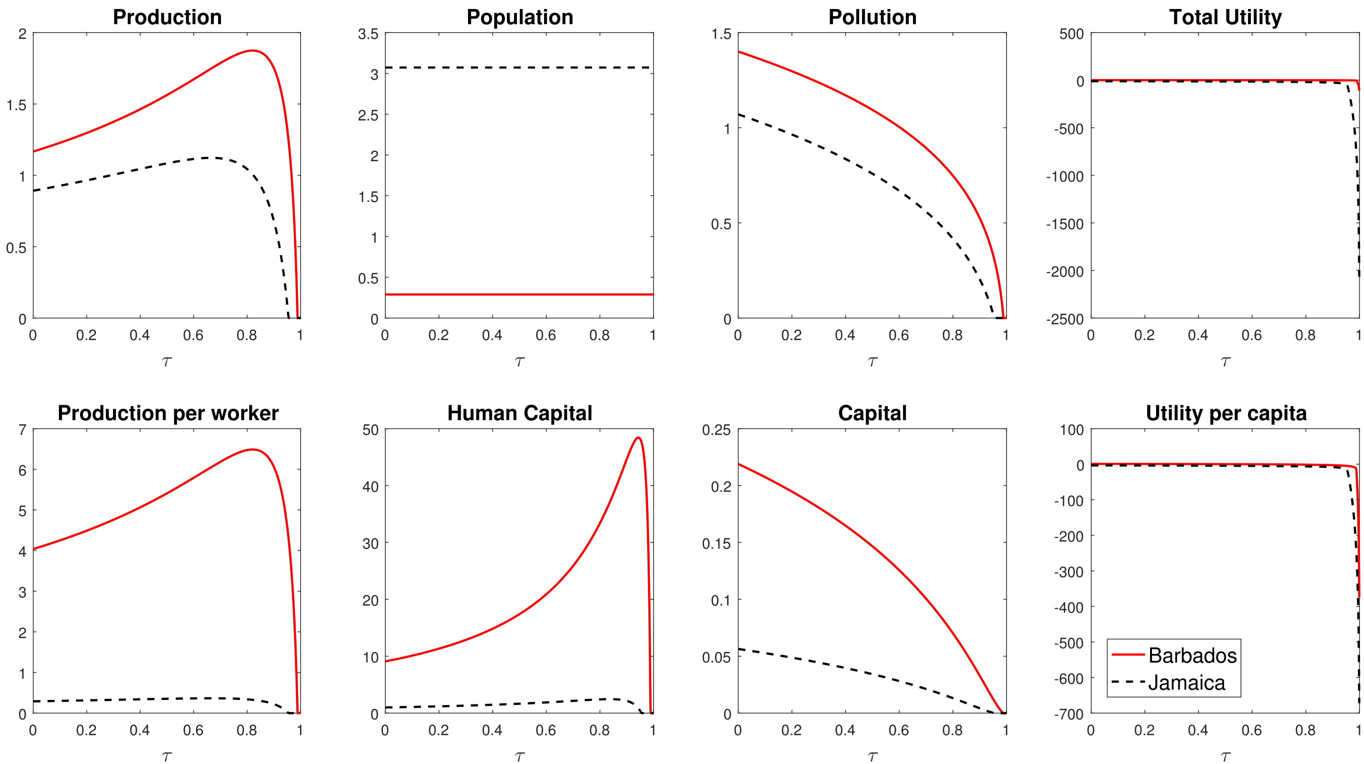

Figure 7. The effect of the environmental tax rate τ for $\Omega = 0.6$, $\xi = 0.5, a = 0.5$.

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The pollution stock and population size are directly impacted by the value of the emigration rate. By contrast, the effects of the emigration rate on human capital and the capital stock depend on the elasticity of pollution with respect to ρ. Indeed, the positive effects of ρ on population dynamics also change the pollution level and thus can have adverse effects on human capital and capital. This is the main novelty of this case concerning migration with respect to the case where the environmental policy is efficient. To clarify this, numerical simulations of the steady-state values of the model's variables with respect to ρ are conducted for Barbados and Jamaica.

Figure 8 displays the results for production, population size, production per capita, the pollution stock, the capital stock and human capital according to the emigration rate, while figure 9 depicts total and per capita utility. The studied interval for $\rho \in [0, 0.6]$ includes the potential emigration rates observed in the Caribbean region (Ait Benhamou and Cassin, 2020).

For both countries, the relationship between the emigration rate and total production or pollution is described by inverted U-shaped curves. In contrast, the effects of the emigration rate on human capital, production per capita and utility – total and per capita – are described by U-shaped curves. In the case of an efficient environmental policy, these effects were also described by inverted U-shaped curves. Indeed, a certain level of emigration enhances the production stock thanks to the larger population size. This is due to the increased incentives to have children when migration enhances the gains from investments in children. The problem is that higher production leads to higher pollution emissions and thus to an increase in the environmental externalities on human capital accumulation. When the rise in production is not accompanied by an increase in human capital, the production per capita might be decreasing. This is amplified by the reduction in physical capital that occurs if savings are strongly reduced to increase fertility and if income is reduced because of the loss of human capital.

If the emigration rate exceeds a certain limit, the population size is reduced because the larger number of children does not compensate for the loss of adults through migration. Consequently, the capital stock is negatively impacted by the contraction of the number of savers in the economy and by the substantial substitution away from savings in favor of investments in children. The decrease in physical capital results in a reduction in production that is larger than the population decrease. Quite surprisingly, this is when migration has a positive effect on utility per capita, while exactly the opposite was the case under an efficient environmental policy. Indeed, the reduction in production decreases the pollution stock. This leads to an increase in human capital and household income (defined as $w_t h_t$, where w_t is the wage). While the negative substitution effect on savings is still an important mechanism in the economy, its impact on the physical capital stock is lessened by this positive income effect. Therefore, despite the contraction of physical capital, the increase in human capital results in gains in utility per capita.

These results differ substantially from those of typical analyses of migration. While there is still a debate on the mechanisms involved in migration, it is broadly accepted that emigration enhances economic growth if it is not too high. In contrast, here, high emigration reduces the damage from the externality and thus leads to economic gains.

The effect of intergenerational transfers, γ

Proposition 8: *The steady-state values of the population size, the pollution and physical capital stocks and the level of human capital are positively correlated with γ under the*

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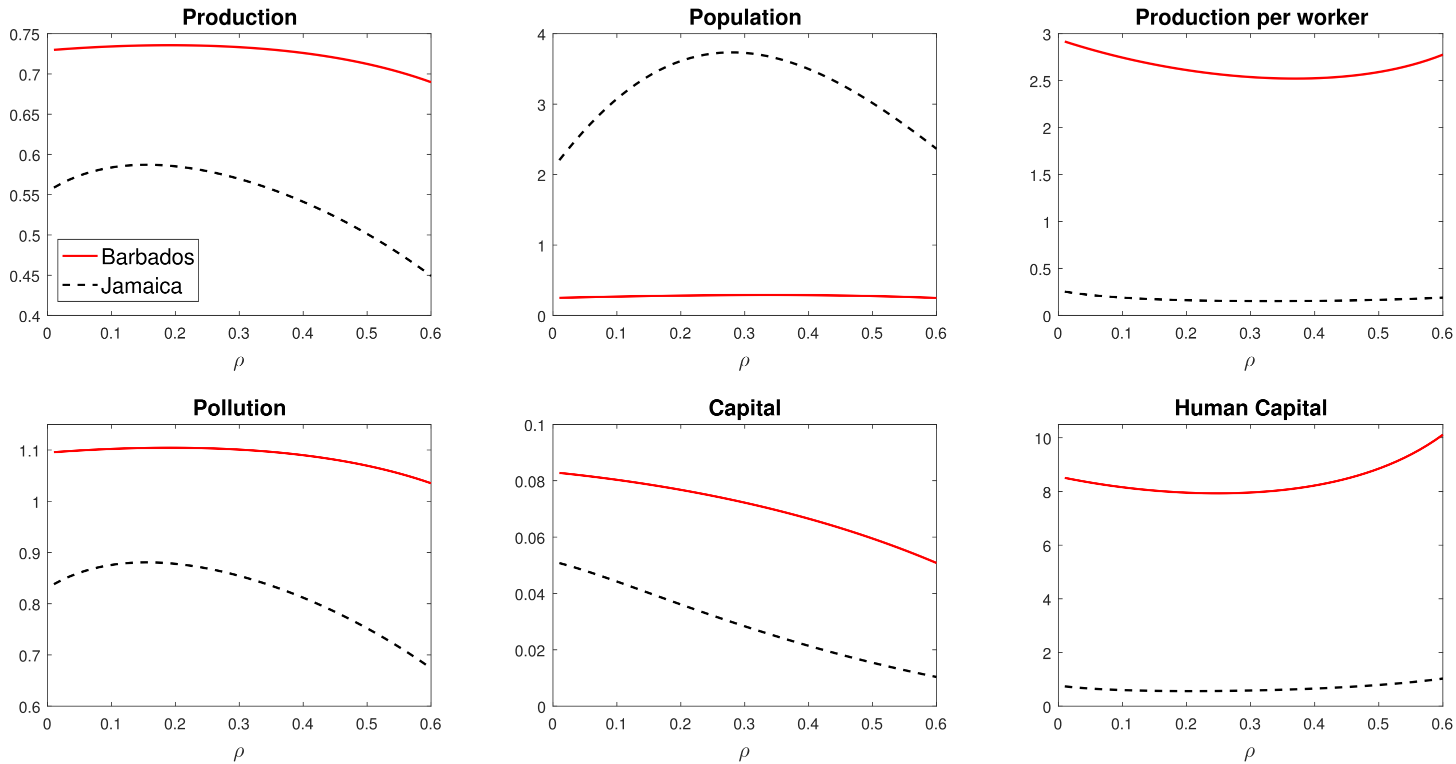

Figure 8. Effect of changes in ρ on the economy.

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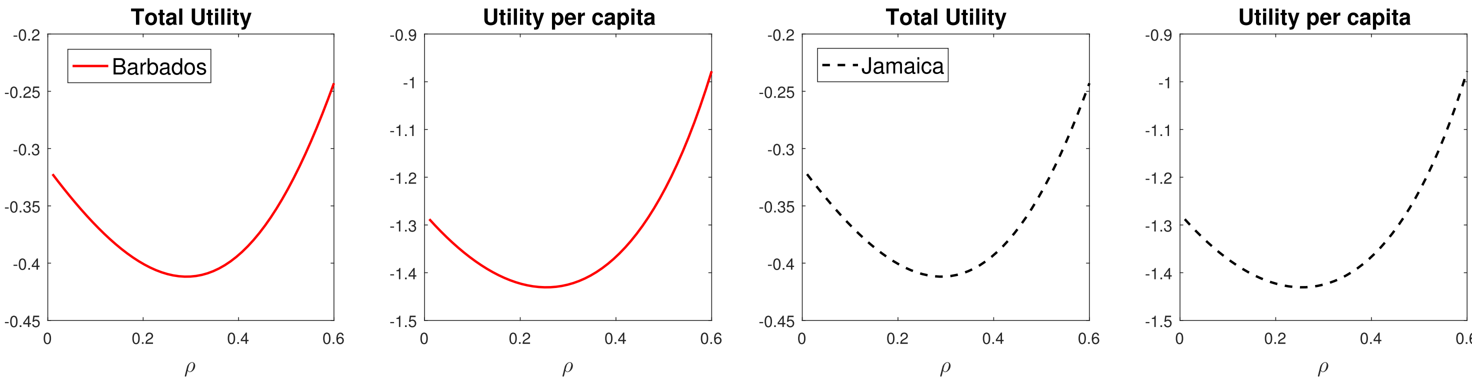

Figure 9. Effect of changes in ρ on utility.

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following conditions:

$$\frac{\partial N^\star}{\partial \gamma} > 0 \Leftrightarrow \gamma < \frac{\sqrt{\alpha(1-\rho)}\left[\sqrt{[\alpha(1-\rho)+(1-\alpha)(1\rho+\rho\varepsilon)]}-\sqrt{\alpha(1-\rho)}\right]}{(1-\alpha)(1-\rho+\rho\varepsilon)}$$

$$\frac{\partial Z^\star}{\partial \gamma} > 0 \Leftrightarrow \gamma < \frac{\sqrt{\begin{array}{c}[\alpha(1-\alpha)(1-\rho+\rho\varepsilon)+\alpha(1-\rho)(2-\alpha)]^2\\ +4\alpha(1-\rho)(1-\alpha)^3(1-\rho+\rho\varepsilon)\end{array}}}{2(1-\alpha)^2(1-\rho+\rho\varepsilon)} - \frac{[\alpha(1-\alpha)(1-\rho+\rho\varepsilon)+\alpha(1-\rho)(2-\alpha)]}{2(1-\alpha)^2(1-\rho+\rho\varepsilon)}$$

$$\frac{\partial K^\star}{\partial \gamma} > 0 \Leftrightarrow \zeta_\gamma > \frac{\gamma(1-\rho+\rho\varepsilon)-\gamma\alpha\rho\varepsilon}{(1-\gamma)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}$$

$$\frac{\partial h^\star}{\partial \gamma} > 0 \Leftrightarrow \zeta_\gamma > \left[\frac{1}{\delta} - \frac{\gamma(1-\alpha(1-\delta))[(1-\alpha)(1-\rho+\rho\varepsilon)+\alpha(1-\rho)]}{\delta(1-\alpha)(1-\gamma)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right],$$

where $\zeta_\gamma = (\partial\theta^{-1}(\chi)/\partial\gamma)(\gamma/\theta^{-1}(\chi))$ *is the elasticity of steady-state pollution with respect to the intergenerational transfers,* γ*.*

The impacts of γ on the steady-state variables are very intricate because this parameter is involved in numerous mechanisms. Indeed, on the one hand, there is a negative effect from the reduction in adult income. As noted above, this effect results in a decrease in adult consumption, savings, fertility and education expenditures. On the other hand, an increase in intergenerational transfers changes the incentives to invest in children through education and fertility. Therefore, here, in response to an increase in those variables, there are increases in the population size, production and thus in pollution. This reduces human capital and thus income, which can have an indirect effect on the physical capital stock. This explains the conditions on the positive effect of γ in Proposition 8. Here, again, these conditions depend directly on the value of γ for $Z^\star$ and $N^\star$, while for $h^\star$ and $K^\star$, the conditions are related to the elasticity of pollution with respect to this parameter. To clarify those trends, a numerical analysis is displayed in figure 10 – production, population size, pollution stock, capital stock and total utility – and in figure 11 – production per capita, human capital and utility per capita.

While the emigration rate might be null, if the intergenerational transfer rate is null, there is no reason to have children, and the economy collapses. Therefore, there are two asymptotes, one at $\gamma = 0$ and the other at $\gamma = 1$. Between these two values, inverted U-shaped curves are depicted for population size, production and the pollution stock with respect to the value of γ. Due to the negative income effect for adults, there is a strong decrease in production and the pollution stock after a certain threshold. This leads to a rise in human capital and utility until the collapse of the economy because adult income is null when γ approaches 1. In fact, except for the smallest (or the highest) value of γ, which is close to the asymptote, human capital and utility per capita are positively correlated with γ. Therefore, intergenerational transfers could be quite positive for utility per capita or human capital accumulation. However, if one considers the smallest values of γ, utility per capita might be very high, but with a quasi-null population size. This indicates that pollution depends strongly on population features and demographic growth.

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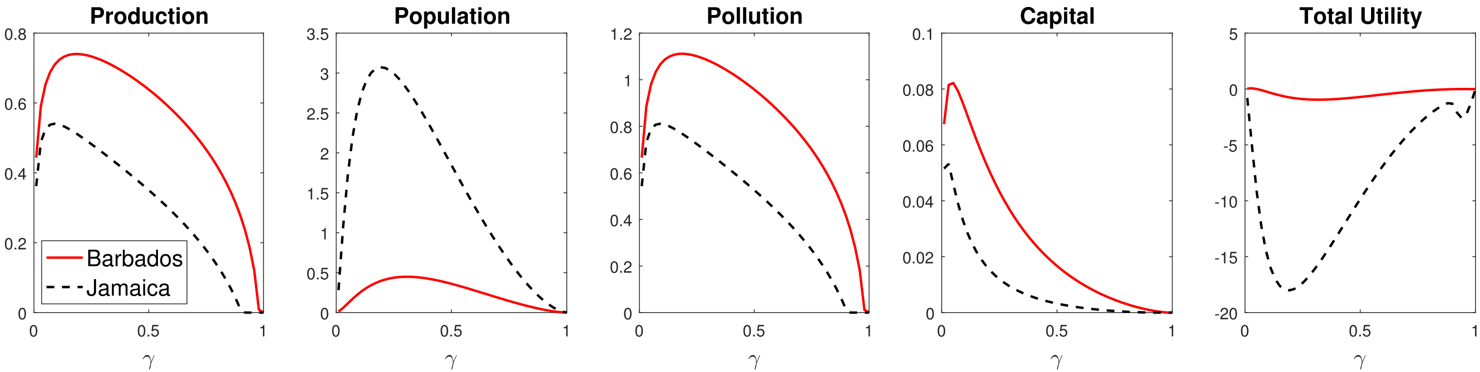

Figure 10. Effect of changes in γ on the economy (1).

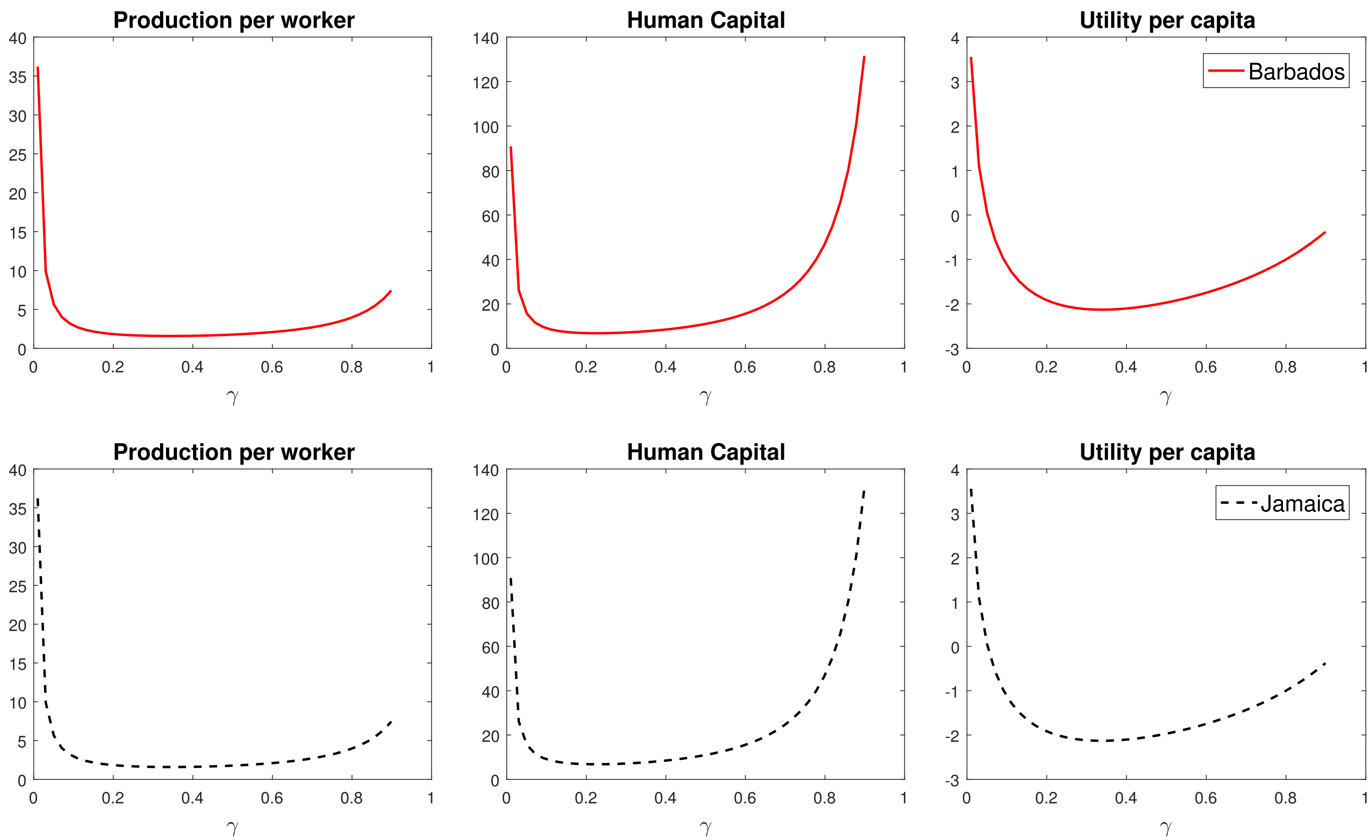

Figure 11. Effect of changes in γ on the economy (2).

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6. Conclusion

This work presented an OLG model to explain the interplay among economic activities, pollution emissions and investments in human and physical capital, according to the demographic structure of island economies. In this model, the demographic structure is strongly dependent on the pollution dynamics and migration, which directly impact human capital accumulation. Two cases are presented. In the first case, an environmental policy consisting of tax and public maintenance is sufficient to completely overcome pollution degradation. Migration could thus present the features described in the literature: it must not be too high, and remittances must not exceed a certain volume. In the second case, due to the pollution emissions or the inefficiency of the policy, public tools might not be sufficient to cope with the degradation. Migration and its interactions with pollution are thus key determinants of the accumulation of production stock.

Indeed, in both cases migration strongly changes the parents' choices in terms of education and savings. Provided that children will help their parents during their retirement period, migration may lead to an increase in fertility and thus in population size. With environmental degradation, the population rise enhances aggregate production – but not necessarily production per capita – and thus the pollution stock. This hampers the accumulation of human capital and thus economic gains from migration. This occurs despite the incentives to invest in human capital induced by migration – through remittances. In that case, while remittances have been identified in the literature as a lever for economic growth when they are small, this work shows that they could also have a strong negative impact on development and that a brain gain is not possible in many cases. In this context, only high values benefit the local economy, thanks to the lower demographic pressure on the environment. Moreover, the decrease in production is slower than the decrease in population; therefore, economic and (local) environmental gains can be obtained simultaneously.

The model also reveals that the steady-state level of human capital is impacted by pollution effects during the transitional period. Therefore, the capital stock and human capital generated in the early stages of economic development are key features that trigger strong economic growth in subsequent periods. In that context, the existence of remittances or intergenerational transfers could hamper the accumulation of human capital if they quickly boost pollution emissions.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X20000236

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