Université Paris Nanterre
200 av. de la République
92001 Nanterre Cedex
www.parisnanterre.fr

Membre de l'université Paris Lumières

École doctorale 396 : Économie, organisation, société
EconomiX - UMR7235

Lesly Cassin

Développement, Dynamiques démographiques et Environnement dans les Petits Etats Insulaires en Développement des Caraïbes

Thèse présentée et soutenue publiquement le 27/11/2019
en vue de l'obtention du doctorat de Sciences économiques de l'Université Paris Nanterre
sous la direction de M. Alain AYONG LE KAMA, Professeur des universités, Univ. Paris Nanterre
et de M. Fabien PRIEUR, Professeur des universités, Univ. de Montpellier

Jury :

Rapporteur :	M. Mouez FODHA	Professeur des universités, Université Paris 1 Panthéon-Sorbonne
Rapporteure :	Mme. Natacha RAFFIN	Professeure des universités, Université de Rouen
Membre du jury :	Mme. Johanna ETNER	Professeure des universités Université Paris Nanterre
Membre du jury :	M. Agustin PEREZ BARAHONA	Professeur des universités, Université de Cergy-Pontoise
Membre du jury :	M. Ingmar SCHUMACHER	Professeur des universités, IPAG Business School

Paris Nanterre University

Thesis defended on November 27th 2019
in fulfillment of the requirement for the Doctor of Philosophy degree in Economics

Development, Demographics and Environment in Caribbean Small Island Developing States

Author:
Lesly Cassin

Supervisors:
Pr. Alain Ayong Le Kama
Pr. Fabien Prieur

Thesis Committee:

Pr. Mouez Fodha, Paris 1 Panthéon-Sorbonne University
Pr. Natacha Raffin, University of Rouen
Pr. Johanna Etner, Paris Nanterre University
Pr. Agustin Perez-Barahona, University of Cergy-Pontoise
Pr. Ingmar Schumacher, IPAG Business School

Cette thèse a été réalisée à EconomiX,
UMR7235, Université Paris Nanterre, Bâtiment Maurice Allais,
200 avenue de la République, 92001 Nanterre CEDEX, France
Membre de l'Université Paris Lumières

Remerciements

Dès ma première année d'étude, j'ai su que je souhaitais poursuivre en doctorat. J'avais donc commencé très tôt à me renseigner pour me préparer au mieux, mais je n'avais pas anticipé l'épreuve que ce serait. Maintenant que j'arrive au bout de ce chemin, ce long chemin, je tiens à remercier toutes les personnes qui ont rendu cela possible.

Je commencerai par remercier mes directeurs de thèse, Alain Ayong Le Kama et Fabien Prieur. Je remercie Alain, qui m'a fait l'honneur d'accepter d'être mon directeur de thèse. Je suis très reconnaissante de la confiance qu'il m'a accordée et de ses encouragements à étudier un sujet qui me tenait à cœur. Je tiens à remercier Fabien pour son accompagnement, son écoute et son assistance ces dernières années. Je suis très honorée et reconnaissante d'avoir pu évoluer sous sa direction. J'espère avoir été digne de leur confiance et de leur engagement, à tous les deux.

Tous mes remerciements vont aussi à Mouez Fodha, Natacha Raffin, Johanna Etner, Agustin Perez Barahona et Ingmar Schumacher qui me font l'honneur d'accepter d'être membres de mon jury. Je les remercie pour le temps accordé, les conseils avisés et la bienveillance dont ils ont fait preuve, notamment lors de la pré-soutenance. Cette dernière m'aura permis d'améliorer grandement la qualité de ce travail, qui je l'espère saura satisfaire l'intérêt qu'ils ont accepté de porter à mes travaux. J'en profite pour exprimer ma gratitude en particulier à Natacha et Johanna, qui tout au long de ma thèse m'auront gratifiée de leurs conseils.

J'exprime aussi mes plus chaleureux remerciements à tous les membres d'EconomiX. Aboutir ma thèse signifie aussi de devoir quitter un laboratoire stimulant et accueillant, dans lequel je me suis épanouie tant sur le plan scientifique que sur le plan humain. C'est donc avec un pincement au cœur que j'adresse tout d'abord mes remerciements à Cécile Couharde, Ludovic Julien, Valérie Mignon et Lionel Ragot pour leur disponibilité et leurs enseignements. J'en profite pour remercier toutes les personnes qui m'auront aidée à améliorer la qualité de mes travaux et m'auront encouragée: Karine Constant, Paolo Melindi Ghidi, Olivier Renault, Marc Baudry et Jean-Philippe Nicolaï, entre autres. comme il est très important de bien démarrer la journée, merci aussi à tous les compagnons du café du matin, notamment Nasam, Gilles, Florian, Benjamin, Frédéric ou Catherine. Merci aussi à mes collègues de bureau, Stellio, Kymble, Liza, Harouna, Maha, Shella, Abdelhakim, Nathaly, Anouk, Valentin et Edouard, de même qu'aux autres doctorants du troisième étage, Maxime, Ouaffa, Gaëtan, Baptiste et Jérôme, pour leur sympathie et leur bonne humeur. Je souhaite aussi adresser une pensée à Penda avec qui j'ai partagé mes premiers enseignements et qui m'a grandement aidée. Plus généralement, je souhaite exprimer ma reconnaissance à tous les doctorants du laboratoire pour la joyeuse entraide qui a caractérisé la très grande majorité de nos interactions. Enfin, un grand merci à Zouhair avec qui j'ai tant partagé sur le plan scientifique et amical.

Avant EconomiX, j'ai eu la chance de passer par la Chaire Économie du Climat. Ma gratitude va donc à tous ces membres et plus particulièrement à Bénédicte, Jill, Benjamin et Solène qui sont devenus de grands amis. Ceci m'amène à remercier tous les autres amis qu'ils viennent de master, de licence, du handball, de l'Amap ou de toujours. Merci à tous ces copains que je ne citerai pas ici, merci de votre soutien et d'être restés à mes côtés, même quand mon capital sympathie était au plus bas. Je promets de fêter l'aboutissement de ce chemin, consciencieusement avec chacun d'entre vous.

Pour terminer, merci à ma famille. Vous êtes ma force, mon meilleur atout en tout temps. Je ne parle pas uniquement des multiples relectures de Gaëlle, d'Allan, d'Astrid, de Roxanne et de Maurel. Je ne fais pas seulement référence aux longues discussions avec Tatie Kattia ou aux nombreux débats familiaux arbitrés par Dedette, qui m'auront permis d'aiguiser mon esprit. Je ne pense pas seulement au soutien sans faille de mes parents, Dany et Eddy, de ma Marraine, de mon Parrain ou de mes oncles et tantes. Et bien que cela ait compté largement dans la balance, il ne s'agit pas non plus de la chaleur de nos rassemblements familiaux, qu'ils soient à deux avec Anélia ou avec la cousinade dans son intégralité. Quand je pense aux membres de ma famille, c'est surtout cette assurance, que quoi que je fasse et que quelle que soit mon aventure, je vous ai à mes côtés. Je n'y serai pas arrivé sans vous, je n'aurai probablement pas essayé, donc merci à tous.

Short abstract - Court résumé

Abstract

Sustainable development in Caribbean Small Islands Developing States (SIDS) is difficult to obtain because of their economic and social vulnerabilities. This thesis examines the sustainable resource allocation and economic growth of Caribbean SIDS using theoretical and numerical methods, and focusing on interactions between demographic and environmental dimensions. Due to their regional importance, I examine the effects of migration and remittances while taking into account local pollution and climate change.

First, I describe the impacts of remittances on savings, fertility and education, with a special focus on intergenerational strategies. I show that potential positive effects from migration or remittances depend strongly on its positive effect on human capital accumulation, *i.e.* whether it is larger or not than the population growth.

Because human capital accumulation also depends on the environment, in the second chapter I study the potential interactions between migration gains and environmental quality. If pollution exposure during childhood harms the human capital process, first there are new conditions for gains from migration which can decrease the demographic pressure on natural assets, second an environmental policy is beneficial.

Finally, Caribbean SIDS cannot reduce the extent of climate change, leaving them no choice but to adapt to its effects, however this is costly and difficult to implement. The third chapter of this thesis addresses the use of migration, which leads to remittances that can fund adaptation measures. Therefore, I test whether there is a complementarity or a substitutability between the two strategies and show that it depend on the fundamentals of the economy.

Keywords: Economic growth, Sustainable Development, Caribbean SIDS, Demographics, Environment, Migration

Résumé

Les Petits Etats Insulaires en Développement (PEID) des Caraïbes font face à des défis pour soutenir leur croissance, du fait de leurs vulnérabilités économiques et environnementales. En mobilisant des analyses théoriques et numériques, cette thèse examine la situation de ces PEID en se concentrant sur les interactions entre démographie et limites environnementales. Ici la migration et les rémittences, qui sont centrales pour ces pays, sont étudiées avec les pollutions locales et le changement climatique.

Premièrement, j'étudie l'impact des rémittences sur les choix d'épargne en intégrant les stratégies familiales en termes de fertilité et d'éducation. Je démontre que l'impact positif de transferts intergénérationnels ou de rémittences dépend de l'accumulation du capital humain qui doit être plus rapide que l'accroissement de la fertilité généré par la migration.

Deuxièmement, l'acquisition de capital humain dépend aussi de l'environnement dans lequel les agents évoluent. J'étudie donc les interactions entre exposition à la pollution durant l'enfance, accumulation de capital humain et gains de la migration. Ici, une forte migration peut réduire la pression démographique sur l'environnement et générer des gains économiques sous des conditions qui diffèrent du cas sans pollution. Dans tous les cas, il est aussi souhaitable de mettre en place une politique environnementale.

Enfin, les PEID doivent s'adapter au changement climatique pour assurer leur développement, ce qui est coûteux. J'étudie alors la migration comme méthode alternative pour l'adaptation au changement climatique. Les rémittences générées par la migration pouvant financer l'adaptation conventionnelle, il s'agira d'établir à quelles conditions il y a substituabilité ou complémentarité entre les deux.

Mots-clés: Croissance économique, Développement soutenable, PEID des Caraïbes, Démographie, Environnement, Migration

Contents

General Introduction

0.1 Context

Growth process and its determinants are one of the main topic studied by economists. First, scholars try to discover how human societies have transited from a period of low economic and population growth to a period of sustained economic growth per capita and population growth. Second, knowing that economic transition has not been experienced by all countries, another question is related to the differences between developed and developing countries. More specifically, development economists try to understand the sources of this great divergence between the two groups, as well as the solutions in order to enhance the economic growth in developing countries. Currently, while convincing arguments have been developed on these topics, it is still difficult to have a clear understanding of the economic growth process, especially when the environmental and the demographic dimensions are taken into account. Indeed, the study of the development is often associated to the analysis of sustainability. A sustainable development has been defined in the World Commission on Environment and Development's 1987 report, *Our Common Future*, "as a development that meets the needs of the present, without compromising the ability of future generations to meet their own needs".

Beyond distinguishing between developed and developing countries, some countries, such as the Small Island Developing States (SIDS), have specific characteristics in terms of sustainable development. The United Nations (U.N.) defines the SIDS as a group of developing countries facing specific social, economic and environmental vulnerabilities (UN-OHRLLS (2015)). There is also a strong consensus that SIDS countries exhibit a higher degree of economic vulnerability compared with other developing economies (Briguglio (1995, 1998, 2003); Briguglio and Galea (2003), Adrianto and Matsuda (2004), Guillaumont (2010), van der Velde et al. (2007)). This is explained by structural challenges such as their small size, which makes it difficult to achieve economies of scale in the production chain, and their limited access to natural resources, which forces them to import most of the raw materials. The inhabitants of these islands have all the reasons to be innovators to take into consideration limits to growth, however it is not the case. Including all these vulnerabilities is challenging, but particularly interesting in a sustainable development approach. Therefore, in this thesis I intend to contribute to the literature on sustainable development with a special focus on SIDS. I focus on Caribbean SIDS because their economies and their environmental constraints present similar characteristics.[1]

0.2 Caribbean SIDS - Some Facts

Some features of Caribbean islands in terms of economic development, demographic characteristics and environmental issues deserve to be highlighted, particularly in explaining the methodological choices and the particular focus adopted in this thesis.

0.2.1 General overview

The Caribbean consists of approximately 31 countries, depending on the list retained. Most of them are islands–with the exception of Belize, Guyana and Suriname–that are classified as countries or territories. Most of these countries are regrouped in the CARICOM (CARIbbean COMmunity), an organization of 20 states (15 independent countries and five non-independent associate members).[2,3] While these countries share a comparable experience, marked by invasion and the slave trade, they present a certain heterogeneity in many aspects, such as population size, geographic size, connections with other continents and economic groups. This region is home to between 40 million and 60 million people (depending on the countries or territories included in the group), with the largest population in Cuba (11 million) and the smallest one in

[1]Indeed, SIDS are located in at least five different regions, and according to their location they do not face the same constraints or the same commercial or historical links with developed or developing countries.

[2]https://caricom.org/

[3]Among the SIDS there are many non-independent territories, but in this work I will focus on independent SIDS which are on the UN's list: Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint-Kitts and Nevis, Saint-Lucia, Saint Vincent and the Grenadines, Suriname as well as Trinidad and Tobago.

Saba (2,000). Most of these countries are in the group of upper middle income or high income countries (except for Haiti, which is a low income country). However, this situation hides large inequalities both among and within the countries. This is aggravated by their strong vulnerabilities, knowing that the aid they have received from the international community–as well as their economic growth–has decreased since the beginning of the century. This is because the Caribbean islands rank as middle income countries (ECLAC (2017, 2018)).

Some data from the World Development Indicators are displayed in Table 1: income group, land area, population size, growth and density, as well as the GDP per capita and growth. This table perfectly illustrates the strong heterogeneity of the region despite their shared demographics (*e.g.*, the important relative weight of migration) and economic features.

Table 1: General Data on Caribbean SIDS (2015)

Countries	Income group	Land area[a]	Population			GDP per capita	
			Size	Growth[b]	Density[c]	Value[d]	Growth[b]
ATG	HIC	440	93,566	1.1	212.7	21,426.3	2.9
BHS	HIC	10,010	374,206	1.0	37.4	29,366.1	0.1
BRB	HIC	430	285,324	0.2	663.5	16,396.3	0.7
BLZ	LMY	22,810	360,933	2.1	15.8	7,976.9	1.3
CUB	LMY	104,020	11,324,781	0.2	108.9		4.3
DMA	LMY	750	71,183	0.1	94.9	10,215.3	-2.7
DOM	LMY	48,310	10,281,680	1.1	212.8	1,3717.4	5.8
GRD	LMY	340	109,599	0.6	322.4	12,435.6	5.8
GUY	LMY	196,850	767,432	0.5	3.9	7,086.9	2.6
HTI	LMY	27,560	10,695,542	1.4	388.1	1,653.6	-0.2
JAM	LMY	10,830	2,891,021	0.6	266.9	8,047.1	0.4
KNA	HIC	260	51,203	0.8	196.9	27,178.9	1.3
LCA	LMY	610	179,126	0.5	293.6	11,568.3	-0.2
VCT	LMY	390	109,148	0.3	279.9	10,472.2	1.1
SUR	LMY	156,000	559,143	1.1	3.6	14,488.0	-4.4
TTO	HIC	5,130	1,370,328	0.6	267.1	31,460.0	1.2

Legend: **ATG**: Antigua and Barbuda, **BHS**: Bahamas, The, **BRB**: Barbados, **BLZ**: Belize, **CUB**: Cuba, **DMA**: Dominica, **DOM**: Dominican Republic, **GRD**: Grenada, **GUY**: Grenada, **HTI**: Haiti, **JAM**: Jamaica, **KNA**: St. Kitts and Nevis, **LCA**: St. Lucia, **VCT**: St. Vincent and the Grenadines, **SUR**: Suriname, **TTO**: Trinidad and Tobago
HIC: High Income Countries, **LMY**: Low and Middle Income Countries, **a**: Square kilometers, **b**: Annual growth, **c**: Population per square kilometers, **d**: Purchasing Power Parity 2011$

Source: Author, based on the WDI

0.2.2 Demographic features

The population growth in Caribbean countries is quite small compared to other developing countries. This is explained by their large negative migration rate. Indeed, these countries have had an important tradition of migration since their colonization by the European countries (Thomas-Hope (1992)). Initially, they were receivers of European migration trends starting in the 17th century, followed by the forced migration of the African slaves. After the end of slavery, in the 19th century, Caribbean islands experimented strong intra-regional migrations and immigration from the Asian countries to replace the slaves. The beginning of the 20th century was marked by an increasing emigration depending on the European wars or the labor needs in developed countries. Finally, Since the period of independence of these countries in the 1960s (Thomas-Hope (1992)), population movements have continued and have become more and more intricate, depending on bilateral relationship with developed countries, catastrophic events, etc. Anyway, it appears that population movements are perceived as potential economic opportunities for these countries. In 2007, the Economic Commission for Latin America and the Caribbean (ECLAC) (ECLAC (2018)) has established that 15.5% of the Caribbean natives was living in a foreign country. Consequently, studying the Caribbean demographics trends of the region necessitates giving special focus on emigration.

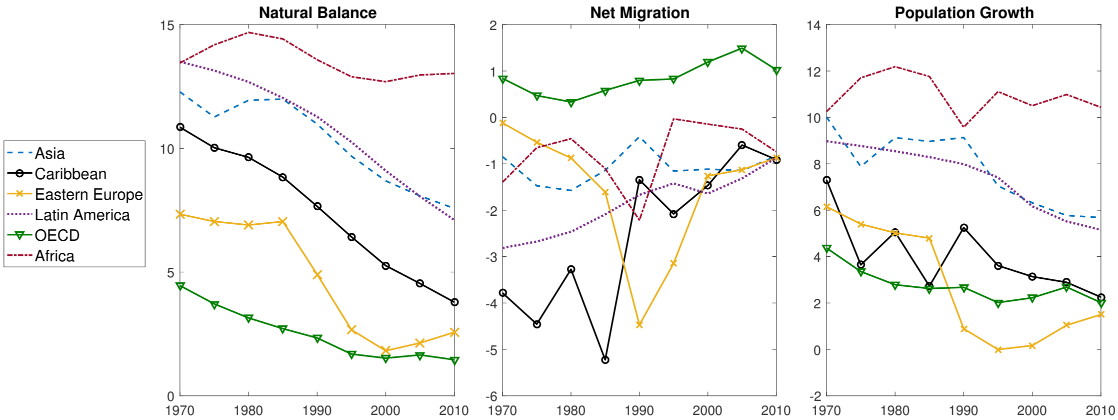
Using data from the World Bank's World Development Indicators (WDI), Figure 44 plots natural balance, migration balance, and population growth in percentage of population within 5 years, in Africa, Asia, the Caribbean, Latin America and Eastern Europe as well as countries of the Organisation for Economic Co-operation and Development (OECD).[4] United Nations Statistics Division (UNSD) releases migration flows data defined as the migrants stocks net change, between the years 1 and 5. We use the same 5-year interval in order to plot the other variables.

Except for the Eastern Europe, in comparison with other low and middle income countries, the Caribbean shows a strong negative migration balance, which is compensated by a positive natural balance. The extent of migration flows is quite significant for this regional group, the highest among emerging economies in our country sam-

[4]Middle East and North African countries are not represented because their demographic features exhibit strong volatility due to conflicts.

ple.[5,6] As a result, population growth in the Caribbean is close to OECD levels, which is quite low compared to the other groups' levels.

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



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

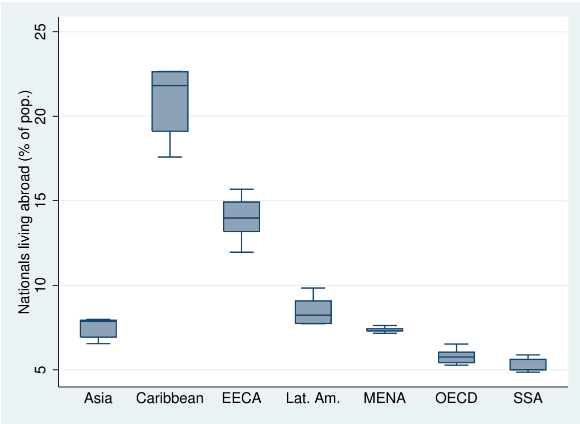
Figure 44 shows that the emigration flows have decreased strongly since 1990 for Caribbean countries. However, the size of the diaspora compared to the domestic population is still significant, especially if compared to other regions. Figure 45 represents the average of the share of nationals living 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% 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. Although the majority of these migrants are considered unskilled workers, the skill migration from the Caribbean is rising. Contrary to other sending regions, over half of the migrants heading to Northern America are skilled women. Moreover, the majority of migrants tend to be young and at a productive age, except for those from Cuba, who are on average over 45 years old. Migration may have several negative effects on the Caribbean economy, the most obvious being the potential adverse effects from the brain drain of skilled people leaving the island. For example, over 80% of individuals with post-secondary education from Jamaica, Haiti, Guyana and Grenada live abroad (Arslan et al. (2016), Docquier and Marfouk (2006)).

[5]Eastern Europe exhibits also a strong migration features since the implementation of the Schengen Area

[6]In the 1970s, migration was especially high. This is due to the immigration policies in the receiving countries, especially in the U.K. and the U.S.

Figure 2: Long-term average of nationals living in a foreign country by region (% of total population)

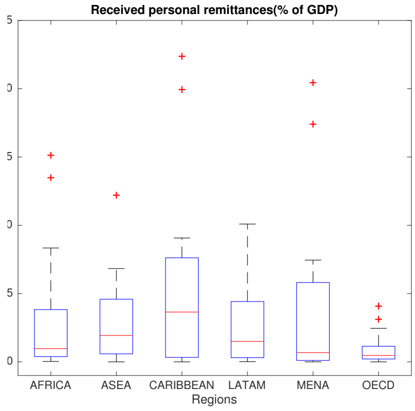


Legend: **EECA**: Eastern Europe and Central Asia, **Lat. Am.**: Latin America, **MENA**: Middle East and North Africa, **SSA**: Sub-Saharan Africa
Source: Author, based on the UNSD migration dataset and the WDI

However, the strong links between the diaspora and their family in the domestic area creates networks, especially through the *transnational family* (Thomas-Hope (2002)). These networks could trigger technological transfers between the receiving countries and the sending countries, as well as promote international integration (Alleyne and Solan (2019)). This connection between family members leads to important remittances–*i.e.* transfers between the diaspora and their family in the domestic area (ECLAC (2017, 2018)). In the Caribbean, the weight of remittances in the local GDP is extremely high because of the scale of migration. Figure 3 displays a comparison of the percentage of received personal remittances relative to GDP across regional groups for the period 1961-2014. Despite some outliers in the other regions, it shows that the median remittances appear to be higher among the Caribbean (3.65% of GDP), followed by South Asia and Pacific, as well as Central Europe and the Balkans at 1.93% and 1.63% of GDP, respectively.

An analysis at the country level of the migration features among Caribbean SIDS highlights a strong heterogeneity. Results are displayed in Table 2 and in the Figures 4 and 5. Countries such as Jamaica and Saint-Lucia are large senders of migrants, while some countries are net receivers of migrants. Because of this heterogeneity in the weight of migration, there are also large differences in the amount of remittances received and in the share of GDP percentage (see Figures 4 and 5). It is interesting to compare the level of remittances to the amount of savings received. In countries where remittances are large, such as Jamaica, Haiti and the Dominican Republic, savings are

Figure 3: Remittances in percentage of GDP by region



Source: Author, based on the WDI

relatively lower than in other Caribbean countries. On the contrary, countries that exhibit a smaller level of remittances have a larger level of savings in terms of GDP. Since migration is a common characteristic of Caribbean SIDS, it is the first element that must be taken into account.

Table 2: Caribbean SIDS: Demographic dynamics

Countries[a]	**Natural Balance**[b] (total per 1000 pop.)			**Migratory sold**[c] (percent)		
	1972	1992	2012	1972	1992	2012
CSS	24,07	16,92	9,71	-5,78	-4,13	-1,78
ATG	20,38	11,8	10,41	-4,28	4,13	-0,06
BHS	20,16	17,97	9,45	0,5	-0,15	2,6
BRB	10,49	6,04	1,84	-2,25	-1,24	0,77
CUB	20,37	8,73	3,01	-2,11	-1,12	-0,71
DOM	29,98	22,74	15,51	-1,49	-1,93	-1,51
HTI	21,24	23,31	16,82	-1,8	-1,9	-1,46
JAM	26,06	17,77	10,88	-5,35	-4,54	-3,51
LCA	28,93	19,74	8,71	-9,06	-3,39	0,02
VCT	30,26	17,37	9,53	-9,51	-8,04	-4,57
TTO	19,15	11,01	5,64	-3,03	-2,58	-0,37

Source: World Development Indicators, World Bank

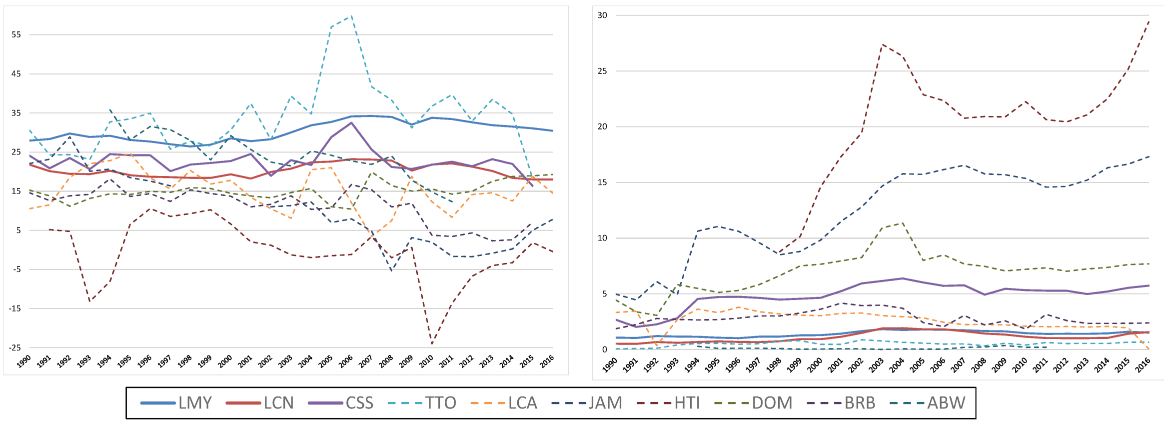
[a]**Legend: CSS**: Caribbean Small States, **ATG**: Antigua and Barbuda, **BHS**: Bahamas, The, **BRB**: Barbados, **CUB**: Cuba, **DOM**: Dominican Republic, **HTI**: Haiti, **JAM**: Jamaica, **LCA**: St. Lucia, **VCT**: St. Vincent and the Grenadines, **TTO**: Trinidad and Tobago

[b]Natural Balance is defined as the number of births minus the number of deaths in a year

[c]Migratory sold is directly extracted from the WDI

Figure 4: Savings in Caribbean SIDS and Developing countries (% of GDP)

Figure 5: Received remittances in Caribbean SIDS and Developing countries (% of GDP)



LMY, Low and middle income countries, **LCN**, Latin american countries, **CSS**, Caribbean Small States, **TTO**, Trinidad and Tobago, **VCT**, Saint-Vincent and The Grenadines, **LCA**, Saint-Lucia, **JAM**, Jamaica, **HTI**, Haiti, **DOM**, Dominican Republic, **BRB**, Barbados, **ABW**, Aruba

0.2.3 The Environment in the Caribbean SIDS

0.2.3.1 Environmental characteristics of SIDS and their impacts on economic specialization

The vulnerability is determined by the combination of exposure to a risk and the ability to recover from the stress induced by this risk. As stated earlier, Caribbean SIDS suffer from multiple but common environmental vulnerabilities, which come from their structural characteristics (*e.g.*, small size, isolated location, etc.). Caribbean islands are also diverse in terms of environmental features or resources (*e.g.* topography, size, coastal area and geological formation) (James (2005), Robert B. Potter (2004)). Three biophysical differences that affect the islands' economic opportunities keep our attention. First, the *islandness* depends on the ratio of coastline to land area or on the proximity of the interior land to the coast. In the Caribbean, this indicator varies widely among the islands, from 1 to 30, according to Heileman and Walling (2005). When this ratio is large, the land scarcity is relatively smaller. In certain economies, land size is sufficient in order to develop a large agriculture base, while in many islands the land scarcity is too high to develop other economic sectors besides fisheries, tourism or other services. Second, the *flatness* of the islands will define the variety of ecosystems that will be present. In countries such as Anguilla or Antigua and Barbuda with ancient geological formations (volcanic rock covered with sediments), water scarcity is higher and ecosystems are less diverse. However, the landscapes are more appreciated by international tourists, thanks to the beauty of the coastal zone. In countries with more recent volcanic geological formation, such as Dominica or Saint-Lucia, there are higher mountains, the water is more abundant, the land biodiversity is richer and the land is more fertile. Nonetheless, the rugged terrain inhibits the development of agriculture, and the black sand from the volcanic rock is less attractive for tourists (ECLAC (2018)). The third biophysical difference is the type of resources available. In some islands, such as Cuba or Trinidad and Tobago, minerals and oil are available and exported, while in most islands, such resources are not available. Therefore, the weight of natural resources related sectors differs largely across countries.

In terms of GDP, the main sector related to the environment in the Caribbean is tourism (ECLAC (2018)). Because of the isolation of the islands and their different topographies, the Caribbean region is a hotspot for biodiversity, with diverse and endemic ecosystems. This characteristic constitutes a weakness and a strength for these countries in terms of development. These specific and fragile ecosystems lack resilience: more than 700 species are defined as endangered (ECLAC (2018), Wege et al. (2010), Robert B. Potter (2004)). However, their rarity is a comparative advantage for tourism (Croes (2011)). In the Caribbean islands, the share of tourism in economies has been continuously growing for the last 30 years. This is one of the lessons to be drawn from the WDI displayed in Figure 6). The other important factor influencing the economy is the employment created by agriculture and fisheries. This sector is quite small compared to other developing states, but it counts on average for 15% of the employment in the region and thus should not be neglected.

Figure 6: Tourism Receipts in 2015
(% of GDP)

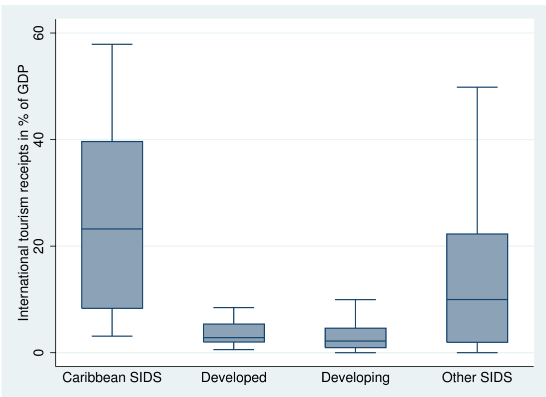
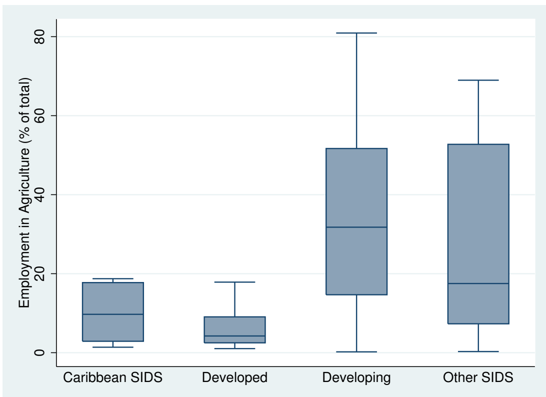


Figure 7: Employment in Agriculture
(% of total employment)



Source: Author, based on the WDI

The strong heterogeneity in specialization among the natural assets in Caribbean islands leads to various economic specialization among these countries. For example, in Trinidad and Tobago, which has a stock of oil, and in Haiti, which has comparable characteristics to other developing countries, tourism is not as important of a sector. This is illustrated in Figure 8 and 9.

Figure 8: Tourism Receipts between 1995 and 2015, (% of GDP)

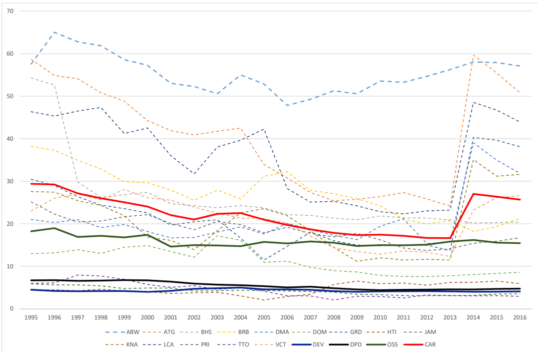
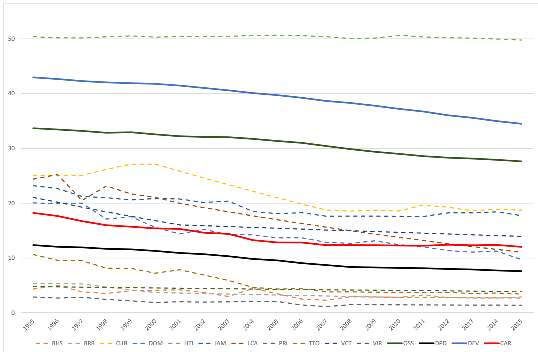


Figure 9: Employment in agriculture (% of total)



DPD, Developed Countries, **DEV**, Developing Countries, **CAR**, Caribbean Small States, **OSS**, Other Small States, **CUB**, Cuba, **TTO**, Trinidad and Tobago, **VCT**, Saint-Vincent and The Grenadines, **LCA**, Saint-Lucia, **JAM**, Jamaica, **HTI**, Haiti, **DOM**, Dominican Republic, **BRB**, Barbados, **ABW**, Aruba

Source: Author, based on the WDI

0.2.3.2 Environmental hazards in SIDS

Acknowledging the weight of natural capital in Caribbean economies gives a special focus to the sustainability of economic processes.[7] Despite the growing importance of this topic in the public policies, it appears that the quality of the Caribbean environment is decreasing (UNEP (2016), Heileman and Walling (2005)). The sources of negative environmental impacts are numerous and important in the Caribbean region. They can be endogenous and come from the domestic economic activities (*e.g.* ecosystem degradation caused by tourism, agriculture, consumption, etc.), they can be exogenous and depend on natural dynamics (*e.g.* earthquakes or volcanic eruptions) or other countries' pollution emissions (*e.g.* climate change or oil spill in the Caribbean Sea). In this thesis, for the analysis on the exogenous environmental impacts, I focus on climate change, which is projected to account for nine out of 10 extreme events in the future (ECLAC (2017)).

Endogenous environmental damages: Local pollution in Caribbean SIDS

[7]The evolution of the environmental quality in the Caribbean has been scrutinized, especially in the context of the Global Environment Outlook.

Heileman and Walling (2005) describes many risks induced by human activities in Caribbean islands. First, while tourism depends strongly on the natural capital quality, this sector can have tremendous negative effects on the environment. This is due to the large number of fragile ecosystems as well as the increased strain put on their infrastructures. Indeed, some islands have as many tourists as they have residents.[8] In that case, waste infrastructures and wastewater facilities may be insufficient in these territories or demand tremendous changes of the landscape. In the report of the Caribbean Environment Outlook, it is shown than most SIDS do not have the systems or the physical capacity to isolate and dispose of most waste, sewage, and dangerous substances (*e.g.* pesticides, waste oil or heavy metals) (UNEP (2016)). This leads to problems such as pollution from domestic sewage, industrial effluents and agricultural runoffs of the groundwater, as well as the land and marine ecosystems. For instance, traces of fecal pollution in Puerto Rico and Trinidad and Tobago have been found (Bachoon et al. (2010); Wade et al. (2015)). This pollution, present in several sites where fishing or sports activities occur, comes from human or bovine source. Its impact on human health is impossible to predict because the fecal pollution is not routinely monitored.

In addition, the Food and Agriculture Organization of the U.N. (FAO) confirmed only as recently as 2017 that 11 Caribbean countries were free from their stocks of obsolete pesticides. This is the result of a project titled "Disposal of Obsolete Pesticides Including POPS, Promotion of Alternatives and Strengthening Pesticides Management in the Caribbean," which started in the 2000s.[9] Before this date, stocks of these obsolete pesticides were managed by private entities without any controls from the governments of these islands.[10]

The success of this project shows that Caribbean SIDS' public planners give a growing importance to environmental issues. Since the 1990s, some SIDS have spent a considerable amount of time and financial resources on developing regulations and infrastructure. However, the tools to monitor the risk and implement efficient solutions are still lacking (Klöck and Nunn (2019)), and the enforcement of these new regulations or the use of the infrastructure is largely inefficient because of inadequate institutional and human resources to enforce them. The effect of these degradations are amplified

[8]For instance in The Bahamas there were 1,427,000 arrivals of international tourists for a population of 370,633 people (WDI, Wolrdbank)

[9]http://www.fao.org/americas/informations/ver/fr/c/1068631/

[10]See the Background on the management of obsolete pesticide stockpiles in the Caribbean

by some structural characteristics. First of all, a local degradation impacts a large share of the population because of the high density of population. The effects on health and natural habitats can be huge. Additionally, even when the effects of these pollutants are not that important, the bad publicity related to these degradations can have major adverse economic impacts through tourism.

Exogenous environmental damages: The climate change impacts in SIDS

A large part of the environmental vulnerability of SIDS is strongly related to climate change. Climate change is the result of the increased anthropogenic greenhouse gas (GHGs) emissions into the atmosphere. However, while the contribution of Caribbean SIDS to the GHG stock is negligible, the impact of climate change is dramatic for these countries. They are expected to suffer more and sooner than in other regions. The vulnerability to climate change depends on three main factors: exposure, economic sensitivity and adaptive capacity (Bierbaum (2009)). There is little to do with the first two components–SIDS only have a few opportunities to diversify their economies and reduce their dependence on natural capital. Therefore, according to the Intergovernmental Panel on Climate Change (IPCC), the cost of potential climate change damages in these countries will be so large that adaptation is a prerequisite of their sustainable economic development (See for instance UN-OHRLLS (2017)).[11]

Isolating the climate change impacts in the Caribbean islands is particularly challenging because it interacts strongly with other exogenous climatic characteristics such as El Niño and La Niña events (Nurse et al. (2014)). However, several risks have been identified with a good confidence.[12] Among other things, SIDS face an increase in the occurrence of extreme weather events (more frequent and severe storms and hurricanes, etc...), variations in rainfall (an increase in variability of precipitation and a decrease in water stock), rise in sea level accompanied by degradation of natural capital and health problems, including infectious diseases (Klöck and Nunn (2019), Nurse et al. (2014)) (*cf.* Table 3).

According to Cashman and Nagdee (2017) and Monioudi et al. (2018), due to the Sea Level Rise (SLR) which will be at least 0.35 meters and which can be as much as 1.4 meters by the end of the century or the increase of the number of hurri-

[11] http://unohrlls.org/custom-content/uploads/2017/09/SIDS-In-Numbers_Updated-Climate-Change-Edition-2017.pdf

[12] See Kelman and West (2009) for an overview of the impacts of climate change.

canes, coastal infrastructure and settlements are at risk.[13] Indeed, during the colonial era, most islands were specialized in the exportation of agricultural goods. This led to dispersed settlements in rural areas, while most of the urban areas were located around the harbor. This has been maintained after the independence of the countries. Thus, even in islands where the land elevation might be high, the population is concentrated in vulnerable near-shore areas, with approximately 70% of the Caribbean's population living in coastal zones (Mycoo (2017)). Second, significant effects on health are expected from extreme events such as heat waves or hurricanes (Stephenson and Jones (2017)) from the reduction of water availability (Cashman et al. (2010)) or from the increase in vector-borne infectious diseases (Cloos and Ridde (2018)). Third, degradation of the marine ecosystem can reduce the gains from tourism, because of acidification (Melendez and Salisbury (2017)), increase in Sea Surface Temperature (SST) (Michael A. Taylor (2017)), extreme events (Stephenson and Jones (2017)) or decrease in the quality of coral (McField (2017)) and mangroves (Wilson (2017)). Finally, climate change reduces the agricultural productivity because of the reduction in water availability (Cashman et al. (2010)), increases in temperatures (Dye et al. (2017)) or more frequent extreme events (Stephenson and Jones (2017)).

Table 3: Key risks with respect to the climate change drivers

Key risks	**Continuous drivers**	**Risky events drivers**
Loss of livelihoods, coastal settlements, infrastructure, ecosystem services and economic stability	Warming trend – Ocean Acidification – Increase in SST – SLR	Extreme Precipitation – Damaging Cyclone
Degradation of natural assets (coral reefs, biodiversity)	Warming trend – Ocean Acidification – Increase in SST	Damaging Cyclone
Damages on low-lying coastal areas	SLR – Change in the precipitation	Damaging cyclone

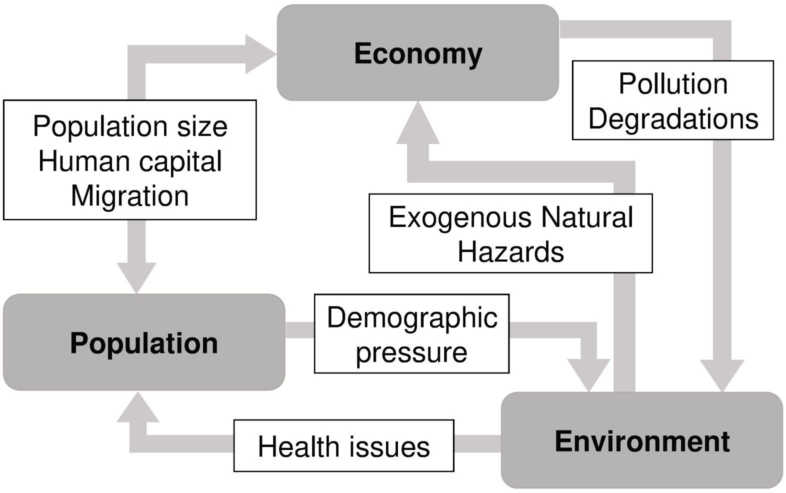
Source : Authors based on Nurse et al. (2014)

0.3 Linking all the dimensions

As said earlier, the focus in this work is on interactions between different dimensions of sustainable development. The facts given in the preceding section show that migration drives most of the demographic features of the Caribbean countries. On the other hand, the main environmental issues are linked to local pollution and exogenous natu-

[13]The first figure is given by Nurse et al. (2014).

ral hazards, such as climate change. In the figure below, I show potential interactions and returns effects that must be taken into account with Caribbean characteristics.[14]



The aim of this section is to describe the literature on the different components and interactions of our problem. More specifically, I will focus on the models that allow us to take into account environmental issues and demographic characteristics, with a special focus on migration.[15] Three aspects of the literature deserve particular attention in this thesis. First, I explore the economic literature on migration and remittances in the perspective of sending countries of emigrants. Second, I study the environmental economics literature with a special focus on the interaction between population and degradations of the local environment. Finally, I describe the models that allow us to take into account exogenous hazards in economic studies.

0.3.1 The migration for the sending countries

The economic literature on migration is very diverse, even when it is narrowed to the sending countries perspective.[16] Indeed, the causal link between migration and economic growth goes in both directions. Therefore, the authors have studied the economic determinants of the migration, knowing that since the seminal work of Sjaastad (1962), it is well accepted that migrants are economic "opportunity seekers." Consequently, migration can be seen as the result of an optimization strategy of the income

[14]Characterizing climate change as an exogenous degradation for SIDS is motivated by their inability to change the occurrence of this threat. Indeed in their case, even if they have tools to absorb carbon (with corals or mangroves for instance), their contribution to the mitigation will be negligible.

[15]Note that this thesis is related to the neoclassical theory, and thus I will focus on the tools developed by this theory to treat environmental issues as well as demographic questions.

[16]See Rapoport and Docquier (2006) for a review of the subject.

or as an investment in order to be materially better off (Brunow et al. (2015)). Many studies have then focused on gains from migration explained by differences in return from labor or in wages (Lewis (1954), Sjaastad (1962), Todaro (1969)), in diversification of the activities or in the reduction of the risks in rural areas. Changes in economic growth or labor markets may have effects on the decision of migration. In that context, motivations to migrate are defined as push-factors or pull-factors. Table 4 gives a partial list of these factors:

Table 4: Push and Pull factors

Push factors	Low salaries, Informality, Unemployment, Lack of land, Income variability, Political or economic crises, Conflicts, Insecurity, Repressive regime, Lack of social security programs
Pull Factors	High Salaries, Employment opportunities, Available land, Stability, Peace, Security, Freedom, Social security programs

Source: ECLAC (2018)

The study of the relative weight of these factors is not evident. This is because migration decision is not only based on objective differences between two locations, but also on the perception by migrants of their characteristics. Moreover, migration is not only an individual decision but can correspond to a family strategy (Lauby and Stark (1988); Stark and Lucas (1988)). Several papers show effects of migration as a tool to develop personal networks (Woodruff and Zenteno (2007)).

Conversely, authors have focused on the effect of emigration on sending countries, especially in terms of economic growth, human capital accumulation, international trade and financial development, among others. In the case of Caribbean islands, two drivers of migration impacts have retained my attention: human capital dynamics and remittances–*i.e.* cash transfers between the diaspora and the domestic country.[17]

The early literature on emigration in the 1970s finds that migration is negative for sending countries, especially because of a potential *brain drain*–*i.e.* a loss of human capital in the domestic area. These results were based on the idea that the social marginal loss of skilled labor was higher (for example with the loss of doctors), than the private marginal gain (for instance, with the increase in the wages thanks to the reduction in labor supply) (Bhagwati and Rodriguez (1975), Hamada and Bhagwati (1975)). However, these results have been challenged by the works of Stark et al.

[17]Obviously, many drivers could be considered, such as international trade or the networks effects (Alleyne and Solan (2019)).

(1997), Mountford (1997), Beine et al. (2006) or Docquier et al. (2008), among others. These authors defend the idea that *a beneficial brain drain* or more simply a *brain gain* was possible thanks to migration. Knowing that human capital enhances the probability of migration or remuneration abroad, the possibility to migrate creates an incentive to invest in education. However, some of the high-skilled do not migrate, which could lead to a rise in the mean human capital in the domestic area. In his paper, Beine et al. (2001), finds that a doubling of the migration rate might increase the acquisition of tertiary education by 5%. The conditions to have a *brain gain* depends on the countries' characteristics and on the features of emigration. A brain gain is more likely to happen if the barriers to migration in receiving countries (*e.g.* cost or procedures) are important, if the initial levels of human capital in the domestic area is weak, or if the emigration rate is small. Several empirical papers have studied the brain gain, and some large developing countries seem to have experienced it (Beine et al. (2011), Sampson (2013)).

Despite the abounding literature on the impact of remittances on economic growth, however, economists have not yet reached a consensus. Part of the literature finds a positive effect from remittances. These positive effects can be induced by the direct effect of the increase in incomes (Adams and Cuecuecha (2010), Giuliano and Ruiz-Arranz (2009), Yang (2008), Osili (2007); Woodruff and Zenteno (2007)), in education spending (Acharya and Leon-Gonzalez (2014), Adams and Cuecuecha (2010), Alcaraz et al. (2012), Azizi (2018), Bansak and Chezum (2009), Calero et al. (2009), Salas (2014)) or in health expenses (Amuedo-Dorantes and Pozo (2011), Azizi (2018)). As a result, remittances can enhance labor productivity (Mamun et al. (2015)). Remittances are also considered to have some effect on income redistribution in the sending countries, with reduction in poverty (Adams and Page (2005), Anyanwu and Erhijakpor (2010), Gupta et al. (2009)) or in inequalities (Bang et al. (2016), Li and Zhou (2013)). Finally, remittances are also supposed to improve financial development–for instance number of bank accounts per inhabitant–in order to deal with the increasing capital flows from abroad (Aggarwal et al. (2011), Chowdhury (2011), Demirgüç-Kunt et al. (2011), Gupta et al. (2009), Fromentin (2017))

However, another study finds that the positive effect from the remittances depends on strict conditions. For instance, Sobiech (2019) shows that only countries in the early stages of development, with a small financial sector, might experience positive effects from remittances. Otherwise, a substitution effect between capital market and remittances is possible. Combes and Ebeke (2011) for instance, find that remittances must not exceed 6% of the receiving country's GDP in order to keep providing stabilization. Moreover, Coon (2014) shows that remittances have a positive effect on investment rather than consumption, depending on the degree of efficiency in domestic banking services. Finally, the way remittances are used in the economy matters. Indeed, papers suggest that remittances only fund household consumption or increase the stability of the family's revenue (Brown and Ahlburg (1999), Combes and Ebeke (2011), Durand et al. (1996)). This enhances the economic growth if the share of the imports in the consumption is not too high.

Contrary to the most optimistic findings, however, some authors such as Acosta (2011), Adams and Klobodu (2016), Coulibaly (2015) or Rao and Hassan (2011), show that the effects of remittances are either very small and indirect or statistically insignificant. In addition, authors identify remittances as a source of adverse effects, such as the Dutch disease (Acosta et al. (2009), Bourdet and Falck (2006), Guha (2013)), increased capital volatility (Imai et al. (2014), Nyamongo et al. (2012)) or exacerbated informality in the financial system (Brown et al. (2013), Opperman and Adjasi (2019), Raza and Jawaid (2014)). Finally, cash transfers may also reduce labor supply thanks to the income effect that benefits domestic receivers. That may also lead to an appreciation in real domestic wages that can generate an inflationary trend in which case the central bank will have to raise the interest rate in order to curb the ensuing inflation (Cox-Edwards and Rodríguez-Oreggia (2009), Mandelman (2013)).

In the first chapter of this thesis, I focus on the impact of remittances on physical capital accumulation and especially on savings. The mechanisms introduce the interplay between migration and education expenditures with endogenous fertility in the tradition of Mountford and Rapoport (2011) or Marchiori et al. (2008). This topic has not been scrutinized in the literature on remittances, and before linking the demographic dimension to the environmental dimension, it seems interesting to study this particular topic. Hence, in the first chapter, I try to answer the following question: what is the impact of remittances on savings?

0.3.2 Population dynamics and environmental quality

As emphasized in the migration literature, positive effects from migration depend strongly on a potential increase in human capital stock with migration–*i.e.* a *brain* *gain*. Yet this stock embraces two components that can be directly affected by local pollution: the number of workers and the productivity per worker. The former varies with longevity and fertility, while the latter varies with cognitive skills and abilities to attend school. All of these health dimensions, it should be noted, are negatively affected by local pollution.

Undeniably, the effects of pollution on human health are now described in scientific literature and recognized by international organizations. It can concern directly morbidity and mortality (Pope III et al. (2002), Evans and Smith (2005), Pope III et al. (2004)). According to World Health Organization (WHO), almost all humans (91%) did not breathe clean air in 2016, which resulted in 3.8 million deaths due to heart disease, stroke or cancer. Moreover, unsafe drinking water, unsafe sanitation and lack of hygiene have caused 870,000 deaths in 2016 (WHO (2016)). Moreover, exposure to pollutants can decrease the fertility (Vizcaíno et al. (2016), Carré et al. (2017)), and several studies have found a link between productivity and exposure to pollutants, especially air pollution. For instance, studies have found negative effects of pollution on the productivity in learning activities (Marcotte and Marcotte (2017), Power et al. (2016), Pujol et al. (2016), Bharadwaj et al. (2017), Isen et al. (2017), Lett et al. (2017), Omanbayev et al. (2018)) or in labor (Ambec and Lanoie (2008), He et al. (2019)).[18]

Economic literature on environmental regulation and health issues is abundant, so I do not intend to describe all the potential tools to study the interactions between environment and demographic dynamics. Instead, I will focus on Overlapping Generations models that allow us to take into account the environmental issues as intergenerational problems in tradition of John and Pecchenino (1994). In these models, several generations live at the same time, knowing that each individual made their choice in order to maximize their utility for all periods. This type of model allows us to introduce a life-cycle optimization problem. This seems particularly useful for our questions, where environmental quality and human capital are the result of intergenerational choices. Moreover, in this type of model, the competitive equilibrium might not be Pareto-optimal (de la Croix and Michel (2002)). It is possible to obtain equilibrium with overaccumulation of capital or under-accumulation. In the case of overaccumulation, it is possible to increase the consumption of at least one generation without decreasing the consumption of others. In the case of under-accumulation,

[18] See Currie et al. (2014) for a recent literature review.

however, at least one generation should experience a decrease of consumption level in order to increase physical capital and thus production efficiency.

Papers using OLG models and incorporating health issues linked to environment can be classified according to their topic: longevity, productivity, fertility and/or human capital. First, the literature on the interaction between optimal environmental policy and longevity has shown that the relationship between environmental regulation and longevity or economic outcomes is not always linear (Pautrel (2009, 2012)). Knowing that the only incentive to save in OLG models comes from the consumption in the retirement period, several papers find a slowdown of physical and/or human capital accumulation when longevity decreases (Chakraborty (2004), Mariani et al. (2010), Varvarigos (2010), Varvarigos (2013), Wang et al. (2015)). This can result in multiple long-term equilibria with poverty traps where both environmental quality and life expectancy are low (Mariani et al. (2010), Varvarigos (2014)).

Second, Aloi and Tournemaine (2011) introduce explicitly as a health sector in an R&D-based growth model, knowing that health enhances labor productivity. In their work, a better environment boosts the economic growth through two channels: by increasing the labor productivity and by reallocating resources toward the health sector instead of the polluting sector.

Finally, several works introduce explicit interactions between human capital accumulation and environment. These interactions can be bidirectional or not. For example, Constant (2018) introduces an interaction between life expectancy, human capital and pollution through an inequality nexus. In her work, the vulnerability to pollution is lower for skilled agents and leads to two different equilibria. In the first one, there are no inequalities, while in the second, inequalities increase on the balanced growth path. Raffin (2012) introduces a negative externality on individual health, whether they are children or adults. In this case, children do not reach the expected level of human capital and the productivity of adult workers is hampered. Finally, two equilibria were obtained with a poverty trap (with low environmental quality) and situations where both environmental quality and human capital are higher.

Therefore, most of the theoretical papers show that the relationship between environmental regulation and economic growth is not linear, through the health channel. It depends on the return effects of the increase in population size, human capital or longevity. Indeed, through their positive effects on economic production, all these factors might lead to adverse effects in terms of pollution. Therefore, there is no simple answer for an environmental policy that leads to a reduction in pollution stock and an increase in per capita welfare. According to the literature, it depends strongly on the type of externalities that are considered and on the demographic dynamics that are included in the model.

In the context of Caribbean SIDS where migration is large, potential degradation of cognitive skills, among other things, might have a strong, indirect effect on migration gains, which are partly connected to the effects of remittances on education expenditures and to the potential *brain gain*. In countries that rely heavily on remittances and migration, the question that arises is this: what is the effect of migration if environmental degradation has an impact on the cognitive skills and thus on the *brain gain*? This is treated in the second chapter of this thesis.

0.3.3 Adaptation to climate change and population dynamics

As stated earlier, most of the Caribbean's environmental vulnerabilities are explained by climate change, and the only solution to cope with this threat is adaptation. IPCC defines adaptation as "the process of adjustment to the actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to the expected climate and its effects." According to this definition, a large set of actions (private or public) can be considered as adaptation strategies to climate change (Chambwera et al. (2014), Smit et al. (2000)).[19]

The decision of investments in adaptation measures depends on the tradeoff between their costs (including the opportunity cost) and the benefits from the reduction of climate-related damages. However, it is difficult to predict the cost linked to climate change (which implies uncertainty), as well as economic gains or costs of adaptation. This is especially true if the side effects of the adaptation on other components of the economy (such as employment or inequalities, for example) are taken into consideration. Moreover, adaptation strategies may imply market failures, such as positive and negative externalities or information asymmetry (Chambwera et al. (2014)). In that context, cost-benefit analysis appears to be challenging and public intervention seems

[19] A partial list includes altered patterns of management, investments, insurance, public infrastructure, technology development, information campaign, emergency response procedures, as well as broad changes in norms, regulations or individual behaviors (Chambwera et al. (2014)).

mandatory to coordinate adaptation measures. This carries particular significance in developing countries, where adaptation strategies should be intertwined with broader sustainable development goals.

First, in theoretical papers, some authors focus on the tradeoff between mitigation and adaptation strategies (among others Klein et al. (2005), Tol (2005), Shalizi and Lecocq (2009), Buob and Stephan (2011), Zemel (2015)). Others study the timing of adaptation (Tsur and Withagen (2013), Catalano et al. (2019)). In this second group, sometimes there is a distinction between preventive (also denoted, proactive, facilitative or ex ante) and reactive (or ex post) adaptation. In both groups of papers, an increasing number of features, such as uncertainty or strategic behaviors, have been introduced. Due to the SIDS' impossibility of implementing mitigation, the analysis in this thesis is related to this second group of papers, which is less developed than the first one.

Second, I use the classification of Tol et al. (1998) to distinguish empirical papers on adaptation in three groups. Some authors try to compute cost-benefits analysis according to scenarii in climate change and adaptation. Others study the optimal adaptation investments according to a welfare function and the cost of certain measures. Finally, some authors study the existing adaptation strategies in order to assess their efficiency and to predict if they can be used in analog situations. Most of the papers on adaptation in SIDS are in the latter category (Mercer et al. (2012), Robinson (2017), Murray and Watson (2019)). In fact, given their present and future experience of climate change damages, SIDS are expected to be early adopters to climate change. However, literature reviews on SIDS show that climate change adaptation in SIDS is difficult to tackle because of technical, institutional and finance limits (Scobie (2016), Thomas and Benjamin (2018), Klöck and Nunn (2019)). Indeed, most of the SIDS are caught in a low growth/high debt trap (Greenidge et al. (2010), Alleyne et al. (2017)). Consequently, the possibilities to fund climate change adaptation through taxes or international capital market are sparse. In addition, even when adaptation investments are made, they are often inefficient because there are institutional, capacity, and sometimes cultural constraints on traditional adaptation solutions used in other countries (Klöck and Nunn (2019)).

Therefore, in the demographic context of Caribbean islands, it is crucial to study the migration induced by climate change damages. Indeed, many researchers–as well as many public decision-makers–claim that migration will increase with climate change.

For instance, works such as Marchiori and Schumacher (2011), show that human displacements increase if no mitigation strategies are implemented by large emitters of GHG. According to this result, empirical papers try to predict a correlation between the evolution of migration and climate change. Their work is based on observations of environmental factors such as rainfall variability, precipitation volume or increase in temperature. While it is not possible to conclude that international migration will increase in all impacted areas (Hugo (2011)), internal migration might increase with climate changes and/or variability (Barrios et al. (2006), Farbotko and Lazrus (2012), Lilleor and den Broeck (2011), Marchiori et al. (2012), Nawrotzki et al. (2015), Thiede et al. (2016)). For small islands, it is reasonable to state that those internal migrations might be insufficient to cope with damages because the entire society can be impacted (Murray and Watson (2019)). Furthermore, there could be interactions between migration and other adaptation tools, in particular in countries where the number of emigrants is high. For instance, Julca and Paddison (2010) or Hugo (2011) link the vulnerability to climate change of SIDS to migration impact, and more peculiarly to remittances. The first study concludes that migration or remittances could be helpful, while raising the issue of dependence on remittances for these economies. The latter find that sending areas will experiment many different economic, demographic and social adjustments that are difficult to anticipate.

There are only a few papers in the literature that study the choices between two types of adaptation, and even fewer that focus on the interaction between migration and adaptation. Therefore in the third chapter of this thesis, I try to understand how SIDS policy makers should implement short-term adaptation or migration strategies to manage the impacts of climate change.

0.4 Ouline and results

Several questions emerge from the description of the Caribbean context and from the literature related to our topics. Three of them are treated in the following chapters.

0.4.1 Chapter 1: Migration, remittances and capital stocks in Caribbean SIDS

Problematic and Method

In Chapter 1, we answer the following question: what is the impact of remittances on economic growth?

We proceed with a two-stage approach. First, we formulate a theoretical framework designed to assess the effect of migration on intertemporal household choices. Specifically, we scrutinize the level of savings as well as the demographic choices in terms of fertility and education. Overlapping Generations (OLG) models are well-suited to deal with dynamics of economic growth and demographic structure affected by intergenerational choices, such as fertility or education spending, or by migration and remittances (Marchiori et al. (2008), Docquier and Rapoport (2012), Delogu et al. (2018)). In the first chapter's framework, an individual lives three periods. In the first, they are children that receive an education according to the investments of their parents. In the second, if they stay on the island, they work and allocate their income to children's education, consumption, or savings, knowing that having children implies a cost in terms of time. This cost introduces a congestion effect *i.e.*: if the population density is high, it is more costly to have children.[20] Moreover, they transfer a share of their second period income to their parents. Finally, during the third period, they use their savings or the transfers from their own children to fund their consumption.

In the model, migration intervenes between childhood and adulthood. If people migrate, they do not participate in the economy, but they transfer a share of their income abroad–which is higher than in the domestic area–to their parents. Consequently, households face three tradeoffs. First they choose between adult and old age consumption. Second they also choose between savings or investing in children. Finally, they decide whether they increase the number of children or the given education per child in order to receive more transfers. Migration changes relative gain from education because of the higher wages in the destination countries. The proposed model is kept as tractable as possible in order to underline the main mechanisms regarding the tradeoff between savings and education.

[20] This aspect is introduced as in de la Croix and Gobbi (2017), de la Croix and Gosseries (2012)

However, due to the intricate dynamics involved in the model, the overall effect of migration is not clear. Hence, as a second step, thanks to the model calibration, we focus on five Caribbean islands–Barbados, Dominican Republic, Haiti, Jamaica as well as Trinidad and Tobago. In particular, we conduct a counterfactual analysis on the main parameters of the model that control the effects of migration. Thanks to changes in the values of the parameters controlling the gain from migration, we are able to evaluate the impact of a migration policy. These policies can foster the emigration–thanks to bilateral arrangements, for example–or encourage return from migrants–thanks to tax reduction for instance.

Results

With the theoretical model laid out in this paper, we find that migration has a positive impact on education expenditure, fertility, human capital stock and production. This result is in line with migration models such as Mountford (1997), Beine et al. (2006) or Docquier et al. (2008). More importantly, we find a strong substitution effect induced by migration gains between returns from domestic savings and those of investments in human capital. Consequently, migration can adversely affect physical capital accumulation due to the substitution effect induced by remittances dominating the income effect in the economy. One should expect to see a negative correlation between remittances and domestic savings, but not necessarily between the former and capital stock. The relationship between economic growth and migration is thus defined by an inverted U-shaped curve. When the emigration rate increases, there is an initial increase in all the stocks, until it reaches a threshold where the substitution effect is too high or the labor force reduced. This leads to a strong contraction of productive stocks–stocks of efficient labor and of capital.

The numerical analysis is conducted thanks to data on the Caribbean islands sample. It shows that the Dominican Republic, Haiti and Jamaica have developed a *migration* strategy that leads to a higher stock of efficient labor, while Barbados and Trinidad and Tobago invest more in physical capital because the gains from migration are reduced–due to the low level of remittances received. In the counterfactual study, countries with high emigration rates or high potential gains from migration appear to be so dependent on incoming flows of remittances that they have only two paths to increase their long-term economic growth. The first one is when these countries become fully dependent of remittances while decreasing domestic intergenerational transfers. However, in such an outcome they should not capture the whole of the diaspora income because of negative effects from the substitution between domestic savings and fertility as well as education expenditures. The second case is when they can decrease their emigration rate in order to reduce the substitution effect, which hampers their economic growth. In these countries, specialization in migration is high enough that they lose all other opportunities of development, should they maintain their current migration choices. In other countries, where the incentive created by migration is not high, policymakers should increase domestic intergenerational transfer, while trying to capture the totality of the diaspora income. Indeed, international transfers in that case do not create an income effect on the contrary of the intergenerational transfers for the adult generation.

To sum-up, in this chapter using a theoretical approach and a counterfactual analysis, we are able to characterize the effect of migration on economic growth through the savings channel. The novelty of this work relies on the explanation of the savings choices in a context where migration increases the incentives to invest in children. We were thus able to define the critical conditions to obtain a *brain gain* and enhancement of physical capital stock, instead of a pure substitution between these two productive assets.

0.4.2 Chapter 2: Migration, pollution and human capital in Caribbean SIDS

Problematic and Method

In Chapter 2, we answer the following question: what is the effect of migration if environmental degradation has an impact on the cognitive skills and thus on the *brain gain*?

To answer this question, we introduce a pollution externality on human capital accumulation within the model developed in the previous chapter. As in the first chapter, households' decisions in terms of savings, fertility and education are examined. However, in the present model, households take a decision in terms of education expenditures, while they are not able to anticipate or take into account the environmental externality on their children's abilities. This externality directly impacts the efficiency of human capital accumulation, which represents the ability of one to acquire human capital, whether it comes from the parents' transmissions or the education received. To correct this environmental externality, the policymaker introduces a tax on pollution emissions.

Similar to the preceding chapter, we use a two-stage approach to analyze the model. First, some analytical results are explored using comparative statics. Second, in order to clarify some trends of this model, a numerical analysis on the steady-states expressions is conducted. This allows us to evaluate the impacts of environmental tax and the different parameters linked to emigration.

Results

In this chapter, there are still two tradeoffs: between savings and intergenerational transfers and between quality and quantity of children. The results differ strongly from the first chapter's tradeoffs. Positive effects from migration depends now on migration characteristics and on environmental damage function.

In the first chapter, we have found a positive effect of emigration or remittances on human capital or production until a threshold is reached, where the investments in physical capital are too small to sustain the economy. In the second chapter, the long-term relationship between production or human capital and emigration rate is described by a U-shaped curve. Indeed, if migration is low, an increasing emigration rate leads to a rise in population size because it increases the incentive to have children. Consequently, with a larger population base, the production is also larger as well as pollution emissions. However, the steady-state production per capita and the utility are reduced. After a threshold is reached, pollution emissions decrease due to the reduction of population size. Moreover, a rise in emigration, remittances or domestic intergenerational transfers leads to a decline in the long-term level of physical capital in most of the cases, because of the combined effects of the decrease in human capital, population and the substitution effect. In every case, environmental tax improves the situation if the pollution intensity of production is small enough. If emissions are high, the tax must be set at a level that abates almost all the emissions of pollution. Indeed a high pollution intensity associated to a small tax still results in a decrease in human capital and in capital stock in the first periods of the economy. The problem is that future human capital accumulation depends strongly on past level of human capital.

Hence, in the short term, this reduction puts the country on a path where productive stock accumulation is slower, and thus where the steady-state values will be lower on the long-run.

In conclusion, in this chapter, we characterize the interplay between migration and pollution externality on human capital, thanks to the inclusion of the environmental dimension in our previous theoretical framework. The novelty of this work relies on the explanation of the changes on the conditions to obtain a *brain gain* as well as a larger steady-state level of consumption in the presence of an environmental externality.

0.4.3 Chapter 3: Confronting Climate Change: Adaptation vs. migration strategies

Problematic and Method

In Chapter 3 we answer the following question: how should SIDS policymakers implement short-term adaptation or migration strategies to manage the impacts of climate change?

To answer this question, we develop a theoretical model where we adopt a centralized perspective to assess the optimal policy of a SIDS facing the negative repercussions of climate change. Since both climate change and adaptation process involve a temporal dimension, we develop a dynamic framework in which the policymaker has two means to cope with climate-related damages: a *migration strategy* and an *adaptation strategy*. The objective is to maximize the total utility which is derived from consumption, knowing that there is a cost of migration, but that it is possible to receive remittances.[21] The technology of production incorporates labor and natural capital which decreases at a continuous rate because of climate change. Economic conditions on the island are directly linked to two sources of wealth. First, wealth has a local component thanks to the production of a final good. An active migration policy induces a contraction of the output because of a decreasing labor force, but also more remittances received from abroad. This forms the second external source of funding of the economy.

[21] There is no fertility in this chapter, changes in the domestic population size or the diaspora, are entirely driven by the rate of emigration.

Varying the population size has two effects. It releases the pressure on natural assets and it affects welfare both directly (*cf.* the total utility criterion) and indirectly by changing the amount of per capita consumption. There is a direct cost of adaptation in terms of foregone consumption, while the benefit stems from the capacity to maintain the stock of natural capital to a higher level and for a longer period of time. The analysis of the optimal policy is conducted in two phases. The first one is devoted to a theoretical investigation, with the second one consisting of a calibration of the model. The analysis of intertemporal decision problem is challenging because it produces a four-dimensional dynamic system. There are four different regimes, depending on whether the two instruments, migration and adaptation, are operative or not. To circumvent these difficulties, in a first step, regimes with only one tool are studied. In a second step, the results are combined to understand what is going on in the regime where both instruments are used.

To dig further into the analysis of the nature of the optimal policy, we finally resort to a calibration of the model to real-world data. This calibration is a way to emphasize the role of the initial conditions, which are the initial size of the population and the initial endowment in natural capital. More importantly, this exercise ultimately helps us understand which policy is optimal for which SIDS, given its characteristics. It also allows us to explain when adaptation and migration, as policy instruments, prove to be complements or substitutes.

Results

From the theoretical investigation, we obtain two conditions that shed some light on the SIDS' preferred policies to deal with climate change. One condition is linked to migration while the other defines the use of adaptation strategy. If migration is implemented, the emigration rate decreases until the optimal size of the population is reached. If a policymaker chooses to conduct an adaptation strategy, they will stick to this strategy permanently. This strategy allows a larger population and natural capital in the domestic area. According to the evolution of the natural capital and the population size, it is possible to start in a situation where one (or none) of the tools is used and to switch to a regime where both tools are (or one is) implemented.

Utilizing the calibration exercise, we observe that the conditions of the theoretical model depend strongly on the population size. In fact, small changes in the natural capital endowment in the initial period do not really impact the policymaker choice, while the size of the population directly defines whether there is complementarity or substitution between the two tools. In this calibration, the group of the bigger countries such as Jamaica, Haiti or the Dominican Republic, implement the two tools. Most of the smaller islands only implement one tool–migration–and for these islands, there is a substitution between the migration and the conventional adaptation strategy. However, this situation is not necessarily permanent.

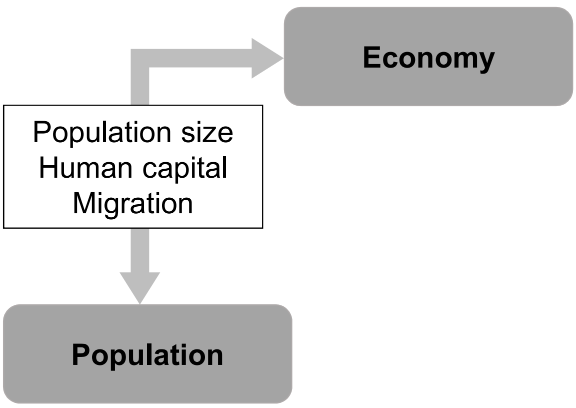
In conclusion, in this chapter, thanks to a theoretical framework and a calibration, we are able to characterize the optimal policy mix between migration and conventional adaptation measures. The novelty of this work relies on the combination of two types of adaptation strategies, knowing that most of climate change studies focus on the tradeoff between adaptation and mitigation.

Chapter 1

Migration, remittances and capital stocks in Caribbean SIDS[1]

Abstract

This paper adapts an OLG model framework in order to capture the economic and demographic effects of remittances and migration in countries such as the Caribbean islands. We scrutinize household decisions on education spending, fertility and savings where the elderly receive remittances and domestic transfers from the active generation. In a given economy, the model predicts that migration boosts education spending at the expense of the savings. The model also predicts inverted U-shaped curves between remittances and physical capital as well as economic growth because of this substitution effect. Furthermore, numerical simulations of the model and counterfactual analysis on five Caribbean islands show that different strategies towards migration seem possible in order to increase the economic gains, depending on the scale of migration or the transfer rate.



[1]This chapter is a joint work with Zouhair Ait Benhamou. An earlier version is available as Ait Benhamou and Cassin (2018)

1.1 Introduction

In 2017, the remittances received in the Caribbean Small States represented 6% of this group's GDP, according to the World Development Indicators of the World Bank. As said earlier in the general introduction, this share can even be higher in countries such as Haiti or Jamaica, where it exceeds 15% of the national GDP. Although there are definite effects of remittances on receiving countries, the literature fails to reach a consensus regarding their magnitude or their effect on economic growth. Indeed, remittances can provide funding for economic development, in the form of increased investment in human capital, or relaxing credit constraints for further physical capital accumulation. However, several studies find insignificant effects or even adverse effects–*e.g.* increased informality (Brown et al. (2013); Raza and Jawaid (2014); Opperman and Adjasi (2019)) a Dutch disease (Acosta et al. (2009)) or capital volatility (Nyamongo et al. (2012); Imai et al. (2014)).

In this paper, we place emphasis on the key features of interactions between remittances, demographic dynamics and economic growth. Indeed, the literature provides exhaustive insights into the relationship between remittances and financial development or human capital. However, we lack descriptions of the interactions between domestic savings and remittances, knowing that there are the main engine of physical capital accumulation and thus recognized as one of the sources of economic growth. The main goal of this work is therefore to fill these gaps answering the following crucial questions. What are the impacts of remittances on the savings in the sending area? Do remittances promote economic growth and at which conditions?

According to Guzmán et al. (2006), demographic transition–defined as the simultaneous reduction of the fertility and the mortality–represents an economic opportunity for the Caribbean, thanks to the increase in productive capital *per capita*. The high emigration is expected to have a positive economic impact since it amplifies the effects of the demographic transition and leads to additional economic returns, in the form of remittances. However, emigration alters the determinants of fertility or education–*e.g.* the cost of raising children or the potential remuneration of human capital, etc.–and thus can change strongly the demographic dynamics of countries with large emigration rates.

In this chapter, we present a tractable OLG model, close to the models developed in

Marchiori et al. (2008, 2010), knowing that in these papers, the impact of remittances on savings is completely ignored. The model's features of chapter 1 seek to capture the various tradeoffs faced by the households. In particular, we focus on the effects received remittances may have on domestic savings, as well as capital accumulation. The model highlights how potential gains from education and migration–in the form of higher future remittances–may affect households' decisions on savings, fertility and education expenditure. If future gains stemming from received remittances outweigh those of capital accumulation, households may decide to shift their investment schedule over to fertility and education expenditure, thus lowering the amount of resources allocated to physical capital accumulation. The model also describes the dual tradeoffs on household's inter-temporal consumption, as well as old age pension sources–*i.e.* capital investment or expected remittances from their offspring.

The next step of our analysis is then to focus on five Caribbean islands–Barbados, Dominican Republic, Haiti, Jamaica as well as Trinidad and Tobago. We conduct a counterfactual analysis in order to study the impact of migration for these countries, with respect to their demographic features. Second we introduce changes in their structural parameters, in order to reproduce policies on the remittances and the migration rate. Some of these policies have been originally implemented in sending countries with high level of migration and remittances–*e.g.* in Asian countries (Athukorala (1993a,b); Desai et al. (2004)).

Thanks to the theoretical model, we find that migration has a positive impact on education expenditure, fertility, human capital stock and production. This result is in line with Beine et al. (2006) or Docquier et al. (2008). Nevertheless, there is a strong substitution effect induced by migration gains between returns from domestic savings and those of investments in human capital. Here, migration can affect adversely physical capital accumulation if the substitution effect induced by remittances dominates over the income effect in the economy. Consequently, one should expect a negative correlation between remittances and domestic savings, but not necessarily with the capital stock.

The numerical analysis shows that countries as Dominican Republic, Haiti and Jamaica exhibit higher level of emigration and thus have developed a *migration* strategy. Due to the incentives to invest in education or fertility induced by migration, these countries exhibit a higher stock of units of efficient labor. On the contrary, countries as Barbados and Trinidad and Tobago invest more in physical capital because the gains from migration are reduced. This is due to the small difference between remuneration abroad and in the domestic area, or the low amount of received remittances. Second, in our counterfactual study, we show that countries with high specialization in migration may lose all other opportunities of development, should they maintain their current migration choices. Indeed, in order to enhance their economic growth their first option is to set their domestic intergenerational transfer to zero and to become fully dependent of remittances. However, in such an outcome, they should not capture the whole of the diaspora income because of the negative effects from the substitution between domestic savings and investments in children. Another solution is to decrease their emigration rate in order to reduce this substitution effect which hampers their economic growth. On the contrary, in countries with small incentives created by migration, domestic intergenerational transfers should increase and it is optimal to capture the totality of the diaspora income. In their case, international transfers do not create strong negative income or substitution effects.

The rest of the paper is structured as follows. Section 1.2 gives some Stylized Facts on the Caribbean islands. Section 1.3 introduces the modified OLG model. Section 1.4 highlights key results through equilibrium analysis, while section 1.5 presents results from numerical simulations for our five islands sample. Finally, the last section draws conclusions.

1.2 Stylized Facts

Although the model presented in this chapter is focused on Caribbean SIDS countries, we seek to ground its hypothesis in global empirical facts. Indeed, our idea is that Caribbean countries exhibit characteristics that exacerbate the effect of migration and remittances on savings. However, the mechanisms involved are not specific to this region. Therefore, we should be able to observe them but with lesser effects in other territories. This is why, in this section, we present stylized facts on fertility and savings with respect to the migration features in a global perspective.

We formulate a specification to explain fertility. We select a number of variables that can be used as proxies for determinants of fertility as well as variables which are relevant to the model. We use data from WDI and the University of Pennsylvania World Table (PWT) datasets to build a sample set of 141 countries. Their long-run averages are computed for the period 1961-2014 or any available data points within that time period. The benchmark specification writes:

$$FERT_i = \alpha_0 + \alpha_1 GDP_i + \alpha_2 HC_i + X_i'\delta + \varepsilon_i \tag{1.2.1}$$

For each country i, $FERT$ denotes fertility–measured as the average number of children per women. GDP refers to real GDP *per capita*, and HC to the human capital index developed by Barro and Lee (2013). X' is a vector with the additional controls we incorporate in the different specifications. First, we incorporate net migration relative to total population, as well as remittances, computed in their real monetary value in *per capita* terms. In addition, we also incorporate a factor variable that seeks to capture the regional effect, using the OECD country group as the baseline category. The 141 countries are broken down according to their respective geographical areas: Sub-Sahara Africa, South Asia and Pacific, the Caribbean, Central-Eastern Europe and Balkans, Latin American and Middle East and North Africa. The regional dummy seeks to capture category-specific heterogenous effects. Odd-numbered specifications incorporate the regional dummy effects, while even-numbered ones do not.

Table 5 reports the estimated coefficients α_i, and the vector of controls' coefficients δ. We also display summary statistics that offer a broader picture of each specification's reliability. Specifications (1) and (2) regress fertility on real GDP and Human capital index. Specifications (3) and (4) incorporate an interaction term, one that takes into account the covariates between human capital and real GDP *per capita*. For all intents and purposes, the interaction effect between real GDP and human capital seeks to filter out separate estimates for both variables and their influence on fertility. Specifications (5) to (8) incorporate further controls: (5) and (6) take into account the migration effects on fertility by using net migration relative to total population as a proxy.

Before going further, it is important to describe the migration data. Indeed, obtaining reliable data on emigration is quite challenging. In the WDI dataset, all migration information is obtained thanks to census in the receiving countries, that measure the size of the immigrants group from each country. The bilateral immigration flow from a country j to a country i, is thus defined as the evolution of the legal migrants stock from the country j between two dates (in this dataset, they retain a 5-year time gap). Total immigration in the country i is the sum of all these bilateral immigration flows. In the perspective of the sending country the dataset comprises the numbers of nationals living in other countries. Therefore, bilateral emigration flow to another country is computed as the change in the diaspora between two dates. Total emigration from the country i is the sum of all these bilateral emigration flows. Finally the Net Migration given in the WDI dataset, is the difference between the total immigration and the total emigration that have been measured during this 5-year gap. Consequently, a change in the net migration could be due to a change in the immigration and/or in the emigration. Moreover it is not possible to know when exactly the migrants have entered or left the country. In our analysis we do not correct all these elements but take long-term average of the net-migration relative to domestic total population. This is why, the net migration data from the WDI dataset is considered as a proxy for the net migration, instead as the true migration data.

Finally, specifications (7) and (8) add remittances expressed in *per capita* terms and logged values. Table 6 reports the details of the regional effects and thus the results of specifications (1), (3), (5) and (7) for the regional dummies. All specifications account for a substantial share of variance in the fertility rate among the sample set: the adjusted R^2 values range from 0.781 to 0.870, which is a significant result and *prima facie* case that our model is grounded in empirical facts.

Real GDP *per capita* and the Human capital index exhibit a negative and statistically significant relationship with fertility =for all specifications (1) through (8). This is an expected result, since the literature has produced evidence that as countries become wealthier and more intensive in human capital, one would expect a decline in fertility.

Furthermore, looking at specifications (1) and (2), the regional dummy effect on the covariate between real GDP *per capita* and fertility does not seem to be large. Indeed, the estimated coefficient of the covariate does not change significantly, and retains its high degree of statistical significance. By contrast, there are important changes for the estimated coefficient of human capital–it is more than doubled when the regional dummy effect is taken into account, even as it remains statistically significant. This suggests that there is a region-specific characteristic for human capital and fertility, which is observed in almost all regional groups relative to the OECD. This is also confirmed as we compare the adjusted R^2 for specifications (1) and (2). In table Table 6, the Caribbean regional group in particular exhibits a statistically significant higher fertility rate relative to the OECD, though not as high as observed in other regional groups of emerging economies. Specifications (3) and (4) alter slightly the estimated coefficients for GDP and human capital index, as they take into account the interaction effect between GDP and the Human capital index. However, the estimated coefficient is not statistically significant.

Large flows of immigration–measured as positive net migration relative to total population–are associated with high fertility, the estimated coefficient is statistically significant. This is due to the fact that fertility is higher in poorer countries, and that a substantial share of migrants worldwide come from those countries. As a result, the estimated coefficient for net migration will be positive, as the host country benefits from a higher migrant fertility. Nevertheless, note that the coefficient changes significantly whether the regional dummy effect is taken into account–specification (5) more than doubles the estimated coefficient when the regional dummy is taken out in specification (6).

In particular, specifications (7) and (8) are relevant to the model when remittances *per capita*–in log terms–are incorporated. Remittances are positively correlated to the fertility, even when the regional effect is taken into account. The interaction variable between Human capital index and real GDP *per capita* is positive but statistically not significant, except for specification (8). In this case, the influence of net migration and remittances *per capita* is such that the interaction effect between human capital and GDP is positively correlated with fertility.

Table 5: Fertility - number of children per woman: 1961-2014.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Real GDP *per capita*	-0.409***	-0.384***	-0.606***	-0.587***	-0.656***	-0.753***	-0.887***	-0.909***
	(0.084)	(0.086)	(0.178)	(0.188)	(0.178)	(0.167)	(0.18)	(0.157)
Human Capital Index	-0.592***	-1.608***	-1.437	-2.385***	-1.334*	-2.261***	-1.847***	-2.501***
	(0.202)	(0.194)	(0.902)	(0.738)	(0.879)	(0.688)	(0.837)	(0.63)
Human Capital Index x GDP			0.104	0.097	0.093	0.107	0.141	0.126*
			(0.097)	(0.083)	(0.095)	(0.076)	(0.091)	(0.07)
Net Migration (% Population)					3.804**	8.426***	1.109	5.674***
					(1.759)	(1.259)	(2.065)	(1.671)
Log Remittances *per capita*							0.152***	0.157***
							(0.054)	(0.048)
Intercept	7.745***	10.478***	9.181***	12.035***	9.655***	12.908***	11.349***	13.866***
	(0.753)	(0.381)	(1.515)	(1.383)	(1.5)	(1.245)	(1.451)	(1.162)
Count	141	141	141	141	141	141	137	137
R2	0.868	0.783	0.87	0.785	0.874	0.809	0.886	0.828
Adjusted R2	0.86	0.78	0.861	0.781	0.864	0.804	0.876	0.822
RSS	57.395	94.588	56.666	93.471	55.062	83.063	49.251	74.176
RMSE	0.659	0.828	0.658	0.826	0.651	0.782	0.628	0.752
Fisher	179.053	356.065	175.288	276.66	170.372	232.106	150.34	190.889
Log-Likelihood	-136.705	-171.925	-135.803	-171.087	-133.779	-162.764	-124.315	-152.367
Regional Dummy	YES	NO	YES	NO	YES	NO	YES	NO

Note: Dataset built using WDI and PWT databases. Non-weighted averages are computed over the period 1961-2014 or any available data points within the time period. Specifications (7) and (8) drop 4 countries from the sample set due to data points unavailable for remittances. Dummy regional variables refer to unweighted five regional groups in addition to the OECD baseline. Estimated coefficients of the regional dummy effect refer to regional mean group difference with respect to OECD group. Estimated results are reported with standard errors in parenthesis. Levels of significance are referred to with stars.
Legend *** p $\leq$ 1%, ** 5% and * 10%.

In order to show how the Caribbean region group fares in comparison to other developing and emerging economies, we also report on table 6 the estimated coefficients for the regional effects. Using the OECD regional group as base level, we can see that the Caribbean group has indeed a higher (and statistically significant) fertility than the base level, when controlling for various effects. Note that in the other regions, the difference with the OECD group is higher and significant too, except in South Asia and in Central-Eastern Europe.

Table 6: Fertility (regional effects) - number of children per woman: 1961-2014.

Variable	(1)	(3)	(5)	(7)
Regional Group (OECD Base group)				
MENA	1.877***	1.885***	1.635***	1.655***
Latin America	0.815***	0.895***	0.795***	0.815***
C&E Europe	-0.22	-0.173	-0.265	-0.287
Caribbean	0.469*	0.541**	0.521**	0.532**
South Asia	0.452	0.472	0.329	0.313
Sub-Saharan Africa	1.849***	1.886***	1.696***	1.678***
Count	140	140	140	136
R2	0.867	0.868	0.872	0.874
Adjusted R2	0.859	0.859	0.862	0.862
RSS	57.342	56.959	55.514	54.161
RMSE	0.662	0.662	0.656	0.661
Fisher	175.618	160.324	154.196	143.505
Log-Likelihood	-136.169	-135.699	-133.901	-130.369

Note: For comments, see table 5 above.
Legend *** p $\leq$ 1%, ** 5% and * 10%.

The specification in equation 1.2.1 is augmented to describe domestic savings as a function of similar explanatory variables. The second specification writes:

$$S_i^d = \alpha_0 + \alpha_1 Remitt_i + \alpha_2 HC_i + \alpha_3 Kap_i + X_i'\delta + \varepsilon_i \tag{1.2.2}$$

Domestic savings S^d are regressed on remittances (expressed in logged real 2005 \$), the Human capital index, physical capital stock (in logged terms), and additional explanatory variables in vector X_i'. This vector incorporates variables for relative wealth measured through the GDP ratio of each country in the sample set relative to average OECD real GDP per capita, foreign capital flows, and demographic indicators–*i.e.,* migration scale and flows–whether it is immigration or emigration.[2] All specifications account for a substantial share of variance in the savings among the sample set: the

[2]The specification reported in table 7 does not incorporate regional dummies in contrast with table 5.

adjusted R^2 values range from 0.906 to 0.926. The balance effect of migration is captured by the dummy variable 'Sign', which takes the value of 1 if the migration balance is negative and 0 otherwise. The monetary variables are all expressed in logarithmic terms.

All specifications (1) through (5) show that remittances and domestic savings are negatively correlated, which is in line with our model's predictions. The estimated coefficients vary slightly from one specification to the other, but they remain statistically significant: in real terms, a 1% increase in received remittances is associated with a decline in savings ranging from -2.2% to -6.1%. Such an explanation is further bolstered by the estimated coefficient for human capital–the index correlates negatively with domestic savings. The higher the returns from human capital are, the lower the incentive to save.

In contrast, there is a positive relationship between domestic savings and physical capital stock. The estimated coefficient is positive and fits well with our predictions that higher capital stock correlates with higher levels of domestic savings. The estimated coefficient declines significantly–without losing its statistical robustness–in specifications (3) through (5), which means that the capital stock is affected by other explanatory variables in these specifications. Physical capital elasticity depends on the specification, as it ranges from 0.56 to 1.38. The interaction effect between physical and human capital is positive and statistically significant. This lends credence to the underlying assumption of increasing returns to physical capital *per capita*, owing to the education effects on human capital.

Relative GDP is computed as the ratio of real GDP to OECD-wide average real output. There are decreasing returns in domestic savings. The estimated coefficient remains statistically significant and robust to all three specifications (3) through (5). Finally, the demographic indicators also generate predicted results. Positive net migration–relative to the total population–means that the country receives more than it sends in population flows. This is mainly associated with developed economies whose domestic savings *per capita* are higher, with all things being equal.

We supplement the stylized facts reported above with additional data on fertility and density in a large country sample. The figure below plots logarithmic density per square kilometer against fertility, measured by the average number of children per woman in a sample set of 205 countries between 1960 and 2018. The sample set is

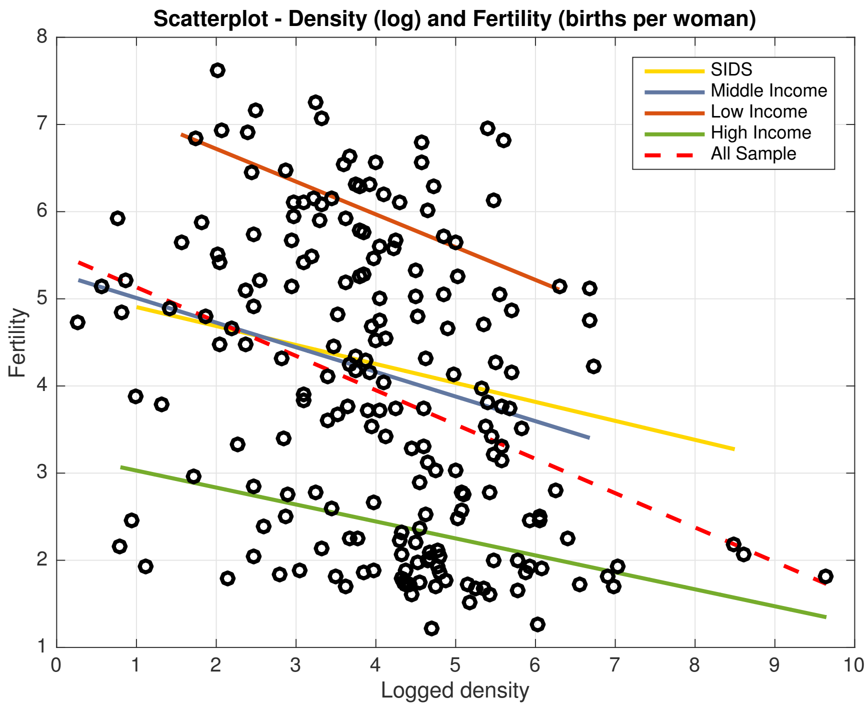
Table 7: Domestic savings : 1961-2014

Variable	(1)	(2)	(3)	(4)	(5)
Remittances	-3.354***	-3.262***	-2.241**	-4.741***	-6.103***
	(1.127)	(1.114)	(1.074)	(1.380)	(2.219)
Human Capital Index	-0.124	-1.515**	-3.193***	-2.314***	-2.314***
	(0.115)	(0.678)	(0.750)	(0.768)	(0.793)
Physical Capital Stock	1.389***	1.134***	0.570***	0.565***	0.571***
	(0.059)	(0.136)	(0.184)	(0.179)	(0.179)
H.C x P.C		0.138**	0.306***	0.230***	0.216***
		(0.066)	(0.074)	(0.075)	(0.077)
Relative GDP			-0.016***	-0.017***	-0.017***
			(0.004)	(0.004)	(0.004)
FDIs					0.001
					(0.001)
Net Migration (% Population)				6.189**	7.711***
				(2.399)	(3.089)
Net Migration (sign)				-0.217*	-0.188***
				(0.129)	(0.134)
Intercept	-6.275***	-3.782***	1.955	1.938	1833
	(0.412)	(1.266)	(1.800)	(1.736)	(1.744)
Count	133	133	133	133	133
R2	0.908	0.911	0.922	0.930	0.930
R2 Adjusted	0.906	0.909	0.919	0.926	0.926
RSS	41.567	40.208	35.210	31.633	31.477
RMSE	0.568	0.560	0.527	0.503	0.503
Fisher	426.530	329.227	302.024	238.360	207.999
Log-Likelihood	-111.376	-109.166	-100.339	-93.216	-92.886

Note: Dataset built out of WDI and PWT databases. Non-weighted averages are computed over the period 1961-2014 or any available data points within the time period. Logged savings are expressed in real Dollars and regressed over explanatory variables. Remittances, Physical capital stock and foreign direct investment (FDIs) are all expressed in logged real 2005 Dollars. Sign for net migration is a dummy variable which takes 1 if net migration relative to population is negative, 0 otherwise. The sample set of 133 countries is smaller than that used in table 5 due to data availability for the selected indicators. Estimated results are reported with standard errors in parenthesis. Levels of significance are referred to with stars.
Legend *** p $\leq$ 1%, ** 5% and * 10%.

then broken down into sub-categories according to the World Bank ATLAS income methodology. A separate SIDS group category is created using the UN methodology. The figure shows that the whole sample, as well as the different income and SIDS categories exhibit a downward sloping linear fit between logged density and fertility. There are however slight differences as to the sloping coefficients, suggesting that the relationship between the decline in fertility as density rises is not uniformly distributed across levels of income. Low income countries exhibit the steepest slope, which suggests that in these economies, a modest increase in logged density is associated with sharper decline in fertility–which may be accounted for by the fact that the initial levels of fertility are highest among the poorer countries in the sample. SIDS countries exhibit a flatter linear fit in comparison to the whole sample, and tend to mirror the sloping coefficient of High income countries instead.

Figure 10: Correlation between logged density and fertility. Average values 1960-2018.



1.3 The Model

Three main information can be driven from the stylized facts section. First, remittances are positively correlated to the fertility. Second, they are negatively correlated to the savings per capita. Third fertility, decreases with population density. In the present section, we develop a model that can reproduce the characteristics and the mechanisms that might be involved in these stylized facts. We use an OLG model, with discrete time indexed by $t = 0, 1, 2, ..., +\infty$.[3]

1.3.1 Firm behavior

The final good is produced by a representative firm. She combines units of efficient work, $L_t h_t$–where $L_t h_t$ is the efficient labor demand–and capital stock, K_t, following a constant returns to scale output production technology:

$$Y_t = AK_t^{\alpha} (L_t h_t)^{1-\alpha} \tag{1.3.1}$$

In this function, $A > 0$ measures the technology level and $\alpha \in (0, 1)$ is the share of physical capital in the production. Defining $y_t \equiv \frac{Y_t}{L_t h_t}$ and $k_t \equiv \frac{K_t}{L_t h_t}$, respectively, as the production and the capital to efficient units of the labor ratio, we write the following:

$$y_t = Ak_t^{\alpha} \tag{1.3.2}$$

The firm profit is as follows:

$$\Pi_t = AK_t^{\alpha} (L_t h_t)^{1-\alpha} - w_t h_t L_t - R_t K_t \tag{1.3.3}$$

where w_t is the wage for an unit of efficient labor and $R_t \equiv 1 + r_t$ is the return factor of capital, with r_t the interest rate of capital. Assuming that capital fully depreciates in one period, factor prices write as follows:

$$w_t = A(1-\alpha)K_t^{\alpha} (L_t h_t)^{-\alpha} = A(1-\alpha)k_t^{\alpha} \tag{1.3.4}$$

$$R_t = A\alpha K_t^{\alpha-1} (L_t h_t)^{1-\alpha} = A\alpha k_t^{\alpha-1} \tag{1.3.5}$$

1.3.2 Family behavior

The representative household lives through three periods: childhood, adulthood, and old age. At t, a new generation of $n_t N_t$ homogenous agents is born, where n_t is the number of children per household. As in de la Croix and Gosseries (2012), n_t is chosen by the adults of period t, knowing that raising n_t children takes a fraction of the

[3] Each period is assumed to last twenty to thirty years

parents income linked to the population size N_t.[4] Therefore, there is a congestion component in the cost of raising children, which means that the higher the population density is, the more costly fertility is. This assumption is in line with works such as de la Croix and Gobbi (2017) or Sibly et al. (2002), which describe the negative correlation between fertility and population density in developing countries. Second, in the stylized facts section, we have verified that the fertility is negatively correlated to the population size. And in all countries this negative relationship is observed.[5] Therefore we denote raising children takes a fraction $\sigma N_t^{\delta} n_t$ of the income, where $0 < \delta < 1$ captures the overcrowding effect.

We denote the emigration rate by $\rho \in [0, 1[$. Migration implies that only $(1 - \rho)n_t N_t$ children stay in the domestic country after childhood. 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 the following equation:

$$N_{t+1} = n_t N_t (1 - \rho) \tag{1.3.6}$$

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

$$U(c_t, d_{t+1}) = \ln(c_t) + \beta \ln(d_{t+1}) \tag{1.3.7}$$

During childhood, individuals are reared by their parents and do not make any decisions. If they remain in their home country as adults, they supply one inelastic unit of labor, remunerated at wage w_t, per unit of human capital h_t. Adults transfer a fraction γ of their revenue to their parents and use a share $\sigma n_t N_t^{\delta}$ for raising children. They allocate the rest of their income to consumption c_t, savings s_t and children's education $n_t e_t$. Adults who have migrated also transfer the same share γ of their revenue to their parents. However, they can claim a higher wage in their country of residence, which we posit is proportional to the domestic wage, such that $w_t^F \equiv \varepsilon w_t$, where $\varepsilon > 1$ denotes the net gain from migration. In our economy, incoming cash

[4]Note that in the paper of de la Croix and Gosseries (2012), the cost for rearing children σ was defined as a combination of parameters for available land, (T) fertility productivity factor, (λ), and weight of land in the children cost, (δ): $\sigma \equiv \frac{1}{\lambda T^{\delta}}$. Here we simplify this expression by using directly σ.

[5]Moreover, this allows to have a constant population in the long run.

flows from migrants are remittances, while transfers from domestic workers are simply intergenerational transfers. We assume that the migrants are not economically active in the domestic country, except for the remittances sent to their parents. Therefore, we only study the parents' tradeoff between savings, number of children and children's education, knowing that a fraction ρ of the new generation will leave the country and will transfer a larger cash amount. The budget constraint in the first period is given by the following:

$$c_t + s_t + n_t e_t = w_t h_t (1 - \gamma - \sigma n_t N_t^{\delta}) \tag{1.3.8}$$

Human capital per child h_{t+1} depends on education expenditures per child e_t and on the parents' human capital h_t:

$$h_{t+1} = \theta h_t^{1-\mu} e_t^{\mu} \tag{1.3.9}$$

where $\theta > 0$ is the efficiency of human capital accumulation and $0 < \mu < 1$ represents the efficiency of education. Note that, here, corner solutions are possible since there are two different forms of investments. However, we choose not to pay attention to them because $e_t = 0$ would bring the stock of human capital to 0; thus, we set the following condition: $e_t > 0$.

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 they live. That said, there are two tradeoffs in this model; the first one concerns adult *versus* old age consumption. In addition, they must choose between savings or transfers–through human capital investments and the number of children–to finance their consumption when old. The budget constraint in the second period is written as follows:

$$d_{t+1} = s_t R_{t+1} + n_t \gamma (1 - \rho) w_{t+1} h_{t+1} + n_t \gamma \rho \varepsilon w_{t+1} h_{t+1} \tag{1.3.10}$$

Here one can note that $\gamma(1 - \rho + \rho\varepsilon) w_{t+1} h_{t+1}$ is the share of the children's income received by the parents, whether there are in education or fertility. We denote $\Lambda_h = \gamma(1 - \rho + \rho\varepsilon)$ as the share of children income transferred to the parents. It is positively correlated to ε, ρ and γ which are respectively, the net gain from migration, the emigration rate and the intergenerational transfers rate.

Three elements deserve a further discussion in our model. First, there is no altruism towards the children even if the fertility is endogenous, consequently there is no direct utility gain from having children. This specification implied implicitly that the only reason to have children is to invest for old age consumption, and that fertility is solely explained by budget constraints and economic optimization motives. However, according to Zhang and Nishimura (1993) this assumption seems to be partially true in developing countries.

Secondly, islands here are small closed economies only open to emigration, there are no imports, exports or capital flows between the rest of the world and the domestic economy. Our idea is to study the investments in the domestic area and their evolution in a context of high emigration and with remittances recipients. The behaviors of this latter in terms of savings can be modified thanks to the possibility to receive intergenerational transfers. Therefore we do not attempt to solve everything in this paper but only to characterize the tradeoffs between savings and intergenerational transfers to fund old age consumption, as well as their impacts on capital accumulation.

The third element concerns the equality between the relative proportion in the revenue of the intergenerational transfers from the migrants and the non-migrants. Indeed, for the sake of simplicity, we suppose that the proportion of revenue sent to the parents is the same, regardless of the location of the children. This assumption allows to have simple analytical results for the impact of intergenerational transfers, however in the numerical exercise we will test the impact of differentiated γ according to the location of the children.

The consumer program is summarized by the following:

$$\begin{aligned} \max_{c_t,s_t,e_t,n_t} U(c_t,d_{t+1}) &= \ln(c_t) + \beta \ln(d_{t+1}) \\ s.t \qquad c_t + s_t + n_t e_t &= w_t h_t (1 - \gamma - \sigma n_t N_t^{\delta}) \\ d_{t+1} &= s_t R_{t+1} + n_t \Lambda_h w_{t+1} h_{t+1} \\ h_{t+1} &= \theta h_t^{1-\mu} e_t^{\mu} \end{aligned}$$

To solve this model, we proceed by substitution and solves the following:

$$\max_{s_t,e_t,n_t} U(s_t,e_t,n_t) = \ln\left[w_t h_t (1-\gamma-\sigma n_t N_t^{\delta}) - s_t - e_t n_t\right] + \beta \ln\left[s_t R_{t+1} + n_t \Lambda_h w_{t+1} h_{t+1}\right] \quad (1.3.11)$$

The first order condition (FOC) of the household's problem with respect to s_t shows the consumption tradeoff over the life-cycle. It depends on the psychological discount factor, β, and the return factor on savings, R_{t+1}:

$$\frac{1}{c_t} = \frac{\beta R_{t+1}}{d_{t+1}} \tag{1.3.12}$$

The two others FOC of the household's problem with respect respectively to education and fertility suggest that the remuneration from intergenerational transfers and savings should be equal on the equilibrium. It leads to the following:

$$\frac{1}{c_t} = \frac{\beta\mu\Lambda_h w_{t+1} h_{t+1}}{e_t d_{t+1}} \tag{1.3.13}$$

$$\frac{1}{c_t} = \frac{1}{\sigma N_t^{\delta} w_t h_t + e_t}\frac{\beta\Lambda_h w_{t+1} h_{t+1}}{d_{t+1}} \tag{1.3.14}$$

Combining (1.3.14) and (1.3.13), we get a first no-arbitrage condition that ensure that the household is indifferent between education and fertility. This expression equates the opportunity costs of education and fertility. The first ratio is the return of education measured as a fraction μ of future wages (per unit of human capital) relative to education expenditures. The second ratio is equal to future wages (per unit of human capital) relative to children costs, which depend on child rearing costs, congestion effect and education expenditure per child:

$$\frac{\mu\Lambda_h w_{t+1} h_{t+1}}{e_t} = \frac{\Lambda_h w_{t+1} h_{t+1}}{\sigma N_t^{\delta} w_t h_t + e_t} \tag{1.3.15}$$

Second, combining (1.3.14) and (1.3.12), we get another no-arbitrage conditions that ensure that the household is indifferent between investments in children and savings. This expression equates the returns of savings R_{t+1} and the future intergenerational transfers relative to the children cost:

$$R_{t+1} = \frac{\Lambda_h w_{t+1} h_{t+1}}{\sigma N_t^{\delta} w_t h_t + e_t} \tag{1.3.16}$$

The first no-arbitrage condition directly determines the level of education expenditures:

$$e_t^{\star} = \frac{\mu\sigma N_t^{\delta}}{1-\mu} w_t h_t \tag{1.3.17}$$

This choice depends solely on the adult income, on the cost of raising children and on the efficiency of education. Moreover, the adult population size has a positive effect on the education expenditures because of the congestion effect that increases the cost of fertility in a densely populated area. Thus, the larger the income and/or the adult population size, the higher the education expenditures are.

Introducing the optimal choice of education into the second no-arbitrage conditions, we get a relationship essentially between equilibrium input prices at $t+1$:

$$R_{t+1} = \frac{(1-\mu)\Lambda_h}{\sigma} \frac{w_{t+1}h_{t+1}}{w_t h_t N_t^{\delta}} \tag{1.3.18}$$

Rewriting the adult's budget constraint according to the optimal choice of education gives the investments in children in one term.[6]

$$w_t h_t (1-\gamma) = c_t + s_t + n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu} \tag{1.3.19}$$

We denote the present income which is not consumed at the first period by x_t. It is given by the following expression:

$$x_t = s_t + n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu} \tag{1.3.20}$$

the left hand side capturing household's savings as defined in a global sense.

The next step is to solve the inter-temporal optimization of the household. To do so, we introduce the expression (1.3.18) and the budget constraints in the FOC with respect to the savings (equation (1.3.12)). We get the following expression:

$$\beta R_{t+1} c_t = d_{t+1} \Leftrightarrow \frac{\beta(1-\gamma)}{1+\beta} w_t h_t = s_t + n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu} \tag{1.3.21}$$

Here, a new expression for $x_t \equiv \frac{\beta(1-\gamma)}{1+\beta} w_t h_t$ appears and leads directly to the consumption expression, given by the following expression:

$$c_t = \frac{1-\gamma}{1+\beta} w_t h_t \tag{1.3.22}$$

Equations (1.3.22) and (1.3.21) depict a tradeoff between adult and old age con-

[6]The terms $n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu}$ is the combination of the two options in order to increase the intergenerational transfers (*i.e.* the fertility and the human capital).

sumption through investment, *i.e.* between c_t and x_t. Both variables are negatively affected by parameter γ, the intergenerational transfer share of income. A high γ generates a negative income effect on adults, thus reducing available resources for consumption, c_t, and investment x_t. Nevertheless γ has an ambiguous effect on old age consumption, since high values for the parameter mean that the elderly get higher intergenerational transfers. This puts a lower burden on investing to fund future consumption d_{t+1}. Finally, the discount factor, β has a positive (negative) effect on x_t (c_t).

From the two expressions of x_t we obtain a first relation between the savings and the intergenerational transfers:

$$s_t = w_t h_t \left(\frac{\beta(1-\gamma)}{1+\beta} - n_t \frac{\sigma N_t^{\delta}}{1-\mu} \right) \tag{1.3.23}$$

At this point, the trade off between fertility and savings is not solved, thus we need an additional equation between the savings and the fertility. The representative household has perfect foresight as to future returns from their investment (de la Croix and Michel (2002)). As a result, future remuneration of production inputs can be written as a function of present tradeoffs. Indeed, the optimal choices of the households solve simultaneously their problem of optimization of the inter-temporal income and the Market Clearing Conditions (MCC), given in the following equations:

$$\begin{aligned} K_{t+1} &= s_t N_t && (1.3.24) \\ L_{t+1} &= N_{t+1} = n_t N_t (1-\rho) && (1.3.25) \\ h_{t+1} &= \theta e_t^{\mu} h_t^{1-\mu} && (1.3.26) \end{aligned}$$

To solve this equilibrium, we introduce the inputs prices (w_{t+1} and R_{t+1}) and the MCC in the equality (1.3.18). The expression (1.3.18) is rewritten according to the factor prices (equations (1.3.4) and (1.3.5)).

$$\alpha A K_{t+1}^{\alpha-1} (L_{t+1} h_{t+1})^{1-\alpha} = \frac{(1-\mu)\Lambda_h}{\sigma} \frac{(1-\alpha) A K_{t+1}^{\alpha} (L_{t+1} h_{t+1})^{-\alpha} h_{t+1}}{w_t h_t N_t^{\delta}}$$

After some simplifications, we have:

$$\frac{N_{t+1}}{K_{t+1}} = \frac{1-\alpha}{\alpha} \frac{(1-\mu)\Lambda_h}{\sigma w_t h_t N_t^{\delta}} \tag{1.3.27}$$

With the MCC, we find:

$$s_t = n_t \left[\frac{1-\alpha}{\alpha} \frac{(1-\mu)\Lambda_h}{(1-\rho)\sigma w_t h_t N_t^{\delta}} \right]^{-1} \tag{1.3.28}$$

Solving the system defined by the equations (1.3.23) and (1.3.28), we find the optimal choices of the consumer.

$$s_t^{\star} = \frac{\beta\alpha(1-\rho)(1-\gamma)}{(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} w_t h_t \tag{1.3.29}$$

$$n_t^{\star} = \frac{\beta\Lambda_h(1-\gamma)(1-\alpha)(1-\mu)}{\sigma(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} N_t^{-\delta} \tag{1.3.30}$$

We conduct a comparative static analysis on household choices given by equations (1.3.17), (1.3.29) and (1.3.30).[7] On the one hand, there is a tradeoff between savings and investments in children to fund old age consumption–*i.e.* s_t versus $n_t \frac{\sigma w_t h_t N_t^{\delta}}{1-\mu}$. On the other hand, there is a tradeoff between quantity and quality of children to maximize intergenerational transfers–*i.e.,* n_t and e_t. First, according to equation (1.3.29), savings are negatively correlated to Λ_h, the share of children income received by the parents. Thus, increases in the net gain from migration, ε, the emigration rate ρ and/or the intergenerational transfer, γ, lead to increases in children at the expense of the savings. For γ this is aggravated by the negative income effect that comes from the term $(1-\gamma)$.

Second, the tradeoff between fertility and education depends on the one hand on the incentives to invest in education, and on the other hand, on migration. Indeed, as said earlier household chooses to invest in education expenditures if the efficiency of education and the child-rearing costs–measured, respectively, by parameters μ and σN_t^{δ}–are higher. On the other hand, migration has a strong impact on fertility and not directly on education. More specifically, ρ and ε are positively correlated to n_t, while the impact of γ depends on the interaction between the share of the children income received Λ_h and the negative income effect induced by $(1-\gamma)$. This interaction corresponds to the balance between two effects which are captured by the condition

[7] Derivatives expression are given in the Appendix A.1.1.

below:[8]

$$\frac{\partial n_t}{\partial \gamma} > 0 \quad \Leftrightarrow \quad \frac{\gamma^2}{1-\gamma} < \frac{\alpha(1-\rho)}{(1-\alpha)(1-\rho+\rho\varepsilon)}$$
$$\frac{\partial n_t}{\partial \gamma} > 0 \quad \Leftrightarrow \quad \frac{\gamma}{1-\gamma} < \frac{\alpha(1-\rho)}{\Lambda_h(1-\alpha)}$$

Finally, the number of children per household depends also on the overcrowding effect. In a more densely populated area, fertility is decreased for the benefit of education expenditures. Therefore, migration can have an impact on education through its impact of fertility. To clarify this mechanism it is necessary to study first the population dynamics and the labor force market.

1.4 Equilibrium

1.4.1 Intertemporal equilibrium

The MCC for capital, labor and human capital per worker, are given respectively by the equations (1.3.24), (1.3.25) and (1.3.26). The values of the household's optimal choices $s_t^\star$, $n_t^\star$ and $e_t^\star$ are given in equations (1.3.29), (1.3.30) and (1.3.17). The wage and the return factor on capital correspond, respectively, to (1.3.4) and (1.3.5). In the preceding section, we have solved the equilibrium at each period, using all our findings and after some computations, we can deduce the intertemporal equilibrium.

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

$$\begin{cases} K_{t+1} = \Psi\alpha A(1-\rho)K_t^{\alpha}N_t^{1-\alpha}h_t^{1-\alpha} \\ N_{t+1} = \Psi\Lambda_h(1-\rho)\dfrac{(1-\mu)}{\sigma}N_t^{1-\delta} \\ h_{t+1} = \theta\left[\dfrac{\sigma\mu A(1-\alpha)}{1-\mu}\right]^{\mu}K_t^{\alpha\mu}N_t^{\mu(\delta-\alpha)}h_t^{1-\alpha\mu} \end{cases} \tag{1.4.1}$$

[8]Another way to put this condition is: $\frac{\partial n_t}{\partial \gamma} > 0 \Leftrightarrow \gamma < \frac{\sqrt{\alpha(1-\rho)}\left[\sqrt{[\alpha(1-\rho)+(1-\alpha)(1\rho+\rho\varepsilon)]}-\sqrt{\alpha(1-\rho)}\right]}{(1-\alpha)(1-\rho+\rho\varepsilon)}$

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

Therefore, the ratio of the capital to efficient units of labor k_t can be defined as follows:

$$k_{t+1} \equiv \frac{K_{t+1}}{N_{t+1}h_{t+1}} = \left(\frac{A\sigma}{1-\mu}\right)^{1-\mu} \frac{\alpha}{\theta\Lambda_h[\mu(1-\alpha)]^{\mu}} k_t^{\alpha(1-\mu)} N_t^{\delta(1-\mu)} \tag{1.4.2}$$

We define g_t^K, g_t^h and g_t^N respectively, as the growth factors of the stock of physical capital, the human capital per capita and the adult population growth.

$$g_t^K = \frac{K_{t+1}}{K_t} = \Psi\alpha A(1-\rho)k_t^{\alpha-1} \tag{1.4.3}$$

$$g_t^h = \frac{h_{t+1}}{h_t} = \theta\left[\frac{\mu A\sigma(1-\alpha)}{1-\mu}\right]^{\mu} k_t^{\alpha\mu} N_t^{\mu\delta} \tag{1.4.4}$$

$$g_t^N = \frac{N_{t+1}}{N_t} = \Psi\Lambda_h(1-\rho)\frac{(1-\mu)}{\sigma}N_t^{-\delta} \tag{1.4.5}$$

First of all, it appears that the evolution of the labor force, given by equation (1.4.5), depends solely on the structural parameters of the economy. Consequently, the population dynamics has an impact on the human capital as well as on the physical capital. However, the evolution of the production or the income does not change the fertility choices. Thus the steady state value is directly given by the following equation:[9]

$$N^{\star} = \left[\Psi(1-\rho)\Lambda_h\frac{(1-\mu)}{\sigma}\right]^{\frac{1}{\delta}} \tag{1.4.6}$$

The steady state size of the labor force is increased by all the parameters that are positively correlated to n_t, except for ρ, whose effect depends on the following condition.[10]

$$\frac{\partial N^{\star}}{\partial \rho} > 0 \Leftrightarrow \frac{1-\rho}{1-\rho+\rho\varepsilon} > \sqrt{\frac{\gamma(1-\alpha)}{\alpha(\varepsilon-1)}} \tag{1.4.7}$$

Due to the constant returns to scale for human and physical capital, there is no steady state in this economy but a balanced growth path (BGP).

Proposition 2. *On the BGP, the system satisfies the* ***Proposition 1*** *and the stock of*

[9] The growth rate of the population is directly given by $n_t^*(1-\rho)$, and on the steady state $n^* = 1/(1-\rho)$

[10] It is possible to have a decrease of the adult generation size until $N^{\star}$ is reached. This is the case, if the initial population size is larger than $N^{\star}$.

physical and efficient units of labor grows at the same constant rate $g_{BGP} = g^K = g^h$*; therefore,* $k_t = k_{BGP}$ *is constant. There is a unique locally stable equilibrium for which the values of* k *and* g *are as follows:*

$$k_{BGP} = \left[\frac{\alpha[\Psi A(1-\rho)]^{1-\mu}}{\theta[\mu\Lambda_h(1-\alpha)]^{\mu}}\right]^{\frac{1}{1-\alpha(1-\mu)}} \quad (1.4.8)$$

$$g_{BGP} = \left[[\theta[\mu\Lambda_h(1-\alpha)]^{\mu}]^{1-\alpha}[\Psi\alpha^{\alpha}A(1-\rho)]^{\mu}\right]^{\frac{1}{1-\alpha(1-\mu)}} \quad (1.4.9)$$

Proof of Proposition 2. see Appendix A.1.2 □

Proof of the stability of the equilibrium. see Appendix A.1.2 □

Proposition 3. *On the BGP, there is a negative correlation between* k_{BGP} *and the efficiency of human capital accumulation,* θ*, as well as the share of the children's income transfers to the parents,* Λ_h*–knowing that* Λ_h *is positively correlated to 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 long term ratio of capital per units of efficient labor, k_{BGP}, result respectively from the increase in the production and from the decrease in the number of children due to the extra cost–*i.e.* the decrease in the next generation size. The negative impact of the other parameters on this ratio is explained by the increase in the number of units of efficient labor in the economy–with respect to ε, θ, γ and ρ.

Proposition 4. *On the BGP, the economic growth,* g_{BGP}*, is positively impacted by: the technology factor,* A*, the psychological discount factor,* β*, the efficiency of human capital accumulation,* θ *and the net gain from migration,* ε*. The effects of the intergenerational trasnfer rate,* γ*, and the emigration rate,* ρ*, depend on the condition below:*

$$\frac{\partial g_{BGP}}{\partial \rho} > 0 \Leftrightarrow \frac{1-\rho}{1-\rho+\rho\varepsilon} > \frac{[\varepsilon-(1-\alpha)(\varepsilon-1)(1-\rho)]}{\alpha(\varepsilon-1)(1-\rho)} \quad (1.4.10)$$

$$\frac{\partial g_{BGP}}{\partial \gamma} > 0 \Leftrightarrow \frac{1-\alpha}{\alpha}\frac{1-(1-\alpha)(1-\gamma)}{(1-\alpha)(1-\rho)-\gamma} > \frac{(1-\rho)}{\Lambda_h} \quad (1.4.11)$$

Firstly, it is important to note that the long-term growth factor gives directly the growth of the production per capita, because of the constant population size. In that case, the growth factor of the production per capita can be directly translated in the growth of utility, which depends strongly on the consumption (*cf.* Appendix A.1.4 for details).

For the growth rate of the economy, g_{BGP}, a rise in the technological factor, A, and in the efficiency of human capital accumulation, θ, lead to more efficient economy. While, increases in the psychological discount factor, β, result in higher investments for the future through human capital or savings and subsequently to an increase in the economic growth. Moreover, an increase in the net gain from migration, ε enhance the income of the old age generation and leads to an increase in the production per capita growth.

However the effects of the other features of migration–*i.e.* the emigration rate, ρ, and the intergenerational transfer rate, γ–are not clear. 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.[11] Difficulties to interpret the analytical results on the ρ and γ, could be explained by the opposite effects that are observed on the household choices and on the aggregate variables.

On the one hand, there is the effect of ρ, the emigration rate. This parameter creates an incentive to have more children through the increase in the net gain from migration. However, because there are more adults who leave the territory at the next period it can lead to a decrease in the number of units of efficient labor. Second, with the increase in population size, the education expenditures can increase because of the congestion effect, this is reinforced by the substitution effect between investments in children and savings that occurs when the emigration rate increases. In that context, a higher migration can lead to an increase of the human capital and thus to an increase of the income which is directly given by $w_t h_t$. Therefore, the emigration rate effect on the capital stock is three-fold. First, by increasing the number of children, there is a rise in the rearing expenditures and thus a decrease in the savings, this is the substitution effect, on the intensive-margin. Second, there is the role of the extensive-margin in capital stock. Migration can lead to a decrease (an increase) of the adult population size, which induces a reduction (a rise) of the capital stock because of the smaller (larger) number of contributors. Finally, there is the migration effect on

[11]These conditions are given in Appendix A.1.3.

the education expenditures and thus on the human capital dynamics. In a wealthier economy, even if the share of the income devoted to savings is reduced, the capital stock might be larger.

On the other hand, there is the effect of γ. As said earlier, the effect of γ on the fertility is described by an inverted U-shaped curve, this is due to the income effect that reduces the fertility when γ is high. Therefore, while the mechanisms are different, its impacts through the net gains from migration are the same than those of ρ. First it leads to a rise in the units of efficient labor, but if γ is too high, savings are low, the population size may decline as well as the human capital.

In conclusion, two main intuitions can be driven from this model. The first one is that there is a strong tradeoff between intergenerational transfers and savings. The 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 are a gain in human capital and in the labor force. Consequently, it is possible to have an emigration rate which 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 give clear insights of the migration effects. Thus a numerical analysis is conducted in the next section in order to clarify certain trends of the model. and to specify the results for a sample of Caribbean islands.

1.5 Numerical analysis

The proposed theoretical analysis underlines the importance of the demographic characteristics of these countries to study the long-run development. The next step is to give more insights on the migration effects thanks to a numerical analysis according to the countries' specificities. This section deals with steady state analysis of five Caribbean SIDS: Barbados, Dominican Republic, Haiti, Jamaica as well as Trinidad and Tobago. In order to describe the dynamics of individual Caribbean countries, we need to assign specific numerical values to the model structural parameters in every aspect, and not just demographic dynamics and human capital formation. We calibrate numerical values for each country using macroeconomic data from PWT and

WDI datasets. Long run averages and ratios allow us to specify individual sets of numerical values.

Moreover, this section also develops an analysis of migration policies on remittances amounts and emigration rate.

1.5.1 Structural parameter values estimation and calibration

Table 8 below reports the model's structural economic parameters, their respective economic interpretations, the support range for credible values as well as the calculation methods. We use data from the World Bank (2018) World Development Indicators (WDI) as well as the University of Pennsylvania World Table (PWT).

Table 8: Model structural parameters

Economic Parameters	**Range**	Method	Data source
Preference factor for the future	$\beta \in [0, 1[$	Calibration	WDI
Capital intensity in production	$\alpha \in [0, 1]$	*idem*	WDI & PWT
Technology level	$A > 0$	*idem*	PWT
Emigration rate	$\rho \in [0, 1]$	*idem*	WDI
Net gain from migration	$\varepsilon > 1$	*idem*	*idem*
Share of income remitted	$\gamma \in [0, 1]$	*idem*	*idem*
Efficiency - education	$\mu \in [0, 1]$	Estimation	WDI & PWT
Efficiency - human capital accumulation	$\theta > 0$	*idem*	*idem*
Cost of child-rearing	$\sigma \in [0, 1]$	Calibration	*idem*
Congestion parameter	$\delta \in [0, 1]$	Calibration	*UN Data*

The purpose of the calibration exercise is twofold. First, calibration ensures that the model performs credibly well for each parameter value with respect to the features of economies we seek to replicate. Second, when the model proves to be able to match defining moments for the benchmark economy, it provides an adequate analytical framework, and thus predicts a set of relevant outcomes with respect to policy changes and instruments. As such, proper calibration can yield useful results for policymaking. Nonetheless, credible values for structural parameters are contingent upon available data. This is particularly the case for small emerging economies, such as the Caribbean islands.

Kydland and Prescott (1991) provide a comprehensive framework for discussing calibration in general equilibrium models. While they insist on the method to choose the benchmark values for structural parameters, in the absence of panel studies on households and firms–which are optimal to compute agent behavior parameters–we focus as much as possible on standard calibration. It relies on steady state expressions of our model, and use long-run averages of variables in the dataset built for the sample of SIDS countries.

Most available data can be traced back to the 1970s, and we build a dataset for the time period 1970-2014. Numerical simulations will be then computed with initial values corresponding to the year 1970. We focus on five countries with up-to-date and exhaustive data for our numerical analysis: Barbados, The Dominican Republic, Haiti, Jamaica and Trinidad & Tobago. The other structural parameters of the model are calibrated and/or estimated using the following steps:

- The selected variable for Human Capital is derived from PWT which is an index computed on the basis of returns to education and years in schooling. Due to the lack of data on private education for emerging economies, we posit that in the long-run, the share of private education expenditures in total education spendings of these countries will converge toward the observed share in OECD economies, which is estimated at 20% (OECD (2019)). Given the fact that we have no tangible indicator of human capital stock, we rely on a mixture of estimation and calibration in order to assign numerical values to parameters μ and θ. To that effect, we use equation (1.3.9), in order to define human capital elasticity to education expenditure as follows:

$$\varepsilon^h(\mu) = \frac{\partial h_{t+1}}{\partial e_t}\frac{e_t}{h_t}$$

  We regress logged future human capital h_{t+1} on education expenditure in logs in order to estimate its elasticity $\varepsilon^h(\mu)$. We denote $\Delta\bar{h}$ as the empirical long-run average change in human capital. This allows us to write an expression for parameter μ such:

$$\mu = \frac{\varepsilon^h(\mu)}{1+\Delta\bar{h}}$$

  The next step is to plug the numerical value μ for each country in order to calibrate for θ. Using long-run averages for the selected variables, we write:

$$\theta = \ln\frac{\Delta\bar{h}}{\mu(\bar{e}-\bar{h})}$$

  Large numerical values for μ suggest that there is a higher elasticity of future human capital to education expenditure than to its present value. θ is a scale parameter that also measures the efficiency of present human capital and education expenditure.

- Parameter β which denotes psychological discount factor. The discount factor is usually calibrated using the risk-free interest rate in the United States at an annual rate of 4%. The calibrated value for the discount factor is computed as follows:

$$\beta = \frac{1}{1+\bar{r}}$$

There is a large consensus in the literature that the interest rate is a good proxy for households' discounting factor, though average long-run interest rates change significantly across countries. King and Rebelo (1999) compute values of 0.961 in annual terms, using the 3-months maturity for the United States Treasury Bills. By contrast, Cooley and Prescott (1995) compute an alternative expression for the discount factor β, one that calls for additional parameters. Using the Euler equation at the steady state, and assuming no growth in consumption, they calibrate a value of β that is function of capital share of output α, capital depreciation δ and the capital-to-output ratio k/y at the steady state. We retain the previous method as it is parsimonious in its use of data, and use the long-run interest rate averages for each country in our sample set. These range from about 6% in countries like Barbados, Jamaica as well as Trinidad and Tobago, to almost 12% for Dominican Republic and Haiti. As a result, values of parameter β range from 0.940 to 0.894.

- A similar approach is used to calibrate the capital share in output α at 1/3, which is the usual value used in the literature and derived from Solow (1957). The credible range of values has been set in Christiano and Fitzgerald (1998) using the interval $[0.24; 0.43]$.We calibrate the specific values for each SIDS in our country set using logged expressions of capital stock, out put *per capita*l and productivity such that:

$$\alpha = \frac{\ln y - \ln A - \ln n}{\ln k - \ln n}$$

We obtain values close to 1/3 except for Barbados and Trinidad, both of which fall in the lower bound of the interval of credible values computed in Christiano and Fitzgerald (1998). Both countries have a comparatively higher level of human capital, and their respective economies, so any relevant comparison within our SIDS sample set needs to correct for differences in human capital. We obtain credible values for parameter α when we compute the output-to-capital ratio relative to human capital.

- The PWT dataset offers estimates of the Solow residual as a proxy for TFP productivity. It is computed as a percentage of productivity in the United States, and we use the long-run average real growth *per capita* at 2% as a benchmark. In order to compute the technology level of a given country in our sample set, we multiply the PWT 1970 value for TFP in each country as a percentage of that in the United States. For instance, the value for Jamaica, 1.014, translates into a long-run average TFP growth rate of 1.14% in 1970.

- Parameter ρ is the emigration rate for a given individual. In order to provide a calibrated value for this parameter, we assume that the emigration rate is the same for all individuals in each country in our sample set. This means that a fraction ρ of the population migrates over one period. The empirical equivalent of share ρ is computed as the 30-year rolling average ratio of changes in the population that are not accounted for by births and deaths. This means that for each country in our sample set, we compute the rolling average of the following expression:
$$\rho = \frac{n_t N_t - N_{t+1}}{N_{t+1}}$$

- ε is the premium wage individuals in SIDS economies expect to receive when they migrate. We assume that wages are proportional to GDP, therefore the long-run average ratio of real GDP *per capita* in the US over that of the simulated economy is a good proxy for the potential gains made from emigration.

- γ are remittances paid to the elderly and retired individuals in the economy. The WDI dataset provides remittances as a percentage of GDP. We compute γ by expressing remittances in monetary terms instead, and then multiply by the share of elderly individuals–aged 65 above–in the total population. This allows us to compute the fraction of remittances that benefit the elderly in the recipient economy.

- $N^\star$ is the steady-state population value. We use data from the World Bank and its forecast of population levels by 2050, and extend it until demographic growth is close or equal to zero. We then extrapolate steady-state population $N^\star$ at the corresponding dates.

- δ is the congestion parameter, and captures the speed of convergence to the steady-state population level. We use the following expression to estimate its value:

$$N_{t+1} = \Lambda_n N_t^{1-\delta}$$

  Where Λ_n is a collection of structural parameters of our model. The equation is re-written in log terms and differentiated, so that δ is estimated by regressing future demographic growth on logged present population, namely:

$$\Delta\% N_{t+1} = \ln \Lambda_n - \delta \ln N_t$$

  A logistical transformation is introduced in order to make sure that estimated values for parameter δ always belong to the interval $(0, 1)$.

- σ denotes the child-rearing cost per individual. Its value is calibrated in order to match the parameters listed above, as well as the estimated values of μ and θ. We incorporate the congestion component of our model such that σ matches the following expression:

$$\sigma = \frac{\gamma\beta(1-\rho+\rho\varepsilon)(1-\gamma)(1-\alpha)(1-\rho)(1-\mu)}{N^{\star\delta}(1+\beta)\left[\alpha(1-\rho)+(1-\alpha)\gamma(1-\rho+\rho\varepsilon)\right]}$$

Similar adjustments are carried out for the initial values for capital, output and efficient units of labor. Output is normalized to unity in 1970, and the capital stock is computed using capital-to-output ratio for the same year. The figures in Table 9 report harmonized initial values for physical capital for comparison purposes. The same calibration is computed for efficient units of labor, which are derived from normalized output and capital. We use the Cobb-Douglas equation (1.3.1) to deduce $N_0 h_0$ for a given K_0 and $y_0 = 1$. Finally, given that human capital is reported as an index in PWT, we retain the 1970 value for all countries. We report all the economic parameters in Table 9 below:

1.5.2 Results

Table 10 reports results for capital per efficient unit of labor and growth on the balanced growth path in the Caribbean economies. The model predicts that the dynamics of each country are driven on the one hand by the amount of physical capital stock

Table 9: Calibrated values for structural parameters - SIDS Caribbean countries.

Parameters		**BRB**	**DOM**	**HTI**	**JAM**	**TTO**
Preference factor for the future	β	0.940	0.898	0.894	0.944	0.938
Capital intensity in production	α	0.340	0.361	0.225	0.312	0.208
Technology level	A	1.034	1.014	1	1.014	1.038
Education efficiency	μ	0.130	0.145	0.082	0.162	0.191
Efficiency of human capital accumulation	θ	5.025	5.301	3.863	4.898	4.861
Cost of rearing a child	σ	0.171	0.019	0.023	0.063	0.032
Emigration rate	ρ	0.370	0.183	0.160	0.490	0.374
net gain from migration	ε	1.91	9.68	51.00	6.58	3.03
Share of income remitted	γ	0.121	0.130	0.098	0.200	0.018
Congestion parameter	δ	0.636	0.726	0.865	0623	0.601
Capital stock	K_0	0.021	0.279	0.143	0.335	0.115
Human capital stock	h_0	1.367	0.817	0.631	1.083	1.102
Labour	N_0	0.006	0.092	0.169	0.051	0.028

Note: Calibrated values for individual countries use available data points for the period 1961-2014. Initial values for capital stock and labour are given with a factor of 10^6
Legend: **BRB:** Barbados. **DOM:** Dominican Republic, **HTI:** Haiti, **JAM:** Jamaica, **TTO:** Trinidad and Tobago

accumulated over time, and on the other hand, the number of units of efficient labor. The respective contributions of each are weighted by a combination of parameters in the equilibrium equation (equation (1.4.2)). A high value for k_{BGP} means that capital growth accumulation is large in a given country relative to the others in our sample set. On the other hand, if g_{BGP} is high while k_{BGP} is small, economic growth would have been driven mainly by the accumulation of units of efficient labor. Moreover, we compute $k_{BGP}N^{\star}$ which is the ratio of physical capital to human capital. It exhibits the relative weight of the cumulative stocks–*i.e.* human and physical capital–on the long run, without the population size effect. We also compute $\frac{\partial Y_{BGP}}{\partial k_{BGP}}$, which is the long-run rate of return of capital. This value allows to evaluate if there is under-accumulation or over-accumulation in these economies.

Table 10: Values of capital to units of efficient labor ratio and growth on the BGP

	BRB	**DOM**	**HTI**	**JAM**	**TTO**
k_{BGP}	0.025	0.016	0.010	0.007	0.122
$\frac{\partial Y_{BGP}}{\partial k_{BGP}}$	4,031	5,215	7,717	9,447	1,141
$k_{BGP}N^{\star}$	0.007	0.209	0.171	0.023	0.186
g_{BGP}	2.281	2.294	2.562	1.980	1.776
$\frac{N^{\star}}{N_0}$	46.34	144.65	97.40	61.98	55.65

Legend: **BRB:** Barbados. **DOM:** Dominican Republic, **HTI:** Haiti, **JAM:** Jamaica, **TTO:** Trinidad and Tobago

Results reported in table Table 10 show that cross-country human capital accumulation is highly heterogenous. Trinidad and Tobago, as well as Barbados exhibit the highest levels of capital per efficient unit of labor among the five islands. The latter exhibits a higher economic growth though, because of Trinidad and Tobago's lower incentive to invest in human capital. The country exhibits indeed a comparatively smaller level of intergenerational transfer ($\gamma = 0.018$) and lower levels of net gains from migration ($\varepsilon = 3.030$). By contrast, share of intergenerational transfer is higher in Barbados, which provides a strong incentive to accumulate human capital, even though the country does not benefit substantially from migration, as it exhibits the lowest value $\varepsilon = 1.91$ among the five islands. There is therefore one crucial difference between the two countries: capital stock per unit of human capital is significantly lower in Barbados relative to Trinidad and Tobago. This is due to the fact that human capital stock is much higher in Barbados. Trinidad and Tobago on the other hand does not exhibit a significant difference between stock levels of capital per efficient unit of labor, and capital per unit of human capital, suggesting that its human capital investment is comparatively moderate.

In addition, economic growth is higher in the Dominican Republic and Haiti, just as their respective stocks of capital per efficient unit of labor is lower compared to Barbados and Trinidad and Tobago. The contribution of demographic growth can be readily observed, with both former countries exhibiting a significantly higher demographic growth ratio from initial levels of the workforce to its steady-state value. Such dynamics can be readily observed in the computed values of capital stock per unit of human capital, which are comparatively higher for the Dominican Republic and Haiti, suggesting that demographic growth plays a more important role there than in the rest of the Caribbean islands in our sample set.

These differences on the balanced growth path suggest that our model identifies three profiles among the five islands with respect to fertility, physical capital accumulation and education expenditure: Barbados–and to some extent, Trinidad and Tobago–exhibits low demographic growth and high education expenditure, the Dominican Republic and Haiti exhibit a demography-fueled economic growth, whereas Jamaica lies in between, with strong demographic growth, as well as substantial investment in education and human capital. These profiles affect the economic benefits of migration, and may give some insights as to how migration policies may be implemented.

Finally, according to de la Croix and Michel (2002), "there is under-accumulation (or over-accumulation) when the long rate of return $f'(k_{BGP}) - 1$ is higher (or lower) than the growth rate of the population." In our case, the population is constant on the BGP, this means that there is under-accumulation if $\frac{\partial Y_{BGP}}{\partial k_{BGP}} > 1$. Therefore, all countries in our sample are in an equilibrium with under-accumulation of capita. This is consistent with the intuitions on the substitution between savings (and thus physical capital) and investments in children in economies driven by migration related gains.

1.5.3 Migration policy

The last step of this numerical exercise is a counterfactual analysis on parameters ρ and γ, which denote respectively the individual emigration rate, and intergenerational transfers as a share of children's income. The purpose of this exercise is to give a first analysis of the migration policies in the perspective of the sending countries. Indeed, for a long time, migration policies were interpreted as a tool that could be implemented only by the receiving countries. However, there is a growing literature on the diaspora strategy and international development agencies plead that migration could foster development in the sending countries (De Haas (2010)). These diaspora strategies (also referred as management of transnationalism) are described by Ragazzi (2014), who develops an index on the attitude of the sending country toward its diaspora.

In the present analysis, two main channels are explored, the first is the emigration rate. While a government cannot force people to stay or to leave their country, diplomatic relationship with receiving countries of migration, developing academic networks or facilitating political participation abroad could foster emigration. On the contrary, return migration policies such as tax reduction for returnees, may lower the net emigration rate. Second, we study the remittances level that could be enhanced by efforts in order to reduce the cost of international transfers.

This analysis intents to evaluate the economic gains if parameters ρ and γ are controlled by the social planner. To do so we compute the BGP level of economic growth over all possible values for these parameters, and study their impact *ceteris paribus* on economic growth on the BGP. The results are reported on figures 11 and 12. The inverted U-shaped curve between migration or intergenerational transfers on the one side, and economic growth on the other, reported for all five SIDS countries is as expected. For small values of migration rate (ρ) or intergenerational transfers rate (γ), there are increasing and concave returns to higher migration and transfers, up to the point where the curve reaches its extremum, and then declines to zero when ρ and γ get close to 1.

First, in Figure 11 that describes the effect of the emigration rate, the calibrated values of ρ in Dominican Republic as well as Trinidad and Tobago are smaller than the optimal values in terms of economic growth. The emigration rate is almost optimal in Haiti, while it is too high in Jamaica and Barbados. However, the cost of the migration excess in the Barbadian economy is small compared to the loss of growth in Jamaica due to migration level. This is explained by the Jamaican level of intergenerational transfers, which leads to a stronger substitution effect than in other countries. By contrast, in Trinidad and Tobago, the lower value of intergenerational transfers leads to a reduced substitution effect between transfers and domestic savings. Thus, if migration was the only way to increase the economic growth in this island, a substantially large increase would be necessary. Finally, in Figure 12, the intergenerational transfer rate appears to be close to the optimum values in all countries except for Jamaica where it is too strong, and Trinidad and Tobago where it is too small.

Figure 11: Effects of a change in ρ on g^{BGP}:

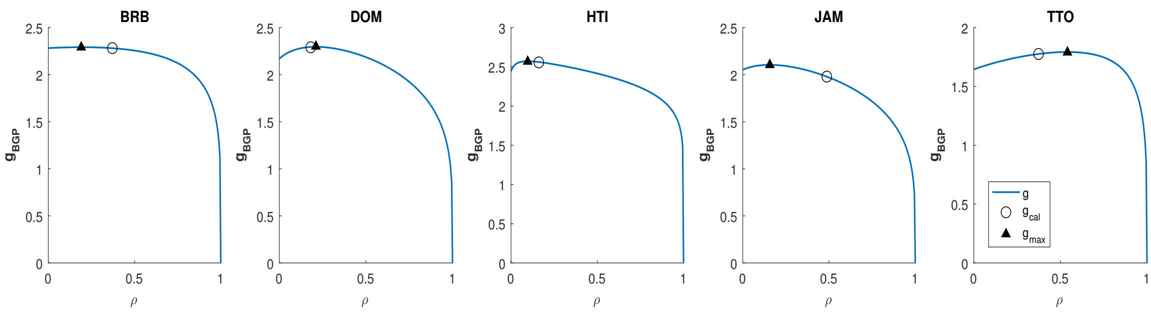
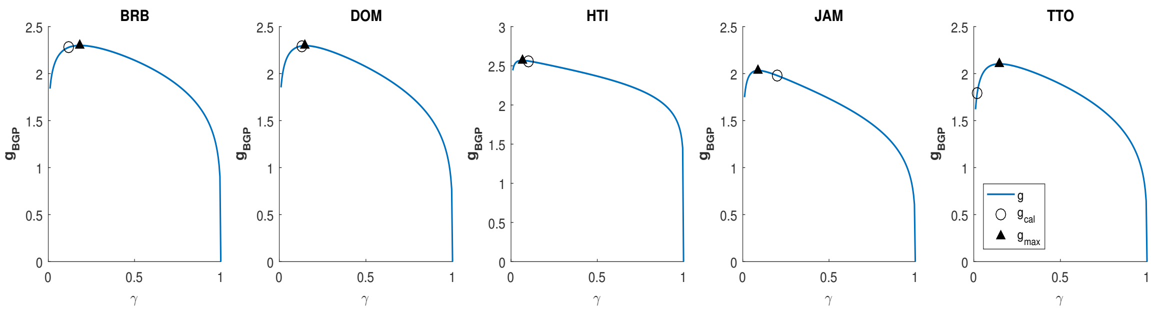


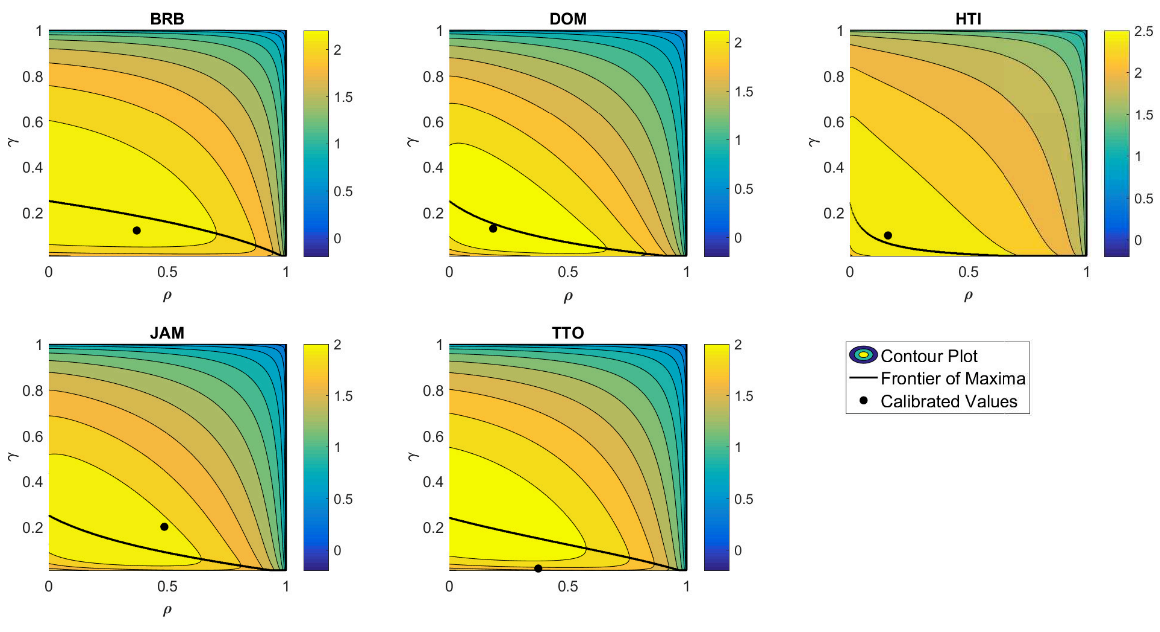
Figure 12: Effects of a change in γ on g^{BGP}:



Legend: **BRB:** Barbados. **DOM:** Dominican Republic, **HTI:** Haiti, **JAM:** Jamaica, **TTO:** Trinidad and Tobago, Opt: optimal value, Cal: calibrated value

This preliminary analysis of the structural parameters of the model establishes some key results for further policy discussion, on potential control of migration flows or remittances transfers for instance. Nevertheless, these figures may be misleading. If both policies are implemented simultaneously, the results differ strongly. In order to take into account these obstacles, we report on figure 13 the BGP growth rate of the economy as a function of parameters couples $g_{BGP}(\rho, \gamma)$. On the basis of the BGP expression yielded by our model, the figure shows that changing the intergenerational transfer or the emigration rate alone is inefficient in terms of economic growth and that better outcomes can be attained if these strategies are combined. The black thick line drawn on each figure represents the frontier of maximum values that can be attained thanks to a simultaneous change in both parameters, while the yellow region represents the highest values of the growth rate. Darker shades report lower growth values on the BGP. From Figure 13, it can be inferred that the Dominican Republic and Haiti are the only countries that do not benefit strongly from changes in the migration rate, ρ and in the intergenerational transfers, γ. All other island countries can improve their economic growth by varying these parameter values. More specifically, Jamaica should decrease both parameters, while Barbados as well as Trinidad and Tobago, could improve their economic growth if they rely more on the migration.

Figure 13: Effects of a change in ρ and in γ on g^{BGP}



BRB: Barbados, **DOM:** Dominican Republic, **HTI:** Haiti, **JAM:** Jamaica, **TTO:** Trinidad and Tobago

We conduct the same exercise with different values of intergenerational transfer according to the location of the children. While the control of the remittances is less direct, control of domestic intergenerational transfer is quite easy. Indeed, a system with a tax on the adult income to fund a pension system could be implemented, knowing that OLG models have been extensively used to study such tools.

We take γ_d for the transfer rate from the children in the domestic country and γ_f for the remittances transfer rate. In that case, the household choices in terms of savings and fertility become the following:

$$s_t^* = \frac{\beta\alpha(1-\rho)(1-\gamma_d)}{(1+\beta)[\alpha(1-\rho)+(1-\alpha)\hat{\Lambda}_h]} w_t h_t \tag{1.5.1}$$

$$n_t^* = \frac{\beta(1-\gamma_d)(1-\alpha)(1-\mu)\hat{\Lambda}_h}{\sigma(1+\beta)[\alpha(1-\rho)+(1-\alpha)\hat{\Lambda}_h]} \tag{1.5.2}$$

where $\hat{\Lambda}_h = (\gamma_d(1-\rho)+\gamma_f\rho\varepsilon)$ is the new share of the children income received by the parents.

Therefore, the equilibrium is modified, according to the equations below:

$$k_{BGP} = \left[\frac{\alpha(A\sigma)^{1-\mu}}{\theta[\mu(1-\alpha)]^{\mu}(1-\mu)^{1-\mu}\hat{\Lambda}_h}\right]^{\frac{1}{1-\alpha(1-\mu)}} \tag{1.5.3}$$

$$g_{BGP} = \frac{\alpha\beta A(1-\alpha)(1-\gamma_d)(1-\rho)}{(1+\beta)\left[\alpha(1-\rho)+(1-\alpha)\hat{\Lambda}_h\right]}\left[\frac{\alpha(A\sigma)^{1-\mu}}{\theta[\mu(1-\alpha)]^{\mu}(1-\mu)^{1-\mu}\hat{\Lambda}_h}\right]^{\frac{-(1-\alpha)}{1-\alpha(1-\mu)}} \tag{1.5.4}$$

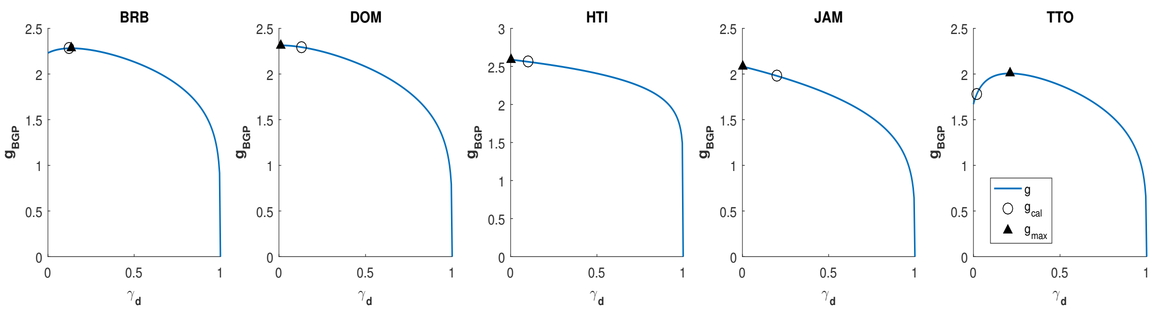
In Figures 14 and 15, we depict economic growth rate as a function of the two levels of intergenerational transfers, namely, domestic γ_d and foreign γ_f.[12] The former, γ_d induces a substitution effect between domestic savings and human capital accumulation as well as an income effect, as reported in the analytical results. In contrast, γ_f does not generate an income effect since it does not reduce income for active adults in the home country.

First, we focus on the impact of the local intergenerational transfer rate on economic growth. On the one hand, countries, such as Jamaica, Dominican Republic or Haiti, benefit from a reduction of γ_d to zero. This is possible because they have large gains from migration thanks to the high values of remittances (γ_f), emigration rate (ρ) and net gains from migration (ε). Thanks to the reduction of γ_d to zero, these countries can mitigate the initial negative income effect on the adult income that is due to the domestic transfers. At the same time, they continue to benefit from large flows of remittances from abroad. However, this implies that besides the adult savings, they become fully dependent on remittances for the funding of old age consumption. On

[12]Note that we fix the other component of intergenerational transfers to the precedent value of γ. Therefore, here, only one γ at a time is different from the calibrated structural parameter.

the other hand, other countries may not experience large gains from migration, due to small levels of emigration or a lower wealth gap with developed economies. This is characterized by smaller values of ρ or ε. In the cases of small senders of migrants, the choice of the domestic intergenerational transfer depends on tradeoffs between the negative income effect from transfers (γ_d) and economic gains induced by the incentive to invest in human capital.[13] Consequently, countries such as Barbados or Trinidad and Tobago will gain from an increase in their intergenerational transfers, due to the benefits gained from increases in human capital accumulation.

Figure 14: Effects of a change in γ_d on g^{BGP}

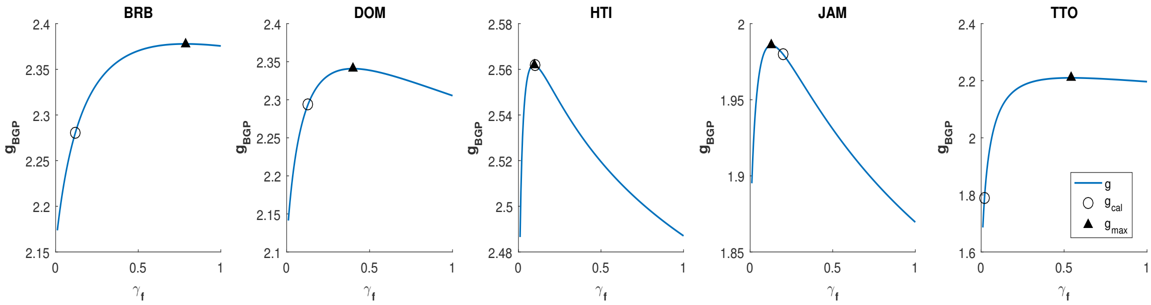


Second, Figure 15 shows that an increase in the intergenerational transfers from abroad, γ_f, is mostly positive for Barbados and Trinidad and Tobago, only very high values of γ_f lead to negative effects on the growth rate of the economy. In Haiti and Jamaica, the calibrated value of γ_f is almost optimal and should not be increased further. While in the Dominican Republic, an increase in the value of γ_f might be beneficial but, the increase must not be too large. To understand that, note that the negative impact from the remittances is only due to the substitution effect on domestic savings, which can lead to a permanent reduction in physical capital accumulation. This occurs only if the reduction in savings is large enough so that any gains from increased human capital or population are wiped away by losses in physical capital. Figure 15 shows the risk from the substitution effect exists mostly in countries that have already large gains from migration.

As in the previous analysis, we study the growth rate on the BGP if combined policies on migration and domestic transfers rate–*i.e.* ρ and γ_d–on the one hand, and emigration rate and remittances rate–*i.e.* ρ and γ_f–on the other, are possible. The first combination of policies is analyzed in the Figure 16. First, in countries such as Jamaica, Dominican Republic or Haiti, if the emigration rate is high, it can be optimal

[13]The substitution effect is still active with an increase in γ_d; however, its impact is lower on domestic intergenerational transfer.

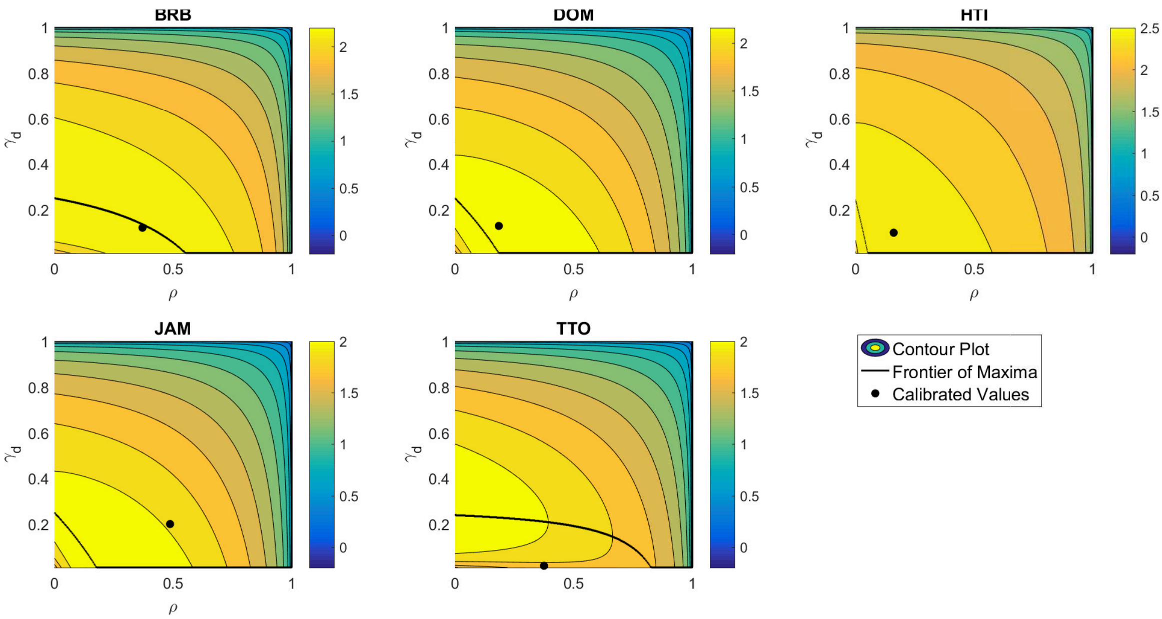
Figure 15: Effects of a change in γ_f on g^{BGP}



Legend: **BRB:** Barbados. **DOM:** Dominican Republic, **HTI:** Haiti, **JAM:** Jamaica, **TTO:** Trinidad and Tobago, Opt: optimal value, Cal: calibrated value

to reduce to the minimum value the domestic transfers rate, because of the large net gain from migration. Second, in Haiti, decreases in the emigration rate enhance the economic growth whatever the value of domestic intergenerational transfers. Finally, in countries such as Barbados as well as Trinidad and Tobago, the optimal value of intergenerational transfers in the local area, is larger and almost independent of the emigration rate. Indeed, in these countries the difference between the wealth abroad and in the domestic area is too small to use solely remittances.

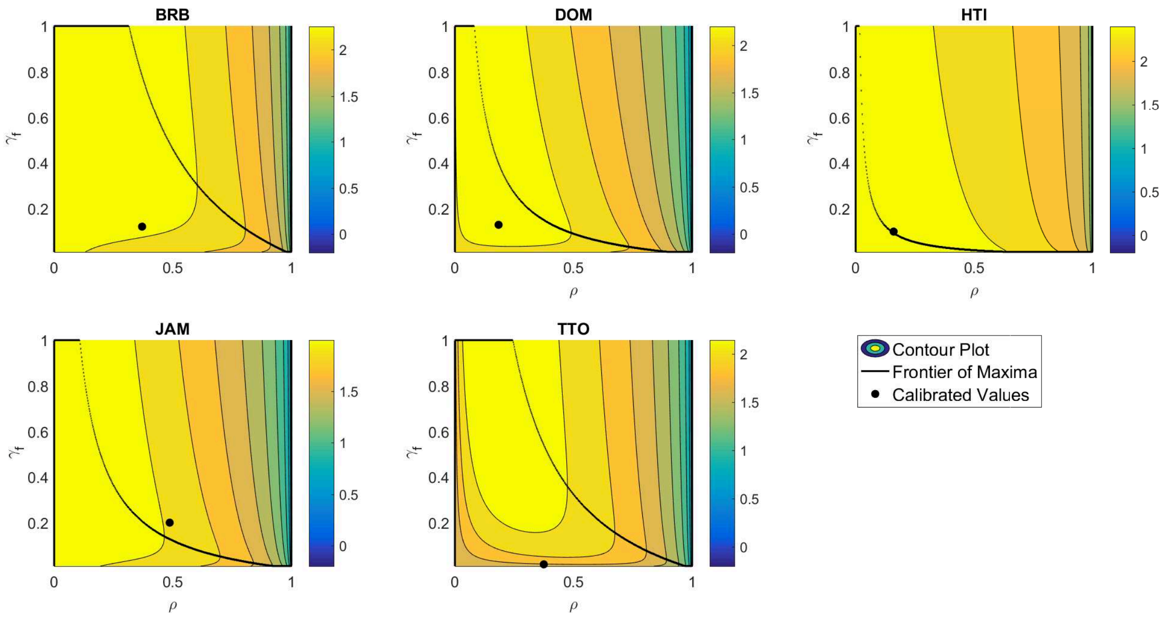
Figure 16: Effects of a simultaneous change in γ_d and ρ on g^{BGP}



BRB: Barbados, **DOM:** Dominican Republic, **HTI:** Haiti, **JAM:** Jamaica, **TTO:** Trinidad and Tobago

Figure 17 shows the results for the combination of the remittances rate and the emigration rate. It appears that if the emigration rate decreases, an increase in remittances should be always profitable. Indeed, when the emigration is small, the substitution effect between savings and human capital investments is very small, and thus this parameter has no adverse effect on the economy. However, when the country is specialized in migration–$i.e. \rho$ is large–, the optimal value of remittances rate slightly decreases from 1 to 0, when ρ is at his maximum. Note that in countries where the net gain from migration, ε, is high, the value of the emigration that induces a substitution effect is lower. For instance, in Haiti there is always a detrimental substitution effect. Second, this Figure confirms that Jamaica has an emigration rate which is suboptimal.

Figure 17: Effects of a simultaneous change in γ_f and ρ on g^{BGP}



BRB: Barbados, **DOM:** Dominican Republic, **HTI:** Haiti, **JAM:** Jamaica, **TTO:** Trinidad and Tobago

On the basis of these results, policymakers in the poorest countries with a strong specialization emigration can reduce domestic transfers to old age adults, making them reliant only on foreign remittances or their savings. This is possible when there are high enough gains from migration, and the diaspora can supply large remittance flows to the elderly.

1.6 Conclusion

In this chapter, we propose a tractable OLG model, which enables us to account for the interplay between economic growth and investments in human and physical capital, according to the emigration from island economies. Within the proposed framework, we introduce migration in order to explain choices made by parents in the representative household, in terms of fertility, education and savings. The model emphasizes how the decision-making schedule is affected when intergenerational transfers are incorporated in adults' budget constraint. More precisely, these transfers are key to our depiction of fertility dynamics among SIDS economies. Indeed, future remittances from the diaspora generate a strong incentive to have more children. As a result, on the long-run migration exerts two contradictory effects on population. The positive effect stems from the higher number of children adults decide to bear. The negative effect can be located in the natural balance itself, due to the departure of a fraction ρ of their offspring when they reach adulthood. As a result, these opposite effects could result in outcomes where economic growth was increases, though at a slower pace, compared to demographic growth, thus leading to a reduction of output *per capita*. Another scenario to entertain is that, to the contrary, a higher emigration rate would decrease population size without impeding economic growth, thus increasing output *per capita*. The main mechanism we shed light on results from the tradeoff between savings and human capital investments. Indeed, the larger the incentive to invest in intergenerational transfer, the lower the amount of savings allocated to physical capital accumulation. In some cases–that we succeeded in characterizing–, there was a compensation effect of reduction in domestic savings by the size of the next adult generation, which was the source of future capital stock. Subsequently, long-term economic growth *per capita* was sustained exclusively by human capital accumulation, or demographic growth. In other cases–also well determined–this compensation effect did not occur, and production declined as a result. That being so, we were able to identify conditions on emigration features under which it was possible to observe gains from migration in terms of economic development. Not surprisingly, these conditions concerned the emigration rate, ρ, net gain from migration, ε and share of intergenerational transfers, γ. These three parameters must not be too large to experiment gains from migration.

We developed a careful numerical analysis, with econometric estimation and calibration for the structural parameters in the model for five islands: Barbados, Dominican Republic, Haiti, Jamaica as well as Trinidad and Tobago. This exercise was particularly interesting since it allowed us to describe the productive capital accumulation according to their demographic features. Our main result is that we observed three economic development strategies. First, islands as Dominican Republic, Haiti or Jamaica, exhibit high rate of human capital accumulation and/or population growth in the first periods thanks to the migration. Yet due to the strong incentive created by migration potential gains, domestic savings in these islands were low. This resulted in a reduction of the accumulation of physical capital in the short-run, and in a negative effect on economic growth in the long-run for Jamaica in particular.

Second, in Trinidad and Tobago, funding for old age consumption came primarily from returns of accumulated physical capital. This is due to the fact that the domestic savings effect dominated over remittances, due to the small level of intergenerational transfers. Moreover, lower levels of child-rearing cost resulted in a relatively high level of fertility for the island. Therefore, in this island the accumulation of physical capital is higher thanks to the increase in savings and the population growth. Finally, in Barbados, intergenerational transfers and migration were high. Nevertheless, the net gain from migration was lower than in the other SIDS countries. Therefore, savings and education expenditures were comparatively more important in this country. In this case, the two productive capital stocks increased at similar rates.

Finally, our approach has the advantage of drawing further policymaking applications. This exercise was all the more relevant as different variables of our model can be linked more or less directly with policy decisions. In the present exercise, we have tested diaspora strategies designed to promote emigration in order to achieve a given welfare objective. However, in high-emigration countries such as the Caribbean SIDS, it is sometimes optimal to reduce the migration, because over-investment in human capital generates permanent decline in their long-run economic growth *per capita*. This can be achieved by a generous policy for return migration. Governments in these economies can implement policies to create incentives for households to increase savings and investments in physical capital instead.

A.1 Appendix

A.1.1 Detailed comparative statics of household choices

Equations of the savings and the fertility are:

$$
\begin{aligned}
n_t^\star &= \frac{\beta\gamma(1-\rho+\rho\varepsilon)(1-\gamma)(1-\alpha)(1-\mu)}{\sigma(1+\beta)[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]}N_t^{-\delta} \\
e_t^\star &= \frac{\mu\sigma N_t^\delta}{1-\mu}w_t h_t
\end{aligned}
$$

The derivative of the fertility with respect to the emigration rate, ρ, the net migration gain, ε, and the transfer rate, γ are respectively:

$$\begin{aligned}
\frac{\partial n_t^\star}{\partial \rho} &= \frac{\beta\gamma\alpha\varepsilon(1-\alpha)(1-\gamma)(1-\mu)}{\sigma N_t^\delta(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} > 0 \\
\frac{\partial n_t^\star}{\partial \varepsilon} &= \frac{\beta\gamma\alpha\rho(1-\alpha)(1-\gamma)(1-\mu)}{\sigma N_t^\delta(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} > 0 \\
\frac{\partial n_t^\star}{\partial \gamma} &= \frac{\beta(1-\alpha)(1-\mu)(1-\rho+\rho\varepsilon)}{\sigma N_t^\delta(1+\beta)} \times \frac{\alpha(1-\rho)(1-2\gamma)-\gamma^2(1-\alpha)(1-\rho+\rho\varepsilon)}{[\alpha(1-\rho)+\Lambda_h(1-\alpha)]^2}
\end{aligned}$$

The sign of $\frac{\partial n_t^\star}{\partial \gamma}$ is given by the numerator of the second term of the derivative. Therefore, the next step is to solve the second degree equation given by:

$$\alpha(1-\rho)(1-2\gamma)-\gamma^2(1-\alpha)(1-\rho+\rho\varepsilon$$

The discriminant, denoted Δ, is positive. It is written as follows:

$$\Delta = 4\alpha(1-\rho)[\alpha(1-\rho)+(1-\alpha)(1-\rho+\rho\varepsilon)]$$

There is only one positive solution, which is given by the following equation. If γ is greater than this value, the derivative of the fertility with respect to the intergenerational transfer rate is negative.

$$\begin{aligned}
\gamma &= \frac{2\alpha(1-\rho)-\sqrt{4\alpha(1-\rho)[\alpha(1-\rho)+(1-\alpha)(1-\rho+\rho\varepsilon)]}}{-2(1-\alpha)(1-\rho+\rho\varepsilon)} \\
\gamma &= \frac{\sqrt{\alpha(1-\rho)}\left[\sqrt{\alpha(1-\rho)+(1-\alpha)(1-\rho+\rho\varepsilon)}-\sqrt{\alpha(1-\rho)}\right]}{(1-\alpha)(1-\rho+\rho\varepsilon)}
\end{aligned}$$

It is worth noting here that the population size is proportional to the fertility, with a factor $(1-\rho)$. Thus, the parameters' impact on fertility are the same than the impact on population size, except for the migration rate, which has also a negative effect on the number of adults staying in the domestic area. Here we give directly, the derivative of the steady state adult generation size with respect to ρ.

$$\begin{aligned}
\frac{\partial N^\star}{\partial \rho} = \frac{1}{\delta}\left[\frac{\beta\gamma(1-\mu)(1-\gamma)(1-\alpha)}{\sigma(1+\beta)}\right]^{\frac{1}{\delta}} &\left[\frac{(1-\rho)(1-\rho+\rho\varepsilon)}{\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)}\right]^{\frac{1-\delta}{\delta}} \\
&\times \left[\frac{\alpha(1-\rho)(\varepsilon-1)(1-\rho)-\gamma(1-\rho+\rho\varepsilon)(1-\alpha)(1-\rho+\rho\varepsilon)}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]^2}\right]
\end{aligned}$$

The sign of this derivative is given by the following condition:

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

$$\Leftrightarrow\; \frac{(1-\rho)}{(1-\rho+\rho\varepsilon)} > \sqrt{\frac{\gamma(1-\alpha)}{\alpha(\varepsilon-1)}}$$

A.1.2 Proof of Proposition 2 and of the stability of the equilibrium

Proof of Proposition 2. The population size is independent of the evolution of the capital per unit of efficient labor. Therefore, when the labor force reaches its steady state level, we have:

$$k_{t+1} = k_t = k_{BGP} = \left(\frac{A\sigma}{1-\mu}\right)^{1-\mu} \frac{\alpha}{\theta\Lambda_h[\mu(1-\alpha)]^\mu} k_{BGP}^{\alpha(1-\mu)} (N^\star)^{\delta(1-\mu)}$$

Replacing $N^\star$ in this equation, we obtain directly the level of capital per unit of efficient labor on the BGP. □

Proof of the stability of the equilibrium. The population dynamics is completely independent on the evolution of the other variables of the economy. Defining $g(N_t) = N_{t+1}$.

$$\lim_{N_t \to 0} f'(N_t) = +\infty$$
$$\lim_{N_t \to +\infty} f'(N_t) = 0$$
$$\lim_{N_t \to +\infty} f(N_t) = +\infty$$

The function $g(N_t)$ is concave and there are two points such as $N_{t+1} = N_t$, which are $N_t = 0$ and $N_t = N^\star$ satisfying $0 < f'(N^\star) < 1$. Therefore, it exists a unique non-trivial equilibrium locally stable on the population dynamics, and N shows a regular convergence. When the population has reached its steady state value, the dynamics of the capital per unit of efficient labor writes as follows:

$$k_{t+1} = \left(\frac{A\sigma}{1-\mu}\right)^{1-\mu} \frac{\alpha}{\theta\Lambda_h[\mu(1-\alpha)]^\mu} k_t^{\alpha(1-\mu)} N^{\star\delta(1-\mu)}$$

We define the function $f(k_t) = k_{t+1}$.

$$\lim_{k_t \to 0} f'(k_t) = +\infty$$
$$\lim_{k_t \to +\infty} f'(k_t) = 0$$
$$\lim_{k_t \to +\infty} f(k_t) = +\infty$$

The function $f(k_t)$ is concave and there are two points such as $k_{t+1} = k_t$, which are $k_t = 0$ and $k_t = k_{BGP}$ satisfying $0 < f'(k_{BGP}) < 1$. Therefore, it exists a unique non-trivial equilibrium locally stable and the model shows a regular convergence. □

A.1.3 Proof of Proposition 3 and 4

Proof of Proposition 3. Replacing Ψ and Λ_h by their values in the equation (1.4.8), we obtain the following:

$$k_{BGP} = \left[\frac{\alpha}{\theta[\mu\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]^{\mu}}\right]^{\frac{1}{1-\alpha(1-\mu)}} \times \left[\frac{\beta A(1-\rho)(1-\alpha)(1-\gamma)}{(1+\beta)[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]}\right]^{\frac{1-\mu}{1-\alpha(1-\mu)}}$$

Without calculations, it appears that $\frac{\partial k_{BGP}}{\partial \theta} < 0$, $\frac{\partial k_{BGP}}{\partial \gamma} < 0$, $\frac{\partial k_{BGP}}{\partial \varepsilon} < 0$, $\frac{\partial k_{BGP}}{\partial A} > 0$, $\frac{\partial k_{BGP}}{\partial \beta} > 0$

For the emigration rate, we have:

$$\frac{\partial k_{BGP}}{\partial \rho} = -\frac{1}{1-\alpha(1-\mu)}\left[\left[\frac{\alpha}{\theta[\mu\gamma(1-\alpha)]^{\mu}}\right]\left[\frac{\beta A(1-\alpha)(1-\gamma)}{(1+\beta)}\right]^{1-\mu}\right]^{\frac{1}{1-\alpha(1-\mu)}} \times \left[(1-\rho+\rho\varepsilon)^{-\mu}\left[\frac{(1-\rho)}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]}\right]^{1-\mu}\right]^{\frac{1}{1-\alpha(1-\mu)}} \times \left[\frac{\mu(\varepsilon-1)}{1-\rho+\rho\varepsilon} + \frac{\gamma\varepsilon(1-\alpha)(1-\mu)}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]}\right] < 0$$

□

Proof of Proposition 4. Replacing Ψ and Λ_h by their values in the equation (1.4.8), we obtain the following:

$$g_{BGP} = \left[[\theta(\mu\gamma(1-\rho+\rho\varepsilon)^{\mu}]^{1-\alpha} \left[\frac{\beta A\alpha^{\alpha}(1-\alpha)^2(1-\gamma)(1-\rho)}{(1+\beta)[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]} \right]^{\mu} \right]^{\frac{1}{1-\alpha(1-\mu)}}$$

Without calculations, it appears that $\frac{\partial g_{BGP}}{\partial \theta} > 0$, $\frac{\partial g_{BGP}}{\partial \varepsilon} > 0$, $\frac{\partial g_{BGP}}{\partial A} > 0$, $\frac{\partial k_{BGP}}{\partial \beta} > 0$

For the net gain from migration, we obtain the following:

$$\frac{\partial g_{BGP}}{\partial \varepsilon} = \left[\theta^{1-\alpha} \left[\frac{\beta A\alpha^{\alpha}(1-\gamma)(1-\alpha)[\mu\gamma(1-\alpha)]^{1-\alpha}}{(1+\beta)} \right]^{\mu} \right]^{\frac{1}{1-\alpha(1-\mu)}}$$
$$\times \frac{\mu\alpha\rho(1-\alpha)}{1-\alpha(1-\mu)} \left[\frac{(1-\rho+\rho\varepsilon)^{1-\alpha}}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]} \right]^{\frac{\mu}{1-\alpha(1-\mu)}-1} (1-\rho+\rho\varepsilon)^{-\alpha}$$
$$\times \left[\frac{(1-\rho)+\Lambda_h}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]^2} \right] > 0$$

For the emigration rate, we have:

$$\frac{\partial g_{BGP}}{\partial \rho} = \left[\theta^{1-\alpha} \left[\frac{\beta A\alpha^{\alpha}(1-\gamma)(1-\alpha)[\mu\gamma(1-\alpha)]^{1-\alpha}}{(1+\beta)} \right]^{\mu} \right]^{\frac{1}{1-\alpha(1-\mu)}}$$
$$\times \frac{\mu(1-\alpha)}{1-\alpha(1-\mu)} \left[\frac{(1-\rho+\rho\varepsilon)^{1-\alpha}(1-\rho)}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]} \right]^{\frac{\mu}{1-\alpha(1-\mu)}-1} (1-\rho+\rho\varepsilon)^{-\alpha}$$
$$\times \left[\frac{\alpha(1-\rho)(\varepsilon-1)(1-\rho)-\Lambda_h[\varepsilon-(1-\alpha)(\varepsilon-1)(1-\rho)]}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]^2} \right]$$

Therefore we obtain the following condition:

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

The derivative of the growth factor on the BGP with respect to γ is:

$$\frac{\partial g_{BGP}}{\partial \gamma} = \left[\theta^{1-\alpha} \left[\frac{\beta A\alpha^{\alpha}(1-\rho)(1-\alpha)[\mu(1-\rho+\rho\varepsilon)(1-\alpha)]^{1-\alpha}}{(1+\beta)} \right]^{\mu} \right]^{\frac{1}{1-\alpha(1-\mu)}}$$
$$\times \frac{\mu}{1-\alpha(1-\mu)} \left[\frac{\gamma^{1-\alpha}(1-\gamma)}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]} \right]^{\frac{\mu}{1-\alpha(1-\mu)}-1} \gamma^{-\alpha}$$
$$\times \left[\frac{\alpha(1-\rho)[(1-\alpha)(1-\gamma)-\gamma]-(1-\alpha)\Lambda_h[1-(1-\alpha)(1-\gamma)]}{[\alpha(1-\rho)+\gamma(1-\rho+\rho\varepsilon)(1-\alpha)]^2} \right]$$

Therefore we have the following condition:

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

However it is important to note that if the intergenerational transfer rate is strong, $(1-\alpha)(1-\gamma)-\gamma$ can be negative.

□

A.1.4 Steady-state values of consumptions

On the steady state, the adult and old age consumptions are given by the following equations:

$$\begin{aligned} c_t &= \frac{1-\gamma}{1+\beta} w_t h_t \\ d_{t+1} &= s_t R_{t+1} + n_t \Lambda_h w_{t+1} h_{t+1} \end{aligned}$$

Introducing in the household choices in terms of savings and fertility (s_t and n_t), the factor prices (w_{BGP} and R_{BGP}) and the labor force on the BGP, ($N^\star$), we get:

$$\begin{aligned} c_t &= \frac{1-\gamma}{1+\beta}(1-\alpha)A{k_{BGP}}^{\alpha} h_t \\ d_{t+1} &= \frac{(1-\alpha)A{k_{BGP}}^{\alpha}}{\alpha\Psi A\alpha} h_t \left[{k_{BGP}}^{1-\alpha} + \frac{(1-\alpha)\Lambda_h}{(1-\rho)\alpha\Psi A\alpha}\frac{h_{t+1}}{h_t} \right] \end{aligned}$$

On the BGP, $\frac{h_{t+1}}{h_t}$ is given by the growth rate of the economy, g_{BGP}, therefore we have:

$$\begin{aligned} c_t &= \frac{1-\gamma}{1+\beta}(1-\alpha)A{k_{BGP}}^{\alpha} h_t \\ d_{t+1} &= \frac{(1-\alpha)A{k_{BGP}}^{\alpha}}{\alpha\Psi A\alpha} h_t \left[{k_{BGP}}^{1-\alpha} + \frac{(1-\alpha)\Lambda_h}{(1-\rho)\alpha\Psi A\alpha} g_{BGP} \right] \end{aligned}$$

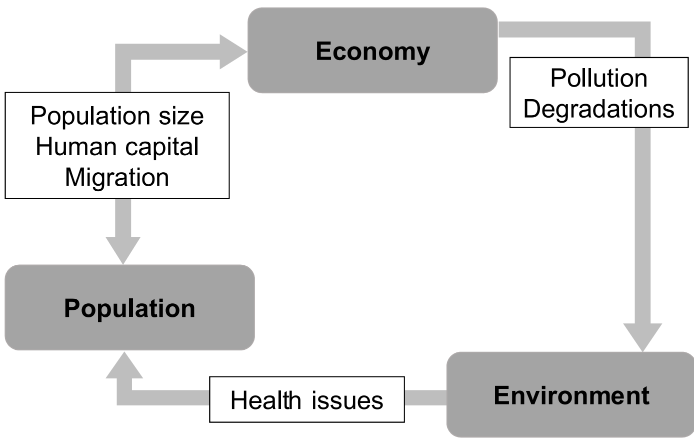
On the BGP, when the growth factors $\frac{c_{t+1}}{c_t}$ and $\frac{d_{t+2}}{d_{t+1}}$ are written, everything simplifies except for the human capital dynamics. This means than on the BGP, it is equivalent to study the growth rate of the economy or of the inter-temporal utility per capita linked to consumption.

Chapter 2

Migration, pollution and human capital in Caribbean SIDS

Abstract

This work aims at studying the interplay between demographic features and environmental impact in Caribbean small island countries. For that, we build a simple overlapping generations model reproducing the strong dependence of these countries to remittances and the effect of pollution on human capital accumulation. Our theoretical analysis, complemented by numerical results, shows that economic gains and human capital improvement are still possible thanks to migration, despite pollution, if the emigration rate is already high. This occurs when the emigration leads to a reduction of the population but to an increase in production per capita. In this context an environmental tax is tested, however to profit from this policy the tax rate must lead to the complete reduction of emissions, especially if the pollution intensity is high.



2.1 Introduction

Since the end of the twentieth century, the pursuit of sustainable development has occupied researchers, policy makers and more generally human societies. In particular, this has been consecrated by the Earth Summit held in Rio de Janeiro in 1992, where the international community has gathered to discuss this issue. On this occasion, Small Island Developing States (SIDS) were defined "as a special case both for environment and development" issues, because they share common economic, social and environmental vulnerabilities. To trigger a sustainable development of these territories, several interrelated demographic, social and economic determinants could be scrutinized. However, one topic is particularly important in the SIDS' case: the human capital dynamics.

This is explained by two main characteristics. The first one is their structural lack of competitiveness, which is explained by the small size of their economy, their remoteness and the scarcity of the natural resources. In this context, increasing the human capital level is the only way to increase the competitiveness (ECLAC, 2018). Secondly, these countries exhibit a high level of emigration, and more specifically of skilled emigration (ECLAC, 2017). Our main findings in the Chapter 1 confirm that migration enhances economic growth if human capital accumulation is high enough. In other terms, there is a potential *brain gain–i.e.*an increase in the average human capital in the sending economy–because migration possibility creates incentives to invest in education. Our results are in line with the literature, we find that *brain gain* occurs if the emigration rate 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)). Considering the weight of migration in the Caribbean SIDS' demographic feature, it is crucial to determine if they are on a path where they benefit from migration, especially in terms of human capital. However, the possibility for an economy to drive the full potential from its population human capital is not solely defined by the investments in education. In fact, human capital can also be impacted by local pollution.

Several studies have highlighted the link between exposures to local pollutants–among others, metals, pesticides or Persistent Organic Pollutants (POPs)–and the reduction of the cognitive skills (Tzivian et al., 2015, Power et al. (2016), Pujol et al. (2016), Lett et al. (2017)). Moreover, small islands are characterized by the scarcity of land and the proximity between areas with different uses. This leads, on the one hand, to a high probability of contamination of the water sources or of the soil in the residential areas if pollutants are released without treatments. On the other hand, because of the high density of population in the inhabited areas, the share of the domestic population impacted by a local pollutant can be significant for these small countries.

In many developing countries, inefficient governance and informal dumping or recycling lead to inadequate environmental policies of waste management (Thonart Philippe et al., 2005, Wilson et al. (2006), Barton et al. (2008)) or wastewater. A review of this topic has been done by Mohee et al. (2015) for SIDS. Second, the close interaction between ecosystems implies that pollutants may easily travel through all the natural environment, ecosystems and vital stock of water. For example, the proximity of waste facilities and their lack of efficiency are directly responsible of soft water contamination and coasts degradation through anthropogenic seafloor debris (ECLAC, 2018). Finally, agricultural use of pesticides and fertilizers were considered as the main local pollution source between 1980 and 2000, knowing that many pesticides are very persistent in the ecosystems (Rawlins et al., 1998).

This work aims at examining the link between pollution, migration and economic growth, for Caribbean economies to draw qualitative conclusions regarding the impact of migration in a polluted area which is densely populated. Is a *brain gain* from migration still possible when cognitive skills are undermined by local pollution; and if so, under which conditions? In this context, what are the effects of an environmental policy? An environmental tax is tested and a special focus is given to the evolution of the productive capital stocks–*i.e.* on the human capital level and on the physical capital–to assess the efficiency of this policy.

This analysis is based on two important fields of the literature: migration economics and environmental economics. The former has already been described in the general introduction.[1] For the latter, we focus on the effect of local pollution on cognitive skills in this chapter. Indeed, pollution is found to be a key determinant of health. In particular, children are found to be much more vulnerable to pollution because of their developing systems and behaviors (Gordon et al. (2004)). Such health effects have important consequences on human capital accumulation through two main

[1] See Lalonde and Topel (1997), Hatton (2014) or Rapoport and Docquier (2006) for a literature review on the migration effects in the sending countries.

channels. First, there is a direct effect of pollution exposition on the ability to learn. Indeed many studies have showed that the cognitive skills could be hampered in a degraded environment (see for meta-analysis of the subject Power et al., 2016, Lett et al. (2017)). More pecularly, Pujol et al. (2016) finds that urban air pollution affects brain maturation of children under 12 years old. And Lett et al., 2017 finds that the more exposed children to industrial pollutant, have math scores that are 1.63 points lower than their less exposed peers. Second, the health effects have consequences on school attendance. Indeed, there is a strong consensus on the effect of air pollution on the occurrence of asthma or on the health in general (Beasley et al., 2015, Arroyo et al. (2016), Marcotte and Marcotte (2017), Rosa et al. (2017), Liu et al. (2017)). Moreover, the effect of pesticides is clearly negative and many studies call for taking into account the effect of their presence on health, whether these particles are in water, soil or air (Lai, 2017, Lammoglia et al. (2017), Valcke et al. (2017)).

This work arises from the observation that there is no model that includes migration and fertility and/or education choices while dealing with pollution effects on human capital accumulation. Taking into account migration to study the link between human capital and pollution is necessary for the Caribbean SIDS. According to the literature, most of the gain from migration comes from the increase in human capital–*i.e.* the *brain gain*–which is due to the incentives to increase the education expenditures in order to improve the probability of migration or the remuneration abroad. We want to study the effect of migration in a degraded environment, in order to evaluate if the *brain gain* is still possible. We use the same OLG model that in the Chapter 1, except for the environment. Moreover, here, the production is responsible of the emissions of pollution, knowing that the human capital accumulation efficiency depends on the stock of pollution. This model, allows to incorporate in our analysis intergenerational choices and solidarity, as well as their impacts on production, the environment and the population dynamics.

In our model, individuals care about their adult and old-age consumption which can be funded thanks to their savings or the intergenerational transfers from their children. The environment impacts the economy through an externality, therefore, households' decisions in terms of savings, fertility and education are the same than in the previous chapter. In the Chapter 1 on the migration impact on the economic growth, we have described two main trade-offs for the household. The first one is between savings and intergenerational transfers and the second one is between fertility and education of the children. For the former, migration increases the gain from human capital and thus leads to a substitution of the savings by the investments in children–in order to receive more transfers. This is not detrimental for the capital stock, if the increases in the household's income or in the number of people that can save, are large enough to compensate the reduction of the savings (in percentage of the income). This is more likely to happen, if the tradeoff between education and fertility leans in favor of education.

For this second tradeoff, the fertility choice depends on the migration incentives, but also on the opportunity cost of raising children in terms of time–a higher fertility reduces the participation to the labor market and then the wages. This cost includes an overcrowding effect linked to the population size (de la Croix and Gobbi, 2017, de la Croix and Gosseries (2012)). When the cost of the children increases, the parents have a higher incentive to invest in education. Therefore, the overcrowding effect decreases the fertility rate at the benefit of the education expenditures. 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 the departures. The relationship between population size and migration is thus described by an inverted U-shaped curve. Until there, results in Chapters 1 and 2 are the same.

However, for the other aggregate variables, results differ. In Chapter 1, a positive effect from migration on population size leads to an increase in education expenditures due to the overcrowding effects. In other cases, education expenditures and savings decrease. At the aggregate level, this leads to inverted U-shaped relationship between the economic growth and migration–in terms of emigration rate or remittances–due to the combination of the reduction in human capital, population and capital stock. Once again, our findings from Chapter 1 are in line with the literature concerning the existence of a potential *brain gain* when migration is not to large (Beine et al., 2006, Docquier et al. (2008)).

In the Chapter 2, aggregate variables display different dynamics, despite the unchanged household choices. First, instead of a balanced growth path, as in the Chapter 1, we find a unique steady state. This is explained by the pollution stock which hampers the human capital accumulation until the economy reaches an equilibrium. Second, an increase in migration enhances the economic growth only if the population is decreasing, and thus if the demographic pressure on the environment decreases.

Moreover, in the present chapter, to cope with this degradation, we have tested an environmental policy, consisting in a tax on pollution emissions and a publicly funded maintenance. To clarify some trends of this model, a numerical analysis is conducted for a representative economy. This allows to evaluate the optimal level of the environmental tax as well as the impacts of the different parameters linked to the emigration's scale or gain. First, the stability of the steady state values is linked mostly to the environmental damage function in the human capital dynamics. Second, depending on the pollution intensity of the production, a weak environmental tax might have null or adverse effects on the economy; while a strong tax that reduces almost completely the pollution emissions is always positive in terms of utility per capita. Finally, in presence of the environmental externality, the relations between on the one hand the emigration rate and on the other hand, production per capita, human capital and/or agents welfare are described by U-shaped curves. Indeed, if migration is low, an increasing share of emigration leads to a rise in the population size and in the pollution stock. This decreases the average human capital, until a threshold, where the reduction of the population allows to have gains in human capital. The effects of the structure of gains from migration, through the transfer rate or the net gain from migration, are more ambiguous because they do not reduce directly the population size. When these parameters are large, they lead to a decrease in the income which can result in a reduction in fertility. This is due to their negative effect on physical capital stock, if the substitution effect between savings and investments in children is large.

The rest of this chapter is structured as follows. Section 2.2 describes the model and the equilibrium. Section 2.3 is a discussion on the effects of migration and the environment on steady state values. Finally, the last section draws conclusions and defines a roadmap for future research.

2.2 The Model

To analyze economic development in SIDS with pollution, migration and intergenerational transfers, we use an OLG model based on the previous chapter's model in which we introduce an environmental externality on children's cognitive skills. This externality is generated by the production. To correct the externality, a policy maker implement a tax on the production. As the individual choices of the firm and of the households remain the same as in Chapter 1, we do not repeat the analysis and refer to the calculations developed in the previous chapter when it is possible. It will enable us to focus on how pollution affects human capital accumulation and long-term equilibria.

2.2.1 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 a constant returns to scale technology:

$$Y_t = AK_t^{\alpha} (L_t h_t)^{1-\alpha} \tag{2.2.1}$$

where K_t is the aggregate stock of physical capital, L_t is the aggregate labor supply to production, h_t is the human capital per worker, $A > 0$ measures the technology level, and $\alpha \in (0,1)$ is the share of physical capital in the 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. The tax revenue is used to fund pollution emissions reduction, m_t, with $m_t = \tau Y_t$.[2] The firm profit is:

$$\Pi_t = A(1-\tau)K_t^{\alpha} (L_t h_t)^{1-\alpha} - w_t h_t L_t - R_t K_t \tag{2.2.2}$$

where w_t is the wage for one unit of efficient labor, r_t the interest rate and $R_t \equiv 1 + r_t$ is the return factor of capital.

Assuming that the capital fully depreciates in one period, factor prices are as follows:

$$w_t = A(1-\alpha)(1-\tau)K_t^{\alpha} (L_t h_t)^{-\alpha} \tag{2.2.3}$$

$$R_t = A\alpha(1-\tau)K_t^{\alpha-1} (L_t h_t)^{1-\alpha} \tag{2.2.4}$$

The production sector generates a pollution flow. The dynamics of the pollution

[2] In another specification, described in the Appendix A.1.2, the tax revenue is simply redistributed to the households.

stock is such that:

$$Z_{t+1} = \Omega Y_t - m_t + (1-a)Z_t = (\Omega - \tau)AK_t^{\alpha}(L_t h_t)^{1-\alpha} + (1-a)Z_t \quad (2.2.5)$$

where, $\Omega \in]0;1]$ is the pollution intensity of production and $a \in]0;1]$ is the natural absorption rate of pollution.

For simplicity of the analysis, we assume that the pollution abatement effort $m_t = \tau Y_t$, is perfectly converted in a reduction of the pollution emissions of the production, ΩY_t. Here, the abatement effort could include water treatments or waste processing for example.[3] The equation (2.2.5) describes the dynamics of any local pollution such as pesticides, metal or Persistent Organic Pollutant (POP) in water tables, soil, freshwaters, etc. This equation allows to take into account in a simple way, both the intensity of the pollution and the natural capacity of the environment to clean itself, a. If $a = 1$, the model describes a pollution which is not persistent in the environment and thus a pollution flow rather than a stock. Here we do not consider the case where $a = 0$, because it implies that all emissions of pollution would be persistent in the environment forever.

2.2.2 Family's behavior

Compared to the first chapter, the sole novelty for the household program is in the human capital dynamics. Besides the total investments in education e_t and the parents' human capital h_t, the human capital per child h_{t+1} depends on the efficiency of human capital accumulation $\theta(Z_t)$. The function $\theta(Z_t)$ is defined for positive or null real values of Z_t and decreases with the pollution stock, such that $\theta'(Z_t) < 0$.[4] Thus, in a polluted environment the children's cognitive skills are deteriorated, which leads to a decrease of the ability to accumulate human capital, whether it comes from their parents' human capital or the education received. Otherwise, we keep the previous specifications, which is described as follows:

$$h_{t+1} = \theta(Z_t)h_t^{1-\mu}e_t^{\mu} \quad (2.2.6)$$

[3] There are many alternative approaches in the modelling of the pollution dynamics. For instance, it is possible to consider an environmental quality which is degraded by the pollution and improved by a cleanup effort as in John and Pecchenino (1994). These approaches are interesting extensions of the current research and are left for future work.

[4] A numerical analysis of the characteristics of this function is conducted later.

where $0 < \mu < 1$ represents the education efficiency.[5]

Finally, the rest of the ingredients of the model remain the same. The share of income devoted to raising children is given by the following equation:

$$\sigma N_t^{\delta} n_t \tag{2.2.7}$$

where the parameter σ is the total cost of rearing children.

The emigration rate being denoted by $\rho \in [0, 1[$, the evolution of the size of the adult generation writes as follows:

$$N_{t+1} = n_t N_t (1 - \rho) \tag{2.2.8}$$

In this work, we conserve the same utility function–which depends only on the consumption–than in the Chapter 1. An alternative is to incorporate the environmental quality or the pollution stock in the preferences of the household. However, in this chapter, we change the model as little as possible in order to ease the comparisons between the results of the two chapters. Second, the main objective of this thesis is to study the economic effects of migration and thus its interactions with sustainable development goals.[6] Finally, the new consumer program is summarized by the following:

$$\begin{aligned}
& \max_{c_t, s_t, e_t, n_t} U(c_t, d_{t+1}) &=& \ln(c_t) + \beta \ln(d_{t+1}) & (2.2.9)\\
s.t \quad & c_t + s_t + n_t e_t &=& w_t h_t (1 - \gamma - \sigma N_t^{\delta} n_t) & (2.2.10)\\
& d_{t+1} &=& s_t R_{t+1} + n_t \Lambda_h w_{t+1} h_{t+1} & (2.2.11)\\
& h_{t+1} &=& \theta(Z_t) h_t^{1-\mu} e_t^{\mu} & (2.2.12)
\end{aligned}$$

where $\Lambda_h = \gamma(1 - \rho + \rho\varepsilon)$, is the share of the children income transferred to the parents. It depends, on γ and ρ, respectively the intergenerational transfer, and the net gain from migration.

The equations (2.2.10) and (2.2.11) give the budget constraint during the two periods. In the first period, adults consume (c_t), save (s_t) and invest in children (n_t and

[5]We assume that $e_t > 0$, in order to have interior solutions.

[6]Studying the interactions between preferences on the environment and migration is an interesting subject for future research, especially because biodiversity and environmental quality in these countries are recognized for their intrinsic value.

e_t). While in the second period, they consume (d_{t+1}) thanks to their savings remunerated at the return factor R_{t+1} and the transfers from their children wherever they live $n_t \Lambda_h w_{t+1} h_{t+1}$. Agents care about adult and old-age consumptions and thus face the same tradeoffs than in the previous chapter. Their preferences are represented by the function (2.2.9), according to the psychological discount factor, β. As households do not take into account the environmental externality, their optimal choices are the same than in Chapter 1.

$$e_t^\star = \frac{\mu\sigma N^\delta}{1-\mu} w_t h_t \tag{2.2.13}$$

$$s_t^\star = \frac{\beta\alpha(1-\rho)(1-\gamma)}{(1+\beta)[\alpha(1-\rho)+(1-\alpha)\gamma(1-\rho+\rho\varepsilon)]} w_t h_t \tag{2.2.14}$$

$$n_t^\star = \frac{\beta(1-\gamma)(1-\alpha)(1-\mu)\gamma(1-\rho+\rho\varepsilon)}{\sigma(1+\beta)[\alpha(1-\rho)+(1-\alpha)\gamma(1-\rho+\rho\varepsilon)]} N_t^{-\delta} \tag{2.2.15}$$

In that case, whatever the dynamic of human capital, agents will invest in education, fertility or capital in the same way, than in the situation without externality.[7] The determinants of the household choices are described in the Section 1.3 of the Chapter 1.

2.2.3 Intertemporal equilibrium

The market-clearing conditions for physical capital, labor force and human capital level are given by equations (2.2.16) to (2.2.18) respectively while the pollution dynamics is defined by equation (2.2.5).

$$K_{t+1} = s_t N_t \tag{2.2.16}$$

$$L_{t+1} = N_{t+1} = n_t N_t (1-\rho) \tag{2.2.17}$$

$$h_{t+1} = \theta(Z_t) e_t^\mu h_t^{1-\mu} = \theta(Z_t) \left(\frac{\mu\sigma}{1-\mu}\right)^\mu h_t (N_t^\delta w_t)^\mu \tag{2.2.18}$$

The values of the household's optimal choices $s_t^\star$, $n_t^\star$ and $e_t^\star$ are given in equations (2.2.14), (2.2.15) and (2.2.13). The wage and the return factor are given by equations (2.2.3) and (2.2.4). After some computations, we can deduce the intertemporal equilibrium.

[7] If the environment is introduced in the utility 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.

Proposition 5. *Given the initial conditions $K_0 > 0$, $N_0 > 0$, $h_0 > 0$ and $Z_0 \geq 0$, the intertemporal equilibrium is the sequence (N_t, K_t, h_t, Z_t) such that the following system is satisfied for all $t \geq 0$:*

$$\begin{cases} N_{t+1} = \Psi\Lambda_h(1-\rho)\dfrac{(1-\mu)}{\sigma}N_t^{1-\delta} \\ K_{t+1} = \Psi\alpha A(1-\rho)(1-\tau)K_t^{\alpha}N_t^{1-\alpha}h_t^{1-\alpha} \\ h_{t+1} = \theta(Z_t)\left[\dfrac{\sigma\mu A(1-\alpha)(1-\tau)}{1-\mu}\right]^{\mu}K_t^{\alpha\mu}N_t^{\mu(\delta-\alpha)}h_t^{1-\alpha\mu} \\ Z_{t+1} = (\Omega-\tau)AK_t^{\alpha}\left(N_t h_t\right)^{1-\alpha} + (1-a)Z_t \end{cases} \tag{2.2.19}$$

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

Proposition 6. *A Steady-State (SS) is an equilibrium satisfying* ***Proposition 5*** *and where N_t, h_t, K_t and Z_t are constant. There is a unique equilibrium, for which the values of $N^\star$, $K^\star$, $h^\star$ and $Z^\star$ are:*

$$N^\star = \left[\frac{(1-\mu)(1-\rho)\Lambda_h}{\sigma}\Psi\right]^{\frac{1}{\delta}} \tag{2.2.20}$$

$$K^\star = \alpha(1-\alpha)(1-\tau)\Psi(1-\rho)\frac{a\theta^{-1}(\chi)}{\Omega-\tau} \tag{2.2.21}$$

$$h^\star = \frac{a\theta^{-1}(\chi)}{(\Omega-\tau)A}\left[\alpha A(1-\tau)\right]^{-\frac{\alpha}{1-\alpha}}\left[\frac{\sigma}{\Lambda_h(1-\mu)}\right]^{\frac{1}{\delta}}\left(\Psi(1-\rho)\right)^{-\frac{1-\alpha(1-\delta)}{\delta(1-\alpha)}} \tag{2.2.22}$$

$$Z^\star = \theta^{-1}(\chi) \tag{2.2.23}$$

where $\chi = [\mu\Lambda_h(1-\alpha)]^{-\mu}[\Psi A\alpha^{\alpha}(1-\tau)(1-\rho)]^{-\frac{\mu}{1-\alpha}}$ is the efficiency of human capital accumulation in the steady state and $\theta^{-1}(.)$ is the inverse function of $\theta(Z_t)$.[8]

Proof of Proposition 6. We find directly the steady state value of the adult generation size (equation (2.2.20)), thanks to the first equation of the system (2.2.19). This equation is exactly the same than in the previous model. Indeed, the population dynamics is independent of the other variables, and depends exclusively on the structural parameters of the economy as well as the population size.

Using the equation (2.2.20) in the dynamics of the capital, given by the equation

[8] The stability of the equilibrium could not be proven analytically, however we conduct an analysis of the determinants of the stability in the next section.

K_{t+1} in the system (2.2.19), we find a relation between the steady state values of the capital stock $K^\star$ and the human capital level $h^\star$.

$$K^\star = \left[\frac{\alpha\beta A(1-\tau)(1-\alpha)(1-\gamma)(1-\rho)}{(1+\beta)\left[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)\right]}\right]^{\frac{1}{1-\alpha}} N^\star h^\star \tag{2.2.24}$$

We introduce equations (2.2.24) and (2.2.20) ($N^\star$) in the equation of the human capital dynamics, given by the equation (2.2.6).

$$h^\star = \theta(Z^\star)\left[\frac{\mu A\sigma(1-\alpha)(1-\tau)}{1-\mu}\right]^{\mu} (K^\star)^{\alpha\mu}(N^\star)^{\mu(\delta-\alpha)}(h^\star)^{1-\alpha\mu} \tag{2.2.25}$$

After some computations we obtain the steady state value of $\theta(Z^\star) \equiv \chi$:

$$\chi = \left[\gamma\mu(1-\rho+\rho\varepsilon)(1-\alpha)\right]^{-\mu}\left[\frac{\beta A\alpha^{\alpha}(1-\tau)(1-\rho)(1-\gamma)(1-\alpha)}{(1+\beta)\left[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)\right]}\right]^{-\frac{\mu}{1-\alpha}} \tag{2.2.26}$$

It is worth noting that the steady state value of the efficiency of human capital accumulation is not linked to the level of emissions. The stock of pollution can be defined as the value of the inverse function of $\theta(Z_t)$ written $\theta^{-1}(.)$. Thus, on the steady state, $Z^\star$ is defined as $Z^\star = \theta^{-1}(\chi)$.[9] Finally, using the dynamics of the pollution stock, given by the last equation in the sytem (2.2.19), we obtain another expression of the steady state human capital:

$$h^\star = \left[\frac{aZ^\star}{(\Omega-\tau)A}K^{\star-\alpha}N^{\star\alpha-1}\right]^{\frac{1}{1-\alpha}} \tag{2.2.27}$$

Replacing the steady state values of population and pollution stock (given respectively by (2.2.20) and (2.2.23)), in the system of equations defined by (2.2.24) and (2.2.27), we obtain the values of $h^\star$ and $K^\star$:

$$\begin{aligned} h^\star &= \frac{a\theta^{-1}(\chi)}{\Omega-\tau}\left[\alpha A(1-\tau)\right]^{-\frac{\alpha}{1-\alpha}}\left[\frac{\sigma}{\gamma(1-\mu)(1-\rho+\rho\varepsilon)}\right]^{\frac{1}{\delta}}\left[\Psi(1-\rho)\right]^{-\frac{1-\alpha(1-\delta)}{\delta(1-\alpha)}} \\ K^\star &= \Psi\alpha(1-\rho)(1-\tau)\frac{a\theta^{-1}(\chi)}{\Omega-\tau} \end{aligned}$$

where $\Psi \equiv \frac{\beta(1-\gamma)(1-\alpha)}{(1+\beta)[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)]}$ □

[9]The properties of the function $\theta(.)$ are studied in the numerical analysis.

2.2.4 Stability and dynamics of the economy

The model being a four-dimensional problem, it is quite difficult to study the stability of the equilibrium.[10] Therefore in the present section, we give some insights on the mechanisms that might have an impact on the dynamics of the model. We identify two main determinants for the stability: the population dynamics and the pollution dynamics. Indeed, the stability analysis in the first chapter has shown that if the population size converge to its steady state value, both human capital and physical capital will grow at the same rate because of the accumulation of human capital. This has led to a balanced growth path in the model without pollution. In the present model, there is a steady state because of the pollution stock, which prevents human capital from increasing on the long run. In this chapter, with a growing human capital, production increases as well as the pollution stock. This generates an increase in the externality effect that reduces human capital at the next period, and thus the production too.

According to the population dynamics (given by equation (2.2.20)), population changes are totally independent of the other variables. Therefore, in this analysis we will focus on the determinants of the stability of the pollution stock. On the one hand, we analyze the damage function, $\theta(Z_t)$. On the other hand, we will study the natural absorption rate, a, and the pollution intensity, Ω. In fact, robustness tests on the parameters have shown that these are the sole features that might have an impact on the stability. The parameters linked to the migration–such as ρ, ε or γ–change the level attained by the population size, the human capital and the capital stock, but they do not impact the stability.

To conduct the numerical analysis, we use parameters for a benchmark economy that represents the average Caribbean economy. Parameters are displayed in Table 11. They have been set to the average values of the parameters that were obtained in the previous chapter's calibration for our sample of Caribbean islands.[11] Moreover, we normalize all the initial values, K_0, L_0 and h_0 to 1, while the pollution stock is set to 0 at the initial period.

First of all, we test two functions for $\theta(Z_t)$ that respect the conditions given in

[10] The population dynamics being independent of the other variables, the system can be reduced to a three-dimensional problem. However even in that case stability is not easy to prove analytically.

[11] We use directly the precise calibration for several islands that has been conducted in Chapter 1 (cf. Table 9 in Chapter 1, Section 1.5).

Table 11: Parameters of the model

Parameters		Benchmark
Preference factor for the future	β	0.98
Capital intensity in production	α	0.29
Technology level	A	1.02
Education efficiency	μ	0.14
Emigration rate	ρ	0.32
Net gain from migration	ε	14.43
Share of income remitted	γ	0.11
Density impact on fertility cost	δ	0.69
Cost for raising children	σ	0.06
Initial value of human capital efficiency	$\bar{\theta}$	4.79

the model (see Section 2.2); *i.e.* they are defined for positive or null values of Z_t and their first derivatives with respect to Z_t are negative. Moreover, we introduce the parameter $\bar{\theta}$, as the maximum value attained by the efficiency of human capital, hence corresponding it corresponds to the situation without any pollution. We take $\bar{\theta} = 4.79$, the average efficiency of human capital accumulation in the calibration. The two functions tested are the following:

$$\theta_1(Z_t) = \frac{\bar{\theta}}{1 + Z_t} \tag{2.2.28}$$

$$\theta_2(Z_t) = \frac{\bar{\theta}}{1 + Z_t^2} \tag{2.2.29}$$

In the Figure 18, we display the dynamics of the following variables for the benchmark economy: production (Y_t), capital stock (K_t), pollution stock (Z_t) and human capital (h_t). The plain line represents the benchmark economy with $\theta_1(Z_t)$ while the dashed line is related to the situation with $\theta_2(Z_t)$. The first specification allows to have a stable equilibrium with damped-oscillations, while the second shows an unstable dynamics with regular oscillations around the steady state. In the figure 19, the second derivatives of the functions $\theta_1(Z_t)$ and $\theta_2(Z_t)$ are represented in order to define whether these functions are convex or concave. The signs of these second derivatives are not always the same in the interval represented here. It appears that the second function is concave for some values of Z_t, this leads to an unstable equilibrium when Z_t is in this interval. Therefore, in the rest of this analysis, we use the first specification. A sufficient assumption in the model to insure the stability of the equilibrium should be that: $\theta'(Z_t) < 0$ and $\theta''(Z_t) \geq 0$.

Second, we test the effect of the values of Ω and a. In the Figures 20 to 22,

Figure 18: The effect of $\theta(Z_t)$ on the steady state stability

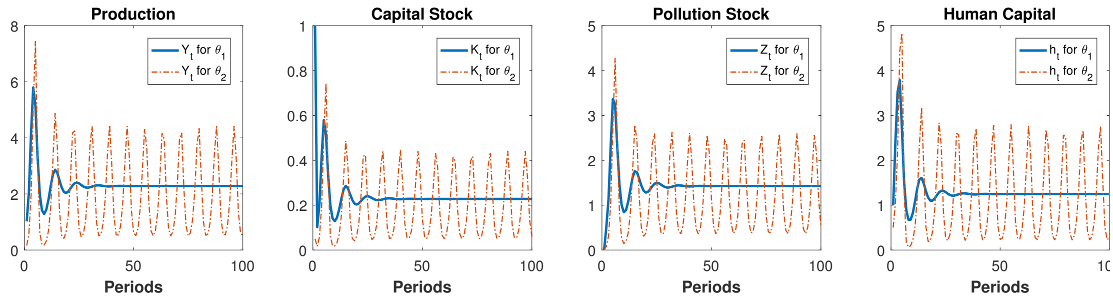
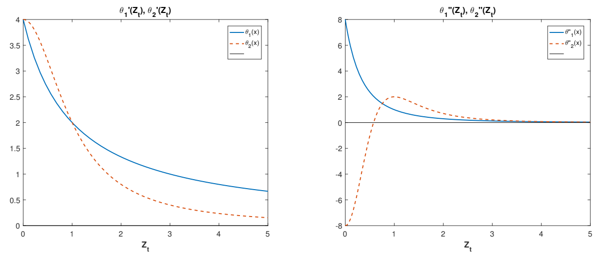


Figure 19: The functions $\theta_1(Zt)$ and $\theta_2(Z_t)$ and their second derivatives



production (Y_t), physical capital (K_t), pollution (Z_t) and human capital (h_t) of the benchmark economy, are represented according to different values of absorption rate–*i.e.* $a = \{0.2, 0.5, 0.8\}$–and of pollution intensity–*i.e.* $\Omega = \{0.2, 0.5, 0.8\}$.

In the first chapter, in the absence of the pollution externality, human capital increases monotonically on the steady state. This has a positive effect on production and on capital stock. In presence of pollution emissions, human capital cannot increase without leading to an increase in pollution. When the pollution is high, this leads to an abrupt decrease in human capital and in capital stock (because the amount saved is lower). With the resulting decrease in human capital, the production also is lessened and thus the pollution stock. At that moment another cycle begins, with human capital accumulation, growing production and physical capital. However, increases–for all variables–are slower because the future human capital depends on the past human capital. Consequently, it is possible to reach a steady state with damped oscillations. This cyclical convergence has also been found by Varvarigos (2013) with similar mechanisms.

Before the steady state is reached, a high pollution intensity, Ω, or a low natural absorption of pollution, a, accelerate the constitution of the pollution stock. This, results in a larger cycles' amplitude. On the steady state, the increase in human capital that would normally occur, is exactly compensated by the reduction in abilities due to pollution. The level where there is this equilibrium depends on χ.

What is surprising, is that the steady state pollution stock is the same whatever are the pollution intensity or the natural absorption of pollution by the ecosystems. This is due to the fact that the equilibrium is reached when the marginal increase in human capital is exactly compensated by the marginal loss in reduction in cognitive skills. This equalities does not depend on pollution intensity, but on parameters that changes the human capital dynamics. Consequently, long-term pollution only depends on the level that will stop the accumulation of the human capital and thus on the economic tradeoffs, which appears in χ. When those tradeoffs are solved, all the economic variables are constant and thus the pollution linked to this level is also constant. Here, only the time necessary to stop the fluctuations, as well as their extent are impacted by those parameters, but not the steady-state value.

Therefore, effects of environmental features depend on the time scale considered. At short term, the pollution intensity has a strong impact on the pollution stock. This has an impact on the human capital obtained in the short-term, the income and thus on the amount saved. If a is small or Ω is high, the pollution stock is higher in the first periods. The level reached by the economic results is hampered by a higher pollution intensity or a smaller absorption rate, because, human capital accumulation depends on past values. If the earlier level of human capital are high, the later level of human capital are lower too. This leads to a decrease in the steady state values of production, $Y^\star$ and physical capital, $K^\star$. However, there will be convergence of the pollution stock value to the same steady state value–determined with χ–whatever the values of the environmental features.

Next, an analysis of the effects of the various parameters on the steady state values $N^\star$, $h^\star$, $K^\star$ and $Z^\star$ is conducted. Note that in the steady state, the dynamics of the population size is considered to be equivalent to the adult generation size.[12] Therefore in the rest of this work, population size and adult generation size present exactly the same features and both terms can be used indifferently to describe the population.

[12]The size of the adult and old age generation is the same, and before the migration there are $n^\star(1-\rho)$ children. In any case the total population size is directly proportional to the adult generation size, because the fertility is constant on the BGP: $n^\star = \frac{1}{1-\rho}$

Figure 20: The effect of Ω on the convergence, for $a = 0.2$

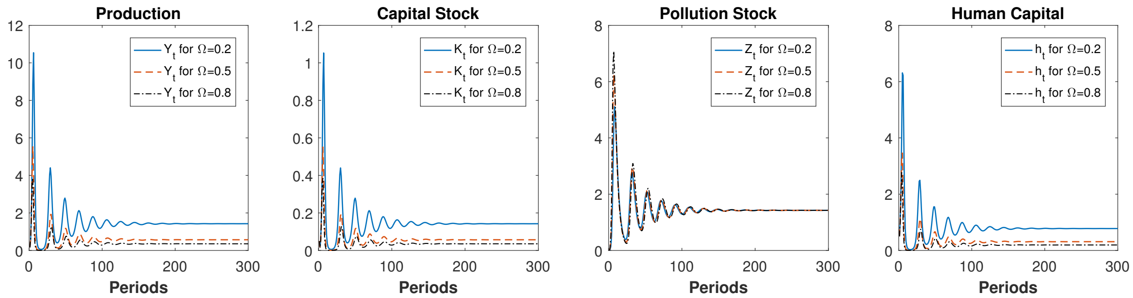


Figure 21: The effect of Ω on the convergence, for $a = 0.5$

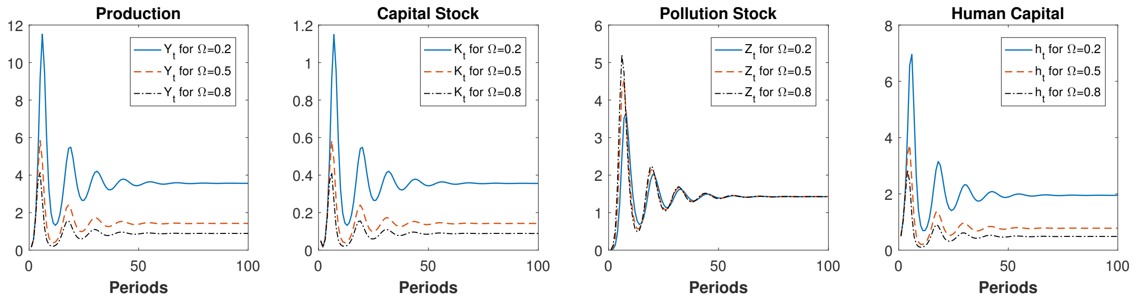
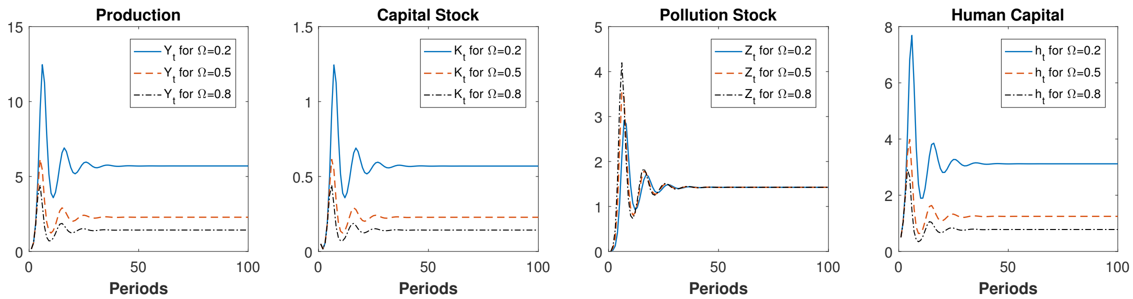


Figure 22: The effect of Ω on the convergence, for $a = 0.8$



2.3 Migration and the environment

In this section, the focus is on the environmental features and on the parameters that control the migration impact. Static comparatives and numerical simulations are used in this discussion which is conducted in two steps. We study, first the impact of the environmental features and second the impact of the migration features.[13] Most of the discussions are derived from the numerical simulations because of the complexity of the expressions obtained from the analytical exercise. However, the conclusions from the simulations are very consistent to changes in the parameters. We use the parameters values of Table 11.

The aim of this work is not to scrutinize the values of the parameters but rather to exhibit the impacts of their variations on the economies described by this model. Consequently, the variations induced by changes in the parameters will be described but not the levels reached by the different aggregates in the economies. For the simulations used in this section, we retain the following function $\theta_1(Z_t)$ of the previous section:[14]

$$\theta(Z_t) = \bar{\theta}\left[\frac{1}{1+Z_t}\right]$$

2.3.1 The environment and the public policy

Proposition 7. *On the steady state, the pollution intensity, Ω, has a negative effect on the stock of physical capital and the human capital, while it has no effect on the population size and the pollution stock. The productive capital stocks are positively correlated to the absorption rate, a. Finally, the tax reduces the pollution stock, while it has a positive effect on $K^\star$ and $h^\star$ under the following conditions:*

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

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

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

[13] The detailed computations for the static comparatives are presented in the Appendix A.1.1

[14] For simplicity we get rid of the subscript.

First of all, the environmental degradation does not lead to a reduction in the population size, and thus, the environmental tax does not have a natalist effect, unlike the results found by de la Croix and Gosseries (2012).[15] Indeed, 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 impacted by the pollution stock–*i.e.* $\theta^{-1}(\chi)$–, while they increase with the value of χ.

As said earlier, 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, through the study of the dynamics, we know that the pollution intensity of production impacts strongly the transitional dynamics of the pollution stock and thus the accumulation of the human and physical capital stocks in the first periods. If it is high, the efficiency of human capital accumulation is lessened in the first stages of the development. Thus human capital level that can be attained in the steady state is also lower, even if the value of $\theta(Z^\star)$ is the same for all values of Ω. Similarly, the capital stock will be lessened even if the share of savings is independent of the pollution stock. This is due to the loss of income that occurs with the decline in the human capital when Ω is high. In that context, a change in the tax rate, τ, affects the 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 conditions linked to the pollution intensity.

The numerical simulations simplify the analysis of this effect. Figure 23 displays steady state values for production, population size, pollution stock, total utility, production per capita, human capital level, capital stock and utility per capita according to the tax level, $\tau \in [0; 0.8[$.[16] In every figures, there are two curves. The dotted line is for the variables evolution when $\Omega = 0.2$, while the other one represents the effect of the tax if $\Omega = 0.8$.
First, in these figures we observe asymptotes when τ approaches Ω. Second, if Ω is small, it is very profitable to implement a tax–even a small one–because it always leads to an increase in the per capita variables–*i.e* human capital, production per capita and utility–as well as a better capital stock, while pollution is lessened.

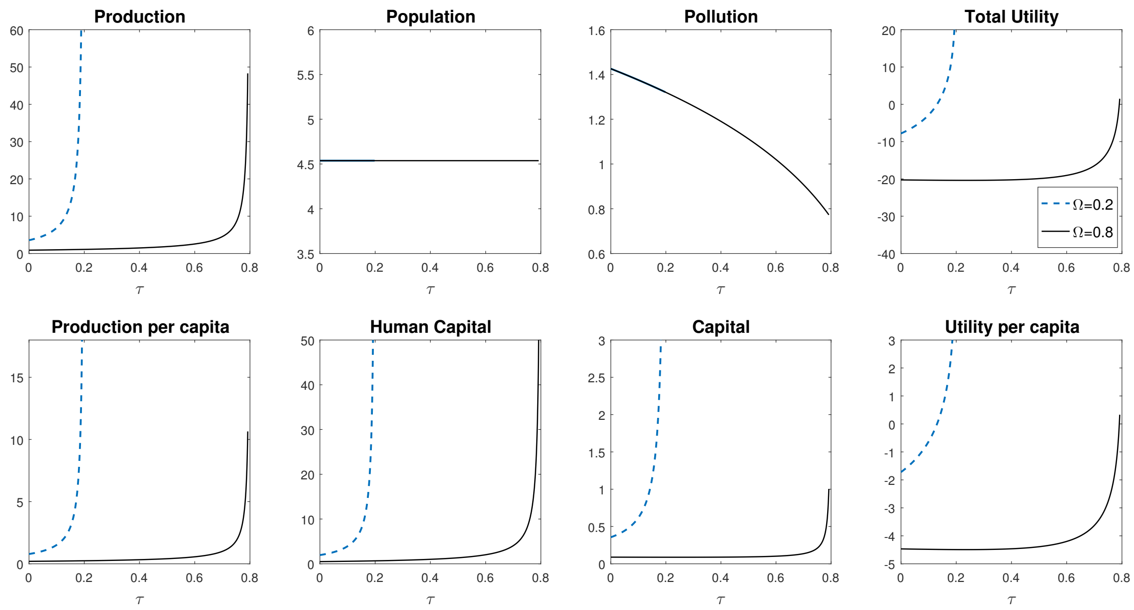
In a context of high emissions, the environmental tax increases the utility per

[15] This is not the case if the tax revenue is redistributed to the household instead of used in order to fund the emissions abatement.
[16] The case, where $\tau = \Omega$ corresponds to the model described by the Chapter 1, but with the supplementary cost of the depollution

capita only for values when τ approaches Ω. One explanation is that the effects of the environmental policy on the environmental externality are too small if the tax is weak. Therefore, the tax leads to an increase in human capital. However, the loss due to the capital stock is higher than the gain from human capital, until a very high value of tax. In that case, it is better to not implement a tax than to introduce a weak environmental policy.

Note that these effects are very consistent to different values of parameters for migration–*i.e.* γ, ρ, ε–as well as for different values of absorption rate or parameters that control the overcrowding effect. Indeed, a and δ introduce a scale effect but they do not change the shapes of the curves for the steady state values.

Figure 23: The effect of the environmental tax rate: τ



2.3.2 The impact of migration

We focus now on the effects of migration features–*i.e.* ρ, ε and γ. Note that a raise in γ means that the intergenerational transfers are more important for all the children wherever they live, while an increase in ε induces a rise in the remittances received in the domestic economy. In the numerical simulations, the values retained for the intensity of the emissions of pollution, θ, the absorption rate, a, and the tax rate, τ are 0.3, 0.5 and 0.29 respectively.

The effect of the emigration rate: ρ

Proposition 8. *The steady state values of the population size, the stock of pollution, the physical capital and the human capital are positively correlated to 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 $\zeta_\rho = \frac{\partial\theta^{-1}(\chi)}{\partial\rho}\frac{\rho}{\theta^{-1}(\chi)}$, *is the elasticity of steady state pollution with respect to the emigration rate, ρ.*

Pollution stock and population size are directly impacted by the level of the emigration rate. On the other hand, the emigration rate effects on human capital and capital stock depend on the elasticity of pollution with respect to ρ. This is the main novelty of this chapter concerning migration with respect to the Chapter 1. On the one hand, migration has a direct impact on these variables, as in the first chapter. On the other hand, because it changes the population dynamics, it also changes the pollution level and thus can have adverse effect on human capital and capital.

To clarify, the mechanisms and the relationship involved, we study the evolution of the different variables according to the value of ρ. Figure 24 displays steady state values for production, population size, pollution stock, total utility, production per capita, human capital, capital stock and utility per capita, according to the emigration rate, $\rho \in [0, 0.6]$. This interval include all the potential emigration rate observed in the Caribbean region.

The values of the aggregate variables with respect to the emigration rate are still described by inverted U-shaped curves. However, the emigration rate effects on human capital, production per capita and the utility per capita are now described by U-shaped curves. While in the Chapter 1, these effects were described by inverted-U shaped curve. Indeed, under a certain level of ρ, the production stock increases thanks to the larger population size. As described in the previous chapter, migration increases the gain from migration and thus creates incentives to have children. The problem is that a higher production leads to larger emissions of pollution, and thus to an increase in the environmental externalities on human capital accumulation. When the increase in the 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 might occur if savings are strongly reduced in order to increase fertility.

If the emigration rate exceeds a certain limit, the population size is reduced by migration, because, the larger number of children does not compensate the loss of adults with migration. Moreover, the substitution of savings in favor of investments in children is substantial if ρ is high. This is aggravated, by the reduction of the number of savers in the economy that comes from the reduction of the population. In that case, the physical capital decreases too much to sustain the production, and we observe that the production reduction is larger than the reduction in population. Quite surprisingly, in this chapter, this is when the migration has a positive effect on the utility per capita while it was exactly the opposite in the Chapter 1. Indeed, the reduction of the production decreases the pollution stock. This leads to an increase in human capital and thus to an increase in households income (defined as $w_t h_t$, where w_t is the wage). While the substitution effect between investments in children and savings is still an important mechanism in the economy, its impact on the physical capital stock is lessened by this positive income effect. Therefore, the decrease in physical capital is reduced. Combined with the increase in human capital, that results in gains in terms of utility per capita.

These results differ largely from those of the first chapter model, where, all the effects of the emigration rate on the variables were described by inverted U-shaped curves. The consensual result is that an increase in migration leads to a gain if the value of the emigration rate is low and to an economic decrease when ρ is high. Here we find exactly the opposite, the emigration rate reduces the damages from the externality when it is high and thus leads to economic gains.

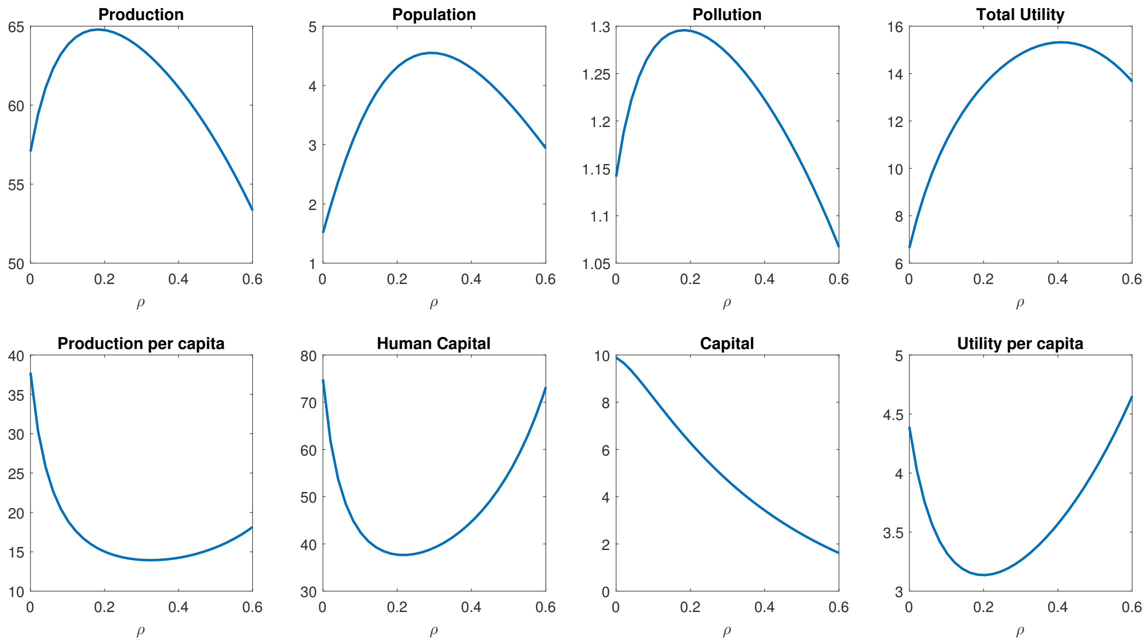
The effect of the net gain from migration: ε

Proposition 9. *The effect of ε on the population size is always positive, while its effects on pollution and physical and human capital depend on the following conditions:*

$$\frac{\partial Z^\star}{\partial \varepsilon} > 0 \Leftrightarrow \varepsilon < \frac{(1-\rho)(1-\gamma)}{\gamma\rho}$$

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

Figure 24: Effect of a variation of ρ on the economy



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

where $\zeta_\varepsilon = \frac{\partial\theta^{-1}(\chi)}{\partial\varepsilon}\frac{\varepsilon}{\theta^{-1}(\chi)}$ *is the elasticity of steady state pollution with respect to the net gain from migration,* ε*.*

The static comparative analysis shows that the effects of ε on $Z^\star$ and $N^\star$ are directly linked to its value. The condition given by the **Proposition 9** shows that the net gain from migration has a positive effect on the pollution stock if all parameters linked to migration are not too high. Indeed, we have shown in the first chapter that if the incentives created by migration are too important, the substitution effect between investments in physical capital and investments in children might lead to a decrease in the economic growth (and in our case, in the steady state value of the production). The pollution stock, is directly correlated to the production, and thus it is impacted by the same mechanisms.

As for the emigration rate, the effect of ε on $h^\star$ and $K^\star$, depends on the elasticity of pollution with respect to ε. In order to clarify the mechanisms, we conduct a numerical analysis, with different values of emigration rate. The numerical analysis has been conducted with values of $\varepsilon \in [1, 50]$. These values could seem very high, but, the economic situation of country as Haiti compared to OECD countries is pretty well described by a value of ε close to 50. We test three levels of emigration rate,

$\rho = \{0.1; 0.315; 0.5\}$.

Figure 25 displays steady state values for production, population size, pollution stock, total utility, production per capita, human capital level, capital stock and utility per capita according to the net gain from migration. In each figure, three curves are represented with respect to different values of emigration rate, ρ. The dashed line displays the results when $\rho = 0.1$, the dotted line displays the results for $\rho = 0.5$, finally the plain line is for the benchmark economy.

The net gain of migration has always a positive effect on the population size. In the absence of an environmental externality, the negative impact of the net gain from migration on production is solely due to the reduction of the physical capital stock. It occurs if the substitution effect between investments in children and savings is strong. In most cases, there is no negative effects from ε on the production.[17]. This means that the pollution stock is positively correlated to the net gain from migration as well.

With the environmental externality, negative impacts from the substitution effect are combined with the decrease in human capital due to pollution. Figure 25 shows that this can lead to a reduction of the production–and thus of the pollution stock–if the other features of the migration–*i.e.* the emigration rate–are large enough. Therefore, for very large values of ε, associated to a large emigration rate, the reduced pollution stock is associated to a higher human capital. We observe in that case, a positive effect of the net migration rate on the per capita values and thus U-shaped curves for the utility per capita with respect to ε.

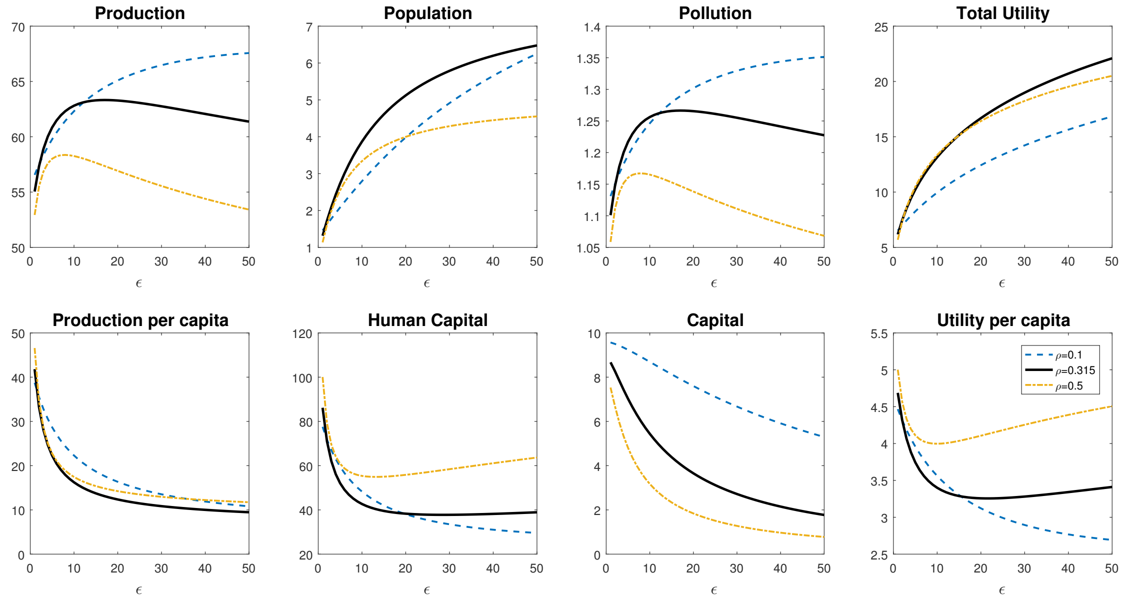
However, these situations are very unlikely. Potential positive impacts from the net gain from migration on utility per capita are observed for very poor countries–ε high–with very high level of emigration rate. In fact, because of its positive effect on the population size, the net gain from migration has an indirect adverse effect in most of the cases. However, if total utility is considered, more gains from migration always increase the outcomes.

The effect of intergenerational transfers: γ

Proposition 10. *The steady state values of the population size, the stocks of pollution and physical capital as well as the human capital level are positively correlated to γ under the following conditions:*

[17]In the Chapter 1, the net gain from migration has always a positive effect on the economic growth.

Figure 25: Effect of a variation of ε on the economy



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

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

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

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

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

Impacts of γ on the steady state variables are very intricate, because this parameter involves even more mechanisms than the other migration features. Indeed, without any environmental externality, in the Chapter 1, on the one hand there is the negative effect from the reduction of the adult income. As said earlier, the negative income effect induced by γ leads to a decrease in adult consumption, in savings and in education expenditures. On the other hand, increase in intergenerational transfers changes incentives to invest in children through education and fertility. Therefore, in the Chapter 2, in return of an increase in those parameters we observe an increase in production and in pollution. This pollution has a negative impact on human capital and thus on income, which can have an indirect effect on the physical capital stock.

This is why, the positive effect of γ will depend on conditions. 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 effect of γ depends on the elasticity of pollution with respect to this parameter.

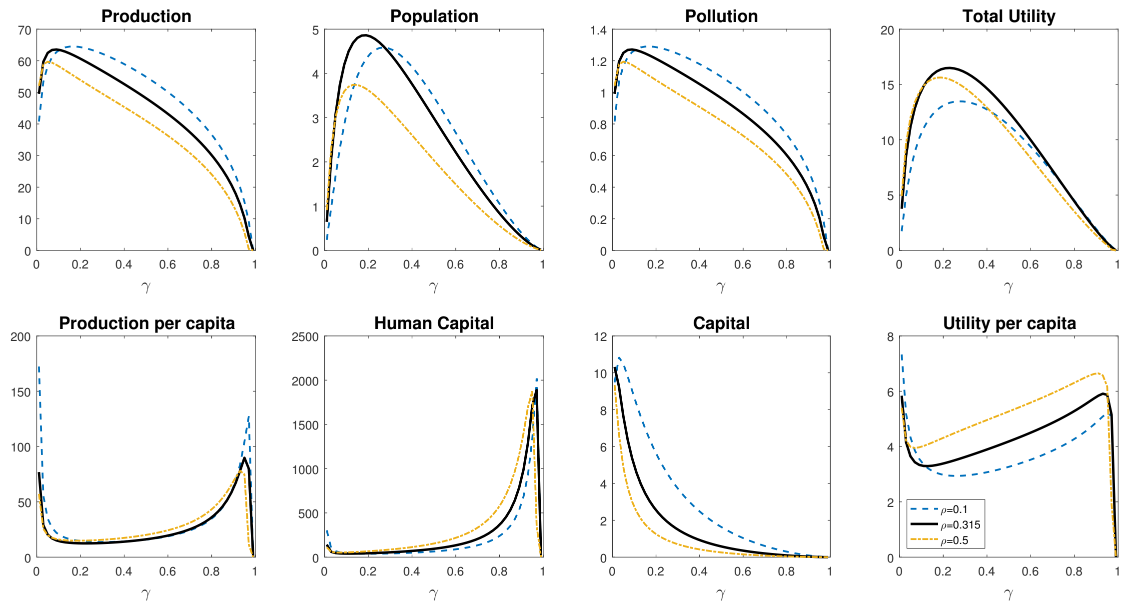
We conduct the numerical analysis for $\gamma \in (0;1)$. Figure 26 displays steady state values for production, population size, pollution stock, total utility, production per capita, human capital, capital stock and utility per capita according to the intergenerational transfer share. We test three levels of emigration rate, $\rho = \{0.1; 0.315; 0.5\}$. As in the previous figures, the dashed line is for values where $\rho = 0.1$, the dotted line for $\rho = 0.5$ and the plain line is for the benchmark economy.

Note that the net effect of γ is not trivial, because while the emigration rate might be null, a reduction of the intergenerational transfer to 0 leads to the collapse of the economy in our model (if $\gamma = 0$, there is no reason to have children). Therefore, on the graphics there are two asymptotes one at $\gamma = 0$ and the other one at $\gamma = 1$. Between these two values, we observe inverted U-shaped curves, for population size, production, pollution stock and total utility with respect to the value of γ. With the strong decrease in the production and the pollution stock that occurs after a certain threshold, the human capital is enhanced. In that case, utility increases when the human capital is growing, 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 are close to the asymptote, human capital and utility per capita are positively correlated to the intergenerational transfers rate. This is explained by the negative income effect, that induces a reduction of the fertility and thus on pollution stock. In that case, the intergenerational transfer is quite positive for utility per capita or human capital accumulation. However, if one consider the smallest values of γ, utility per capita might be very high, but with a quasi-null population size.

2.4 Conclusion

This work presents an overlapping generations model, to explain the interplay between 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, which impacts directly human capital accumulation. Therefore, migration and its interactions

Figure 26: Effect of a variation of γ on the economy



with pollution are a key determinants of the productive stocks accumulation. Indeed, as in the first chapter, migration structure–the gain from migration and the scale of emigration–changes strongly the parents' choices in terms of education and savings. Knowing that children will help their parents during their retirement period, migration may lead to an increase in fertility, and thus in population size. However, in the second chapter, this change in population enhances aggregated production–but not necessarily production per capita–in the domestic area and thus the pollution stock. This last hampers the accumulation of human capital in the first periods and then leads to a reduction in long-term value of human capital. Therefore, even if the possibility to receive transfers–and especially remittances from migrants–creates a strong incentive to invest in their children education, migration can result in a reduction of human capital. In that case, while remittances were identified as a lever for economic growth in the literature, this work showed that they could also have a strong negative impact on development, and that a *brain gain* is not possible in most of the cases.

More specifically, on the one hand, migration could be a source of economic dynamism and thus a source of pollution. But on the other hand, more departures leads to a decrease in the population size and then to a decrease in the pollution stock. Therefore, in some cases, economic and (local) environmental gains can be obtained simultaneously in these economies thanks to migration. We show that this situation occurs only if the emigration rate is already high, thanks to the reduction in the demographic pressure on the environment.

A numerical analysis of our model provides clear insights on the effects of an environmental policy and their dependence to the pollution intensity of production. When pollution intensity is low, a tax on pollution accompanied by a maintenance effort always improves the economic results. While, if the pollution intensity is high, only a tax that compensates completely the emissions is profitable. This result was robust to different specifications of the environmental features and of the migration parameters. Moreover, the model reveals that the steady state level of human capital is not impacted by the steady state value of pollution, but by its dynamics during the transitional period. Therefore, the capital stock and the human capital generated in the early stages of the economic development are key features to trigger a strong economic growth in the next periods. In that context, the existence of remittances or intergenerational transfers could hamper the accumulation of human capital, because they boost quickly the emissions of pollution. To overcome this effect, other types of public policies could be tested, *e.g.* a tax on remittances or a policy on education to compensate the environmental damage on human capital accumulation.

A.1 Appendix

A.1.1 Static Comparatives

A.1.1.1 The efficiency of human capital accumulation, χ and the pollution

The population size on the steady state is the same than in the previous chapter, therefore we do not repeat its analysis here, and we focus on the other variables. The first step to study the variations of pollution, human capital or capital with respect to the parameters, is to define the effect of the different parameters on the long term efficiency of human capital accumulation $\chi \equiv \theta(Z^{\star})$. On the SS, derivatives of χ with respect to the parameters are given by the following equations:

$$\frac{\partial \chi}{\partial \beta} = -\frac{\mu}{1-\alpha}\frac{\chi}{\beta(1+\beta)} < 0 \tag{A.1.1}$$

$$\frac{\partial \chi}{\partial A} = -\frac{\mu}{1-\alpha}\frac{\chi}{A} < 0 \tag{A.1.2}$$

$$\frac{\partial \chi}{\partial \tau} = \frac{\mu}{1-\alpha}\frac{\chi}{\tau} > 0 \tag{A.1.3}$$

Moreover, we find conditions for the other parameters which gives the impact of migration features. The derivative of χ with respect to ρ is given by this equation:

$$\frac{\partial \chi}{\partial \rho} = -\mu\chi \left[\frac{\gamma\varepsilon(1-\alpha)}{(1-\alpha)(1-\rho)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} - \frac{\varepsilon-1}{1-\rho+\rho\varepsilon} \right] \tag{A.1.4}$$

Therefore the sign of this derivative, depends on the following condition:

$$\frac{\partial \chi}{\partial \rho} > 0 \quad \Leftrightarrow \quad \left[\frac{\gamma\varepsilon(1-\alpha)}{(1-\alpha)(1-\rho)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} - \frac{\varepsilon-1}{1-\rho+\rho\varepsilon} \right] > 0$$
$$\frac{\partial \chi}{\partial \rho} > 0 \quad \Leftrightarrow \quad \frac{\varepsilon}{(\varepsilon-1)} > \frac{(1-\rho)[\alpha(1-\rho)+\lambda_h(1-\alpha)]}{\Lambda_h}$$

The derivative of χ with respect to the net gain from migration is as follows:

$$\begin{aligned} \frac{\partial \chi}{\partial \varepsilon} &= \mu\rho \left[\frac{\beta A\alpha^{\alpha}(1-\tau)(1-\rho)(1-\gamma)(1-\alpha)^{2-\alpha}}{(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} \right]^{\frac{-\mu}{(1-\alpha)}} (\gamma\Lambda_h)^{-\mu} \\ &\times \left[\frac{\gamma}{\alpha(1-\rho)+\Lambda_h(1-\alpha)} - \frac{1}{1-\rho+\rho\varepsilon} \right] \end{aligned} \tag{A.1.5}$$

The sign of this derivative depends on the second term of this product:

$$\begin{aligned} \frac{\partial \chi}{\partial \varepsilon} \quad &\Leftrightarrow \quad \frac{\gamma}{\alpha(1-\rho)+\Lambda_h(1-\alpha)} - \frac{1}{1-\rho+\rho\varepsilon} > 0 \\ &\Leftrightarrow \quad \Lambda_h > (1-\rho) \end{aligned}$$

This can be rewritten in order to keep only ε on the left side. The larger γ and ρ are, the lower the threshold to have a positive impact from an increase in ε is.

$$\varepsilon > \frac{(1-\rho)(1-\gamma)}{\gamma\rho}$$

The derivative of χ with respect to the intergenerational transfer rate is as follows:

$$\frac{\partial \chi}{\partial \gamma} = \mu\chi \left[\frac{\alpha(1-\rho)+(1-\alpha)(1-\rho+\rho\varepsilon)}{(1-\alpha)(1-\gamma)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} - \frac{1}{\gamma} \right] \tag{A.1.6}$$

The sign of this derivative depends on the following condition whih is quite difficult to interpret:

$$\frac{\partial \chi}{\partial \gamma} > 0 \quad \Leftrightarrow \quad \left[\frac{\alpha(1-\rho)+(1-\alpha)(1-\rho+\rho\varepsilon)}{(1-\alpha)(1-\gamma)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]} - \frac{1}{\gamma}\right] > 0$$
$$\frac{\partial \chi}{\partial \gamma} > 0 \quad \Leftrightarrow \quad \frac{(1-\alpha)(1-\gamma)}{\gamma} < \frac{\alpha(1-\rho)+(1-\alpha)(1-\rho+\rho\varepsilon)}{\alpha(1-\rho)+\Lambda_h(1-\alpha)}$$

Knowing the effects of the parameters on the steady state value of the efficiency of human capital accumulation, it is now possible to study the other variables on the steady state. First $Z^\star$ depends directly on the level attained by the efficiency of human capital acucmulation, χ, knowing that $\theta(Z_t)$ and its inverse are decreasing and monotonic functions. The stock of pollution is positively correlated to the parameters A, β and is negatively correlated to τ. The effect of the other parameters depends on the opposite of the conditions given for χ.

A.1.1.2 The capital stock: $K^\star$

The equation of $K^\star$ is:

$$K^\star = \frac{\beta\alpha(1-\rho)(1-\tau)(1-\gamma)(1-\alpha)}{(1+\beta)\left[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)\right]} \frac{a\theta^{-1}(\chi)}{\Omega-\tau}$$

Without calculations it appears that $K^\star$ is negatively correlated to the emissions of pollutions Ω and positively correlated to the absorption rate a. The derivatives of this equation with respect to β and A, are given by equation (A.1.7) and (A.1.8) respectively.

$$\frac{\partial K^\star}{\partial \beta} = K^\star \left[\frac{1}{\beta(1+\beta)} + \frac{\partial \theta^{-1}(\chi)}{\partial \beta}\frac{1}{\theta^{-1}(\chi)}\right] \tag{A.1.7}$$
$$\frac{\partial K^\star}{\partial A} = K^\star \frac{\partial \theta^{-1}(\chi)}{\partial A} \tag{A.1.8}$$

Knowing that the derivatives of $\theta^{-1}(\chi)$ with respect to β and A are positive, both derivatives (A.1.7) and(A.1.8) are positive and $K^\star$ also positively correlated to these variables.

The effects of the other parameters according on the natural capital stock depend on conditions. First we give, the derivative of $K^\star$ with respect to the tax on production, τ.

$$\frac{\partial K^\star}{\partial \tau} = K^\star \left[\frac{\partial \theta^{-1}(\chi)}{\partial \tau}\frac{\Omega-\tau}{\theta^{-1}(\chi)} + \frac{1-\Omega}{1-\tau}\right] \tag{A.1.9}$$

We denote the elasticity of pollution with to the tax rate as:

$$\zeta_\tau = -\frac{\partial \theta^{-1}(\chi)}{\partial \tau}\frac{\tau}{\theta^{-1}(\chi)} > 0$$

Therefore the condition to observe an increase in the long term capital stock is:

$$\frac{\partial K^\star}{\partial \tau} > 0 \Leftrightarrow \zeta_\tau < \frac{\tau(1-\Omega)}{(1-\tau)(\Omega-\tau)}$$

Second, the derivatives of $K^\star$ with respect to the emigration rate, ρ, the net gain from migration, ε, and the intergenerational transfer, γ, are given by the following equations:

$$\frac{\partial K^\star}{\partial \rho} = K^\star\left[\frac{\partial \theta^{-1}(\chi)}{\partial \rho}\frac{1}{\theta^{-1}(\chi)} - \frac{\gamma\varepsilon(1-\alpha)}{(1-\rho)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right] \quad \text{(A.1.10)}$$

$$\frac{\partial K^\star}{\partial \varepsilon} = K^\star\left[\frac{\partial \theta^{-1}(\chi)}{\partial \varepsilon}\frac{1}{\theta^{-1}(\chi)} - \frac{\gamma\rho(1-\alpha)}{[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right] \quad \text{(A.1.11)}$$

$$\frac{\partial K^\star}{\partial \gamma} = K^\star\left[\frac{\partial \theta^{-1}(\chi)}{\partial \gamma}\frac{1}{\theta^{-1}(\chi)} - \frac{(1-\rho+\rho\varepsilon)-\alpha\rho\varepsilon)}{(1-\gamma)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right] \quad \text{(A.1.12)}$$

The sign of these derivatives depend on the term between brackets. We denote respectively by ζ_ρ, ζ_ε and ζ_γ the elasticities of the pollution with respect to ρ, ε and γ.

$$\zeta_\rho = \frac{\partial \theta^{-1}(\chi)}{\partial \rho}\frac{\rho}{\theta^{-1}(\chi)}, \qquad \zeta_\varepsilon = \frac{\partial \theta^{-1}(\chi)}{\partial \varepsilon}\frac{\varepsilon}{\theta^{-1}(\chi)}, \qquad \zeta_\gamma = \frac{\partial \theta^{-1}(\chi)}{\partial \gamma}\frac{\gamma}{\theta^{-1}(\chi)}$$

However, it is worth noting that the signs of ζ_ρ, ζ_ε and ζ_γ are not always positive because, the sign of the derivatives of θ^{-1} with respect to these parameters depends on their level. Therefore we find the following conditions on these parameters:

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

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

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

A.1.1.3 The human capital: $h^\star$

Finally, we study the impact of the parameters on steady state human capital. Steady state value of $h^\star$ writes as follows:

$$\begin{aligned} h^\star =& \frac{a\theta^{-1}(\chi)}{\Omega-\tau}\left[\alpha A(1-\tau)\right]^{-\frac{\alpha}{1-\alpha}}\left[\frac{\sigma}{\gamma(1-\mu)(1-\rho+\rho\varepsilon)}\right]^{\frac{1}{\delta}} \\ &\times\left[\frac{\beta(1-\gamma)(1-\alpha)(1-\rho)}{(1+\beta)\left[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)\right]}\right]^{-\frac{1-\alpha(1-\delta)}{\delta(1-\alpha)}} \end{aligned}$$

Without calculations it appears that $h^\star$ is negatively correlated to the emissions of pollution Ω and positively correlated to the absorption rate a and the cost for rearing children. Following the same method as for the capital stock, we give the derivatives of $h^\star$ with respect to A (equation (A.1.13)), β (equation (A.1.14)), τ (equation (A.1.15)), γ (equation (A.1.18)), ε (equation (A.1.17)) and γ (equation (A.1.18)).

$$\frac{\partial h^\star}{\partial A} = h^\star\left[\frac{\partial\theta^{-1}(\chi)}{\partial A}\right]\frac{1}{\theta^{-1}(\chi)}-\frac{1}{A(1-\alpha)}] \tag{A.1.13}$$

$$\frac{\partial h^\star}{\partial \beta} = h^\star\left[\frac{\partial\theta^{-1}(\chi)}{\partial \beta}\frac{1}{\theta^{-1}(\chi)}-\frac{1-\alpha(1-\delta)}{\delta\beta(1-\alpha)(1+\beta)}\right] \tag{A.1.14}$$

$$\frac{\partial h^\star}{\partial \tau} = h^\star\left[\frac{\partial\theta^{-1}(\chi)}{\partial \tau}\frac{1}{\theta^{-1}(\chi)}+\frac{(1-\tau)-\alpha(1-\Omega)}{(1-\alpha)(1-\tau)(\omega-\tau)}\right] \tag{A.1.15}$$

$$\frac{\partial h^\star}{\partial \rho} = h^\star\left[\frac{\partial\theta^{-1}(\chi)}{\partial \rho}\frac{1}{\theta^{-1}(\chi)}-\left[\frac{\varepsilon-1}{\delta(1-\rho+\rho\varepsilon)}-\frac{\gamma\varepsilon(1-\alpha(1-\delta))}{\delta(1-\rho)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right]\right] \tag{A.1.16}$$

$$\frac{\partial h^\star}{\partial \varepsilon} = h^\star\left[\frac{\partial\theta^{-1}(\chi)}{\partial \varepsilon}\frac{1}{\theta^{-1}(\chi)}-\left[\frac{\alpha\rho[(1-\rho)+\Lambda_h\delta]}{\delta(1-\rho+\rho\varepsilon)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right]\right] \tag{A.1.17}$$

$$\frac{\partial h^\star}{\partial \gamma} = h^\star\left[\frac{\partial\theta^{-1}(\chi)}{\partial \gamma}\frac{1}{\theta^{-1}(\chi)}+\left[\frac{(1-\alpha(1-\delta))[(1-\alpha)(1-\rho+\rho\varepsilon)+\alpha(1-\rho)]}{\delta(1-\alpha)(1-\gamma)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}-\frac{1}{\delta\gamma}\right]\right] \tag{A.1.18}$$

The sign of these derivatives depend on the terms between brackets. We denote respectively by ζ_A, and ζ_β the elasticities of the pollution with respect to ρ, ε and γ.

$$\zeta_A = \frac{\partial\theta^{-1}(\chi)}{\partial A}\frac{A}{\theta^{-1}(\chi)}, \qquad \zeta_\beta = \frac{\partial\theta^{-1}(\chi)}{\partial \beta}\frac{\beta}{\theta^{-1}(\chi)}$$

On the SS, the human capital level $h^\star$ is negatively correlated to the emissions of pollutions Ω. It is positively impacted by a, A. Under the following conditions $h^\star$ is positively correlated to the other parameters:

$$\frac{\partial h^\star}{\partial A} > 0 \quad \Leftrightarrow \quad \zeta_A > \frac{1}{1-\alpha}$$
$$\frac{\partial h^\star}{\partial \beta} > 0 \quad \Leftrightarrow \quad \zeta_\beta > \frac{1-\alpha(1-\delta)}{\delta(1-\alpha)(1+\beta)}$$
$$\frac{\partial h^\star}{\partial \tau} > 0 \quad \Leftrightarrow \quad \zeta_\tau < \tau\left[\frac{1-\alpha(1-\Omega)-\tau}{(1-\tau)(1-\alpha)(\Omega-\tau)}\right]$$
$$\frac{\partial h^\star}{\partial \rho} > 0 \quad \Leftrightarrow \quad \zeta_\rho > \left[\frac{\rho(\varepsilon-1)}{\delta(1-\rho+\rho\varepsilon)} - \frac{\rho\gamma\varepsilon(1-\alpha(1-\delta))}{\delta(1-\rho)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right]$$
$$\frac{\partial h^\star}{\partial \varepsilon} > 0 \quad \Leftrightarrow \quad \zeta_\varepsilon > \left[\frac{\alpha\rho[(1-\rho)+\Lambda_h\delta]}{\delta(1-\rho+\rho\varepsilon)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right]$$
$$\frac{\partial h^\star}{\partial \gamma} > 0 \quad \Leftrightarrow \quad \zeta_\gamma > \left[\frac{1}{\delta} - \frac{\gamma(1-\alpha(1-\delta))[(1-\alpha)(1-\rho+\rho\varepsilon)+\alpha(1-\rho)]}{\delta(1-\alpha)(1-\gamma)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}\right]$$

A.1.2 An alternative policy: Redistribution of the tax

A.1.2.1 The behaviors of the firm and the households

In this model, the revenue of the tax can be used, to reduce pollution or can be redistributed to the household according to a parameter η. If $\eta = 1$, the revenue of the tax is used completely to abate pollution, however if $\eta = 0$, the tax revenue is completely redistributed to the households. Therefore, the pollution dynamics writes:

$$Z_{t+1} = (\Omega - \tau\eta)AK_t^\alpha (L_t h_t)^{1-\alpha} + (1-a)Z_t \tag{A.1.19}$$

The households' program is now:

$$\begin{aligned}
&\max_{c_t,s_t,e_t,n_t} U(c_t,d_{t+1}) &=& \ln(c_t) + \beta\ln(d_{t+1}) \\
s.t \quad & c_t + s_t + n_t e_t &=& w_t h_t(1-\gamma-\sigma N_t^\delta n_t) + b_t \\
& d_{t+1} &=& s_t R_{t+1} + n_t\gamma(1-\rho+\rho\varepsilon)w_{t+1}h_{t+1} \\
& h_{t+1} &=& \theta(Z_t)h_t^{1-\mu}e_t^\mu \\
& Z_{t+1} &=& \Omega Y_t + (1-a)Z_t - m_t
\end{aligned}$$

where b_t is the government subvention. If the governement's budget constraint is saturated, the subvention is:

$$b_t = (1-\eta)\tau\frac{Y_t}{N_t} = (1-\eta)\tau\frac{w_t h_t}{1-\alpha} \tag{A.1.20}$$

The resolution of the firm program is the same than in the canonical model. And the resolution of the household's program, gives the following solutions:

$$s_t^\star = \frac{\beta\alpha(1-\rho)[(1-\gamma)(1-\alpha)+\tau(1-\eta)]}{(1+\beta)(1-\alpha)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}w_t h_t \tag{A.1.21}$$

$$n_t^\star = \frac{\beta\gamma(1-\mu)(1-\rho+\rho\varepsilon)[(1-\gamma)(1-\alpha)+\tau(1-\eta)]}{\sigma(1+\beta)[\alpha(1-\rho)+\Lambda_h(1-\alpha)]}N_t^{-\delta} \tag{A.1.22}$$

$$e_t^\star = \frac{\mu\sigma}{1-\mu}w_t h_t N_t^\delta \tag{A.1.23}$$

In this context, household's choices are still independent of the pollution stock and depend exclusively on the migration features, the intergenerational transfers, the received subvention and their intertemporal preferences. While the conclusion of the model on the migration or the intergenerational transfers remain the same, now the tax rate has an effect on the savings and the fertility choice. Indeed, as in de la Croix and Michel (2002), the fertility rate is now positively correlated to the tax rate, because of the subvention. The environmental policy induces a natalist bias. Moreover a static analysis, show that it has never a positive impact on the savings, because, an increase in the tax has a negative effect on the household's income, $w_t h_t$. This effect more than compensates the positive effect from the subvention. Note also, that the tax rate does note change directly the education rate, but only by the income effect. Therefore, the tax rate has always a negative impact on the education expenditures, while it is supposed to have a positive impact on the human capital thanks to the reduction of the emissions.

The next stage is to determine the equilibrium of this economy. Using the method described in the first chapter the intertemporal dynamics is given below.

Proposition 11. *Given the initial conditions $K_0 > 0$, $L_0 > 0$, $h_0 > 0$ and $Z_0 > 0$, the intertemporal equilibrium is the sequence (N_t, K_t, h_t, Z_t) such that the following* *system is satisfied for all $t \geq 0$:*

$$\begin{cases} N_{t+1} &= \frac{\gamma(1-\mu)(1-\rho+\rho\varepsilon)}{\sigma}\Psi_3 N_t^{1-\delta} \\ K_{t+1} &= \alpha A(1-\tau)\Psi_3 K_t^{\alpha} N_t^{1-\alpha} h_t^{1-\alpha} \\ h_{t+1} &= \theta(Z_t)\left[\frac{\mu A\sigma(1-\alpha)(1-\tau)}{1-\mu}\right]^{\mu} K_t^{\alpha\mu} N_t^{\mu(\delta-\alpha)} h_t^{1-\alpha\mu} \\ Z_{t+1} &= (\Omega-\tau\eta)AK_t^{\alpha}\left(N_t h_t\right)^{1-\alpha} + (1-a)Z_t \end{cases} \tag{A.1.24}$$

where $\Psi_3 \equiv \frac{\beta(1-\rho)[(1-\gamma)(1-\alpha)+\tau(1-\eta)]}{(1+\beta)[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)]}$

Proposition 12. *According to the* ***Proposition 11*** *there is a unique equilibrium, for which the values of $N^\star$, $K^\star$, $h^\star$ and $Z^\star$ are:*

$$N^\star = \left[\frac{\Lambda_h(1-\mu)}{\sigma}\Psi_3\right]^{\frac{1}{\delta}} \tag{A.1.25}$$

$$K^\star = \alpha(1-\tau)\frac{a\theta^{-1}(\chi)}{\Omega-\tau\eta}\Psi_3 \tag{A.1.26}$$

$$h^\star = \frac{a\theta^{-1}(\chi)}{(\Omega-\tau\eta)A}\left[\alpha A(1-\tau)\right]^{-\frac{\alpha}{1-\alpha}}\left[\frac{\sigma}{\Lambda_h(1-\mu)}\right]^{\frac{1}{\delta}}\Psi_3^{-\frac{1-\alpha(1-\delta)}{\delta(1-\alpha)}} \tag{A.1.27}$$

$$Z^\star = \theta^{-1}(\chi) \tag{A.1.28}$$

where $\chi_3 = [\gamma\mu(1-\alpha)(1-\rho+\rho\varepsilon)]^{-\mu}\left[\frac{\beta A\alpha^{\alpha}(1-\tau)(1-\rho)[(1-\gamma)(1-\alpha)+\tau(1-\eta)]}{(1+\beta)[\alpha(1-\rho)+\gamma(1-\alpha)(1-\rho+\rho\varepsilon)]}\right]^{-\frac{\mu}{1-\alpha}}$ *is the efficiency of human capital accumulation in the steady state and $\theta^{-1}(.)$ is the inverse function of $\theta(Z_t)$.*

A.1.2.2 Analysis of the policies

In this section, we conduct an analysis of the impact of the tax rate and of the use of the tax revenue on steady state values. The migration here is not described because whatever the policy used the migration features–*i.e.* the emigration rate, ρ, and the remittances, ε–have the same impact on the economy. Indeed, the comparative statics the same conditions than in the benchmark model, and the numerical analysis shows only a parallel translation of the curves according to η, without any change in the shape of the curve. Therefore the only effects described here are induced by the environmental policy, and the use of the revenue.

As said earlier, the tax rate induces a natalist bias that depends negatively on the value of η, however thanks to the reduction in pollution emissions, a positive effect of the environmental policy is still expected. First, the impact of the tax is described when η is null, which means that all the tax is redistributed to the household. In that context pollution dynamics is directly given by:

$$Z_{t+1} = \Omega A K_t^{\alpha} \left(N_t h_t\right)^{1-\alpha} + (1-a) Z_t$$

When η is null, the value of χ_3 is negatively impacted by τ under certain conditions.

$$\begin{aligned}
\chi_3 &= \left[\mu \Lambda_h (1-\alpha)\right]^{-\mu} \left[\frac{\beta A \alpha^{\alpha}(1-\tau)(1-\rho)[(1-\gamma)(1-\alpha)+\tau]}{(1+\beta)\left[\alpha(1-\rho)+\Lambda_h(1-\alpha)\right]}\right]^{-\frac{\mu}{1-\alpha}} \\
\frac{\partial \chi_3}{\partial \tau} &= -\frac{\mu\left[1-[(1-\gamma)(1-\alpha)+2\tau]\right](1-\alpha)^{-\mu}}{(1-\alpha)(1-\tau)[(1-\gamma)(1-\alpha)+\tau]} \chi_3
\end{aligned}$$

The steady state efficiency of human capital accumulation χ_3 is negatively correlated to τ under certain condition. Knowing, that the value of χ_3 is negatively correlated to the steady state pollution stock, this means that τ can have a positive impact on pollution stock.

$$\frac{\partial \chi_3}{\partial \tau} < 0 \Leftrightarrow \tau > \frac{(1-\gamma)(1-\alpha)}{2}$$

In this context, the tax rate enhances steady state values of human and physical capital stocks under the following conditions:

$$\frac{\partial K^{\star}}{\partial \tau} > 0 \Leftrightarrow \zeta_{\tau} < \frac{\tau[1-2\tau-(1-\gamma)(1-\alpha)]}{(1-\tau)[(1-\gamma)(1-\alpha)+\tau]}$$

$$\frac{\partial h^{\star}}{\partial \tau} > 0 \Leftrightarrow \zeta_{\tau} > \frac{1-(1-\gamma)(1-\alpha)}{1+(1-\gamma)(1-\alpha)} \frac{1-\alpha+\delta}{\delta(1-\alpha)}$$

As in previous cases, the interpretation of these conditions is difficult. Therefore, in order to clarify the mechanisms involved, we conduct a numerical analysis with the values used in Table 11. For $\eta = 0$ and $\eta = 1$, two values of emission rate are tested $\Omega = \{0.3, 0.6\}$ with an increase of the tax rate on the interval $[0, \Omega]$. Figure 27 displays steady state values of Production per capita, Physical Capital, Pollution Stock, Utility per capita, Human capital, and Population size when $\Omega = 0.3$. Figure 28 displays the same variables when $\Omega = 0.6$.

A redistribution of the tax always leads to a reduction of utility per capita, especially if it is compared to the case with a use of the tax for the abatement. Indeed, while the production can be improved with the implementation of the tax, the increase in the population is so large that the production per capita and thus the consumption are always decreasing with the tax. This is due to the increase in the pollution for the smallest values of the tax which leads to a decrease in the human capital. Therefore, while the environmental policy is inefficient for the pollution stock when the tax is small, it has adverse effects on the capital stock when the tax is too strong. This holds with small and large value of pollution emissions.

Finally, as in de la Croix and Michel (2002) an environmental tax with a redistribution has an adverse effect on the economy because of the natalist bias. This is increased by the features of the economy that depends strongly on the demographic features. In this model, the use of the tax to abate the pollution can be seen as a policy on the education, because, it has a direct effect on the efficiency of the human capital accumulation.

Figure 27: The effect of the environmental tax rate ($\Omega = 0.3$)

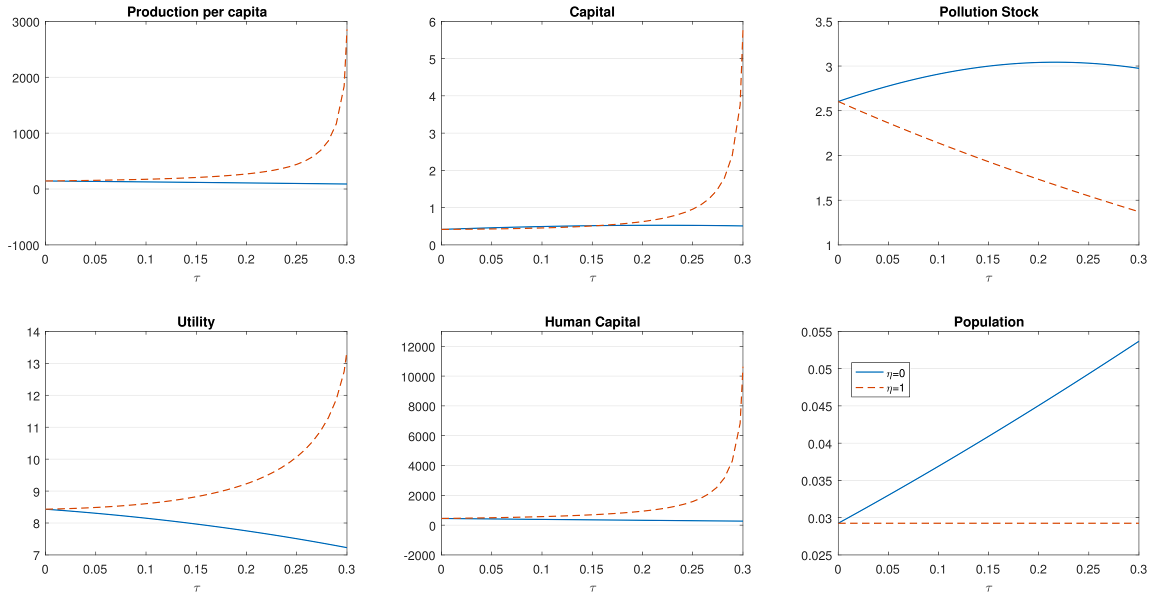
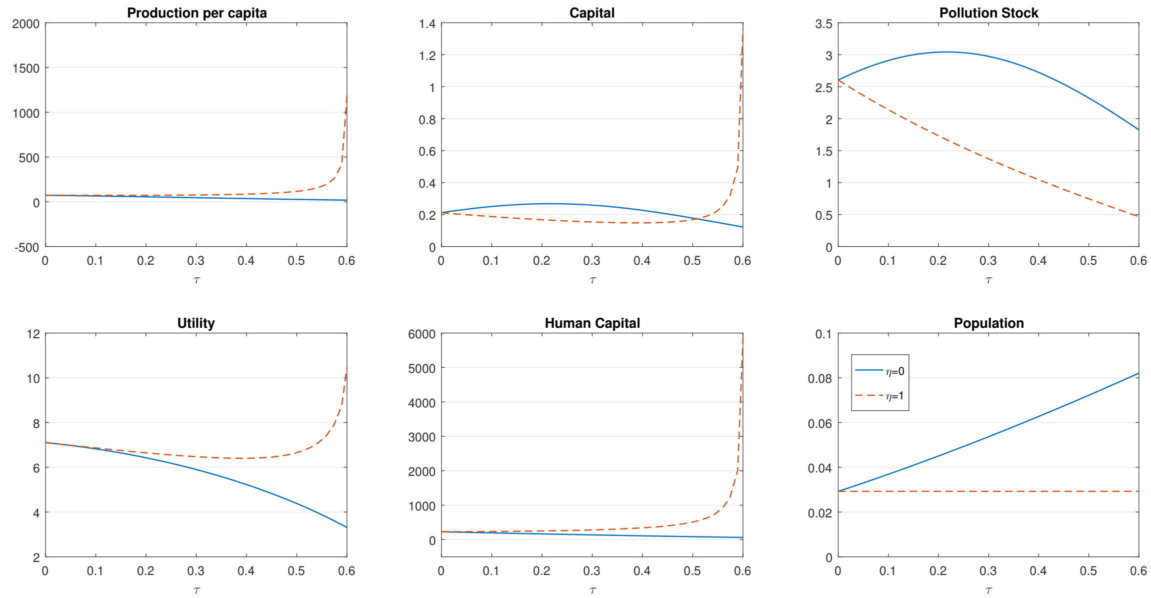


Figure 28: The effect of the environmental tax rate ($\Omega = 0.6$)



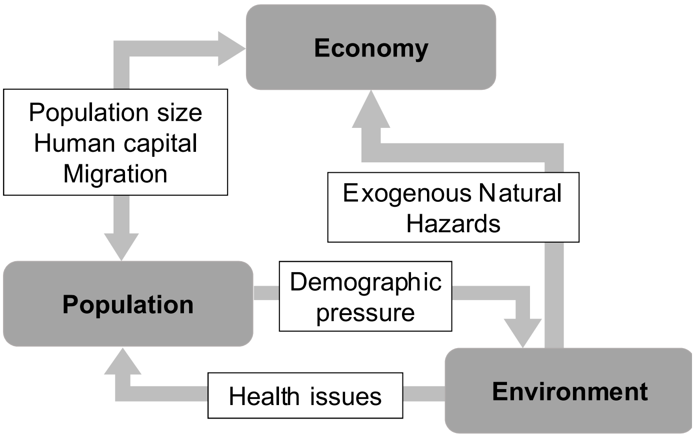
Chapter 3

Confronting climate change: Adaptation vs. migration strategies[1]

Abstract

This paper examines the optimal adaptation policy of Small Island Developing States (SIDS) to cope with climate change. The government has two main policy options: migration and conventional adaptation measures. Convention adaptation refers to every possible means to limit the extent and the repercussions of climate damages. A dynamic optimization problem is built to incorporate the following ingredients: (i) changes in the population size are only driven by migration decisions; (ii) expatriates send remittances back home; (iii) local production uses labor and natural capital, which is degraded as a result of climate change. We show that there exist two types of policy which differ in the nature of the interplay between the two policy instruments that can be either complements or substitutes. Quite interestingly, we are able to identify two critical conditions on the fundamentals of the economy driving most of the results. Using a numerical analysis based on the calibration of the model, we analyze which policy is optimal depending on the States characteristics and initial conditions.

[1]This paper is a joint work with Paolo Melindi-Ghidi and Fabien Prieur



3.1 Introduction

Countries have two main options to deal with climate change: adaptation and mitigation. Mitigation consists in controlling global warming by reducing greenhouse gases emissions, and capturing them thanks to carbon capture and storage techniques. The main objective of adaptation is to limit the repercussions of climate change by investing in protective infrastructure, managing endangered ecosystems, changing production and consumption habits etc. In most cases, a combination of these two strategies is both feasible and recommended to address the climate issue in the best possible way. However, the cost-benefit analysis of adaptation *versus* mitigation techniques greatly differs among regions because of their heterogeneity.

In this chapter, we consider the specific situation of Small Island Developing States (SIDS), that share two characteristics. First they are not responsible for the ongoing increase in temperatures and have no means to stamp it out on their own. Second, they are among the most vulnerable to its repercussions. This implies that in order to cope with climate change, SIDS have no other option but to rely on adaptation measures. According to the Intergovernmental Panel on Climate Change (IPCC), the cost of climate change damages for these countries will be so large that adaptation is a prerequisite for their sustainable economic development (see for instance UN-OHRLLS (2017)).[2] Among other things, SIDS are expected to face an increase in the occurrence of extreme weather events (more frequent and severe storms and hurricanes etc.), the rise in sea level accompanied by the degradation of natural capital, and health problems, including infectious diseases (Nurse et al. (2014), Klöck and Nunn (2019)).

[2] http://unohrlls.org/custom-content/uploads/2017/09/SIDS-In-Numbers_Updated-Climate-Change-Edition-2017.pdf

Despite the central role adaptation must play in the management of the climate threat, one observes that SIDS do not really have a clear adaptation strategy in terms of both investments plans and coordination of adaptative actions (Scobie (2016), Thomas and Benjamin (2018), Klöck and Nunn (2019)).[3,4] Moreover, SIDS adaptation capacity is limited because of insufficient economic, technological and human resources. Conventional adaptation alone thus will not be enough in order for SIDS to resolve the climate problem (locally). But SIDS also have another demographic similarity. They all feature a long tradition of economic migration. Moving from an economic to an environmental motive, migration could then become a long-term adaptation solution.

The main objective of this paper is to understand how policy makers in SIDS may design their adaptation strategy–by combining conventional measures with the migration tool–to successfully deal with climate damages. Considering migration as a long-term adaptation option deserves further discussion. The economic literature on migration makes a key distinction between voluntary migration and forced migration (or displacement). Voluntary migration decisions are driven by many factors, including socio-economic, cultural, and institutional ones.[5] On the contrary, forced migration means that people migrate because they do not have enough resources for subsistence. This is typically the case of uncoordinated environmental migration.

In this paper, we adopt a different perspective by considering that if migration is a direct consequence of the worsening of living conditions in SIDS, this process must be accompanied and eased thanks to the design of appropriate public policies. So the challenge is to turn climate migration, that would otherwise be a last resort option, into a deliberate long term strategy. This climate-induced migration is disruptive on many grounds, as any form migration. But in the context of SIDS, it also comes with additional gains, from the climate perspective. On the one hand, migration is a means to reduce the pressure on natural resources. On the other, migrants provide financial support to the SIDS economies, through remittances, which may help them better cope with climate impacts.

In this chapter, we depart from (positive) studies that assess the impact of climate

[3] Mercer et al. (2012), Middelbeek et al. (2014), Vergara et al. (2015) study adaptation measures in the Caribbean, especially through the preservation of the ecosystems or the coastal areas.

[4] The impacts of climate change have been described with more details in the Introduction.

[5] See Beine et al. (2001) for a literature review on migration decisions and their effect on economic growth.

change on migration (among others Barrios et al. (2006); Gray and Mueller (2012); Marchiori and Schumacher (2011); Marchiori et al. (2012); Thiede et al. (2016)). Indeed, we adopt a normative perspective by asking how to use the migration tool as a specific form of adaptation to climate change. Our approach relies on two observations. First, migration clearly is an important dimension of the demographic features of SIDS, that shapes their economic performance. Second, governments in SIDS are now considering migration as a credible adaptation strategy. For example, the "Migration with dignity" program by the Kiribati government aims at increasing investments in public education and schooling in order to make Kiribati migrants more attractive to receiving countries.[6] Moreover, international organizations such as the World Bank, the United Nations and more specifically the International Organization for Migration (IOM), present migration as an explicit tool to foster economic development because it endows originating countries with additional resources coming from the remittances (Agunias and Newland (2012), Clemens (2017)).[7]

Since the 1990's, the management of the diaspora strategy by the originating country is presented as a new policy tool that has been studied in the political geography literature. De Haas (2010) emphasizes that migration based on individual decisions could be inefficient. Therefore, increases in the migration gains could be obtained thanks to public transnational policies based on the coordination (and the cooperation) with the diaspora (Faist (2008), De Haas (2010), Agunias and Newland (2012), Mullings (2012)). While these papers are not directly in line with our approach, they acknowledge the existence of tools to shape migration, these tools being more relevant in the context of countries experiencing large scale migration like the SIDS. In another strand of literature, scholars have started to examine the link between migration and adaptation. First, migration is a means to reduce the demographic pressure on the environment (Birk and Rasmussen (2014)). Second, the consensus is that migration can enhance investments in adaptation, especially in protective infrastructures. This is because remittances, as an external source of funding of the economy, can help finance adaptation measures (Ng'ang'a et al. (2016)). In the same vein, Julca and Paddison (2010) concludes that migration and remittances are valuable levers for the SIDS economies. But, on the downside, the authors stress the dependence from remittances as a potential growing issue.[8] More generally, the key question is to whether migration

[6] http://www.climate.gov.ki/category/action/relocation/.

[7] http://publications.iom.int/system/files/pdf/mecc_outlook.pdf.

[8] Hugo (2011) take a more nuanced position by claiming that sending areas might experiment many different economic, demographic and social adjustments that are difficult to anticipate.

and adaptation are substitutes or complements. According the analyses above, they seem to be complement. But there is a bunch of papers that supports the opposite view by observing that when migration is (already) very high, the need for adaptation actions is less urgent (see for instance Barnett and Adger (2003)). Embracing this argument boils down to considering migration and adaptation as substitutes.

In this chapter, we adopt a centralized perspective to assess the optimal policy of SIDS facing the negative repercussions of climate change. Since both the climate change and the adaptation process encompass a temporal dimension, we develop a dynamic framework in which policy makers have two means to cope with climate-related damages. On the one hand, it can conduct policies that foster migration to deal with the fact that living conditions get worse as a result of the incurred global warming. We define this policy as the *migration strategy*. On the other, it may choose to slow down this underlying process of degradation of natural assets by engaging in adaptation measures. This latter measure is referred as the *adaptation strategy*. We assume that welfare in the SIDS is defined over the total utility derived from consumption and depends on the cost of migration. Changes in the population size, and consequently the size of the population of expatriates, are entirely driven by the rate of emigration. Economic conditions on the island are directly linked to two sources of wealth: first, wealth has a local component, that is the production of a final good using labor and natural capital. Second, an active migration policy induces a contraction of the output because of a decreasing labor force. However, as local population decreases, the population of emigrants increases, which is associated with more remittances received from abroad. In line with the evidence provided in the stylized facts section of the Introduction, remittances are large enough to involve a real trade-off in the management of the population. Varying the population size is also a means to release the pressure on natural assets. Overall, it is assumed that reducing the population size is good for wealth at the origin. But this is not the end of the story as it affects welfare both directly (*cf.* the total utility criterion), and indirectly by changing the amount of per capita consumption. As far as adaptation is concerned, there is a direct cost of adaptation in terms of foregone consumption, while the benefit stems from the capacity to maintain the stock of natural capital to a higher level, and for a longer period of time.

Our analysis of the optimal policy is conducted in two phases, the first one being devoted to a theoretical investigation, the second one consisting of a numerical calibration of the model.

The analysis of the intertemporal decision problem is quite challenging because it generically produces a four-dimension dynamical system and can exhibit four different regimes, depending on whether the two instruments, migration and adaptation, are operative or not. To circumvent these difficulties, we first have a look to regimes in which the policy relies on one instrument only, and then combine our main findings to understand what is going on in the regime where both instruments are used. Considering first a regime with no adaptation, the SIDS suffers from the impacts of climate change and has no option but to adjust its population size. We find a critical condition on the fundamentals of the economy under which there exist migration incentives at the beginning of the planning period. In this situation, the optimal migration policy is characterized by a monotonically decreasing emigration rate, that vanishes eventually when the optimal population size is reached. When there is no migration incentive initially, but the SIDS bears an increasing environmental constraint because of climate change, we identify a condition that tells us if a switch to a positive migration regimewill occur in finite time.

Next, the study of a regime with no migration is carried out along the same line. In the absence of migration, the only possibility left is to undertake adaptation expenditures. We then find another critical condition, that also involves most of the economy's fundamental, under which the SIDS starts to adapt from the origin. When the regime with positive adaptation is permanent, during the convergence to the saddle point, adaptation expenditures decrease monotonically over time but remain positive, which in turn ensures that the SIDS will enjoy a higher level of natural capital in the long run. Finally, merging both analyses, we conduct a formal discussion on the features of the optimal policy in general terms. When there is no adaptation initially but positive migration, the incentives to switch on the second instrument increase over time as the decrease in the population size reduces the marginal cost of adaptation. In the symmetric situation where there is adaptation but no migration originally, we highlight the condition that triggers a switch to positive migration in finite time. Moreover, if the regime with positive adaptation and migration hosts a steady state, then we show that the SIDS manages to stabilize natural assets to a constant and higher level than in the absence of adaptation. As a result, the population size is also larger in the long run.

To sum-up, from the theoretical investigation we obtain two critical conditions that shed some light on the SIDS's preferred policy to deal with climate change. Using a specification of the model, we discuss which instrument the SIDS will deploy in priority to manage optimally the damages due to global warming, and how this choice depends on the critical parameters. To dig further into the analysis of the nature of the optimal policy, we finally resort to a calibration of the model to real world data. This calibration is a means to emphasize the role of the initial conditions, that is the initial size of the population and the initial endowment in natural capital. More importantly, this exercise ultimately helps us to understand which policy is optimal for which SIDS, given its individual characteristics. Last but not least, it allows us to explain when adaptation and migration, both intended as policy instruments, prove to be complements or substitutes.

The paper is organized as follows. Section 3.2 displays the model, which is then analyzed in Section 3.3. Section 3.4 is devoted to the calibration, while Section 3.5 concludes.

3.2 Model

We consider an infinite horizon SIDS economy and adopt a centralized perspective. Time is continuous and indexed by $t \in [0, \infty)$. Assuming away demographic growth, any change in the population size, $N(t)$, is the result of migration, with $m(t) \geqq 0$ the emigration level:

$$\dot{N}(t) = -m(t). \tag{3.2.1}$$

The emigration rate simultaneously determines the evolution of the population of expatriates, $M(t)$:

$$\dot{M}(t) = m(t). \tag{3.2.2}$$

Three main ingredients are needed to characterize the SIDS: the definition of its welfare, the composition of its wealth, and the impacts of climate change.

Social welfare of the SIDS, $V(c(t), m(t)N(t))$, is made of two components. The first is total utility, $N(t)U(c(t))$, where $c(t)$ represents per capita consumption and $U(.)$ is increasing and concave. The second is the cost of migration, $D(m(t))$, with $D(.)$ increasing and strictly convex. If migration becomes a deliberate strategy to deal with climate change, then the decision maker should take into account the costs borne by those who embark on the resettlement process. These costs are typically linked to the cultural differences, travel distance, and immigration policy in the destination country.[9] Putting together these two elements, we get:

$$V(c(t), m(t), N(t)) = N(t)U(c(t)) - D(m(t)). \tag{3.2.3}$$

Two comments are in order here. First, according to this formulation, the planner cares about the local inhabitants while migrants no longer matter once their resettlement process is completed. The planner's priority is to deal with the local situation that deteriorates thanks to the impacts of climate change. In this context, migration represents a form of long term adaptation. In other words, it is a specific instrument among the tools available to solve the problem. This characteristic prevails over the socio-economic dimension of migration (that encompasses the situation of migrants as individuals). In the literature review, we emphasized that international organizations present migration as a tool to foster economic development. This is not very different from the perspective we adopt here. Second, the question of how society should allocate its resources when the population is not constant is an old and important one. In welfare economics, utilitarianism allows to address this issue. In the utilitarian theory, there exist two conflicting approaches. According to the Benthamite view, society should care about the total utility of the members of the society. This is in contrast to the Millian perspective according to which this is the average utility, not the total utility, that matters. Neither classical nor average utilitarianism provides a satisfactory answer to the issue of how to choose the population size optimally.[10] And both have their advocates and opponents.

Our purpose is not to enter this debate, though quite thrilling. The reason why we choose to use the classical version is the following. Let C be aggregate consumption. Other things equal, the average utility $U(\frac{C}{N})$ is decreasing in N whereas if we take the derivative of the total utility $NU(\frac{C}{N})$ w.r.t N, we get:

$$\frac{\partial NU(\frac{C}{N})}{\partial N} = U\left(\frac{C}{N}\right)(1 - \sigma_u) \text{ with } \sigma_u = \frac{\frac{C}{N}U'(\frac{C}{N})}{U(\frac{C}{N})}.$$

[9]Defining $D(.)$ more generally in terms of m and $M(t)$ would allow us to also account for the social damage from migration in the origin country whose origin is the loss of social interactions, cultural transmission and family links that come with migration. This is left for future research.

[10]Under fairly general conditions, they have implications that are ethically unacceptable, see Razin and Sadka, 2001, and references therein.

Assuming that $\sigma_u < 1$, we get that total utility is increasing in N. Coming back to our motivation, given that we want to study migration driven by environmental (and financial) motives, it seems quite natural and logical to neutralize the other drivers of migration (and population change), and in particular the one related to the way society values the population size. Unlike average utilitarianism, classical utilitarianism allows us to do that since in the absence of remittances and climate change, the SIDS economy would not be willing to experience a decrease in the population thanks to migration.

Wealth in the SIDS, $W(K(t), N(t))$, has two origins. It locally produces a unique final good, $Y(t)$, by means of a constant returns to scale technology using natural capital, $K(t)$, and labor, $N(t)$: $Y(t) = F(K(t), N(t))$, with $F_i > 0, F_{ii} < 0$ for $i = K, N$, and $F_{KN} > 0$. What is worth noticing at this stage is that production capacities are limited by the amount of available natural assets, this is referred to as the environmental constraint. This constraint is expected to be increasing across time, as the negative repercussions of climate change will materialize. The SIDS also receives remittances, $R(M(t))$, from abroad. They are supposed to be increasing and concave with respect to this population.

Combining (3.2.1)-(3.2.2), we get a direct connection between the two populations: $M(t) = N_0 + M_0 - N(t)$ for all t, with $N_0 > 0$ and $M_0 \geq 0$ the initial population size of respectively insular people and the diaspora. This allows us to express total wealth as follows:

$$W(K(t), N(t)) = F(K(t), N(t)) + R(N_0 + M_0 - N(t)). \tag{3.2.4}$$

Under fairly general conditions, the wealth function is either monotone increasing in N, or inverted U-shaped, for K positive and given.[11] We consider the latter case. Denote by $N^*(K)$ the wealth maximizing population size, for K given. At the initial condition, we impose that

Assumption 1. $N_0 > N^*(K_0) \Leftrightarrow W_N(K_0, N_0) < 0$. *This is also equivalent to* $F_N(K_0, N_0) < R'(M_0)$.

This condition means that at the beginning of the planning program, the combination of the environmental constraint and the opportunity to resort the external funding

[11]Take its first derive w.r.t. N: $W_N(K, N) = F_N(K, N) - R'(N_0 - N)$. Assuming $\lim_{N\to 0} F_N(K, N) = \infty > R'(N_0 + M_0)$, W is either always increasing in N on $(0, N_0)$, or $\exists! N^*(K) \in (0, N_0)$ / $W_N(K, N^*(K)) = 0$, with $N^{*\prime}(K) > 0$.

of the economy through remittances is such that there exist incentives to undertake positive migration. This does not mean however that SIDS necessarily finds it optimal to go for positive migration from the origin because Assumption 1 only captures wealth motives, whereas migration is also accompanied by welfare effects. Since, everything else being equal, welfare is increasing in N, the SIDS has no incentive to decrease its population size. In other words, Assumption 1 provides a necessary condition for a regime with positive migration.

This assumption seems to be the most appropriate, especially if one wants to describe the optimal migration policy (even) in the absence of climate damage.[12] A glance at history shows us that the SIDS display a long tradition of migration, whose fundamental causes are partly environmental but not linked to climate change. We by no way claim that the migration flows that have been observed in these islands for decades can be attributed to any sort of optimal policy. Still, historical evidence suggests that positive migration may have been optimal for some SIDS. The key factor here is not the initial population size but the endowment of natural capital per capita. Thus we find it reasonable to give an account of the heterogeneity of SIDS, and resulting differences in migration patterns, which is what Assumption 1 allows.

Climate impacts show themselves in the degradation of the stock of natural asset, at a constant rate $\delta > 0$. Natural capital typically refers to the amount of arable lands, freshwater reserves, the endowment of the SIDS in marine and terrestrial ecosystems etc. To preserve these natural assets, the SIDS can by no way rely on mitigation since it has no capacity to affect the pattern of worldwide emissions on its own. Besides migration, the only option left to cope with climate change is then to invest in adaptation measures. For simplicity, we model adaptation as a decision variable, $s(t) \geq 0$, which suitably captures adaptation expenditures in ecosystems maintenance for instance.[13] Adaptation is a means to slow down the ongoing process of deterioration of $K(t)$. It however comes at an increasing and strictly convex cost, $G(s(t))$. Defining as $\varepsilon(s(t))$ the returns on adaptation, $\varepsilon(.)$ being decreasing and convex with $\varepsilon(0) = 1$, the law of motion of $K(t)$ is given by:

$$\dot{K}(t) = -\delta\varepsilon(s(t))K(t) + \delta\underline{K}_{\infty}. \tag{3.2.5}$$

[12] This corresponds to the case in which K_0 is constant.

[13] Therefore, by construction, our model is not designed to account for investments in adaptation infrastructure such as sea walls and dikes.

Absent any climate change, $K(t)$ would remain constant and equal to K_0. Under ongoing climate change but without public adaptation, $K(t)$ decreases exponentially at rate δ, going asymptotically to a strictly positive, though potentially very low, value $\underline{K}_\infty$.

Before summarizing the decision problem, it is worth formulating a general remark regarding our approach. In the literature review, we emphasized that the emigration policy has been considered as a tool for economic development for a long time. Moreover, we provided support for the perspective we adopt in this work, that consists in considering migration as an extreme form of adaptation. This of course supposes that decision makers can affect migration decisions and flows through targeted public policies.[14] That being said, rather than modeling explicitly the education sector or interactions with the expatriates population and how they relate to migration, we make a shortcut by assuming that the decision maker directly chooses the number of emigrants, $m(t)$.[15]

In the end, the intertemporal decision problem can be written as follows:

$$\max_{\{s(t),m(t)\}} \int_{t=0}^{\infty} V(c(t), m(t), N(t))e^{-\rho t}dt, \tag{3.2.6}$$

with $\rho > 0$ the rate of pure time preference, subject to the resource constraint, $c(t) = \frac{W(K(t),N(t))-G(s(t))}{N(t)}$, (3.2.1), (3.2.3), (3.2.4), and (3.2.5). Consumption is strictly positive whereas we have to account for the non-negativity constraints on $m(t)$ and $s(t)$. Finally, for the problem to be meaningful, we must focus on the situation where $\dot{K}(t) \leq 0$, *i.e.*, there is no man-made natural capital. This would normally require to add another constraint to the optimization. For simplicity, we do not explicitly incorporate this constraint. But we will take care of it in the coming analysis.

[14]Policies that seem particularly relevant are the ones that deal with education and the management of the diaspora.

[15]The assumption is made for simplicity and conveys the idea that governments in SIDS can ultimately control the decision to migrate. This is admittedly an oversimplified description of the real world. We however believe that this is the appropriate way to address the problem, especially because our aim is to study the optimal adaptation policy for SIDS. The alternative approach would have gone through the explicit modeling of individual migration decisions and their links with relevant public policies. This is an interesting extension of the current research that is left for future work.

3.3 Optimal policy

The optimization program above is a two-state two-control variable control problem. Taking into account the non-negativity constraints, the Lagrangian is:[16]

$$\mathcal{L} = NU\left(\frac{W(K,N)-G(s)}{N}\right) - D(m) - \lambda_N m + \lambda_K(-\delta\varepsilon(s)K + \delta\underline{K}_\infty) + \mu_m m + \mu_s s,$$

with λ_N and λ_K the co-state variables associated with N and K, and $\mu_m, \mu_s \geq 0$ the Lagrange multipliers for m and s.

Denote the elasticity of utility with respect to consumption and the elasticity of consumption with respect to N respectively by σ_u and σ_c:

$$\sigma_u = \frac{cU'(c)}{U(c)} \text{ and } \sigma_c(N;K,s) = -\frac{Nc_N}{c},$$

where the elasticity σ_u is assumed to be constant with $\sigma_u \in (0,1)$.

The set of (necessary) optimality conditions is given by:

$$\begin{cases} D'(m) + \lambda_N \geq 0, \; m(D'(m)+\lambda_N) = 0 \\ G'(s)U'(c(N,K,s)) + \varepsilon'(s)\delta\lambda_K K \geq 0, \; s(G'(s)U'(c(N,K,s)) + \varepsilon'(s)\delta\lambda_K K) = 0 \\ \dot{\lambda}_N = \rho\lambda_N - U(c(N,K,s))\,(1-\sigma_c(N;K,s)\sigma_u) \\ \dot{\lambda}_K = (\rho + \delta\varepsilon(s))\lambda_K - F_K(K,N)U'(c(N,K,s)) \\ \dot{N} = -m \\ \dot{K} = \delta(\overline{K}_\infty - \varepsilon(s)K) \end{cases} \tag{3.3.1}$$

where $c(N,K,s)$ is the compact notation for the consumption function.

The first condition in (3.3.1) is related to the choice of m, and we immediately observe that λ_N must be negative for experiencing a regime with $m > 0$. We come back to this point in a moment. The second optimality condition refers to the adaptation strategy. Adaptation involves the following trade-off. A marginal increase in adaptation expenditures is a means to slow down the deterioration of natural capital, a benefit that is measured at its social value. However, such an increase also implies that the economy has less resources available for consumption, this cost being measured in (marginal) utility terms

[16]The time index is omitted when there is no danger of confusion.

Overall the optimality conditions in (3.3.1) define a four-dimension dynamical system that may encompass four regimes depending on whether $m, s \gtreqqless 0$. This kind of system is hardly manageable in general due to the dimensionality and non-linearity problems. Our aim in the following analysis is to get as much insight from the theoretical analysis as possible. For that purpose, we choose to work with projections in plans composed of a state variable and its corresponding control – or co-state – variable, taking the other variables as given. With the support of graphical illustrations, this should allow us to address the following questions: which regime can arise along the optimal solution? What are the dynamic features of these regimes? Is it possible for the economy to experience a switch from one regime to the other? We ultimately want to identify some critical conditions that may help us to understand which policy, in terms of the combination and timing of implementation of the two instruments, is optimal for which SIDS, based on its characteristics.

3.3.1 Insights from the theoretical analysis

We start with the analysis of a regime with no adaptation, $s = 0$, which means that the SIDS incurs the impacts of climate change and has no other option but to design its migration policy optimally in order to adapt to them. All proofs are gathered in the Appendix.

3.3.1.1 Regime with no adaptation

We first study the dynamics of population and migration when assuming that $s = 0$. Then we look at the joint evolution of the stock of natural capital and its shadow value.

The migration decision comes with a direct (marginal) cost, captured by $D'(m)$, and potential benefits through the adjustment of the population size, that are captured by the shadow value of N. Consider the interior solution first ($m > 0$, $\mu_m = 0$). Combining the first condition in (3.3.1) with the one characterizing the dynamics of the shadow value λ_N yields the following dynamic system in the (N, m) plan:

$$\begin{cases} \dot{m} = m\sigma_d^{-1}\left(\rho + \frac{U(c(N,K(t),0))}{D'(m)}(1 - \sigma_u\sigma_c(N; K(t), 0))\right), \\ \dot{N} = -m. \end{cases}$$

with $\sigma_d = \frac{mD''(m)}{D'(m)} > 0$ the elasticity of the marginal damage, also assumed constant, and $K(t) = (K_0 - \underline{K}_\infty)e^{-\delta t} + \underline{K}_\infty$.

Take K as given, and for the ease of discussion, equal to K_0. This means that there is no impact of climate change on the SIDS. In this situation, it is relatively easy to show that the condition

$$\sigma_u \sigma_c(N_0, K_0, 0) > 1 \tag{3.3.2}$$

is necessary and sufficient to get a permanent regime with $m(t) > 0$ for $t < \infty$ (see the Appendix A.1.1.1). This condition involves both wealth and welfare effects. Wealth effects are captured by the elasticity $\sigma_c(N_0; K_0)$ since $\sigma_c(N_0; K_0) = 1 + \sigma_w(N_0; K_0)$ and σ_w is the elasticity of wealth w.r.t the population size. They have been discussed in detail following Assumption 1 that states that there exist migration incentives (as far as wealth is concerned). Welfare effects have to do with σ_u. The size of σ_u, which belongs to $(0, 1)$, tells us about how strongly society is affected by a change in the population size. Indeed, remember that $\frac{\partial NU(\frac{C}{N})}{\partial N} = U\left(\frac{C}{N}\right)(1 - \sigma_u) > 0$. Now the inequality above indicates that the optimal policy features positive migration when the wealth benefit from migration (and the decrease in the population size) exceeds the welfare costs associated with it. Note that this is most likely to be true when σ_u is close to one, which means that society barely feels the impact of the decrease in population (as $\frac{\partial NU(\frac{C}{N})}{\partial N}$ is close to zero in this case).

Under condition (3.3.2), it cannot be optimal to switch to $m = 0$ in finite time. Starting from a positive level of migration, migration flows decrease monotonically. The migration process ends up eventually when the population size approaches its steady state value $\hat{N}(K_0)$, that solves $\sigma_u \sigma_c(N, K_0, 0) = 1$.

Considering the exogenous degradation of K makes the dynamic analysis a bit more complex but does not change the main conclusion (see the Appendix A.1.1.2). Logically, and still assuming that condition (3.3.2) holds, as the burden imposed by the environmental constraint gets stronger and so is the dependence on remittances, the incentives to undertake positive migration are higher at any instant. The optimal migration policy displays the same qualitative features as the one depicted earlier. In the long run, natural capital converges to its degraded stationary value, $\underline{K}_\infty$. This in turn means that the population size has to decrease further in order to adapt to the much lower level of natural capital available to the SIDS. It will stabilize in the long run to the level $\hat{N}(\underline{K}_\infty)$ such that $\sigma_c(\hat{N}(\underline{K}_\infty); \underline{K}_\infty, 0) = \sigma_u^{-1}$. See Figure 29 for an illustration.

When $\sigma_c(N_0; K_0, 0) < \sigma_u^{-1}$, there is no migration incentive originally. Considering a constant K, we would get a trivial stationary solution with no population change. Here however considering the degradation of the stock of natural capital (because of climate change) may lead to a different conclusion. Indeed, provided that the initial emigration ratio is low enough,

$$\frac{M_0}{N_0} < \frac{\sigma_r(M_0)}{\sigma_u^{-1} - 1} \tag{3.3.3}$$

with $\sigma_r(M) = \frac{MR'(M)}{R(M)} > 0$ the elasticity of remittances w.r.t. the stock of expatriates,[17] there exists a (unique) critical stock of natural capital such that it becomes optimal to initiate the migration process: let $\hat{K}(N_0)$ be this stock, which solves $\sigma_c(N_0; K, 0) = \sigma_u^{-1}$. Therefore a switch to migration will occur in finite time if and only if $\underline{K}_\infty < \hat{K}(N_0)$. The intuition of this result is quite simple. Under climate change, the environmental constraint incurred by the SIDS may become so high that at some point it is optimal to undertake positive migration in order to release the pressure imposed on natural assets. From that date on, migration follows an inverted-U shaped trajectory until the convergence to the same steady state. See Figure 30 for an illustration.

Figure 29: Positive migration always

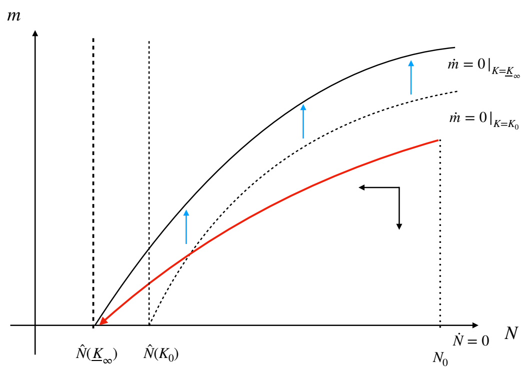
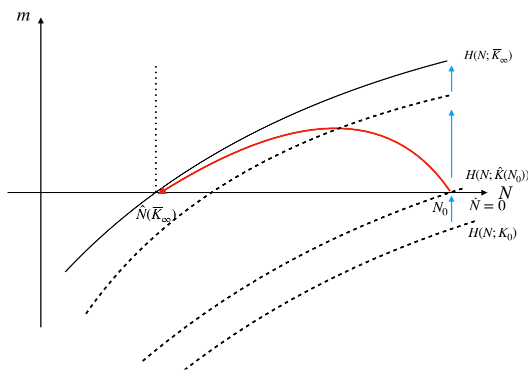


Figure 30: From $m = 0$ to $m > 0$



Let us now examine what is going on in the (K, λ_K) plan. In this regime, the dynamics are simply given by:

$$\begin{cases} \dot{\lambda}_K = (\rho + \delta)\lambda_K - F_K(K, N)U'(c(K, N, 0)) \\ \dot{K} = \delta(\overline{K}_\infty - K) \end{cases}$$

[17] This elasticity is equal to one – and the RHS of (3.3.3) does not depend on M_0 – when remittances are proportional to the size of the diaspora, $R(M) = rM$, a specification that will be used later.

Replacing $s = 0$ in the second condition in (3.3.1) and assuming that it holds with an equality, we can characterize the critical geometric locus that divides the (K, λ_K) into two domains, the one with $s = 0$ and the one with $s > 0$: $\lambda_K = \xi(K; N)$, with $\xi_K(K; N) < 0$ and $s = 0$ when $\lambda_K < \xi(K; N)$.

Working first with N given, the locus $\dot{\lambda}_K = 0$ defines another relationship between λ_K and K, which is parameterized by N: $\lambda_K = \zeta(K; N)$, with $\zeta_K(K; N) < 0$, and $\dot{\lambda}_K > 0$ for $\lambda_K > \zeta_K(K; N)$. Then we immediately obtain that the regime with no adaptation expenditure hosts a unique steady state with $K_\infty = \underline{K}_\infty$ and $\lambda_{K\infty}(N) = \frac{F_K(\underline{K}_\infty, N)U'(c(\underline{K}_\infty, N))}{\rho+\delta}$. During the convergence to the steady state, as the stock of natural capital deteriorates, its shadow value increases monotonically (see Figure 31 and the Appendix A.1.1.3).

Starting from the initial condition (N_0, K_0), such a trajectory is feasible if and only if the domain where $s = 0$ and $\dot{\lambda}_K > 0$ is non-empty. Defining $\tilde{K}(N_0)$ as the unique solution to $\xi(K; N_0) = \zeta_K(K; N_0)$, this boils down to imposing:

$$\tilde{K}(N_0) > K_0. \tag{3.3.4}$$

This condition captures the initial trade-off embodied in the choice of going for adaptation, or not. It basically compares the marginal benefit from the first unit of adaptation with its marginal cost.

Considering the decrease in population size resulting from an active migration policy, things get more complicated. The two critical loci $\xi(K; N)$ and $\zeta(K; N)$ move down, which results in an increase in $\tilde{K}(N)$, and it proves difficult to assess the feasibility of a path featuring $s = 0$ for all t. One can however observe that as N decreases the region of the (K, λ_K) plan in which it is optimal not to adapt shrinks. This also comes as no surprise. Other things equal, with the decrease in N, the SIDS incentives to undertake s get bigger as the opportunity cost of adaptation, in terms of foregone consumption, becomes lower.[18] This means that we cannot in general rule out the occurrence of a regime change from $s = 0$ to $s > 0$. As a rough illustration, Figure 32 depicts the optimal trajectory, in red, obtained for N constant and equal to N_0. With N decreasing and the frontiers moving down, it is possible that by following such a trajectory, the SIDS lies in the domain associated with $s > 0$ at a finite point

[18]Indeed, per capita consumption increases and marginal consumption increases when N decreases.

in time and starts adapting to climate change thanks to this specific instrument.

Figure 31: Regime $s = 0$, N_0 constant

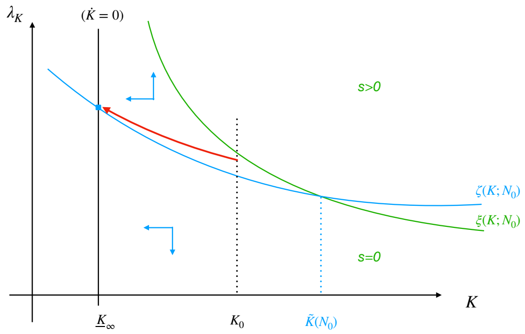
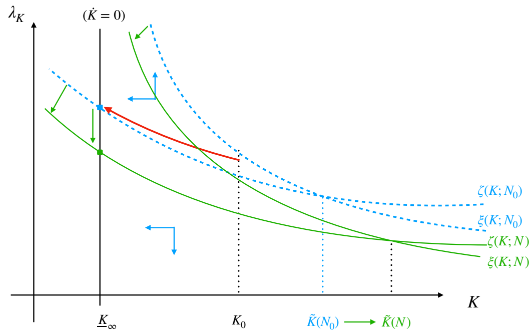


Figure 32: Regime $s = 0$, N decreasing



We now turn to the analysis of the regime with positive adaptation.

3.3.1.2 Regime with positive adaptation

For the sake of simplicity, we continue the ongoing analysis by making use of specific functional forms: $U(c) = \sigma_u^{-1} c^{\sigma_u}$, $\sigma_u \in (0, 1)$; $D(m) = \frac{1}{1+\sigma_d} m^{1+\sigma_d}$, $\sigma_d \geq 1$; $Y = AK^\alpha N^{1-\alpha}$, $A > 0$, $\alpha \in (0, 1)$; $R(M) = rM$, $r > 0$; $G(s) = \gamma s$, $\gamma > 1$; and $\varepsilon(s) = e^{-\eta s}$, $\eta > 0$. For technical elements, refer to the Appendix A.1.2.

Using these specifications, we can define:

$$\Phi(K; N) = \frac{\eta}{\gamma} \alpha A K^\alpha N^{1-\alpha} - 1,$$

and express the dynamical system as follows:

$$\begin{cases} \dot{\lambda}_K = [\rho - \delta \varepsilon(s) \Phi(K; N)] \, \lambda_K \\ \dot{K} = \delta (K_\infty - \varepsilon(s) K) \end{cases}$$

Let us work with N constant, and equal to N_0 first. Noticing that the critical level $\tilde{K}(N_0)$, defined just before, is also the solution to $\Phi(K; N_0) = \frac{\rho}{\delta}$, the condition

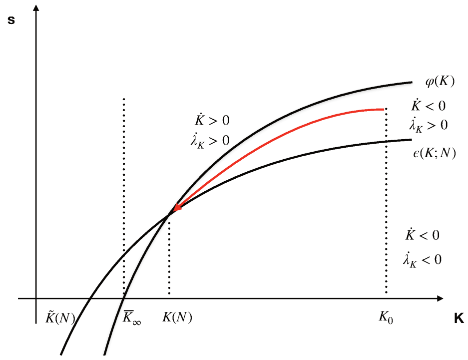
$$\tilde{K}(N_0) < K_0 \tag{3.3.5}$$

is necessary and sufficient for the existence of a well-behaved regime with positive adaptation expenditures. If we further impose:

$$\begin{cases} \tilde{K}(N_0) < \underline{K}_\infty, \\ \Phi(K_0; N_0) < \frac{\rho}{\delta}\frac{K_0}{\underline{K}_\infty}, \end{cases} \tag{3.3.6}$$

then there exists a unique steady state parameterized by N_0, $(K_\infty(N_0), s_\infty(N_0))$, with $K_\infty(N_0) \in [\underline{K}_\infty, K_0]$, $K'_\infty(N) > 0$ and $s'_\infty(N) > 0$. During the transition to the steady state, the natural capital decreases monotonically and so do adaptation expenditures. We can further impose a sufficient condition for the steady state to be a saddle point and represent the dynamical adjustment in the (K, s) (see Figure 33).[19]

Figure 33: Optimal adaptation policy for N_0 given



The optimal level of expenditures, $s = s(K, \lambda_K; N)$, is increasing in both K and λ_K, while decreasing in N. If its behavior w.r.t to λ_K is as expected, the same cannot be said of its behavior w.r.t K. But this is very intuitive after all. Indeed, the returns on adaptation expenditures are larger the larger the stock of natural capital. In other words, it is when the stock of natural capital is high, and the negative impacts of climate change are felt the most (thanks to the exponential decrease of K), that it is worthwhile to invest a lot in protecting the natural capital. That why, in the regime with $s > 0$, expenditure follows a monotone decreasing trajectory. With the degradation of its natural capital, the SIDS progressively reduces its investments until it manages to stabilize it to a degraded, tough better than $\underline{K}_\infty$, level.

Moreover, it is worth noting that a transition from the regime with $s = 0$ to the regime with $s > 0$ cannot take place in finite time. From an economic point of view and as long as the future matters, it does not make sense to maintain natural capital for a period of time and then stop the efforts as all the resources invested in adaptation will be wasted eventually as K converges to its lower bound $\underline{K}_\infty$.

[19] We can get the explicit relationship between s and K corresponding to $\dot{s} = 0$ in this regime. So we simply draw the loci $\dot{\lambda}_K = 0$ and $\dot{K} = 0$.

Going back to the dynamics of population with positive adaptation, condition (3.3.2) is no longer necessary to have positive migration. Besides the usual wealth and welfare effects associated with migration, devoting a positive amount of resources to adaptation gives higher incentives to adjust the population size to get the highest possible income. In such a context, we expect that the dynamics in the (N, m) remain similar to what we get in Section 3.3.1.1. In particular, as long as the SIDS starts with positive migration, the emigration rate should vanish only asymptotically.

The reverse inequality, $\sigma_c(N_0; K_0, 0) < \sigma_u^{-1}$, is now necessary (but not sufficient) for a regime with $m = 0$ together with $s > 0$ to take place initially. In this case, it is relatively easy to provide a necessary and sufficient condition for a switch to $m > 0$ in finite time:

$$\sigma_c(N_0; K_\infty(N_0), s_\infty(N_0)) > \sigma_u^{-1}(> \sigma_c(N_0; K_0, 0)). \tag{3.3.7}$$

A last remark can be formulated. It is difficult to go further in the study of the dynamic behavior of the SIDS when located in the regime with positive adaptation and positive – but asymptotically going to zero – migration. A complete analysis would especially require to deal carefully with the issue of existence of a steady state for the general system (3.3.1). Rather, we simply want to make the following observation, assuming that a steady state exists. When the SIDS economy devotes resources to adaptation, it manages to maintain the stock of natural capital to a level above the lowest bound $\underline{K}_\infty$, which is compatible with a larger population size than in the absence of such expenditures. Not surprisingly, monitoring the speed at which natural capital deteriorates and managing to stabilize its level in the long run ultimately provides the SIDS economy with more latitude for ensuring a good enough standard of living for a larger number of inhabitants.

3.3.2 Discussion

Let us now put together all the pieces of information we get so far. As far as the optimal policy is concerned, our analysis reveals that the SIDS has two qualitatively different options to cope with the negative repercussions of climate change. Interestingly, two conditions on the fundamentals of the economy help to explain which policy is optimal in which context. These conditions involve the ranking between K_0 and $\hat{K}(N_0)$ on the one hand, given that $\sigma_c(N_0; K_0, 0) \gtreqless \sigma_u^{-1} \Leftrightarrow K_0 \lesseqgtr \hat{K}(N_0)$, and between K_0 and $\tilde{K}(N_0)$

on the other.

In order to ease the discussion, one possibility is to represent the situation in the plan of initial conditions (N_0, K_0), which requires to learn a bit more about the properties of $\hat{K}(N_0; r, M_0, \sigma_u, A)$ and $\tilde{K}(N_0; \gamma, \rho, \eta, \delta, A)$.[20]

First, we have already shown that $K_0 < \hat{K}(N_0)$ is either sufficient $(s > 0)$ or necessary and sufficient $(s = 0)$ for an initial regime with positive migration. Moreover, it can easily be checked that $\hat{K}_{N_0} > 0$ and $\hat{K}_{N_0 N_0} > 0$. In other words, the critical locus triggering positive migration is higher the larger the initial population size. For very high N_0, it is optimal to start the migration process in order the release the pressure on natural assets for a larger the set of values of K_0. As to the comparative statics on $\hat{K}(N_0; r, M_0, \sigma_u, A)$, we get:

$$\hat{K}_r, \hat{K}_{\sigma_u} > 0 \text{ whereas } \hat{K}_{M_0}, \hat{K}_A < 0.$$

Other things equal, the higher r and the lower M_0, the higher the returns on migration. On the contrary, a high productivity parameter A makes it worthwhile to maintain a large population to benefit from the local origin of wealth. Finally, the higher σ_u, the lower the welfare cost of migration.

Second, one can note that $\tilde{K}_{N_0} < 0$ and $\tilde{K}_{N_0 N_0} > 0$. The critical initial level of the stock of natural capital at which it is optimal to invest in adaptation decreases as N_0 increases. Indeed, the larger the population, the stronger the incentives to undertake positive adaptation to slow down the degradation of the stock of natural capital. In addition, remember that when $\tilde{K}(N_0) < K_0$, the policy features $s > 0$, at least initially. The reason for this finds its roots in the properties of the optimal level of expenditures, discussed earlier. Regarding the question of how the location of the critical locus $\tilde{K}(N_0; \gamma, \rho, \eta, \delta, A)$ changes with the fundamentals of the economy in the plan of initial conditions (K_0, N_0), we further obtain:

$$\tilde{K}_\gamma, \tilde{K}_\rho > 0 \text{ whereas } \tilde{K}_\eta, \tilde{K}_\delta, \tilde{K}_A < 0.$$

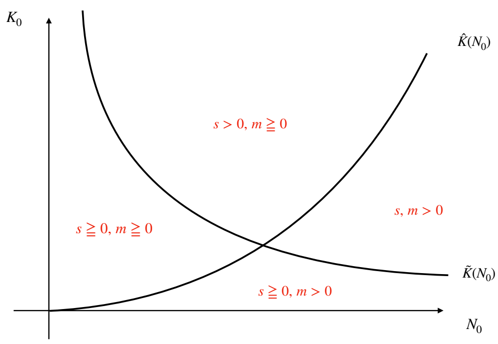
So, we can conclude that the larger γ and/or the lower A, the higher the cost of the adaptation policy. In the same vein, the lower η, the lower the returns on adaptation expenditures. Finally, when ρ is high, people attach less value to what happens in the

[20] Once working with the specifications introduced early, it is possible to make the dependence of these functions on the parameters explicit.

long run, while a low δ means that climate change translates into a slow degradation of the natural capital. This all points to the fact that the set of initial conditions for which it is optimal to choose $s = 0$ expands.

Overall, we can conclude that there exist two main policy alternatives for the SIDS. Either the SIDS implements – at least initially and possibly permanently – a policy relying on only one of the two instruments, which makes them substitutes. Or the SIDS adopts a policy combining adaptation and migration from the origin, the two instruments being complements. Figure 34 provides a representation of the different possible combinations of the two instruments in the special case where $M_0 = 0$.[21] For a large enough N_0 (larger than the intersection between $\hat{K}(N_0)$ and $\tilde{K}(N_0)$), we see that there are three possibilities depending on the initial endowment in natural capital. For a large enough K_0, it is optimal to go for adaptation first, while not using the migration tool. Migration may become operative at some later date, depending on whether condition (3.3.7) is met. Quite on the contrary, for K_0 low enough, there is no point at spending resources in adaptation and the only option left is migration. Finally in intermediate situations, the optimal policy consists of a mix between adaptation and migration right from the beginning.

Figure 34: Different optimal policies in the (N_0, K_0) plan



3.4 Calibration

In this section, we bring the model to the data in order to complement the theoretical analysis presented in the previous section. We calibrate the different parameters as well as the initial conditions for the main variables. In the coming exercise, a particular emphasis will be placed on international comparisons. The most significant difference

[21]In this case, condition (3.3.3) is always fulfilled.

among the SIDS appears to be their size, and we will see that this distinction is the main determinant of the different potential paths of islands.

3.4.1 Parameters calibration

Among the parameters some values common to all the SIDS are taken from the economic literature or computed. In the theoretical analysis, we assume that the cost of infrastructure expenditure is linear: $G(s) = \gamma s$, with $\gamma > 1$. The parameter γ can be interpreted as the marginal cost of public funds. To our knowledge, there is no paper providing an estimation of γ for SIDS countries. We therefore use a value in line with the estimations calculated by Auriol and Warlters (2012) using a sample of African countries, that is $\gamma = 1.2$.[22] The share of labor in production–textiti.e. parameter $(1 - \alpha)$ in our model–is not the same in all countries. Therefore, we consider the average of values for SIDS given in the Pennsylvania World Table (PWT) (Feenstra et al. (2015)), $(1 - \alpha) = 0.55$.[23]

The choice of the value of ρ, the rate of pure time preference, has led to an intense debate in the literature (Tol (2006), Nordhaus (2007), Dasgupta (2008)). We use 0.04, but we have performed the numerical analysis for values ranging between 0.04 and 0.2 to be consistent with the literature (see Appendix A.1.4 for the robustness checks). For the sake of simplicity, we choose a quadratic function for the marginal cost of migration, which implies that $\sigma_d = 1$. As for the utility function, we take $\sigma_u = 0.95$, which means that we work with a function that displays features close to a linear one. We implement robustness tests for $\sigma_u = \{0.9; 0.95; 0.99\}$.[24] The other parameters are determined using the following method:

- The total factor productivity (TFP): A

  The value of the Total Factor Productivity (TFP), A, is calibrated on data from the PWT and the World Development Indicators (WDI). We compute the Cobb-Douglas function of the model using the following data from the PWT:

[22]Note that the results are not very sensitive to the value of γ, when varying between 1 and 2. This claim has been tested in the supplementary comparative statics analysis provided in Appendix A.1.4.

[23]Another solution would be to evaluate the value of α accordingly to the natural capital stock values which are retained. However, in this case, the calibration of the rest of the model, especially for remittances function, would be less accurate. The robustness tests for the calibration with different definitions of natural capital stock are available upon request.

[24]Robustness results are given in the Appendix A.1.4.

population, country level labor share and output stock in Purchasing Power Parity (PPP). Moreover, we define the natural capital stock as the sum of the value added from tourism as well as agriculture, forestry and fisheries (AFF) in the World Development Indicators (WDI).[25] Note that tourism is incorporated in order to capture the economic gains from landscapes on these islands. We apply the standard growth accounting framework to our production function. According to it, economic growth can be decomposed into contributions from inputs, here labor and natural capital. Therefore, in order to obtain annual growth rate of the TFP for country i, we compute the following equations:

$$\begin{aligned} g^i_{TFP} &= g^i_{output} - (1-\alpha)g^i_{labor} - \alpha g^i_{capital} \\ TFP_i &= 1 + g^i_{TFP} \end{aligned}$$

where the growth rate of the variable x is defined as: $g_x = (x(t+1) - x(t))/x(t)$. We use long-term average for SIDS, which is 1.01. Note that we conduct robustness tests on the value of the TFP according to the minimum and the maximum value computed for the SIDS, which are respectively 0.96 and 1.08 (*cf.* Appendix A.1.4).

- Initial Values

  We define the diaspora size as the average of the emigrant stock between 2000 and 2015, using the data-set of the United Nations, Department of Economic and Social Affairs, Population Division (POP/MIG). However, in order to have a better comparison between countries as well as to respect the scale of the model, we divide the values from the different dataset by 10^6 to get the initial conditions for population (N_{i0}), the stock of natural capital (K_{i0}) and the stock of migrants (M_{i0}).

- The remittances coefficient: r

  Next we want to compute the value of r, given the linear specification used: $R(M(t)) = rM(t)$. A preliminary step is to compute the level of remittances perceived in the economy. The total amount received from the diaspora is obtained using the variable "remittances perceived in percentage of GDP" from

[25] We have also conducted a calibration where the natural capital is defined as the sum of the capital stock from the PWT and the value added from tourism and the AFF. For developing countries the latter methodology gives output that are less correlated to the GDP than the retained method, while for SIDS, the results remain the same (*cf.* Appendix A.1.4).

the WDI data-set, this variable is denoted by $\hat{R}_i(t)$ in our calibration. First, we calibrate the value of the remittances, $R_i(t)$, according to the following equation:

$$\begin{aligned} Y_i(t) &= TFP_i(t) \times K_i(t)^\alpha \times N_i(t)^{1-\alpha} \\ R_i(t) &= \hat{R}_i(t) \times Y_i(t) \end{aligned}$$

Then, we regress $R_i(t)$ on the computed values of the diaspora size to get the value of r. The value of this coefficient for the SIDS is reported in Table 12.[26] Note that the results displayed in the table tend to support our choice for the definition of natural capital. Indeed, the coefficient of correlation between the migrants stock and the remittances perceived is higher if capital is computed as the sum of the AFF and tourism added values than with the alternative definition.

Table 12: Correlation between the diaspora and the Remittances

	SIDS		**Developing Countries**	
Variable	**(1)**	**(2)**	**(1)**	**(2)**
Diaspora	20.58	102.87	44.06	236.71
95% Conf. Interval	[17.29; 23.87]	[81.65; 124.09]	[36.50; 51.62]	[205.03; 268.38]
Count	63	62	319	318
R2	0.72	0.60	0.29	0.41
R2 Adjusted	0.71	0.60	0.29	0.40

(1) Capital is defined as the sum of added values of AFF and tourism
(2) Capital is defined as the sum of capital stock from the PWT and aggregate defined by (1).

Table 13 summarizes the parameters values used to calibrate the model.[27] Table 14 gives the long term average values retained for the local population, the diaspora and the stock of natural capital (with the values of tourism and AFF). Islands are classified in two groups, according to their geographical localization: Caribbean SIDS vs Other SIDS. In the analysis of the initial conditions, we compute $\hat{K}$ with $M(0) = 0$ to be able to have a comparison between countries.

[26] This calibration works quite well for islands, with a $R^2 = 0.72$, while the correlation is not as good for other developing countries or developed countries, for the reasons explained above.

[27] The values retained for σ_u, γ, δ, η, and ρ are in bold print, while the other computations are given in A.1.4.

Table 13: Parameters of the model

Parameter		Value
Total Factor Productivity	A	{0.96; **1.01**; 1.08}
Capital share in production	α	0.45
Cost of Public expenditure	γ	{1;**1.2**;1.5}
Elasticity of Utility with	σ_u	{0.9; **0.95**; 0.99}
Rate of pure time preference	ρ	{**0.04**; 0.1; 0.2}
Elasticity of the marginal damage	σ_d	1
Remittances return rate	r	{15; **20**; 25}
Degradation rate	δ	{0.02; **0.1**; 0.25}
Efficiency of adaptation	η	{0.2; **0.4**; 0.6}

3.4.2 Results

The first objective of our numerical analysis is to understand the position of each SIDS in the plan of the initial conditions and thus to answer to the following question: what is the optimal strategy of each island to cope with climate change? Figure 35 displays, in logarithmic scale plots, the position of each island according to their initial values for capital and population. We also represent on the same plan the two critical loci, $\tilde{K}(N)$ and $\hat{K}(N)$, derived in the theoretical analysis, that are given by the following equations:

$$\tilde{K}(N_0) = \left(\frac{\gamma(\rho+\delta)}{\delta\eta A(1-\sigma_F)} N_0^{\alpha-1}\right)^{\frac{1}{\alpha}}, \quad (3.4.1)$$

$$\hat{K}(N_0) = \left(\frac{r N_0^{\alpha-1}(N_0 - M_0(\sigma_u^{-1}-1))}{A(\sigma_u^{-1}-\alpha)}\right)^{\frac{1}{\alpha}}. \quad (3.4.2)$$

Note that these two curves are drawn by assuming that SIDS share what we call *the common parameters*, i.e., all the parameters except the initial conditions. We choose to focus on the heterogeneity with respect to the initial conditions because of the insights given by theoretical investigation. In particular, it has been emphasized that they are crucial to understand SIDS potential development path in a world with climate change.

Remind that if a country is located above the curve $\hat{K}$, optimal migration can be nil, while if it is below the curve, it will always be positive. Moreover, if the country position is below the curve $\tilde{K}$, investments in adaptation measures can be zero, while if it is above the curve there will be positive adaptation expenditures.

Table 14: Initial Conditions

Countries[a]	**Population**[b]	**Mig. Stock**[c]	**AFF**[d]	**Tourism**[e]	**Nat. cap.**[f]
Other SIDS					
COM	653,547.13	97,925.75	471,785,696	54,433,940	526,219,648
CPV	487,067.75	145,873.25	224,986,560	553,566,592	778,553,152
FJI	844,610.19	168,499	684,939,776	1,424,057,600	2,108,997,376
GNB	1,480,094	90,425	890,059,712	30,794,654	920,854,336
MDV	344,131.75	2,139.75	240,465,408	2,589,127,936	2,829,593,344
MUS	1,231,074.25	141,176.75	770,540,736	2,943,838,464	3,714,379,264
STP	165,723.25	30,233	45,970,536	34,740,660	80,711,200
SYC	89,187.75	10,377.75	45,081,308	633,793,280	678,874,560
Caribbean SIDS					
ABW	99,813	13,666.75	15,343,271	1,876,686,592	1,892,029,824
ATG	91,951.88	57,153.75	30,930,550	612,512,640	643,443,200
BHS	344,067.44	35,616.25	116,810,920	2,218,210,560	2,335,021,568
BLZ	302,807.06	53,181.25	298,639,648	438,550,592	737,190,272
BRB	276,888.25	94,207	67,785,448	1,050,887,680	1,118,673,152
CUW	145,550.55	65,692.75	13,903,565	938,107,072	952,010,624
DMA	71,116.94	63,148.5	79,620,696	131,192,264	210,812,960
DOM	9,560,993	1,083,748.25	6,067,153,920	9,270,968,320	15,338,122,240
GRD	103,934	63,629.5	56,855,876	219,942,768	276,798,656
HTI	9,631,816	1,009,448	3,009,077,248	716,374,976	3,725,452,288
JAM	2,776,172.25	940,470.75	1,257,011,456	3,692,628,992	4,949,640,192
LCA	167,849.06	47,970.75	60,580,300	574,474,560	635,054,848
SUR	512,644.13	248,161.25	575,558,464	162,111,264	737,669,760
TTO	1,312,901.5	330,561.5	218,717,136	1,186,257,792	1,404,974,976
VCT	108,885.81	56,054.25	62,329,152	182,764,736	245,093,888

[a]Legend: **COM**: Comoros, **CPV**: Cabo Verde, **FJI**: Fiji, **GNB**: Guinea-Bissau, **MDV**: Maldives, **MUS**: Mauritius, **STP**: Sao Tome and Principe, **SYC**: Seychelles, **ABW**: Aruba, **ATG**: Antigua and Barbuda, **BHS**: Bahamas, The, **BLZ**: Belize, **BRB**: Barbados, **CUW**: Curacao, **DMA**: Dominica, **DOM**: Dominican Republic, **GRD**: Grenada, **HTI**: Haiti, **JAM**: Jamaica, **LCA**: Saint-Lucia, **SUR**: Suriname, **TTO**: Trinidad and Tobago, **VCT**: Saint-Vincent and the Grenadines

[b]Source: PWT

[c]Migrant Stock, source: UNSD

[d]Soure: WDI. Value added, PPP 2011$

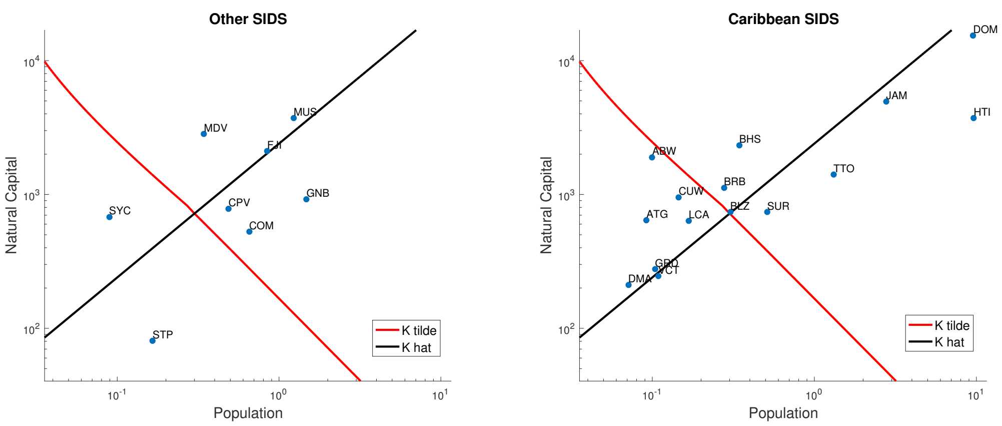
[e]Source: WDI. International receipt, PPP 2011$

[f]Sum of AFF and Tourism

Several remarks arise from the observation of Figure 35. First of all, there exists a critical threshold for the population size, 1.5 million inhabitants, that determines whether it is optimal to systematically go for adaptation. When the population is larger than this threshold, the optimal policy is based on adaptation, that may be complemented with migration. On the contrary, if the population is very small, the island is likely located below the curve of $\tilde{K}$. In this scenario, using adaptation measures is optimal only for countries with very large stock of natural. For example, Barbados and the Bahamas are above the curve $\tilde{K}$ because of their large endowment in natural capital. Indeed, their amount of natural capital, or the economic gains linked to this capital, is almost equal to countries' capital which are ten times larger.

Second, what we can learn from these two figures is that half of the islands are in the region where neither adaptation measures nor migration are undertaken from the beginning and forever. However, most of these islands are very close to the frontiers defined by $\tilde{K}$ and $\hat{K}$. Put differently, switches to situations where migration and/or adaptation measures are implemented is very likely. Indeed, only countries with quite large population and stock of natural capital, combine both adaptation and migration from the origin, with no change expected in their optimal policy. This second group is composed of Dominican Republic, Haiti, Jamaica, Trinidad and Tobago, Suriname, Papua New Guinea, Cabo Verde and Comoros. For them, both tools will be used to cope with climate change. Finally, it appears that a supplementary analysis is necessary for small islands, those where investments in adaptation measures can be null or positive.

Figure 35: Distribution of the SIDS according to their initial conditions



Our analysis also contains robustness tests related to climate change parameters, such as the degradation rate, δ, and the effect of the effectiveness of adaptation measures η. Figure 36 illustrates the effect of a change in δ on the curve $\tilde{K}$. It appears that when the degradation rate is high, almost all the countries implement adaptation measures in order to slow down the pace of natural capital degradation. If the degradation rate is high, the gains from investing in adaptation are large compared to the cost of this policy. Figure 37 displays the effect of a change in η on the curve $\tilde{K}$. As expected, the larger the effectiveness of the adaptation measures, the larger the incentives to undertake investments in adaptation.

Figure 36: Analysis of the effects of the parameter δ

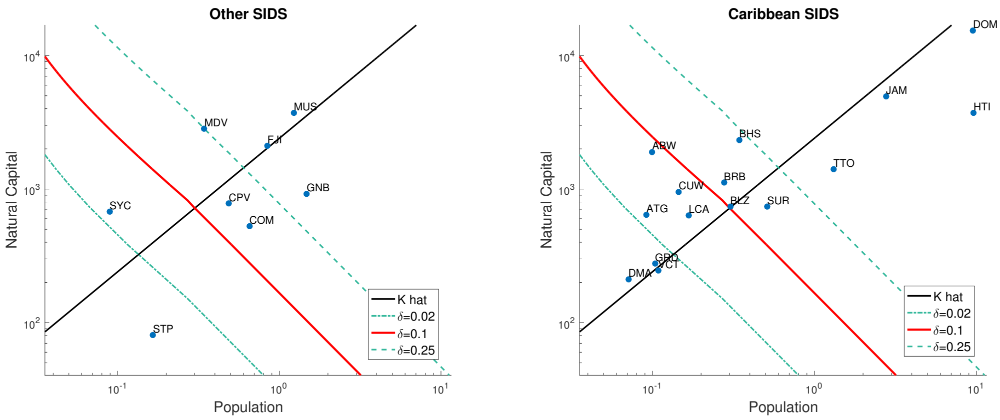
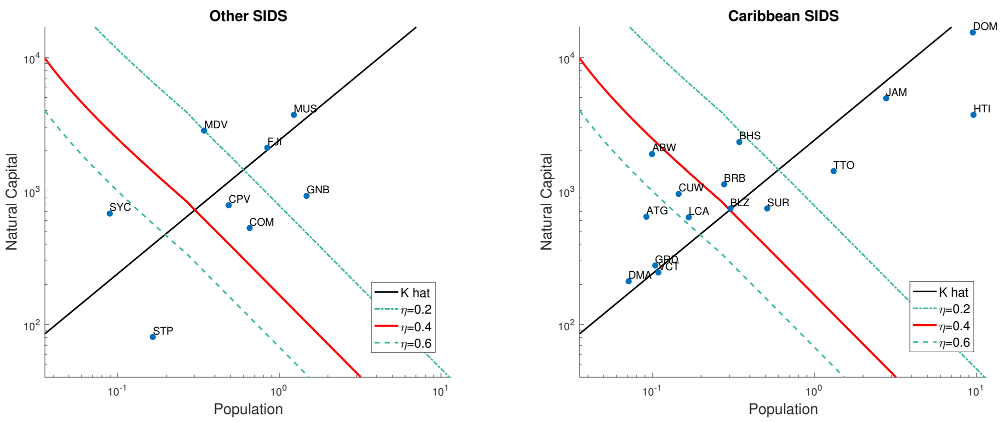


Figure 37: Analysis of the effects of the parameter η

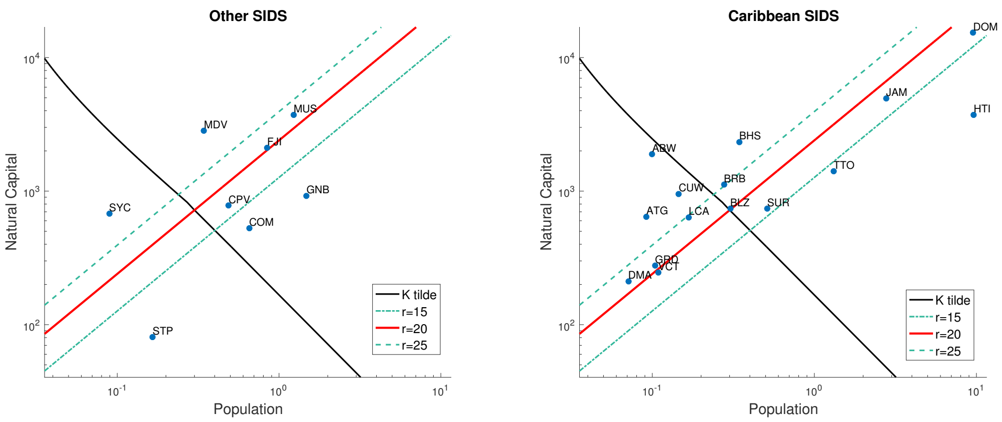


Overall, the analysis of the impact of environmental parameters shows that the climate change scenario plays a critical role in understanding the dynamics of smallest islands. Indeed, because of their proximity with the two loci, a change in these parameters may have a substantial impact on the characterization of their optimal strategy.

The last parameter that deserves a particular attention is r. Changes in r induce large changes in the computation of $\hat{K}$. In the present analysis, we have tested values of the coefficient r obtained in the regression according to approximately the 95%

confidence interval. The interpretation of this parameter is not easy because we obtain very different values depending on the method to calibrate the production function. Here we have selected the values of r which give the highest correlation with the remittances, knowing that they are the most conservative ones. However, r might be larger with another definition of natural capital stock as shown in table 12. In that case, the model predicts that all the islands will implement migration to cope with climate change. Knowing the weight of migration for these islands, this is a plausible conclusion. In this context, the main question is whether or not it is optimal to use adaptation in complement with migration.

Figure 38: Analysis of the effects of the parameter r (1)



3.5 Conclusion

In this paper we adopted a centralized perspective to assess the optimal policy of a SIDS facing the negative repercussions of climate change on its natural capital. We developed a dynamic framework in which economic conditions on the island are directly derived from two sources of wealth: production and remittances. To produce, the economy uses labor and natural capital, while remittances are sent by the diaspora. Therefore, under climate change and in the absence of any intervention, production follows an exogenous decreasing trend. Welfare in the SIDS is defined over the total utility derived from consumption. In this centralized model, the policy maker has two means to cope with climate-related damages: *migration strategy* in order to receive remittances or *adaptation strategy*, in order to slow the degradation process. Migration induces a social cost for the migrant and a contraction of the output because of a decreasing labor force. In this context, reducing the population size might be good for wealth at the origin, but it affects total welfare both directly (*cf.* the total utility criterion), and indirectly (by changing the amount of per capita consumption). The adaptation strategy, generates a direct cost in terms of foregone consumption, while the benefit stems from the capacity to maintain the stock of natural capital to a higher level, and for a longer period of time.

Our analysis of the optimal policy was conducted in two phases, the first one being devoted to a theoretical investigation, the second one consisting of a calibration of the model. From the theoretical investigation, we obtained two conditions that shed some light on the SIDS's preferred policy to deal with climate change. When only migration is possible, we found a critical condition on the fundamentals of the economy under which there were migrations incentives at the beginning of the planning period. In this situation, migration decreases and vanishes only when the optimal population size is reached. In the absence of migration incentive initially, the increasing environmental constraint could lead to a switch to positive migration, according to another condition. On the contrary when only adaptation expenditures are possible, we found another critical condition under which the SIDS starts to adapt from the origin. When the regime with positive adaptation is permanent, adaptation expenditures decrease monotonically over time but remains positive. Consequently, the natural capital remains at a higher level than in the case without adaptation measures.

Finally, merging both regimes analysis, we found that on one hand, if there is no adaptation initially but positive migration, the incentives to switch on the second instrument increase over time as the decrease in the population size reduces the marginal cost of adaptation. Moreover, if both tools are implemented, SIDS could stabilize natural assets to a constant and higher level than in the absence of adaptation. As a result, the population size is also larger in the long run.

In a second step, we calibrated the model. The main objective is to describe the initial conditions on the islands–*i.e.* the initial size of the population and the initial endowment in natural capital–and thus to determine their potential strategy. We found that SIDS could be distinguished in two groups. The first one, composed by countries with very small populations, that is the majority of the islands. The second group is composed of a few islands with larger population. For the latter, the calibration exercise suggests that at each period of time both policy tools should be implemented. In smaller islands results are however ambiguous. In this case, an analysis of the dynamics at a country level should be implemented to define what the optimal paths of these islands are. Indeed, while migration is always implemented during the transition, the adaptation measures could be positive or not.

Therefore in order to improve the analysis of this chapter, a natural development is to study the transitional dynamics through numerical simulations. Finally, several extensions of the model are possible; for example one could model the effect of public policies on education. This would certainly impact the migration rate. Another possibility, is to have natural capital impacted also by local production, in order to introduce directly the pressure induced by the population size.

A.1 Appendix

Total wealth is given by $W(K,N) = F(K,N) + R(N_0 + M_0 - N)$, with first derive w.r.t. N: $W_N(K,N) = F_N(K,N) - R'(N_0 - N)$. For a given K, assuming $\lim_{N\to 0} F_N(K,N) = \infty$, W is either always increasing in N on $(0, N_0)$ or $\exists! N^*(K) \in (0, N_0)$ / $W_N(K, N^*(K)) = 0$, with $N^{*\prime}(K) > 0$. For an interesting problem, we consider the second case and further impose: $N_0 > N^*(K_0)$ (*cf.* Assumption 1).

The set of optimality conditions corresponding to the general problem is given by:

$$\begin{cases} D'(m) + \lambda_N \geq 0, \ m(D'(m) + \lambda_N) = 0 \\ G'(s)U'(c(N,K,s)) + \varepsilon'(s)\delta\lambda_K K \geq 0, \ s(G'(s)U'(c(N,K,s)) + \varepsilon'(s)\delta\lambda_K K) = 0 \\ \dot{\lambda}_N = \rho\lambda_N - (U(c(N,K,s)) + NU'(c(N,K,s))c_N(N,K,s)) \\ \dot{\lambda}_K = (\rho + \delta\varepsilon(s))\lambda_K - F_K(K,N)U'(c(N,K,s)) \\ \dot{N} = -m \\ \dot{K} = \delta(\underline{K}_\infty - \varepsilon(s)K) \end{cases} \tag{A.1.1}$$

with $c(N,K,s) = \frac{W(K,N)-G(s)}{N}$, and λ_K the shadow value of the stock of natural capital.

The system may go through four different regimes depending on whether $m \gtreqqless 0$ and $s \gtreqqless 0$. In any regime, we have to deal with four-dimension systems that are not easy to handle in general. To circumvent the difficulties posed by the analysis, we work hereafter with projections of these systems in two-dimension (sub)spaces, respectively in the plan (K, λ_K) (for $s = 0$) or (K, s) (for $s > 0$) by taking (m, N) as given, and (N, λ_N) (for $m = 0$) or (N, m) (for $m > 0$) by taking (s, K) as given. We then merge the results to characterize the overall solution.

Let us start the analysis of the dynamics in the regime with no adaptation: $s = 0$. First, we take a look at the population dynamics. Next, we consider the evolution of the pair (K, λ_K).

A.1.1 Regime with no adaptation

A.1.1.1 Population dynamics under a constant K

For K constant and equal to K_0, the FOCs are given by:

$$\begin{cases} D'(m) + \lambda_N \gtreqqless 0, \\ \dot{\lambda}_N = \rho\lambda_N - (U(c(N;K_0,0)) + NU'(c(N;K_0,0))c_N(N;K_0,0)), \\ \dot{N} = -m. \end{cases}$$

where λ_N is the shadow price of the population size and $c(N;K_0,0) = \frac{W(N,K_0)}{N}$ the consumption rate, with $c_N = \frac{NW_N - W}{N^2} < 0 \leftarrow N > N^*(K_0)$. Note that $m > 0 \Leftrightarrow \lambda_N <$

0.[28]

Denote by σ_u, the elasticity of the utility function w.r.t c: $\sigma_u = \frac{cU'(c)}{U(c)} \in (0,1)$, constant. Denote also by $\sigma_c(N;K_0)$ (respectively $\sigma_w(N;K_0)$) the elasticity of consumption (resp. wealth) w.r.t N: $\sigma_c(N;K_0,0) = -\frac{Nc_N}{c}$ (resp. $\sigma_w(N;K_0) = -\frac{NW_N}{W}$). $\sigma_w(N;K_0) > 0$ on the interval $(N^*(K_0), N_0)$. Given that $\sigma_c(N;K_0,0) = 1+\sigma_w(N;K_0)$, $\sigma_c(N;K_0,0) > 1$ on this interval. Finally define σ_d as the elasticity of the marginal damage w.r.t m: $\sigma_d = \frac{mD''(m)}{D'(m)} > 0$; also assumed to be constant.

Consider first a regime with $m > 0$. From the associated dynamics

$$\begin{cases} \dot{m} = m\sigma_d^{-1}\left(\rho + \frac{U(c(N;K_0)))}{D'(m)}(1-\sigma_u\sigma_c(N;K_0))\right), \\ \dot{N} = -m, \end{cases}$$

we can define the locus $\dot{m} = 0$, for positive m, (if) only if $1 \leq \sigma_u\sigma_c(N;K_0,0)$. It then yields a relationship between m and N:

$$m = H(N;K_0) \text{ with } H(N,K_0) = (D')^{-1}\left(-\frac{U(c(N;K_0,0))}{\rho}(1-\sigma_u\sigma_c(N;K_0,0))\right).$$

The derivative of σ_w (and σ_c) w.r.t N are:

$$\frac{\partial \sigma_w}{\partial N} = -\frac{1}{W}\left(W_N(1+\sigma_w(N;K_0)) + NW_{NN}\right) > 0,$$

because $W_{NN} = F_{NN} + R''(N_0 + M_0 - N) < 0$.

Now imposing

$$\sigma_c(N_0;K_0,0) > \sigma_u^{-1} \Leftrightarrow \sigma_u(1+\sigma_w(N_0;K_0)) > 1 \tag{A.1.2}$$

is necessary and sufficient for the existence of this regime with $m > 0$. Noticing that $\sigma_c(N^*(K_0);K_0,0) = 1$,[29] we can also define a unique $\hat{N}(K_0) \in (N^*(K_0), N_0)$ that solves $\sigma_c(\hat{N}(K_0);K_0,0) = \sigma_u^{-1}$. The next step is to study the features of $H(N;K_0)$. We get

[28] For the sake of exposition, we omit the arguments of the functions (especially the derivatives) when they are unnecessary.

[29] Actually $\sigma_c(N^*(K);K,s) = 1$ whatever s.

$$\frac{\partial H}{\partial N} = \frac{U(c)\sigma_u}{\rho N D''(m)}\left(\sigma_c(1-\sigma_u\sigma_c) + N\frac{\partial \sigma_c}{\partial N}\right),$$
$$\Leftrightarrow \frac{\partial H}{\partial N} = \frac{U(c)\sigma_u\sigma_c}{\rho N D''(m)}\left(\sigma_c(1-\sigma_u) - \frac{NW_{NN}}{W}\right) > 0.$$

In addition, we get that $H(\hat{N}(K_0); K_0) = 0$.

Starting from a positive level of migration below the locus $H(N; K_0)$, migration flows decrease monotonically until either $H(N; K_0)$ is hit in finite time, which would then lead to the second corner regime ($m = 0$), or it approaches asymptotically the critical level $\hat{N}(K_0)$ at which $\dot{m} = m = 0$. It is easy to show that the first option cannot coincide with the optimal policy. Suppose that there exists $T < \infty$ such that $m(T) = 0 \Leftrightarrow \lambda_N(T) = 0$ and $m(t) = 0$, $N(t) = \bar{N} > \hat{N}(K_0)$ for all $t \geq T$. Solving for the differential equation in λ_N in the corner regime, we get: $\lambda_N(t) = \frac{U(c(\bar{N};K_0,0)(1-\sigma_u\sigma_c(\bar{N};K_0,0))}{\rho}\left(1 - e^{\rho(t-T)}\right)$. But then, the transversality condition, $\lim_{t\to\infty} e^{-\rho t}\lambda_N(t)\bar{N} = 0$, cannot hold. So we get a contradiction.

Under (A.1.2), there exists a permanent regime with $m > 0$. Under the opposite of (A.1.2),

$$\sigma_c(N_0; K_0) < \sigma_u^{-1}, \tag{A.1.3}$$

we get the trivial solution with $m = 0$, $N = N_0$ and $\lambda_N = \frac{U(c(N_0;K_0,0))(1-\sigma_u\sigma_c(N_0;K_0,0))}{\rho} > 0$ for all t.

A.1.1.2 Population dynamics under a decreasing natural capital

To analyze this case, we further need: $c_K = \frac{W_K}{N} > 0$, $\frac{\partial \sigma_c}{\partial K} = \frac{\partial \sigma_w}{\partial K} = -\frac{N}{W^2}(W_{KN}W - W_K W_N) < 0$ since $F_{KN} > 0$.

Let us again consider the regime with $m > 0$: following the same approach – under Assumption 1 – we can define $N^*(K)$, for any $K \in (\underline{K}_\infty, K_0)$ that solves $W_N(N^*(K), K) = 0$. We have $0 < N^*(K) < N^*(K_0)$ for all K in this interval. Assume that condition (A.1.2) holds, the dynamics are given by:

$$\begin{cases} \dot{m} = m\sigma_d^{-1}\left(\rho + \frac{U(c(N;K(t),0)}{D'(m)}(1-\sigma_u\sigma_c(N;K(t),0))\right), \\ \dot{N} = -m. \end{cases}$$

The locus $\dot{m} = 0$, for $m > 0$, still yields a relationship between m and N, parameterized by $K(t)$:

$$H(N;K(t)) = (D')^{-1}\left(-\frac{U(c(N;K(t),0)}{\rho}(1-\sigma_u\sigma_c(N;K(t),0))\right),$$

that exists iff $\sigma_u\sigma_c(N;K(t),0) > 1$. It is possible to show that the derivative of H w.r.t to K is negative: $\frac{\partial H}{\partial K} = -\frac{\sigma_u U}{\rho D''(m)}\left(\frac{c_K}{c}(1-\sigma_u\sigma_c(N;K(t),0)) - \frac{\partial\sigma_c}{\partial K}\right) < 0$ since $\frac{c_K}{c}(1-\sigma_u\sigma_c(N;K(t),0)) - \frac{\partial\sigma_c}{\partial K} = \frac{1}{W}((1-\sigma_u)\sigma_c W_K + NW_{NK}) > 0$. The region featuring $\dot{m} < 0$ expands as K decreases. If this regime is permanent, K asymptotically converges its lower bound $\underline{K}_\infty$. In turn, the population size approaches the value $\hat{N}(\underline{K}_\infty)$ that solves $\sigma_c(N;\underline{K}_\infty) = \sigma_u^{-1}$.

Again we have to determine whether it is possible to enter the second corner regime ($m = 0$) in finite time. Let us proceed as we did before: Suppose that there exists $T < \infty$ such that $m(T) = 0 \Leftrightarrow \lambda_N(T) = 0$ and $m(t) = 0$, $N(t) = \bar{N} > \hat{N}(\underline{K}_\infty)$ for all $t \geq T$. The solution for λ_N in this corner regime is: $\lambda_N(t) = -e^{\rho t}\int_T^t U(c(\bar{N};K(\tau))(1-\sigma_u\sigma_c(\bar{N},K(\tau)))e^{-\rho\tau}d\tau > 0$. But then $\lim_{t\to\infty} e^{-\rho t}\lambda_N(t)\bar{N} = -\bar{N}\int_T^\infty U(c(\bar{N};K(\tau))(1-\sigma_u\sigma_c(\bar{N},K(\tau)))e^{-\rho\tau}d\tau \neq 0$. So the transversality condition is not satisfied and we get a contradiction.

Now, let us assume that (A.1.3) holds. This implies that originally, there is no incentive to undertake migration: $m = 0$ and $N = N_0$. The evolution of λ_N is given by:

$$\dot{\lambda_N} = \rho\lambda_N - U(c(N_0;K(t),0)(1-\sigma_u\sigma_c(N_0;K(t),0))$$

The locus $\dot{\lambda_N} = 0$ gives a relationship:

$$\mathcal{H}(N_0;K) = \frac{U(c)(1-\sigma_u\sigma_c)}{\rho}$$

with $\mathcal{H}_{N_0} = \frac{1}{\rho}\left(c_N U'(c)(1-\sigma_u\sigma_c) - \sigma_u U(c)\frac{\partial\sigma_c}{\partial N}\right) = \frac{U(c)\sigma_u}{\rho W}\left(W_N(1-\sigma_c(\sigma_u-1)) + N_0 W_{NN}\right) <$ 0 and $\dot{\lambda_N} > 0$ for $\lambda_N > \mathcal{H}(N_0;K)$. Under (A.1.3), this locus satisfies $\mathcal{H}(N_0;K_0) > 0$. Now, with K decreasing, noticing that $\frac{\partial\sigma_c}{\partial K} < 0$, we have $\sigma_c \leq \sigma_u^{-1} \Leftrightarrow \frac{F(K,N_0)}{N_0}(\sigma_u^{-1} - 1 + \sigma_f) \geq R'(M_0) - (\sigma_u^{-1} - 1)\frac{R(M_0)}{N_0}$, with $\sigma_f = \frac{NF_N}{F}$ the share of labor in production. Let us work with technologies exhibiting a constant $\sigma_f \in (0,1)$. Then, either M_0 is so large that the RHS is negative and the inequality is always satisfied: the regime with $m = 0$ is permanent and has the same features as the ones studied in Appendix A.1.1.1. Or, M_0 is low enough – and the initial emigration ratio satisfies: $\frac{M_0}{N_0} < \frac{\sigma_r(M_0)}{\sigma_u^{-1}-1}$ with $\sigma_r(M) = \frac{MR'(M)}{R(M)}$ – for the RHS to be positive. In this case, there exists a unique

$\hat{K}(N_0)$ that solves the equation above and $\sigma_c \gtreqless \sigma_u^{-1} \Leftrightarrow K \lesseqgtr \hat{K}(N_0)$. In turn and provided that $\hat{K}(N_0) > \underline{K}_\infty$, this implies that the economy will experience a switch in finite time to the regime with $m > 0$. For K given, in a regime with $m = 0$, the shadow value of N should be constant and equal to $\mathcal{H}(N_0; K)$. Now, given the continuous decrease in K, this shadow value will decrease too still while being given by $\lambda_N(t) = \mathcal{H}(N_0; K(t))$.[30] Let T be the date at which λ_N is equal to 0: $\lambda_N(T) = 0$, or equivalently $K(T) = \hat{K}(N_0)$. From T onwards, we expect that $\lambda_N(t) < 0$ first, experiences a phase where it decreases and then becomes increasing and behaves according to the interior solution analyzed above. This would in turn results in a non-monotone trajectory for m, m being increasing first before it starts to decrease to asymptotically approach 0.

A.1.1.3 Dynamics of natural capital and its shadow value

Take first N as given. In the regime with $s = 0$, the dynamics are:

$$\begin{cases} \dot{\lambda}_K = (\rho + \delta)\lambda_K - F_K(K, N)U'(c(K, N, 0)) \\ \dot{K} = \delta(\underline{K}_\infty - K) \end{cases} \tag{A.1.4}$$

The steady state of this regime is located at the (unique) intersection between the vertical line $K = \underline{K}_\infty$ and the locus $\dot{\lambda}_K = 0$, which now defines a relation between K and λ_K: $\lambda_K = \frac{F_K(K,N)U'(c)}{\rho+\delta} \equiv \zeta(K; N)$, with $\zeta_K(K; N) = \frac{F_{KK}U'(c)+F_K c_K U''(c)}{\rho+\delta} < 0$, $\zeta_N(K; N) > 0$, and $\dot{\lambda}_K \geq 0 \Leftrightarrow \lambda_K \geq \zeta(K; N)$. In addition, it is quite easy to check that this steady state is saddle point stable. This means that convergence can occur only along the part of the stable branch originating in the domain where $\dot{\lambda}_K > 0$ and $\dot{K} < 0$. This makes sense: as natural capital depreciates, its social value increases during the transition to the StS.

The next question is: can a transition from $s = 0$ to $s > 0$ occur in finite time? To provide an answer, we have to define the critical locus that divides the (K, λ_K) into two domains, one with $s = 0$, the other with $s = 0$. To do so, simply replace $s = 0$ in the second FOC of system (A.1.1), and suppose that it holds with an equality. This gives another relation between K and λ_K: $\lambda_K = -\frac{G'(0)U'(c)}{\delta\varepsilon'(0)K} \equiv \xi(K; N)$, with $\xi_K(K; N) = \frac{G'(0)U'(c)}{\delta\varepsilon'(0)K^2}(1 - \frac{Kc_K}{c}\frac{cU''(c)}{U'(c)}) < 0$ and $\xi_N(K; N) = -\frac{G'(0)c_N U''(c)}{\delta\varepsilon'(0)K} > 0$. Moreover,

[30] This confirms that the system cannot start in the regime where $m > 0$ (which features $\lambda_N < 0$ and $\dot{\lambda}_N > 0$) in this case.

we get that $s = 0$ when $\lambda_K < \xi(K;N)$.

Then we obtain $\zeta(K;N) \leq \xi(K;N) \Leftrightarrow KF_K \leq -\frac{G'(0)(\rho+\delta)}{\delta\varepsilon'(0)}$. Given that the LHS of this inequality is equal to $(1-\sigma_f)F(K,N)$, so increasing in K, this is equivalent to $K \leq \tilde{K}(N)$ with $\tilde{K}(N) = F^{-1}\left(-\frac{G'(0)(\rho+\delta)}{(1-\sigma_f)\delta\varepsilon'(0)}; N\right)$. In addition, as it also decreasing in N, we can conclude that: $\tilde{K}'(N) < 0$.

Suppose that $\underline{K}_\infty < \tilde{K}(N_0) < K_0$, then the economy with no adaptation must be originally located in the region with $\dot{\lambda}_K < 0$ and $\dot{K} < 0$, which is not compatible with the existence of an optimal trajectory leading to the corner steady state. In other words, $\tilde{K}(N_0) > K_0$ is a necessary and sufficient condition for the existence of a corner solution with $K_\infty = \underline{K}_\infty$. This also implies that a transition from the corner regime with $s = 0$ to the interior regime with $s > 0$ cannot take place ever.

With N decreasing, that is under positive migration, all the critical loci go down since $\zeta_N(K;N), \xi_N(K;N) > 0$ while $\tilde{K}(N)$ moves up because of the different speeds of adjustment of $\zeta(K;N)$ and $\xi(K;N)$. This first means that the region where it is optimal not to adapt shrinks over time. Clearly, in this situation, starting within the regime with $s = 0$, it may be possible that a switch to $s > 0$ occurs in finite time. But it proves very difficult to provide formal conditions that guarantee such a transition.

A.1.2 Regime with positive adaptation

A.1.2.1 Dynamics of natural capital and adaptation

We first work with for N given. Consider the dynamics in the regime with $s > 0$, represented in the (K, s) plan:

$$\begin{cases} \dot{\lambda}_K = \left[\rho + \delta\varepsilon(s)\left(1 + \frac{KF_K(K,N)}{G'(s)}\frac{\varepsilon'(s)}{\varepsilon(s)}\right)\right]\lambda_K \equiv \left[\rho - \delta\varepsilon(s)\phi(K,s;N)\right]\lambda_K \\ \dot{K} = \delta(\underline{K}_\infty - \varepsilon(s)K) \end{cases} \tag{A.1.5}$$

where

$$\phi(K,s;N) = -\frac{\varepsilon'(s)}{\varepsilon(s)}\frac{1}{G'(s)}KF_K - 1.$$

For a tractable analysis, from now on we consider a specification of the model with the following functional forms: $U(c) = \sigma_u^{-1}c^{\sigma_u}$, $\sigma_u \in (0,1)$; $D(m) = \frac{1}{1+\sigma_d}m^{1+\sigma_d}$, $\sigma_d \geq 1$; $Y = AK^\alpha N^{1-\alpha}$, $A > 0$, $\alpha \in (0,1)$; $R(M) = rM$, $r > 0$; $G(s) = \gamma s$, $\gamma > 1$; and

$\varepsilon(s) = e^{-\eta s}$, $\eta > 0$.

This expression above then reduces to:

$$\Phi(K;N) = \frac{\eta}{\gamma}\alpha A K^{\alpha} N^{1-\alpha} - 1,$$

with $\Phi_K = \frac{\eta}{\gamma}\alpha^2 A K^{\alpha-1} N^{1-\alpha} > 0$ for $K \in [\underline{K}_{\infty}, K_0]$.

We want to deal with the features of the $\dot{K} = 0$ and $\dot{\lambda}_K = 0$ loci, (from which we can infer those of $\dot{s} = 0$ locus) given that the latter is parameterized by N. This leads to the definition of two relations between s and K:

$$\begin{cases} \dot{\lambda}_K = 0 \Leftrightarrow s = \varepsilon^{-1}\left(\frac{\rho}{\delta}\Phi(K;N)^{-1}\right) \equiv \epsilon(K;N), \\ \dot{K} = 0 \Leftrightarrow s = \varepsilon^{-1}\left(\frac{K_{\infty}}{K}\right) \equiv \varphi(K). \end{cases} \tag{A.1.6}$$

Define $\underline{K}(N)$ such that $\Phi(\underline{K}(N);N) = 0$; $\underline{K}(N) = \left(\frac{\gamma}{\eta\alpha A}N^{\alpha-1}\right)^{\frac{1}{\alpha}}$, with $\underline{K}'(N) < 0$. We have $\underline{K}(N) > \underline{K}(N_0)$ for all $N < N_0$. For the first relation to exist, we must focus on the interval $[\underline{K}(N), K_0]$, which is non-empty only if the following condition holds: $\underline{K}(N_0) < K_0$. Moreover, by definition $\varepsilon(s) \in [0,1]$ for $s \geq 0$, and $\varepsilon(0) = 1$. This imposes a stronger restriction on the domain of definition of K: for a solution with $s > 0$ to be well-defined, K should belong to $[\tilde{K}(N), K_0]$, with $\tilde{K}(N) = \left(\frac{\gamma(\rho+\delta)}{\delta\eta(1-\sigma_F)A}N^{\alpha-1}\right)^{\frac{1}{\alpha}} > \underline{K}(N)$ for the functional forms used.[31] This interval is non-empty only if $\tilde{K}(N_0) < K_0$, as $\tilde{K}(.)$ is decreasing in N. So we impose

$$\tilde{K}(N_0) < K_0. \tag{A.1.7}$$

Remind that K is necessarily non-increasing in our problem,[32] so we must restrict the analysis to pairs (K,s) such that $\dot{K} \leq 0 \Leftrightarrow s \leq \varphi(K)$. The $\dot{K} = 0$ satisfies: $\varphi'(K) = \frac{1}{\varepsilon'(.)} \times -\frac{K_{\infty}}{K} > 0$. For our specification we actually get $\varphi(K) = \frac{1}{\eta}\ln(\frac{K}{\underline{K}_{\infty}})$; thus $\varphi(\underline{K}_{\infty}) = \frac{1}{\eta}$, $\varphi'(K) = \frac{1}{\eta K} > 0$, and $\varphi''(K) = -\frac{1}{\eta K^2} < 0$. As to the other locus, $\epsilon'(K;N) = \frac{1}{\varepsilon'(.)} \times -\frac{\Phi_K(K;N)}{\Phi(K;N)^2} > 0$. Again, referring to the functional forms we use, we obtain $\epsilon(K;N) = \frac{1}{\eta}\ln(\frac{\delta\Phi(K;N)}{\rho})$, $\epsilon_K(K;N) = \frac{\Phi_K}{\Phi} > 0$ and $\epsilon_{KK}(K;N) = \frac{1}{\eta}\frac{\Phi_{KK}\Phi-(\phi_K)^2}{\Phi^2} < 0$. Both loci are increasing in concave in K. Given that from the second FOC in (A.1.1), $\lambda_K \geq 0$, we further have $\dot{\lambda}_K \geq 0 \Leftrightarrow s \geq \epsilon(K;N)$. We can

[31] Indeed, $\tilde{K}(N)$ solves $\Phi(\tilde{K}(N);N) = \frac{\rho}{\delta} \Leftrightarrow \epsilon(\tilde{K}(N);N) = 0$ and it must hold that $\Phi(\tilde{K}(N);N) \geq \frac{\rho}{\delta}$.

[32] A restriction that we didn't incorporate in the optimization program for simplicity, but that has to be verified ex-post.

finally observe that as N increases, so does $\epsilon(K;N)$ because $\epsilon_N(K;N) = \frac{\Phi_N}{\eta\Phi} > 0$.

Assume for now that $\varphi(K)$ and $\epsilon(K;N)$ have a unique intersection. By construction, this steady state belongs to the $\dot{s} = 0$ locus. By differentiating the second FOC in (A.1.1), that defines the optimal s as $s = s(\lambda_K, K; N)$, we get

$$\left(\frac{\varepsilon''(s)}{\varepsilon'(s)} - \frac{cU''(c)}{U'(c)}\frac{c_s}{c}\right) ds = -\left(1 - \frac{cU''(c)}{U'(c)}\frac{Kc_K}{c}\right)\frac{dK}{K} - \frac{d\lambda_K}{\lambda_K},$$

noticing that $\frac{\varepsilon''(s)}{\varepsilon'(s)} = -\eta$, $-\frac{cU''(c)}{U'(c)} = 1-\sigma_u$ and using the specifications, this expressions simplifies to:

$$ds = \left(\eta + \frac{\gamma(1-\sigma_u)}{Nc}\right)^{-1}\left[\left(1 + \frac{KF_K(1-\sigma_u)}{Nc}\right)\frac{dK}{K} + \frac{d\lambda_K}{\lambda_K}\right], \tag{A.1.8}$$

which means that $s_K > 0$, $s_{\lambda_K} > 0$ and $s_N < 0$. From that, we directly obtain the expression of $\dot{s}$, whose sign is undetermined when $\dot{\lambda}_K > 0$, given that $\dot{K} < 0$ (except at the steady state). We come back to this later on. In the meantime, the steady state analysis is conducted.

We still work for N given and look at the conditions for the existence of a steady state $(K_\infty(N), s_\infty(N))$. From (A.1.6), a steady state solves: $\varphi(K) = \epsilon(K;N)$. This boils down to finding the solution to: $\frac{\varrho}{\delta}\frac{K}{\underline{K}_\infty} = \Phi(K;N)$. Under (A.1.7), given that $\Phi_K > 0$ and $\Phi(\tilde{K}(N), N) = \frac{\varrho}{\delta} < \frac{\varrho}{\delta}\frac{\tilde{K}(N)}{\underline{K}_\infty} \Leftrightarrow \tilde{K}(N) > \underline{K}_\infty$, if we impose:

$$\begin{cases} \tilde{K}(N_0) < \underline{K}_\infty, \\ \Phi(K_0; N_0) < \frac{\varrho}{\delta}\frac{K_0}{\underline{K}_\infty}, \end{cases} \tag{A.1.9}$$

then we know that there exists a unique $K_\infty(N) \in (\tilde{K}(N), K_0)$ solving the equation above. Actually, $K_\infty(N)$ must be larger than $\underline{K}_\infty$: $K_\infty(N) \in (\underline{K}_\infty, K_0)$. In addition, $K_\infty(N)'(N) > 0$ as $\Phi_N(K;N) > 0$. We finally obtain $s_\infty(N)$ by replacing K with $K_\infty(N)$ in for instance $\varphi(K)$, with $s'_\infty(N) = \varphi'(K)K'_\infty(N) > 0$.

Let us now assess the local stability conditions, for N given. Equation (A.1.8) yields $\dot{s} = 0$ in terms of $\dot{\lambda}_K$ and $\dot{K}$, replacing them with the corresponding law of motion, we get:

$$\dot{s} = \delta\left(\eta + \frac{\gamma(1-\sigma_u)}{Nc}\right)^{-1}\left(\Lambda(K;N) + \frac{(1-\sigma_u)(1-\sigma_f)F(K,N)}{Nc}\left(\frac{\underline{K}_\infty}{K} - \varepsilon(s)\right)\right) \tag{A.1.10}$$

with $\Lambda(K,s) = \frac{\rho}{\delta} + \frac{K_\infty}{K} + \frac{(1-\sigma_f)\varepsilon'(s)F(K,N)}{\gamma}$. Combining this equation with the expression for $\dot{K}$, and linearizing around the steady state, we obtain the Jacobian matrix, J:

$$J = \begin{pmatrix} -\frac{\delta(1-\sigma_f)\varepsilon'(s)F(K,N)}{\gamma} & \frac{\delta\left(\eta+\frac{\gamma(1-\sigma_u)}{Nc}\right)^{-1}}{K}\left(\frac{(1-\sigma_f)^2\varepsilon'(s)F(K,N)}{\gamma} - (1+\frac{(1-\sigma_u)(1-\sigma_f)F(K,N)}{Nc})\frac{K_\infty}{K}\right) \\ -\delta\varepsilon'(s)K & -\delta\varepsilon(s) \end{pmatrix}$$

Direct calculations yield:

$$\det J = \delta^2\varepsilon'(s_\infty(N))\varepsilon(s_\infty(N))\left(\sigma_f(1+\Phi(K_\infty(N);N))-1\right) < 0 \Leftrightarrow \Phi(K_\infty(N);N)) > \frac{1-\sigma_f}{\sigma_f},$$

and under this condition, the steady state $(K_\infty(N), s_\infty(N))$ is a saddle point.

The convergence to the steady state takes place along the stable branch, which means that both s and K follow a monotone path. Note that the second term between parenthesis in (A.1.10) is always negative. Now assume that $\dot{s} > 0$ for all t. We have $\Lambda(K_\infty(N), s_\infty(N)) = 0$, and $s < s_\infty(N)$ and $K > K_\infty(N)$ for any pair (K,s) in the neighborhood of the steady state. Given that $\Lambda_K < 0$ and $\lambda_s > 0$, $\Lambda(K,s) < \Lambda(K_\infty(N), s_\infty(N)) = 0$. This in turn implies that $\dot{s} < 0$ at the instant when the pair (K,s) is achieved, which yields a contradiction. So we can claim that s is monotone decreasing over time.

A.1.2.2 Migration and population dynamics

From here, we do not really provide a formal proof but rather a discussion on the possible outcomes.

In the last step of the resolution, we move back to the analysis in the (N, λ_N), or (N, m), plan. Following the same lines as in the Appendices A.1.1.1 and A.1.1.2, we already know that the properties of σ_c are decisive to characterize the solution. Before we proceed, it is worth noticing that the general definition of σ_c has changed:

$$\sigma_c(N;K,s) = -\frac{1}{Nc}\left(G(s) - W(1+\sigma_w(N,K))\right) \Leftrightarrow \sigma_c(N;K,s) = 1 + \frac{W\sigma_w(N,K)}{W-G},$$

with

$$\begin{aligned}
\tfrac{\partial \sigma_c}{\partial N} &= -\tfrac{c_N}{c}\left(\sigma_c - 1 + \tfrac{W_{NN}}{C_N}\right) > 0,\\
\tfrac{\partial \sigma_c}{\partial K} &= -\tfrac{1}{(Nc)^2}\left(GW_K\sigma_w + \tfrac{N(W-G)}{W}(W_{NK}W - W_KW_N)\right) = -\tfrac{N}{(Nc)^2}\left((W-G)W_{NK} - W_KW_N\right) < 0,\\
\tfrac{\partial \sigma_c}{\partial s} &= \tfrac{G'(s)W\sigma_w}{(Nc)^2} = -\tfrac{\gamma NW_N}{(Nc)^2} > 0.
\end{aligned} \tag{A.1.11}$$

We observe that $\sigma_c(N; K, s) > \sigma_c(N; K, 0)$ for all $s > 0$. Assume that condition (A.1.2) holds. This implies that $\sigma_c(N_0; K_0, s_0) > \sigma_u^{-1}$: there will be incentive to migrate initially. For $s > 0$ and K given, we further know that $\exists!\ N^*(K) \in (0, N_0)$ such that $\sigma_c(N^*(K); K) = 1 < \sigma_u^{-1}$. Taking the pair (K, s) as given, it must exists a unique solution to $\sigma_c(N; K, s) = \sigma_u^{-1}$. Denote this solution as $\hat{N}(K, s)$. But this does not solve the existence issue: we want to be sure that there exists $N \in (0, N_0)$ that solves $\sigma_c(N; K_\infty(N), s_\infty(N)) = \sigma_u^{-1}$. This is not obvious as if we know that σ_c may be varying for at least some period of time in the interval $(1, \sigma_u^{-1})$ and is continuous w.r.t. t, it is difficult to understand how it will change over time because it depends on N, K and s. To be completed.

Next we can use the relation $s = \varphi(K) \equiv s(K)$ to define the steady state population size as a function of K only: $\breve{N}(K) = \hat{N}(K, s(K))$. Then, we compute

$$\breve{N}'(K) = -\frac{\left(\frac{\partial \sigma_c}{\partial K} + \frac{\partial \sigma_c}{\partial s} s'(K)\right)}{\frac{\partial \sigma_c}{\partial N}}$$

Direct manipulations give:

$$\frac{\partial \sigma_c}{\partial K} + \frac{\partial \sigma_c}{\partial s} s'(K) < -\frac{\gamma \Phi(K; N)}{\eta K (W-G)^2} \leq 0 \text{ for } K \geq \tilde{K}(N).$$

Thus, the numerator above is non-negative, which means that a necessary and sufficient condition for $\breve{N}'(K) > 0$ is $\frac{\partial \sigma_c}{\partial N} > 0$, which is indeed the case. There is a clear parallel to draw between the current analysis and the one conducted in the Appendix A.1.1.2. Indeed, the solution we get in this benchmark case can be rewritten (with slight abuse of notation) as $\hat{N}(\underline{K}_\infty, 0)$. Moreover, the solution is clearly continuous in (K, s). As $\hat{N}$ is increasing in s but decreasing in K we then conclude that $\hat{N}(K, s(K)) > \hat{N}(\underline{K}_\infty, 0)$ for $K > \underline{K}_\infty$ and $s(K) > 0$.

Now consider that condition (A.1.3) holds. Compared to the benchmark, this is only necessary for a regime $m = 0$ to take place initially. Assume that this is indeed the case, which requires $s(0)$ be low enough: $\sigma_c(N; K, s(0)) < \sigma_u^{-1}$. Then the question is: would a transition in finite time be possible in this situation? In other words, we want to check to which extent the analysis conducted in the Appendix A.1.1.2 can still apply to the general case. With N constant and equal to N_0 initially (as $m = 0$), we have to study the impacts of the dynamic adjustments in (K, s) on migration incentives. Basically, this boils down to tracking the evolution of σ_c across time, given that: $\dot{\sigma}_c = \frac{\partial \sigma_c}{\partial K}\dot{K} + \frac{\partial \sigma_c}{\partial s}\dot{s}$. Rearranging (that is, using the expression of $\dot{s}$, $\dot{K}$ and of the partial derivatives), we get

$$\begin{aligned}\dot{\sigma}_c =& -\frac{NK}{(Nc)^2}\left(\eta + \frac{\gamma(1-\sigma_u)}{Nc}\right)^{-1} \\ &\times\left[\left((W-G)\left(\eta + \frac{\gamma(1-\sigma_u)}{Nc}\right) - \frac{\gamma W_N}{K}\Phi(K,N)\right)\frac{\dot{K}}{K} + \frac{\gamma W_N}{K}\frac{\dot{\lambda}_K}{\lambda_K}\right]\end{aligned}$$

This expression is positive if $\dot{\lambda}_K > 0$ in this regime. The steady state, analyzed in the (K, λ_K), is a saddle point, which implies that λ_K must be monotone. In addition, it is clear that $\ddot{K} > 0$ in the neighborhood of the steady state, with

$$\begin{aligned}\ddot{K} =& -\delta\varepsilon(s)K\left(-\eta\dot{s} + \frac{\dot{K}}{K}\right) \\ =& \,\delta\varepsilon(s)K\left(\eta + \frac{\gamma(1-\sigma_u)}{Nc}\right)^{-1}\left(\eta\frac{\dot{\lambda}_K}{\lambda_K} + \frac{\gamma(1-\sigma_u)\Phi(K,N)}{Nc}\frac{\dot{K}}{K}\right),\end{aligned}$$

a necessary condition for this to be true is $\lim_{t\to\infty}\dot{\lambda}_K > 0$. Thus $\dot{\lambda}_K > 0$ for all $t < \infty$. In sum, σ_c is increasing over time in this regime. The last question is, will it reach the threshold σ_u^{-1}, that triggers migration, in finite time? The answer depends on the features of the steady state $(K_\infty(N_0), s_\infty(N_0))$. Actually, we can conclude that a transition to the regime with $m > 0$ will occur in finite time if and only if

$$\sigma_c(N_0; K_\infty(N_0), s_\infty(N_0)) > \sigma_u^{-1}. \tag{A.1.12}$$

A.1.3 Further elements

A.1.3.1 Natural capital dynamics, with and without adaptation

Denote respectively by K^s and K^0 the stock of capital corresponding to a situation with permanent adaptation and no adaptation at all. We want to show that $K^s(t) >$

$K^0(t)$ for all t. Let us work by contradiction.

We know that $K^s_\infty = K_\infty(N) > K^s_\infty = \underline{K}_\infty$ and $K^s(0) = K^0(0) = K_0$. Moreover $\dot{K}^s(0) = \delta(\underline{K}_\infty - \varepsilon(s(0))K_0) > \dot{K}^s(0) = \delta(\underline{K}_\infty - K_0)$ because $\varepsilon(s(0)) < 1$ for $s(0) > 0$. So in the neighborhood of $t = 0$, $K^s > K^0$. If there exist instants at which K^s and K^0 take the same value, the number of such instants must be even. Assume that there exists two instants (t_1, t_2), with $t_1 < t_2$ such that $K^s(t_1) = K^0(t_1)$ and $K^s(t_2) = K^0(t_2)$. We necessarily have $\dot{K}^s(t_1) < \dot{K}^0(t_1)$. This is equivalent to $\varepsilon(s(t_1)) > 1$, which is impossible. This yields the contradiction and we can claim that $K^s(t) > K^0(t)$ for all t.

A.1.3.2 Critical threshold $\hat{K}(N_0)$ for the specified model

For our specifications, we get:

$$\hat{K}(N_0) = \left[\frac{r\left(N_0 - (\sigma_u^{-1} - 1)M_0\right) N_0^{\alpha-1}}{A(\sigma_u^{-1} - \alpha)}\right]^{\frac{1}{\alpha}},$$

it is linear in N_0 for $M_0 = 0$, and well defined for $M_0 > 0$ provided that M_0 is low enough.

A.1.4 Calibration

In this section we provide details on the calibration of the theoretical analysis developed in section 3.4.

A.1.4.1 Model Specification

The functional forms used at the different stages of the analysis are the following:

- Power functions with $D(m) = \frac{1}{1+\sigma_d} m^{1+\sigma_d}$, $\sigma_d \geq 1$, and $U(c) = \frac{1}{\sigma_u} c^{\sigma_u}$, $\sigma_u \in (0, 1)$.
- Cobb-Douglas technology:$Y = AK^\alpha N^{1-\alpha}$, and linear remittances: $R(M) = rM$. Then $\sigma_F = 1 - \alpha$, $\sigma_R = \frac{N}{N_0 - N}$, and $\sigma'_R = \frac{N_0}{N_0 - N} = \frac{(1+\sigma_R)}{N_0 - N} > 0$.
- Linear cost of infrastructure expenditure $G(s) = \gamma s$, with $\gamma > 1$ the cost of public funds, and $\varepsilon(s) = e^{-\eta s}$.

A.1.4.2 Parameters description

Table 15: Country level of the TFP

	Cap. (AFF and Tourism)		Cap. (All Stocks)	
Countries	**(1)**	**(2)**	**(1)**	**(2)**
Comoros	1	1	1.01	1.01
Cabo Verde	1.01	1.02	1.01	1.01
Fiji	1.01	1.02	0.98	0.99
Guinea-Bissau	1.00	1.00	1.00	1.01
Maldives	1.02	1.04	1.00	1.02
Mauritius	1.00	1.01	0.98	0.98
Sao Tome and Principe	1.02	1.02	1.00	1.00
Seychelles	1.03	1.03	1.02	1.03
Aruba	0.99	0.99	0.97	0.97
Antigua and Barbuda	1.10	1.02	1.04	1.01
Bahamas, The	0.98	0.99	0.92	0.92
Belize	1.00	1.01	0.98	0.99
Barbados	0.96	0.96	0.94	0.93
Curacao	0.99	0.98		
Dominica	0.83	0.97	0.8	0.96
Dominican Republic	1.03	1.03	1.01	1.01
Grenada	0.98	0.99	0.98	1.00
Haitit	0.97	0.97	0.96	0.97
Jamaica	1.02	1.02	0.97	0.98
Saint-Lucia	1.01	1.01	0.98	0.99
Suriname	1.03	1.03	1.00	1.00
Trinidad and Tobago	1.08	1.08	0.99	0.99
Saint-Vinc. and the Gren.	0.99	1.00	0.95	0.96
Average	1.00	1.01	0.98	0.99
Maximum	1.10	1.08	1.04	1.03
Minimum	0.83	0.96	0.8	0.92

Legend: **(1)**: Labor is given by Employment (PWT), **(2)** Labor is given by the Population (PWT)

Table 16: Correlation coefficient between computed output and observed output (PWT)

	Cap. (All stocks)		Cap. (AFF and Tourism)	
Countries group	**(1)**	**(2)**	**(1)**	**(2)**
SIDS	0.93	0.92	0.93	0.89
Developing Countries	0.6	0.8	0.61	0.78
Developed Countries	0.85	0.89	0.86	0.89

Legend: **(1)**: Labor is defined as the Employment from the PWT, **(2)**: Labor is defined as the Population from the PWT.

A.1.4.3 Comparative statics

In this section we show that the model is robust to changes in the parameters, and that the conclusion for the analysis of the initial conditions are the same for reasonable changes in the parameters values.

Figure 39: Analysis of the effects of the parameter A on $\hat{K}$

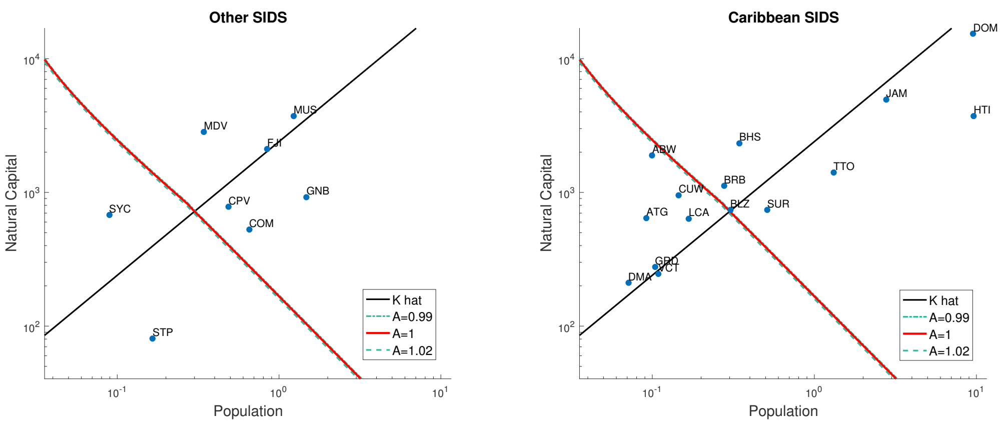


Figure 40: Analysis of the effects of the parameter σ_u

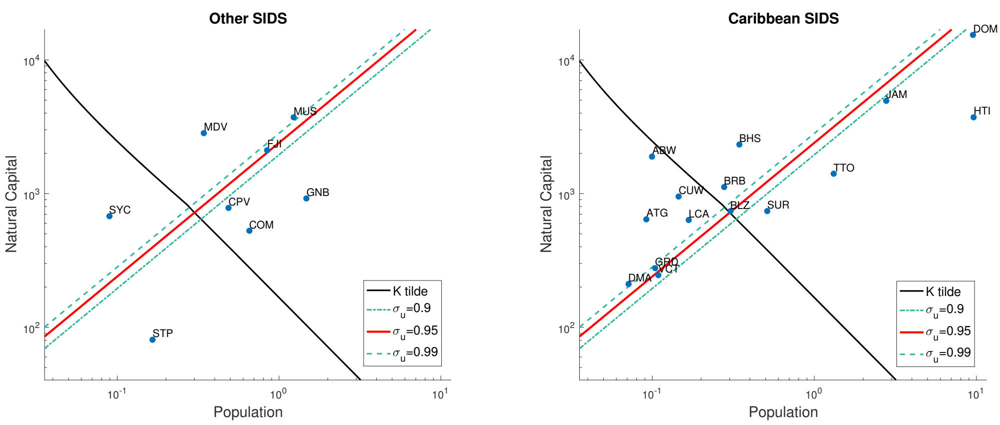


Figure 41: Analysis of the effects of the parameter γ

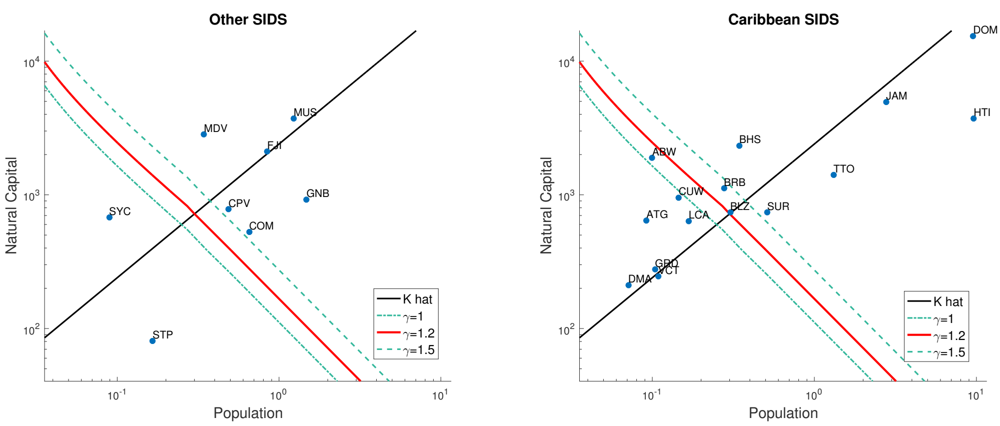


Figure 42: Analysis of the effects of the parameter ρ

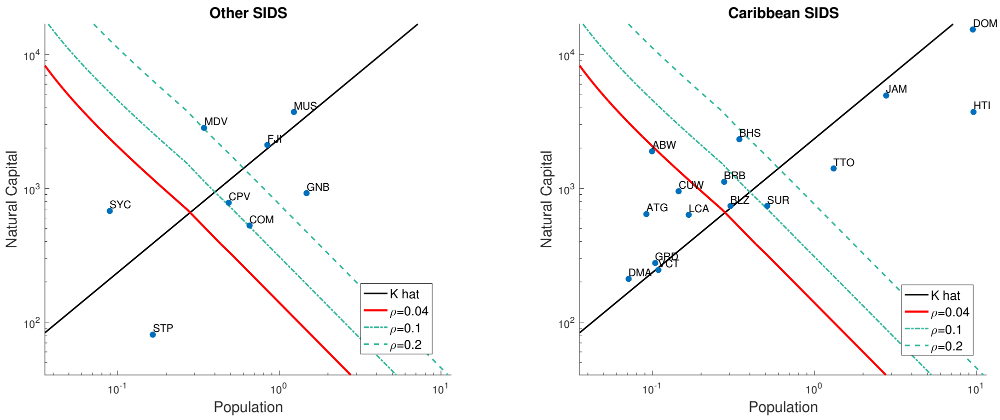
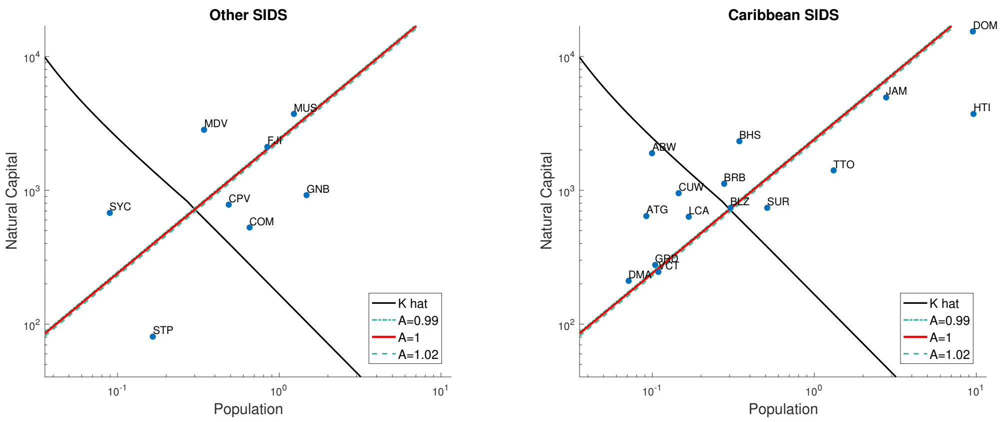


Figure 43: Analysis of the effects of the parameter A on $\tilde{K}$



General Conclusion

In this thesis I conduct an analysis of the sustainable development in Caribbean SIDS. The questions treated in this work were motivated by the main Caribbean islands' characteristics.

These countries present specific economic and environmental vulnerabilities. They are recognized as economies too small to experiment economies of scale, to diversify their economies or to be competitive on the international markets. This is aggravated by their isolation, which induces high costs to import or to export. Many phenomena–which are negligible in another type of country–can affect the entire society of an island because of its high specialization, small size and high population density. This brings us to the second aspect of their vulnerability: environmental hazards. Those islands which are specialized in tourism and agriculture can suffer greatly from a degradation of their natural capital. Those environmental damages can be caused by the domestic economy, for instance, with tourism, sewage and waste management infrastructures can be saturated due to the larger number of people. Moreover, agricultural practices can result in degradation of surface water and soil. Adding to these degradations of natural assets are exogenous events–such as dangerous weather patterns–which can be aggravated by climate change. In this thesis, I have covered local environmental impacts as well as climate change degradations while studying the sustainable development opportunities and strategies for these SIDS.

Caribbean SIDS also present distinct demographic patterns based on large emigration trends. This migration might result in opportunities, such as remittances and *brain gain*, or disadvantages, such as *brain drain* and dependence on remittances. Migration also has an effect on demographic choices in terms of education expenditures and fertility. It also changes the incentive to invest in the local economy. Besides the weight of migration on demographic choices, population density may have an impact on fertility choices as well. Acknowledging all these characteristics, I have built a work in three steps in order to address the different aspects of these vulnerabilities while considering the migration components of these countries.

Summary

In the first chapter, I assess the effect of migration on the economic growth of Caribbean islands. This work arises from the observation that effects of the remittances on savings are not well understood. Moreover, when endogenous fertility and education investments are considered, intricate tradeoffs might appear and hamper the *brain gain* from migration. The objective of this first chapter is to define the potential effects of migration, through the remittances effects on human and physical capital accumulation. To do so, I have adopted an approach that gives significant weight to the intergenerational link between migrants and their family. Indeed, while migration is exogenous and thus known beforehand, the parents can choose the number of children they want to have and the amount of education expenditure they can afford to give. Investing in their children allows them to fund their old age consumption, thanks to their children's financial support in the form of remittances. Another way to fund their consumption during the retirement period is to save. Consequently, this model incorporates a tradeoff between investments in children and savings. Since remuneration abroad is higher than in the domestic area, migration enhances the return on children and thus creates incentives to invest in children, through either fertility or education.

However, this does not mean that migration always lead to increases in human capital and decreases in physical capital. Although remittances and human capital accumulation enhance the income in the economy, migration decreases the population size if the number of adults leaving the country is higher than the increase in the number of children induced by the higher fertility. Consequently, the overall effect of migration and remittances on the growth of consumption is intricate, due to the interactions between population growth, physical and human capital accumulation. To observe a migration-induced increase in the long term growth of consumption per capita, improvement in human capital or physical capital should be higher than those in population size. Second, population size should not be decreasing with a higher migration. Consequently, adverse effects from migration appears in two cases. First if migration leads to a strong increase in fertility, second if migration is so large that labor depletion leads to a contraction of the domestic economy. A numerical analysis of five Caribbean islands has shown that those situations were possible–in Jamaica, for example. We have also tested the effect of migration modification on the economic growth, and it appears that large economic gains could be obtained in islands thanks to changes in remittances and emigration rate. Indeed, countries where migration is not too high should implement strategies that increase the return from migration in terms of remittances. Countries where the emigration is very high should focus on policy that encourage return migration in order to increase the stock of physical capital in the domestic area.

This first analysis of migration has shown the importance of human capital interactions with migration, thus describing the potential economic mechanisms induced by migration. In SIDS, studying human capital accumulation is also motivated by the fact that it is one of the main engines of economic growth and sustainability. Indeed, human capital improves competitiveness and resilience to exogenous shocks, knowing that these countries have only few economic opportunities. However, in the first chapter I have neglected the environmental dimension, while human capital accumulation process depends also on environmental quality. In the second chapter, I address this issue. To do so, I have introduced environmental externalities from pollution on human capital in the first chapter's model. This second framework allows me to study factors such as pesticides and air pollution. Tradeoffs induced by migration in the household programs are still observed here, but the mechanisms involved at the aggregate level are completely different. Here, we have observed that migration leads to a higher economic growth only if long term population size is negatively correlated to the emigration rate. Therefore, only a high level of migration enhances human capital accumulation because it decreases the demographic pressure on environmental quality. An environmental policy consisting in a tax and a maintenance effort has therefore been tested. It appears that only the highest levels of taxes induce improvement of the welfare, and even when a strong environmental policy is implemented.

Finally, in the third chapter, I study another source of SIDS vulnerability: climate change. Using the SIDS as case studies implies focusing on adaptation strategies and incorporating migration. Indeed, those two strategies are the only ways to cope with the expected damages of climate change for small countries with almost no influence on the global GHG stock, low economic opportunities and small size. In this chapter, migration is now introduced as an endogenous variable and a complement to the public tools available to adapt to climate change damages, because the remittances generated by migration can fund conventional adaptation measures. In this chapter, I develop an optimal control model where SIDS governments can control migration rates and/or invest in conventional adaptation measures. Interestingly, two conditions related to these tools emerged from the theoretical analysis. These conditions depend mainly on the fundamentals of the SIDS economies and define whether or not SIDS implement conventional adaptation or migration. Therefore, there are two types of strategy: complementarity or substitutability between the two tools. Using a numerical analysis, I was able to establish that the first strategy will be implemented by the largest countries of the sample, while the smallest countries will implement migration in most cases. When, only migration is implemented, a decreasing population enhances the incentives to invest in conventional adaptation measures. The symmetric is also possible, when only conventional adaptation is used, a switch to positive migration can occur depending on a condition. Therefore, switches from substitutability between the instruments to complementarity is possible. Moreover, the combination of the two instruments hosts a steady state where natural assets are constant and higher than in the situation without adaptation.

In conclusion, while I adopt theoretical methods to study the interplays between migration and other items, I confront the theoretical results to the data using careful calibrations of the models. The novelty of this work and its contribution to the existing literature lie in the combination of migration mechanisms and environmental issues. However, analytical results give intricate mechanisms and it is difficult to identify their relative importance in the overall effect of migration. I use numerical methods in order to clarify the interactions between the different mechanisms at play.

Moreover, in each chapter, policy implications are driven according to the effect of migration on population dynamics and human and physical capital. Indeed, while an increasing number of scholars argue that migration cannot be optimal as a self-implemented phenomenon, it is necessary to evaluate the effect of changes in migration features on economic growth. To do so, I conduct counterfactual analysis on steady-states values. Non-intuitive results appear in this thesis, for instance depending on the environmental impact of the economy in terms of health, the same level of migration will not produce the same results. In fact, this first analysis shows that migration can help manage environmental degradations. If the economic growth or the population growth does not lead to important environmental degradations, migration should not be too high in order to maintain the incentives to invest in the domestic area. When environmental issues are linked to population size or exogenous impacts, there are three possibilities. The first is to do nothing but observe a decrease in the per capita variables. The second is to reduce environmental degradations while using migration in order to lessen the demographic pressure on the fragile ecosystems, knowing that migration generates returns. But this is also possible to only do migration and to use the gains generated to overcome the losses in the domestic area. Finally, it appears that an optimal utilization of the gains from migration can help improve the economic development and thus to cope with vulnerabilities for SIDS.

Limits and prospects

In this thesis, migration impacts were central to the explanation of the mechanisms at play, but in the first two chapters migration was exogenous, and I have examined the choices made to optimize the gains from migration with given migration features. In the third chapter, migration is endogenous, but is controlled directly by the central planner and not based on an individual response to a public policy. This hypothesis was based on the observation that the governments of sending countries may accompany the migration process in order to improve their efficiency for the migrants and the domestic economy. However, migration is a private decision made by individuals or households, with respect to opportunities given by both the sending and the receiving countries. Therefore, in future research, individual determinants of migration should be detailed with a focus on factors such as human capital, unemployment, policies in the receiving countries and family altruism.

This leads to the second missing dimension in this analysis: the determinants of remittances and the potential gains from migration. In this thesis I have considered fixed migration features for those items. Thus, whatever the evolution of the sending countries, contributions from the diaspora and family support remain the same. However, this is obviously a simplification of reality, remittances can exhibit a contracyclical dynamics. For instance after the 2010 natural disasters suffered by Haiti remittances have increased. This is an interesting dimension that could be considered by introducing domestic economic results in the remittances decision, especially if risky events come into play.

Furthermore, in this economic analysis, only two environmental vulnerabilities have been treated. Because of the importance of human capital in these economies, the focus of the second chapter was on a specific externality. However, other externalities change the mechanisms involved by migration. For instance, a reduction in longevity might change the incentives to save or to invest in the children's education. Besides, the risky events are completely set aside, while they are also crucial components in the SIDS vulnerability.

Two subjects appear as insufficiently studied for risky events in Caribbean islands. First, while natural disasters are a rising subject of Caribbean economic studies, migration or other demographic components of these islands are mostly neglected. Second, a special focus on adaptation to climate change with infrastructure investments should be considered concurrently. Indeed, risky events threaten physical capital, so the solution to decrease their consequences is to protect them. In this case, the question of the efficiency of adaptation infrastructure is central because of the durability of such items.

Résumé substantiel de la thèse

Introduction

Les économistes se sont penchés à de nombreuses reprises sur les distinctions entre pays développés et pays en développement, ainsi que sur les déterminants économiques qui sont à l'origine de ces divergences. Cette réflexion est souvent associée à une analyse du développement soutenable, soit un développement qui permette d'assurer les besoins des générations présentes sans dégrader les capacités des générations futures à subvenir à leurs besoins. Cependant, outre la distinction basée sur les niveaux de développement, certains pays, tels que les Petits États insulaires en développement (PEID), présentent des caractéristiques spécifiques en termes de développement durable. L'Organisation des Nations Unies (ONU) définit les PEID comme un groupe de pays en développement confrontés à des vulnérabilités sociales, économiques et environnementales spécifiques et ce même en comparaison des autres pays en développement (UN-OHRLLS (2015)). Cette situation s'explique par des caractéristiques structurelles telles que leur petite taille – qui rend difficile la réalisation d'économies d'échelle dans la chaîne de production – ou leur accès limité aux ressources naturelles, ce qui les oblige à importer la plupart des matières premières.

Les habitants des états insulaires ont donc toutes les raisons d'être des innovateurs sur les questions environnementales et le développement soutenable, pour autant, ce n'est actuellement pas le cas. Compte tenu du fort consensus sur les vulnérabilités de ce type de pays, plusieurs économistes tentent d'identifier les moteurs de la croissance dans leurs cas (Adrianto and Matsuda (2004), Guillaumont (2010), Guillaumont (2010), Adrianto and Matsuda (2004), Guillaumont (2010), Adrianto and Matsuda (2004), Guillaumont (2010)). En effet, dans une analyse du développement soutenable, toutes ces vulnérabilités constituent des paramètres intéressants et stimulants.

Dans cette thèse, il s'agit de contribuer à la littérature sur le développement durable en mettant un accent particulier sur les PEID des Caraïbes.[33] Plus précisément, via des

[33]La région des Caraïbes présente l'avantage d'être plus homogène que le groupe entier des PEID

analyses théoriques et numériques, cette thèse examine la situation des îles caribéennes en se concentrant sur les interactions entre démographie et limites environnementales. Plusieurs approches peuvent guider une étude du développement soutenable dans une telle région. Cependant trois faits ont retenus notre attention et ont permis de définir les problématiques qui seront étudiées dans ce travail.

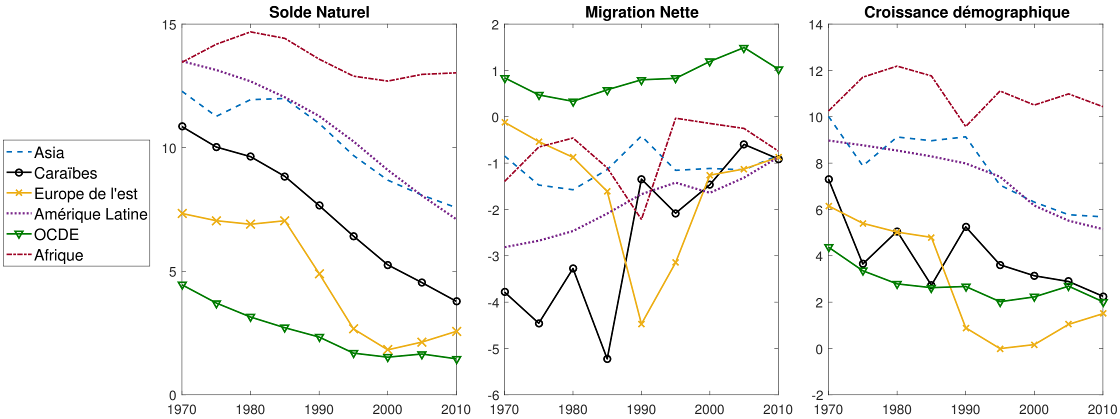
La première observation porte sur le poids de l'émigration dans ces économies. En effet, la dimension migratoire est au cœur des dynamiques démographiques de ces pays, et ce depuis la fondation des sociétés caribéennes, telles qu'elles sont connues aujourd'hui. Initialement, les îles ont reçu la migration européenne à partir du 17e siècle, suivie de la migration forcée des esclaves africains, pour finir par la migration de travailleurs venant d'Asie, lorsque l'esclavage a été aboli durant le 19e siècle. Par la suite tout au long du 20e siècle, les mouvements migratoires dans les deux sens vont s'accélérer au gré des guerres, des contrats de travail proposés par les pays riches ou simplement des instabilités politiques dans les îles (Robert B. Potter (2004)). Les départs à l'étranger et l'ouverture sur l'extérieur sont donc perçus dans ces pays comme une opportunité économique, voire une nécessité. Ainsi, même après les indépendances de ces pays dans les années 1960, les mouvements de population se sont poursuivis avec des mécanismes migratoires de plus en plus complexes (Thomas-Hope (1992)). En 2007, la Commission économique pour l'Amérique latine et les Caraïbes (CEPALC) établit que 15,5% des natifs des Caraïbes vivent hors de leur pays d'origine (ECLAC (2017)).

La migration peut donner lieu à de nombreux avantages mais dans ce travail nous nous concentrons sur les rémittences et les gains potentiels de compétences – *i.e.* le *brain gain* – qui peuvent découler de la migration. En effet, dans les Caraïbes, le poids des rémittences dans le PIB local est extrêmement élevé en raison de l'ampleur de la migration, et peut atteindre 25% en pourcentage de Produit Intérieur Brut (PIB) dans certains pays. D'un autre côté, la migration peut entraîner des effets délétères sur le tissus social et économique, via par exemple la fuite des cerveaux. Dans des pays comme la Jamaïque ou Haïti, plus de la moitié des individus ayant poursuivi des études supérieures quittent leur pays d'origine (ECLAC (2018)).

Le deuxième élément pris en compte dans notre analyse est la contrainte envi-

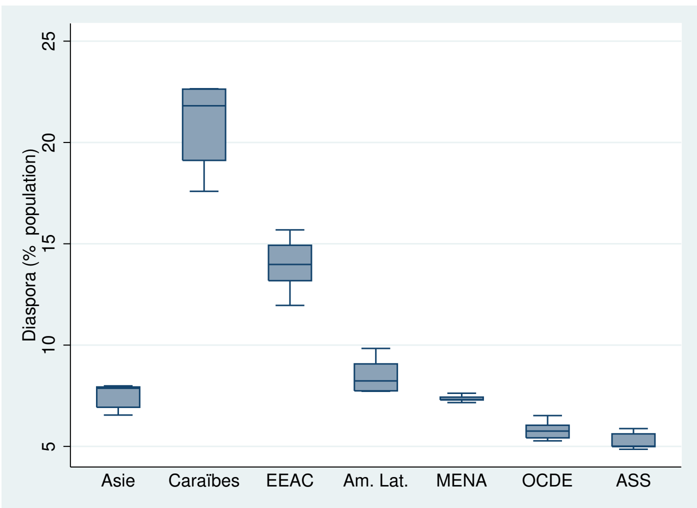
qui sont répartis dans au moins cinq régions différentes. Selon leur situation géographique, les PEID ne sont pas confrontés aux mêmes contraintes, ni n'ont les mêmes liens commerciaux avec les autres pays. Cet aspect n'étant pas pris en compte dans cette thèse, il semble préférable de se concentrer sur un sous-groupe des PEID.

Figure 44: Caractéristiques démographiques par région (% of population)



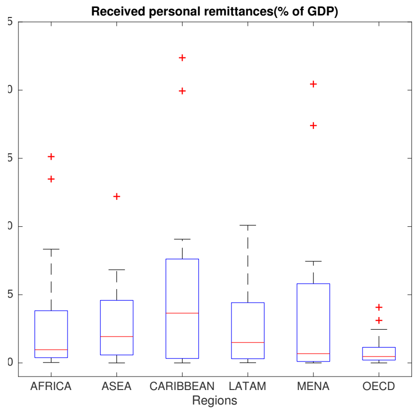
NB: Niveau de croissance quinquennaux en pourcentage de population.
Source: Auteur à partir des données de la Banque Mondiale

Figure 45: Moyenne de long terms de la diaspora par région
(% of population)



Legend: **Am. Lat.**: Amérique Latine, **EEAC**: Europe de l'Est et Asie Centrale, **MENA**: Moyen Orient et Afrique du Nord, **SSA**: Afrique Sub-saharienne
Les valeurs correspondent aux moyennes de long terme par pays entre 2000 et 2015. Elles sont ensuite agrégées par région. Source: Auteur à partir des données de l'ONU et de la Banque Mondiale

Figure 46: Rémittences en pourcentage de PIB par région



Source: Auteurs à partir des données de la Banque Mondiale

ronnementale. A quelques exceptions près, la plupart des îles présentent une forte dépendance à leurs atouts naturels (Heileman and Walling (2005)). Dans ce contexte, les activités développées dépendent souvent des caractéristiques structurelles des pays. Par exemple, de nombreux pays sont trop petits pour développer une agriculture compétitive sur les marchés internationaux. Ces pays se spécialiseront alors dans les secteurs économiques tels que la pêche, le tourisme ou d'autres services (financiers notamment). D'autres pays, comme Antigua et Barbuda ou Anguilla, présentent une faible élévation des terres, ce qui diminue la variété des écosystèmes et conduit à une plus faible pluviométrie. Ce type de pays est souvent caractérisé par une formation géologique ancienne avec des roches volcaniques recouvertes de sédiments. Dans ce cas, c'est la beauté des paysages, notamment de la zone côtière, qui sera mise à profit pour développer le tourisme. Dans les pays avec une formation géologique plus récente, tels que la Dominique ou Sainte-Lucie, les montagnes sont plus hautes, l'eau est plus abondante, la biodiversité et la fertilité des terres sont plus élevées. Néanmoins, le terrain accidenté empêche le développement d'une agriculture intensive et le sable noir de la roche volcanique attire moins les touristes (ECLAC (2018)). Enfin, certains pays possèdent des ressources en métaux ou en hydrocarbure, cela est le cas notamment de Cuba ou de Trinité-et-Tobago. Ces pays auront alors une plus faible dépendance aux aléas environnementaux mais une très forte dépendance aux cours des matières premières (Heileman and Walling (2005)).

Ce qu'il faut retenir, c'est qu'en termes de PIB, le principal secteur lié à l'environnement dans les Caraïbes est le tourisme (ECLAC (2018)). En raison de l'isolement des îles et de leurs différentes topographies, la région des Caraïbes est un haut lieu de la biodiversité, avec des écosystèmes endémiques. Cette caractéristique constitue une faiblesse et une force pour ces pays. En effet, ces écosystèmes spécifiques et fragiles manquent de résilience: plus de 700 espèces sont considérées comme en voie de disparition (ECLAC (2018), Wege et al. (2010), Robert B. Potter (2004)). Cependant, leur rareté constitue un avantage comparatif pour le tourisme (Croes (2011)). L'autre facteur important à considérer, est l'agriculture et les pêcheries. Ces secteurs génèrent 15 % de l'emploi dans la région, même si leur poids en part de PIB semble modeste, si les PEID des Caraïbes sont comparés à d'autres pays en développement.

Figure 47: Dépenses des touristes internationaux, (% de PIB)

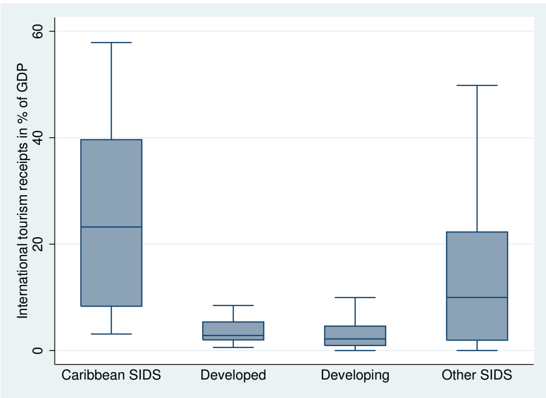
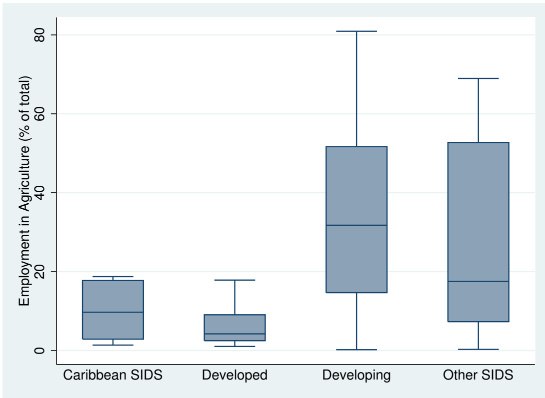


Figure 48: Emploi dans l'Agriculture, les pêcheries et la foresterie (% de l'emploi total)



Source: Author, based on the WDI

Reconnaître le poids du capital naturel dans les économies des Caraïbes nous pousse à accorder une attention particulière à la durabilité des procédés économiques.[34] Malgré l'importance grandissante de ce sujet dans les politiques publiques, il apparaît que la qualité de l'environnement caribéen est en baisse (UNEP (2016), Heileman and Walling (2005)) du fait des nombreuses sources de dégradations environnementales. Ces sources peuvent être endogènes et provenir des activités économiques nationales (*e.g.* dégradation de l'écosystème causée par le tourisme, l'agriculture, la consommation, etc.), elles peuvent être exogènes et dépendre de phénomènes complètement naturels (*e.g.* tremblements de terre ou éruptions volcaniques) ou de phénomènes anthropiques mais provenant d'autres pays (*e.g.* changement climatique ou pollution par le pétrole dans la mer des Caraïbes). Dans cette thèse, pour l'analyse des impacts environnementaux exogènes, je me concentre sur le changement climatique, qui devrait être à l'origine de neuf événements extrêmes sur dix dans le futur (ECLAC (2017)).[35]

[34] L'évolution de la qualité de l'environnement dans les Caraïbes a été examinée de près, en particulier dans le contexte de "Global Environment Outlook".

[35] Qualifier le changement climatique de procédé exogène se justifie ici par l'impossibilité de modifier significativement le stock de gaz à effet de serre pour ces territoires.

Chapitre 1

Motivations

L'étude de la migration du point de vue des pays envoyeurs de migrants a fait l'objet d'un débat depuis les années 1960 au moins. Tout au long de cette période divers consensus ont été adoptés puis remis en question. Premièrement, dans les années 1970 la migration est définie comme étant négative pour les pays d'origine, en raison notamment d'un risque de fuite des cerveaux – *i.e.* une réduction du niveau de compétence dans le pays. Ces résultats reposaient sur l'idée que la perte sociale marginale de main-d'œuvre qualifiée (par exemple avec la perte de médecins), était plus élevée que le gain marginal privé (par exemple avec l'augmentation des salaires grâce à la réduction de l'offre de main-d'œuvre) (Bhagwati and Rodriguez (1975), Hamada and Bhagwati (1975)). Par la suite, ces résultats ont été remis en cause, entre autres par les travaux de Stark et al. (1997), Mountford (1997) ou Beine et al. (2006). Ces auteurs défendent l'idée qu'une *fuite des cerveaux bénéfique* ou plus simplement un *brain gain* est possible grâce à la migration. Cette dernière augmenterait les incitations à se former et donc à acquérir du capital humain, car celui-ci augmente la probabilité de migration et la rémunération à l'étranger. Cependant, certains des travailleurs hautement qualifiés n'émigrent pas, ce qui pourrait entraîner une augmentation du capital humain moyen dans le pays. Dans son article, Beine et al. (2001), défini ainsi qu'un doublement du taux de migration pourrait augmenter de 5% l'acquisition d'un diplôme de l'enseignement supérieur. Il est aussi établi, que les conditions pour obtenir un *brain gain* sont assez restrictives : d'importants obstacles à la migration dans les pays d'accueil (coûts ou procédures), un faible taux d'émigration ou un niveau initial de capital humain plutôt faible.

Deuxièmement, en dehors de cet effet général de la migration, plusieurs auteurs ont étudié l'impact des rémittences. Néanmoins, malgré une littérature abondante sur le sujet, un consensus peine à émerger. En effet, une partie de la littérature constate un effet positif, notamment sur les revenus (Adams and Cuecuecha (2010), Giuliano and Ruiz-Arranz (2009), Yang (2008), Osili (2007); Woodruff and Zenteno (2007)), les dépenses d'éducation (Acharya and Leon-Gonzalez (2014), Adams and Cuecuecha (2010), Alcaraz et al. (2012), Azizi (2018), Bansak and Chezum (2009), Calero et al. (2009), Salas (2014)) ou les dépenses de santé (Amuedo-Dorantes and Pozo (2011), Azizi (2018)). Cependant d'autres études trouvent que les rémittences auront un impact positif en fonction de certaines conditions. Par exemple, Sobiech (2019) montre que seuls les pays aux premiers stades de développement, dotés d'un petit secteur financier, pourraient bénéficier des effets positifs des rémittences. Sinon, un effet de substitution entre marché des capitaux et rémittences est possible. Pour finir, d'autres auteurs mettent en évidence des effets négatifs provenant des rémittences. Par exemple, Acosta et al. (2009), Bourdet and Falck (2006), Guha (2013) trouvent des preuves d'un risque de maladie hollandaise. Imai et al. (2014) ou Nyamongo et al. (2012) montrent qu'il est possible d'observer un accroissement de l'instabilité du capital. Tandis que Brown et al. (2013), Opperman and Adjasi (2019) ou Raza and Jawaid (2014), trouvent une corrélation positive entre informalité dans le système financier et niveau de rémittences dans le PIB.

Le premier chapitre de cette thèse présente donc les résultats d'une analyse de l'impact des rémittences sur l'accumulation de capital physique et en particulier sur l'épargne. Les mécanismes introduisent une interaction entre la migration et les dépenses d'éducation ou la fécondité qui est endogénéisée dans la tradition de Mountford and Rapoport (2011) ou Marchiori et al. (2008). En effet, ce sujet n'a pas été étudié de manière approfondie dans la littérature sur les rémittences. Avant de lier la dimension démographique à la dimension environnementale, il semble intéressant d'étudier ce sujet particulier. La question traitée est donc: quel est l'impact des rémittences sur l'épargne et la croissance économique des PEID ?

Méthode

Pour répondre à la problématique, nous procédons avec une approche en deux étapes. Premièrement, nous formulons un modèle théorique conçu pour évaluer l'effet de la migration sur les choix intertemporels des ménages. Nous examinons plus précisément le niveau d'épargne ainsi que les choix démographiques en termes de fécondité et d'éducation. Les modèles à générations imbriquées (OLG) conviennent tout particulièrement pour cet exercice car ils reposent sur les interdépendances des choix de différentes générations, de même que sur une approche en cycle de vie. De plus, ce type de modèle est régulièrement utilisé dans la littérature sur la migration (Marchiori et al. (2008), Docquier and Rapoport (2012), Delogu et al. (2018)).

Dans le modèle développé dans ce chapitre, un individu vit trois périodes: l'enfance, l'âge adulte, et la vieillesse. Pendant la première période, lorsque les agents sont enfants, ils reçoivent un certain niveau d'éducation en fonction des investissements de leurs parents et du niveau de formation de la société. A la période suivante, lorsqu'ils sont adultes et s'ils restent sur l'île, les agents font un certain nombre d'enfants ce qui implique un coût qui est proportionnel à leur revenu obtenu via leur travail. Le reste de cette rémunération est allouée, à l'éducation de leurs enfants, à la consommation et à l'épargne. Le coût de la fertilité intègre aussi un effet de congestion, c'est-à-dire que que dans un pays à forte densité de population, il est plus coûteux d'avoir des enfants.[36] De plus, les adultes transfèrent une partie de leur revenu à leurs parents, ceci est motivé par un fonctionnement de solidarité intergénérationnelle, obligatoire. Enfin, au cours de la troisième période les individus sont à la retraite, ils peuvent alors bénéficier de la solidarité intergénérationnelle. Le financement de leur consommation est alors assuré par les transferts provenant de leurs enfants ou par leur épargne.

Dans ce modèle, la migration intervient entre l'enfance et l'âge adulte. Si les personnes émigrent, elles ne participent pas à l'économie, mais elles transfèrent à leurs parents une partie de leur revenu à l'étranger, qui est plus élevé que dans l'espace domestique. Par conséquent, les ménages sont confrontés à trois arbitrages économiques. Premièrement, ils répartissent leur consommation sur l'ensemble des périodes. Deuxièmement, ils choisissent entre épargne et investissements dans les enfants pour financer leur consommation à la deuxième période. Enfin, ils décident d'augmenter le nombre d'enfants ou l'éducation de chaque enfant afin de recevoir davantage de transferts. La migration modifie le gain relatif de l'éducation ou de la fertilité en raison des salaires plus élevés dans les pays de destination. Ce modèle se veut le plus simple possible, de façon à souligner les principaux mécanismes relatifs aux arbitrages entre épargne et éducation, dans un fort contexte migratoire. Bien entendu, il ne capture pas l'ensemble des motivations régissant la fertilité ou les interactions au sein d'un ménage.

Malgré ces simplifications, les dynamiques induites par la migration restent complexes et multiples, ce qui rend l'interprétation de l'effet global de la migration sur la croissance économique difficile à évaluer via des outils analytiques uniquement. Ainsi, dans un deuxième temps, grâce au calibrage du modèle, nous nous concentrons sur cinq îles des Caraïbes – La Barbade, la République dominicaine, Haïti, la Jamaïque

[36]Cet aspect est directement dérivé des résultats de de la Croix and Gobbi (2017) et de la Croix and Gosseries (2012). En s'appuyant notamment sur le marché de l'immobilier ou de ressources en terres.

et Trinité-et-Tobago. En particulier, nous effectuons une analyse contrefactuelle des principaux paramètres du modèle contrôlant les effets de la migration. Grâce aux modifications des valeurs de ces paramètres, nous sommes en mesure d'évaluer l'impact d'une politique de migration portant sur le niveau d'émigration, l'obtention de rémittences ou la mise en place d'un système local de redistribution intergénérationnelle.

Résultats

Le modèle théorique du chapitre 1, permet de définir que la migration a un impact positif sur les dépenses d'éducation, la fécondité, le stock de capital humain et la production sous certaines conditions. A première vue, ces résultats rejoignent ceux de Mountford (1997), Beine et al. (2006) ou Docquier et al. (2008). Néanmoins, dans notre travail les conditions qui régissent l'effet positif de la migration ou des rémittences sur la croissance économique sont liées aux variations des quantités de capitaux physique et humain, et donc à l'impact de la migration ou des rémittences sur l'épargne et l'éducation.

Nous constatons un effet de substitution induit par les gains de la migration entre l'épargne et les investissements dans les enfants, que ce soit via la fécondité ou via l'éducation. Ceci signifie que le taux d'émigration et de transferts intergénérationnels (domestiques ou internationaux) conduisent à une diminution du niveau d'épargne par habitant au profit d'une augmentation du niveau d'éducation ou de fécondité. Ceci a un effet négatif sur l'accumulation de capital physique qui peut néanmoins être compensé par deux phénomènes. Le premier est l'augmentation du niveau de richesse dans l'économie, si les agents sont mieux formés du fait de dépenses en éducation plus élevées. Le second phénomène est l'accroissement du nombre d'épargnants du fait d'une fertilité plus élevée. Ici les mécanismes liés à la taille de la population sont différents pour l'émigration et le niveau de transferts intergénérationnels. Une augmentation du niveau d'émigration conduit à une diminution du nombre d'adultes résidant dans le pays, mais la fécondité, elle, est augmentée par l'opportunité de migration. Un niveau d'émigration plus élevé peut donc conduire à une augmentation de la taille de la population si l'augmentation du nombre d'enfants est plus élevée que le nombre de départs à l'âge adulte. Le niveau de rémittences qui définit aussi le niveau de transferts intergénérationnels dans l'économie peut conduire à une hausse de la taille de la population suite à l'augmentation des incitations à avoir des enfants.

Mais en même temps, une augmentation des transferts domestiques peut résulter en une baisse de la taille de la population du fait de la diminution du revenu disponible à cause de la plus grande part de revenu transférée aux parents. Cette diminution conduit à une baisse de la fécondité car avoir des enfants implique un coût.

Pour résumer, il faut s'attendre à une corrélation négative entre épargne intérieure et rémittences ou migration, mais pas nécessairement entre ces derniers et le stock de capital. La relation entre croissance économique d'une part et migration ou rémittences d'autre part, est donc définie par une courbe en cloche. Si les paramètres régissant les gains à la migration sont faibles, une augmentation de ces derniers entraîne une hausse initiale des variables économiques (population, croissance économique, capitaux physique et humain). Après un certain seuil, une augmentation de ces paramètres conduit à une diminution de la taille de la population et à une forte contraction de l'épargne. Dans ces cas, la croissance économique diminue fortement tout comme le niveau de capital humain.

Pour évaluer les mécanismes identifiés grâce au modèle théorique, nous réalisons une analyse numérique sur un échantillon de cinq îles des Caraïbes. Il en ressort que la République dominicaine, Haïti et la Jamaïque ont mis au point une stratégie de *migration* permettant d'accroître le stock de main-d'œuvre efficace. Tandis que la Barbade et Trinité-et-Tobago investissent davantage dans le capital physique, car les gains tirés de la migration sont réduits. En effet, dans ces pays, le niveau de rémittences est plutôt faible ainsi que l'écart de richesse avec les pays développés.

Dans l'étude contrefactuelle, les pays avec des taux d'émigration élevés ou des gains de la migration potentiellement élevés, semblent être confrontés à deux choix: conserver des caractéristiques migratoires très fortes, voire les accentuer, ou les réduire fortement. Dans le premier cas, ils peuvent devenir totalement dépendants des rémittences et donc réduire les transferts domestiques entre générations à zéro. Dans le deuxième cas, ils peuvent au contraire tenter de diminuer les taux d'émigration afin de limiter l'effet de substitution, qui entrave leur croissance économique. Cela entraînera aussi une baisse du recours aux rémittences pour soutenir la consommation des retraités. Dans d'autres pays, où les incitations créées par la migration ne sont pas très élevées, les décideurs devraient accroître les transferts nationaux entre générations, tout en essayant de capter la totalité du revenu de la diaspora via les rémittences. En effet, les transferts internationaux dans leurs cas créent un effet de substitution qui est très faible, donc très peu d'effets négatifs pour l'économie domestique.

En résumé, dans ce chapitre, en utilisant une approche théorique et une analyse contrefactuelle numérique, nous pouvons caractériser l'effet de la migration sur la croissance économique par le canal de l'épargne. La nouveauté de ce travail repose sur l'explication des choix d'épargne dans un contexte où la migration augmente les incitations à investir en faveur des enfants. Nous avons ainsi pu définir les conditions critiques pour obtenir un *brain gain* et une valorisation du stock de capital physique, au lieu d'une pure substitution entre ces deux actifs productifs.

Chapitre 2

Motivations

Comme souligné dans la littérature sur les migrations et dans le premier chapitre, les effets positifs de la migration dépendent fortement de l'accroissement potentiel du stock de capital humain associé à la migration – *i.e.* le *brain gain*. Cependant, ce stock comprend deux composantes pouvant être directement affectées par la pollution locale: le nombre de travailleurs et la productivité par travailleur. La première varie en fonction de la longévité et de la fécondité, tandis que la dernière varie en fonction des capacités cognitives et de l'accès à l'école.

Indéniablement, les effets de la pollution sur la santé humaine sont maintenant amplement décrits dans la littérature scientifique et reconnus par les organisations internationales. Par exemple la pollution augmente directement la morbidité et la mortalité (Pope III et al. (2002), Evans and Smith (2005), Pope III et al. (2004)). Selon l'Organisation Mondiale de la Santé (OMS), la quasi-totalité des êtres humains (91%) ont été confrontés à un air pollué en 2016, ce qui a entraîné 3,8 millions de décès dus à une maladie cardiaque, à un accident vasculaire cérébral ou à un cancer. De plus, une qualité de l'eau médiocre, un assainissement insuffisant des eaux usées et le faible accès à des infrastructures sanitaires ont causé 870 000 décès en 2016 (WHO (2016)). A ces effets directs de l'exposition à la pollution, s'ajoutent des effets néfastes sur la fertilité (Vizcaíno et al. (2016), Carré et al. (2017)) ou la productivité. Par exemple, des études ont révélé des effets négatifs de la pollution sur l'efficacité de l'éducation (Marcotte and Marcotte (2017), Power et al. (2016), Pujol et al. (2016), Bharadwaj et al. (2017), Isen et al. (2017), Lett et al. (2017), Omanbayev et al. (2018)) ou au travail (Ambec and Lanoie (2008), He et al. (2019)).[37] Ces pollutions proviennent souvent de sources locales, identifiées ou diffuses.

Dans les îles des Caraïbes, Heileman and Walling (2005) décrivent de nombreux risques liés aux activités humaines. Premièrement, alors que le tourisme dépend fortement de la qualité du capital naturel, ce secteur peut avoir des effets négatifs significatifs sur l'environnement. Cela est dû au grand nombre d'écosystèmes fragiles et à la pression accrue exercée sur les infrastructures. En effet, certaines îles ont autant de touristes que de résidents.[38] Dans ce cas, les infrastructures de traitement des déchets et de traitement des eaux usées peuvent être insuffisantes ou exiger des adaptations considérables. Le rapport du, "Caribbean Environment Outlook" montre que la plupart des petits États insulaires en développement ne disposent pas des systèmes nécessaires pour isoler et éliminer efficacement les déchets, les eaux usées et les substances dangereuses (pesticides, huiles usagées ou métaux lourds) (UNEP (2016)).

Il en découle une forte contamination des écosystèmes terrestres et marins ainsi que des stocks d'eau douce, par les eaux usées domestiques, les effluents industriels et les eaux de ruissellement agricoles. Par exemple, des traces de pollution fécale ont été découvertes à Porto Rico et à Trinité-et-Tobago (Bachoon et al. (2010); Wade et al. (2015)). Cette pollution, présente dans plusieurs sites de pêche ou de baignade, est d'origine humaine ou bovine. Son impact sur la santé humaine est impossible à prévoir car la pollution fécale n'est pas régulièrement surveillée et ne peut donc être liée à l'état de santé général. En outre, les pollutions d'origine agricole restent préoccupantes même si les pratiques se sont améliorées (Rawlins et al. (1998)). Par exemple, l'Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO) informe que ce n'est qu'en 2017, que la campagne visant à éliminer les pesticides obsolètes dans la Caraïbe a porté ses fruits. Cette campagne a permis à 11 pays des Caraïbes d'obtenir un certificat prouvant qu'ils étaient exempts de stocks de pesticides périmés.[39] L'effet de ces dégradations est amplifié par certaines caractéristiques structurelles. Tout d'abord, une dégradation locale affecte une large part de la population en raison de la forte densité de population.

Dans le contexte des PEID des Caraïbes où la migration est importante, la dégra-

[37] *cf.* Currie et al. (2014) pour une revue de littérature récente.

[38] Par exemple, aux Bahamas, 1 427 000 visiteurs internationaux sont venus s'ajouter à une population de 370 633 personnes durant l'année 2016 (World Development Indicators, Banque Mondiale).

[39] C'est le résultat d'un projet qui a débuté dans les années 2000 (*cf.* La gestion des stocks de pesticides périmés dans les Caraïbes).

dation potentielle des capacités cognitives pourrait, entre autres choses, avoir un effet indirect important sur les gains de migration. Ces derniers sont en partie liés aux effets des rémittences sur les dépenses d'éducation et au *brain gain* potentiel. La question qui se pose et à laquelle nous répondons dans le deuxième chapitre est la suivante: quel est l'effet de la migration si la dégradation de l'environnement a un impact sur les capacités cognitives et donc sur le *brain gain*?

Méthode

Pour répondre à cette question, nous introduisons une externalité de pollution sur l'accumulation de capital humain dans le modèle développé dans le chapitre précédent. Cette externalité est due au stock de pollution découlant des émissions de la production. Lorsque les enfants sont exposés à cette pollution, leur capacité à accumuler du capital humain, qu'il provienne des transmissions des parents ou de l'éducation reçue, diminue. Plus précisément, ici les pollutions qui pourraient être décrites par le modèle sont des pollutions en flux, comme la pollution de l'air, ou les pollutions en stock comme les Polluants Organiques Persistants (POP). Comme dans le premier chapitre, les décisions des ménages en matière d'épargne, de fécondité et d'éducation sont examinées. Cependant, dans le modèle actuel, les ménages prennent une décision en termes de dépenses d'éducation, alors qu'ils ne sont pas en mesure d'anticiper ou de prendre en compte l'externalité environnementale sur les capacités de leurs enfants. Pour corriger cette externalité environnementale, le décideur introduit une taxe sur les émissions de pollution. Le revenu de la taxe est utilisé directement pour réduire les émissions de pollutions, plutôt que le stock de pollution lui-même. Par exemple, cela pourrait impliquer de financer des changements de technologies dans les procédés de production ou d'installer des stations d'épuration à la sortie des usines.

Comme dans le chapitre précédent, nous utilisons une approche en deux étapes pour analyser le modèle. Tout d'abord, certains résultats analytiques sont explorés dans un exercice de statique comparative. Deuxièmement, afin de clarifier certaines tendances de ce modèle, une analyse numérique des expressions à l'état d'équilibre est réalisée. Cela nous permet d'évaluer les impacts de la taxe environnementale et les différents paramètres liés à l'émigration. L'objectif de cet exercice n'est pas d'étudier avec précision un échantillon de pays comme dans l'analyse précédente. Au contraire, nous étudions plutôt qualitativement les déterminants environnementaux des mécanismes introduits dans le modèle, pour tester leur robustesse.

Résultats

Premièrement, puisque la pollution est une externalité, les arbitrages des ménages et des firmes sont les mêmes dans l'analyse théorique. Ainsi, pour financer leur consommation lorsqu'ils sont retraités, les adultes choisissent entre épargner et/ou d'investir dans leurs enfants. Néanmoins au niveau agrégé dans l'économie, les résultats diffèrent fortement de ceux du premier chapitre. En effet, les effets positifs de la migration dépendent maintenant aussi de la fonction des dommages environnementaux et des effets indirects sur la croissance du capital humain.

Dans le premier chapitre, nous avons constaté un effet positif de l'émigration ou des rémittences sur les niveaux de capital humain ou de production de long terme jusqu'à ce qu'un seuil soit atteint. Au-delà de ce dernier, si le niveau d'émigration ou de transferts augmentait, les investissements en capital physique seraient trop faibles pour soutenir l'économie. Au contraire, dans le deuxième chapitre, l'analyse numérique montre que la relation à long terme entre la production ou le capital humain d'une part et d'autre part, les paramètres contrôlant les gains à l'émigration – taux d'émigration et niveau de transferts – est décrite par une courbe en U. Lorsque le taux de migration, ou les rémittences reçues sont faibles, une augmentation dans l'un ou l'autre de ces paramètres entraîne un accroissement de la population du fait d'une fertilité plus grande. En conséquence, avec une base de population plus importante, la production est également plus importante, ce qui génère des émissions de pollution croissantes. En présence d'une pollution plus forte, le niveau de long terme du capital humain décroît, ce qui a un effet néfaste sur la production par habitant et donc sur la consommation. Comme dans le chapitre précédent, après un certain seuil, une augmentation de la migration ou des rémittences entraîne la décroissance de la population, à cause des départs d'adultes ou de la baisse des revenus. Ceci conduit à une baisse de la production ainsi qu'à une baisse des émissions de pollution. Dans ce contexte, l'économie peut expérimenter une augmentation de la production par tête, grâce à la baisse des externalités négative de pollution et donc à un capital humain qui s'accumule plus rapidement. De plus, l'augmentation du capital humain permet d'accroître les revenus et donc d'observer une croissance du niveau de capital physique, et ce même si le niveau d'épargne est faible (à cause de l'effet de substitution qui est large lorsque la migration est forte).

Dans tous les cas, la taxe environnementale alliée à l'effort de réduction des émissions améliore la situation si l'intensité de la pollution de la production est suffisamment faible. Si les émissions sont très élevées, bien que le stock de pollution de long terme ne soit pas modifié, la forte intensité de la pollution entraîne une diminution du capital humain et du stock de capital au cours des premières phases de développement (les premières périodes de notre simulation). Or, le niveau de capital humain futur dépend fortement du niveau de capital humain passé. Par conséquent, à court terme, la réduction des stocks de capitaux met le pays sur une voie dans laquelle l'accumulation de stocks productifs est plus lente et, par conséquent, dans laquelle les valeurs d'équilibre seront plus faibles à long terme. Ainsi, pour que la taxe s'avère bénéfique dans ce cas, il faut qu'elle soit très forte.

En conclusion, dans ce chapitre, nous caractérisons l'interaction entre externalités de migration et de pollution sur le capital humain, grâce à la prise en compte de la dimension environnementale dans notre précédent cadre théorique. La nouveauté de ce travail repose sur l'explication des modifications apportées aux conditions permettant d'obtenir un *brain gain* et un niveau de consommation par habitant plus élevé, en présence d'une externalité environnementale sur le capital humain. Dans ce contexte, une très forte migration pourrait améliorer la situation, grâce à une réduction de la pression démographique. Bien sûr, il est aussi possible d'investir plus en protection environnementale afin d'obtenir une réduction de l'effet de l'externalité.

Chapitre 3

Motivations

Une grande partie de la vulnérabilité environnementale des PEID est fortement liée au changement climatique. Les changements climatiques résultent de l'augmentation des émissions anthropiques de gaz à effet de serre (GES) dans l'atmosphère. Cependant, non seulement la contribution des PEID des Caraïbes au stock de GES a été négligeable, mais ces derniers ne disposent pas de moyens de réduire significativement l'ampleur du changement climatique futur par leurs propres moyens.[40] D'autre part, leur pouvoir de négociation pour inciter les autres pays à réduire leurs émissions est faible. Pour les PEID, le changement climatique apparaît donc comme un phénomène en grande partie exogène. Ceci est d'autant plus grave que l'impact du changement climatique est dramatique pour ces pays, qui souffriront de ce dérèglement davantage et plus tôt que d'autres régions. La vulnérabilité au changement climatique dépend de trois facteurs principaux: l'exposition aux risques, la sensibilité économique et la capacité d'adaptation (Bierbaum (2009)). Pour les deux premiers composants peu d'actions sont possibles – les PEID ont de faibles opportunités pour diversifier leurs économies et réduire leur dépendance au capital naturel.

En effet, une brève description des effets du changement climatique dans les SIDS, indique que les infrastructures côtières et les zones de peuplement sont en danger en raison de l'élévation du niveau de la mer – qui peut atteindre 1,4 mètre à la fin du siècle – et de l'augmentation du nombre des ouragans (Cashman and Nagdee (2017) et Monioudi et al. (2018)). En effet, à l'époque coloniale, la plupart des îles étaient spécialisées dans l'exportation de produits agricoles. Cela a conduit à un peuplement des zones rurales épars et à une densification des zones urbaines autour des ports. Cela a été maintenu après l'indépendance des pays. Ainsi, même dans les îles où l'élévation du territoire est élevée, la population est concentrée dans les zones côtières vulnérables, avec environ 70% de la population des Caraïbes vivant dans les zones côtières (Mycoo (2017)). Deuxièmement, des effets extrêmes sur la santé sont attendus. Ces derniers peuvent découler de l'augmentation du nombre de vagues de chaleur, des répercussions des ouragans (Stephenson and Jones (2017)), de la réduction des ressources en eau (Cashman et al. (2010)) ou de l'augmentation des maladies vectorielles (Cloos and Ridde (2018)). Troisièmement, la dégradation des écosystèmes marins peut entraîner une réduction des gains tirés du tourisme et des pêcheries. La perte de biodiversité ou d'écosystèmes remarquables seraient alors due à l'acidification des océans (Melendez and Salisbury (2017)), à l'augmentation de la température de surface de la mer (SST) (Michael A. Taylor (2017)), aux événements extrêmes (Stephenson and Jones (2017)), à une diminution de la qualité des coraux et des mangroves (McField (2017), Wilson (2017)). Enfin, le changement climatique réduit la productivité agricole en raison de la réduction de la disponibilité en eau

[40] Les PEID possèdent des atouts leur permettant de développer des puits de carbone naturels grâce aux mangroves ou aux récifs coralliens par exemple. Mais même dans ce cas, leur contribution à la mitigation – c'est-à-dire à la réduction – du changement climatique resterait faible.

(Cashman et al. (2010)), de l'augmentation des températures (Dye et al. (2017)) ou de phénomènes extrêmes plus fréquents (Stephenson and Jones (2017)). Tous ces phénomènes conduisent à une perte de capital naturel, c'est-à-dire à la dégradation des atouts naturels à l'origine de procédés économiques. Cette perte de capital naturel peut alors être continue ou abrupte.

Pour y faire face, il ne reste que l'adaptation. C'est notamment ce qui est soutenu par le Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC). Selon eux, le coût des dommages potentiels liés au changement climatique dans les PEID sera si important que l'adaptation est une condition préalable pour un développement économique durable (voir par exemple UN-OHRLLS (2017)).[41] Cependant, les efforts d'adaptation dans les PEID des Caraïbes restent faibles. La décision d'investir dans des mesures d'adaptation dépend de l'arbitrage entre leur coût et les avantages de la réduction des dommages. Toutefois, il est difficile de prévoir les coûts liés au changement climatique (ce qui implique une incertitude), ainsi que les gains économiques ou les coûts d'adaptation. Cela est particulièrement vrai si les effets secondaires de l'adaptation sur d'autres composantes de l'économie (telles que l'emploi ou les inégalités, par exemple) sont pris en compte. De plus, les stratégies d'adaptation peuvent impliquer des défaillances du marché, telles que des externalités positives et négatives ou une asymétrie de l'information (Chambwera et al. (2014)). Dans ce contexte, l'analyse coûts-avantages semble difficile et l'intervention publique souhaitable pour coordonner les mesures d'adaptation. Cela revêt une importance particulière dans les pays en développement, où les stratégies d'adaptation doivent être étroitement liées aux objectifs de développement durable plus larges. La plupart des articles sur l'adaptation dans les PEID montrent que cette dernière est insuffisante. Ceci est dû aux limites techniques, institutionnelles et financières de ces îles (Scobie (2016), Thomas and Benjamin (2018), Klöck and Nunn (2019)). En effet, la plupart des PEID sont pris dans un piège à faible croissance et d'endettement élevé (Greenidge et al. (2010), Alleyne et al. (2017)). Par conséquent, les possibilités de financer l'adaptation au changement climatique par des taxes ou sur les marchés financiers sont restreintes. En outre, même lorsque les investissements d'adaptation sont réalisés, ils sont souvent inefficaces en raison des contraintes institutionnelles, financières et parfois culturelles des solutions conventionnelles utilisées dans d'autres pays (Klöck and Nunn (2019)).

Par conséquent, dans le contexte démographique des îles des Caraïbes, la migration

[41] http://unohrlls.org/custom-content/uploads/2017/09/SIDS-In-Numbers_Updated-Climate-Change-Edition-2017.pdf

apparaît comme une autre forme d'adaptation possible. De manière plus globale, de nombreux chercheurs – ainsi que de nombreux décideurs publics – affirment que la migration augmentera avec le changement climatique. Par exemple, Marchiori and Schumacher (2011) montre que les déplacements humains augmentent si aucune stratégie d'atténuation n'est mise en œuvre par les grands émetteurs de GES. Selon ce résultat, des articles empiriques tentent de prédire une corrélation entre l'évolution de la migration et le changement climatique. Leur travail est basé sur l'observation de facteurs environnementaux tels que la variabilité des précipitations, le volume des précipitations ou l'augmentation de la température. Bien qu'il ne soit pas possible de conclure que la migration internationale augmentera dans toutes les zones touchées (Hugo (2011)), la migration interne pourrait augmenter avec les changements climatiques et/ou la variabilité climatique (Barrios et al. (2006), Farbotko and Lazrus (2012), Lilleor and den Broeck (2011), Marchiori et al. (2012), Nawrotzki et al. (2015), Thiede et al. (2016)). Pour les petites îles, il est raisonnable d'affirmer que ces migrations internes pourraient être insuffisantes pour faire face aux dommages, car toute la société peut être touchée et la population y est déjà très urbaine (Murray and Watson (2019)). De plus, il pourrait y avoir des interactions entre la migration et d'autres outils d'adaptation, en particulier dans les pays où le nombre d'émigrants est élevé. Par exemple, Julca and Paddison (2010) ou Hugo (2011) associent la vulnérabilité au changement climatique des PEID à l'impact de la migration, et plus particulièrement aux rémittences. La première étude conclut que la migration ou les rémittences pourraient être utiles pour l'adaptation, tout en soulevant la question de la dépendance des pays receveurs à leur égard. Dans le deuxième article, les auteurs constatent que les régions d'origine expérimenteront de nombreux ajustements économiques, démographiques et sociaux difficiles à anticiper.

Il n'y a que peu d'articles dans la littérature qui étudient via une analyse normative les choix entre deux types d'adaptation et encore moins qui traitent de l'interaction entre migration et adaptation. Par conséquent, dans le troisième chapitre de cette thèse, j'analyse comment les décideurs politiques des PEID devraient mettre en œuvre des stratégies d'adaptation ou de migration à court terme pour gérer les impacts du changement climatique.

Méthode

Pour répondre à cette question, nous développons un modèle théorique dans lequel nous adoptons une perspective centralisée pour évaluer la politique optimale d'un PEID confronté aux répercussions négatives du changement climatique. Étant donné que le changement climatique et le processus d'adaptation comportent tous deux une dimension temporelle, nous développons un cadre dynamique dans lequel le décideur dispose de deux moyens pour faire face aux dommages liés au climat: une *stratégie de migration* et une *stratégie d'adaptation*. L'objectif est de maximiser l'utilité totale tirée de la consommation, sachant que la migration implique un dommage sur le bien-être, mais aussi un gain économique en rémittences.[42] La technologie de production incorpore le travail et le capital naturel qui décroît à un rythme continu en raison du changement climatique. Finalement l'économie locale comporte deux composantes. Premièrement, la production locale d'un bien final. Une politique migratoire active induit une contraction de la production à cause de la diminution de la main-d'œuvre. Deuxièmement, les rémittences provenant d'une émigration plus forte. Ceci constitue une source externe de financement de l'économie.

Premièrement, faire varier la taille de la population a deux effets. Cela réduit la pression sur les actifs naturels et modifie la consommation par tête, tout en générant des rémittences. Cela affecte aussi le bien-être à la fois directement (*i.e.* dans le critère d'utilité totale) et indirectement en modifiant le montant de la consommation par habitant. Deuxièmement, l'adaptation entraîne un coût direct en termes de consommation perdue, tandis que l'avantage découle de la capacité à maintenir le stock de capital naturel à un niveau supérieur et pendant une période plus longue. L'analyse de la politique optimale se déroule en deux phases. La première est consacrée à une investigation théorique. L'analyse du problème de décision intertemporelle est difficile car elle produit un système dynamique à quatre dimensions. Il existe quatre régimes différents, selon que les deux instruments, migration et adaptation, fonctionnent ou non. Pour contourner ces difficultés, dans un premier temps, des régimes avec un seul outil sont étudiés. Dans un deuxième temps, les résultats sont combinés pour comprendre les mécanismes en jeu dans le régime dans lequel les deux instruments sont utilisés.

[42]Ce chapitre ne contient pas de fécondité, seule l'émigration définitive a un impact sur la taille de la diaspora et de la population.

La seconde phase consiste en une calibration du modèle sur des données réelles, pour approfondir l'analyse de la politique optimale. Cette calibration permet de souligner le rôle des conditions initiales, que sont la taille initiale de la population et la dotation initiale en capital naturel. Plus important encore, cet exercice nous aide à comprendre quelle politique est optimale pour quel PEID, compte tenu de ses caractéristiques. Cela nous permet également d'expliquer à quel moment l'adaptation et la migration, en tant qu'instruments politiques, se révèlent être des compléments ou des substituts.

Résultats

L'exercice théorique permet d'obtenir deux conditions qui permettent de mieux comprendre les politiques privilégiées par les PEID pour faire face au changement climatique. Une condition est liée à la migration tandis que l'autre définit l'utilisation de la stratégie d'adaptation conventionnelle. Si la migration est mise en œuvre, le taux d'émigration diminue jusqu'à ce que la taille optimale de la population soit atteinte. Si un décideur décide de mener une stratégie d'adaptation, il s'en tiendra à cette stratégie de manière permanente. Cette stratégie permet de maintenir une population et un capital naturel plus importants dans la zone domestique. En fonction de l'évolution du capital naturel et de la taille de la population, il est possible de commencer dans une situation où un seul (aucun) des outils est utilisé et d'opter par la suite pour un régime dans lequel avec les deux (ou un seul) outils mis en œuvre. Ces changements de stratégies dépendent de conditions sur l'évolution de la population ou du stock de capital naturel.

Grâce à la calibration du modèle nous observons que les conditions du modèle théorique dépendent fortement de la taille de la population. En fait, de petits changements dans la dotation en capital naturel au cours de la période initiale n'affectent pas vraiment le choix des décideurs publics, tandis que la taille de la population définit directement s'il existe une complémentarité ou une substitution entre les deux outils. Ainsi, le groupe des plus grands pays tels que la Jamaïque, Haïti ou la République dominicaine met en œuvre les deux outils. Alors que la plupart des petites îles ne mettent en œuvre qu'un seul outil, la migration. Pour ces petites îles, il existe donc une substitution entre la stratégie de migration et la stratégie d'adaptation conventionnelle. Cependant, cette situation n'est pas nécessairement permanente, et des dépenses d'adaptation peuvent être faites.

En conclusion, dans ce chapitre, nous sommes en mesure de caractériser la combinaison de politiques optimale entre les mesures de migration et les mesures d'adaptation conventionnelle. La nouveauté de ce travail repose sur la combinaison de deux types de stratégies d'adaptation, sachant que la plupart des études sur le changement climatique se concentrent sur le compromis entre adaptation et atténuation du changement climatique.

Conclusion

En conclusion, le chapitre 1 développe un modèle théorique pour rendre compte des effets économiques et démographiques des rémittences et de la migration dans les îles des Caraïbes. Nous examinons de près les décisions des ménages en matière de dépenses d'éducation, de fécondité et d'épargne, lorsque les personnes âgées reçoivent des rémittences et des transferts domestiques de la génération active. Dans une économie donnée, le modèle prédit que la migration augmente les dépenses d'éducation au détriment de l'épargne. Cet effet de substitution conduit alors à une relation en cloche entre rémittences ou migration d'une part et capitaux physique et humain ou croissance économique, d'autre part. En outre, des simulations numériques du modèle et une analyse contrefactuelle sur cinq îles des Caraïbes montrent que différentes stratégies en matière de migration semblent possibles pour accroître les gains économiques en fonction de l'ampleur de la migration ou du taux de transfert.

Par la suite, dans le chapitre 2, j'intègre l'interaction entre les caractéristiques démographiques et l'impact environnemental dans ces même pays. Pour cela, une externalité environnementale est ajoutée au modèle du chapitre 1. L'externalité découle des émissions de pollution par la production et réduit les capacités d'apprentissage des enfants. Nos analyses théoriques et numériques montrent que la migration peut toujours générer des gains économiques et une amélioration du capital humain, mais seulement si le taux d'émigration ou les rémittences sont déjà élevés. Cela se produit lorsque la migration entraîne une réduction de la population mais une augmentation de la production par habitant. Dans ce contexte, une taxe environnementale est testée. Toutefois, pour pouvoir bénéficier de cette politique, le taux de la taxe doit aboutir à la réduction complète des émissions, en particulier si l'intensité de la pollution est élevée.

Enfin, le chapitre 3 examine la politique d'adaptation optimale des PEID pour faire face au changement climatique. Le gouvernement a deux le choix entre deux politiques principales: la migration et les mesures d'adaptation conventionnelles. L'adaptation conventionnelle fait référence à tous les moyens possibles pour limiter l'étendue et les répercussions des dommages climatiques. Nous montrons qu'il existe deux types de stratégie qui diffèrent par la nature de l'interaction entre les deux instruments. Ces derniers peuvent être des compléments ou des substituts. Il est intéressant de noter que nous sommes en mesure d'identifier deux conditions critiques sur les fondements de l'économie qui sont à la base de la plupart des résultats. À l'aide d'une analyse numérique basée sur la calibration du modèle, nous analysons quelle politique est optimale en fonction des caractéristiques des états et des conditions initiales.

Tous ces résultats ont permis d'explorer différentes dimensions de la vulnérabilité des PEID des Caraïbes. Néanmoins plusieurs aspects ont été mis de côté. Par exemple, dans les trois chapitres, le processus individuel de décision de migration a été considéré comme fixe et donné. En effet, dans les deux premiers chapitres, la migration était exogène, et j'ai analysé les choix qui ont été faits pour optimiser les avantages de la migration avec des caractéristiques de migration données. Dans le troisième chapitre, la migration est endogène mais elle est contrôlée par le planificateur central. Cette hypothèse reposait sur l'observation selon laquelle le gouvernement des pays d'origine pourrait accompagner le processus de migration afin d'améliorer son efficacité pour les migrants et l'économie nationale. Cependant, la migration est une décision privée prise par des individus ou des ménages, qui tiennent compte des opportunités offertes à la fois par les pays d'origine et les pays d'accueil. Par conséquent, dans les extensions potentielles de ces travaux, les déterminants individuels de la migration devraient être détaillés en mettant l'accent sur le capital humain, le chômage, les politiques migratoires des pays d'accueil, l'altruisme familial, etc.

Cela amène à la deuxième dimension manquante de cette analyse, les déterminants des rémittences et des gains potentiels de la migration. Dans cette thèse, ces éléments étaient fixes. Cela signifie que quelle que soit l'évolution des pays d'origine, les contributions de la diaspora et le soutien aux familles restent les mêmes. Cependant, ceci est une simplification de la réalité. Dans les PEID des Caraïbes, les rémittences présentent une dynamique contracyclique. Par exemple, après la crise financière ou les catastrophes naturelles de 2008 et 2010, les rémittences ont augmenté à Haïti. C'est une dimension intéressante qui pourrait être prise en compte grâce à l'introduction des résultats économiques nationaux dans la décision relative aux rémittences.

Enfin, dans cette analyse économique, seules quelques vulnérabilités environnementales ont été traitées. En effet, en raison de l'importance du capital humain dans ces économies, l'accent a été mis sur une externalité spécifique. Cependant, cela ne signifie pas que d'autres externalités ne modifient pas les mécanismes impliqués par la migration, bien au contraire. Par exemple, une réduction de la longévité pourrait modifier les incitations à épargner, mais aussi à investir dans l'éducation des enfants. En outre, les événements à risque sont complètement mis de côté, alors qu'ils sont également cruciaux dans l'analyse de la vulnérabilité des PEID. Alors que les catastrophes naturelles font l'objet d'un engouement grandissant pour les études sur les PEID, la migration ou d'autres composantes démographiques de ces îles sont la plupart du temps négligées. Il serait intéressant dans de futurs projets de travailler sur les liens entre catastrophes naturelles et démographie.

Bibliography

Acharya, C. P. and Leon-Gonzalez, R. (2014). How do Migration and Remittances Affect Human Capital Investment? The Effects of Relaxing Information and Liquidity Constraints. *The Journal of Development Studies*, 50(3):444–460.

Acosta, P. (2011). School Attendance, Child Labour, and Remittances from International Migration in El Salvador. *The Journal of Development Studies*, 47(6):913–936.

Acosta, P. A., Lartey, E. K., and Mandelman, F. S. (2009). Remittances and the Dutch disease. *Journal of International Economics*, 79(1):102 – 116.

Adams, R. H. and Cuecuecha, A. (2010). Remittances, Household Expenditure and Investment in Guatemala. *World Development*, 38(11):1626 – 1641.

Adams, R. H. and Page, J. (2005). Do international migration and remittances reduce poverty in developing countries? *World Development*, 33(10):1645 – 1669.

Adams, S. and Klobodu, E. K. M. (2016). Remittances, regime durability and economic growth in Sub-Saharan Africa (SSA). *Economic Analysis and Policy*, 50:1 – 8.

Adrianto, L. and Matsuda, Y. (2004). Study on assessing economic vulnerability of small island regions. *Environment, Development and Sustainability*, 6(3):317–336.

Aggarwal, R., Demirgüç-Kunt, A., and Pería, M. S. M. (2011). Do remittances promote financial development? *Journal of Development Economics*, 96(2):255 – 264.

Agunias, D. R. and Newland, K. (2012). *Developing a road map for engaging diasporas in development: A handbook for policymakers and practitioners in home and host countries*. International Organization for Migration.

Ait Benhamou, Z. and Cassin, L. (2018). The effects of migration and remittances on development and capital in Caribbean Small Island Developing States. EconomiX Working Papers 2018-41, University of Paris Nanterre, EconomiX.

Alcaraz, C., Chiquiar, D., and Salcedo, A. (2012). Remittances, schooling, and child labor in Mexico. *Journal of Development Economics*, 97(1):156 – 165.

Alleyne, D. and Solan, I. (2019). *Leveraging the Caribbean Diaspora for Development: The Role of Network Effects*, pages 55–77. Springer International Publishing, Cham.

Alleyne, T. S. C., Ötker, İ., Ramakrishnan, U., Srinivasan, K., and Walutowy, M. F. (2017). *Unleashing growth and strengthening resilience in the Caribbean*. International Monetary Fund.

Aloi, M. and Tournemaine, F. (2011). Growth effects of environmental policy when pollution affects health. *Economic Modelling*, 28(4):1683–1695.

Ambec, S. and Lanoie, P. (2008). Does It Pay to Be Green? A Systematic Overview. *Academy of Management Perspectives*, 22(4):45–62.

Amuedo-Dorantes, C. and Pozo, S. (2011). New evidence on the role of remittances on healthcare expenditures by Mexican households. *Review of Economics of the Household*, 9(1):69–98.

Anyanwu, J. C. and Erhijakpor, A. E. O. (2010). Do International Remittances Affect Poverty in Africa?*. *African Development Review*, 22(1):51–91.

Arroyo, V., Díaz, J., Ortiz, C., Carmona, R., Sáez, M., and Linares, C. (2016). Short term effect of air pollution, noise and heat waves on preterm births in Madrid (Spain). *Environmental Research*, 145:162 – 168.

Arslan, C., Dumont, J.-C., Kone, Z., Çaglar Özden, Parsons, C., and Xenogiani, T. (2016). International Migration to the OECD in the Twenty-First Century. Economics Discussion / Working Papers 16-13, The University of Western Australia, Department of Economics.

Athukorala, P. (1993a). International Labour Migration in the Asian-Pacific Region: patterns, policies and economic implications. *Asian-Pacific Economic Literature*, 7(2):28–57.

Athukorala, P. (1993b). Improving the contribution of migrant remittances to development: the experience of Asian labour-exporting countries. *International migration (Geneva, Switzerland)*, 31(1):103—124.

Auriol, E. and Warlters, M. (2012). The marginal cost of public funds and tax reform in Africa. *Journal of Development Economics*, 97(1):58 – 72.

Azizi, S. (2018). The impacts of workers' remittances on human capital and labor supply in developing countries. *Economic Modelling*, 75:377 – 396.

Bachoon, D. S., Markand, S., Otero, E., Perry, G., and Ramsubaugh, A. (2010). Assessment of non-point sources of fecal pollution in coastal waters of Puerto Rico and Trinidad. *Marine Pollution Bulletin*, 60(7):1117 – 1121.

Bang, J. T., Mitra, A., and Wunnava, P. V. (2016). Do remittances improve income inequality? An instrumental variable quantile analysis of the Kenyan case. *Economic Modelling*, 58:394 – 402.

Bansak, C. and Chezum, B. (2009). How Do Remittances Affect Human Capital Formation of School-Age Boys and Girls? *American Economic Review*, 99(2):145–48.

Barnett, J. and Adger, W. N. (2003). Climate dangers and atoll countries. *Climatic change*, 61(3):321–337.

Barrios, S., Bertinelli, L., and Strobl, E. (2006). Climatic change and rural-urban migration: The case of sub-Saharan Africa. *Journal of Urban Economics*, 60(3):357 – 371.

Barro, R. J. and Lee, J. W. (2013). A new data set of educational attainment in the world, 1950–2010. *Journal of Development Economics*, 104:184 – 198.

Barton, J., Issaias, I., and Stentiford, E. (2008). Carbon – Making the right choice for waste management in developing countries. *Waste Management*, 28(4):690 – 698. OECD Workshop - Soils and Waste Management: A Challenge to Climate Change.

Beasley, R., Semprini, A., and Mitchell, E. A. (2015). Risk factors for asthma: is prevention possible? *The Lancet*, 386(9998):1075 – 1085.

Beine, M., Docquier, F., and Oden-Defoort, C. (2011). A Panel Data Analysis of the Brain Gain. *World Development*, 39(4):523 – 532.

Beine, M., Docquier, F., and Rapoport, H. (2001). Brain drain and economic growth: theory and evidence. *Journal of Development Economics*, 64(1):275 – 289.

Beine, M., Docquierb, F., and Rapoport, H. (2006). Measuring international skilled migration: New estimates controlling for age of entry. *World Bank Research Report*.

Bhagwati, J. and Rodriguez, C. (1975). Welfare-theoretical analyses of the brain drain. *Journal of Development Economics*, 2(3):195 – 221.

Bharadwaj, P., Gibson, M., Zivin, J. G., and Neilson, C. (2017). Gray matters: Fetal pollution exposure and human capital formation. *Journal of the Association of Environmental and Resource Economists*, 4(2):505–542.

Bierbaum, Rosina M.; Fay, M. R.-L. B. (2009). World development report 2010 : development and climate change.

Birk, T. and Rasmussen, K. (2014). Migration from atolls as climate change adaptation: Current practices, barriers and options in Solomon Islands. In *Natural Resources Forum*, volume 38, pages 1–13. Wiley Online Library.

Bourdet, Y. and Falck, H. (2006). Emigrants' remittances and Dutch Disease in Cape Verde. *International Economic Journal*, 20(3):267–284.

Briguglio, L. (1995). Small island developing states and their economic vulnerabilities. *World Development*, 23(9):1615 – 1632.

Briguglio, L. (1998). Small Country Size and Returns to Scale in Manufacturing. *World Development*, 26(3):507 – 515.

Briguglio, L. (2003). The vulnerability index and small island developing states: A review of conceptual and methodological issues. *AIMS Regional Preparatory Meeting on the Ten Year*.

Briguglio, L. and Galea, W. (2003). Updating and Augmenting the Economic Vulnerability Index. (December 1997):1–15.

Brown, R. P. and Ahlburg, D. A. (1999). Remittances in the South Pacific. *International Journal of Social Economics*, 26(1/2/3):325–344.

Brown, R. P. C., Carmignani, F., and Fayad, G. (2013). Migrants' Remittances and Financial Development: Macro- and Micro-Level Evidence of a Perverse Relationship. *The World Economy*, 36(5):636–660.

Brunow, S., Nijkamp, P., and Poot, J. (2015). Chapter 19 - The Impact of International Migration on Economic Growth in the Global Economy. In Chiswick, B. R. and Miller, P. W., editors, *Handbook of the Economics of International Migration*, volume 1 of *Handbook of the Economics of International Migration*, pages 1027 – 1075. North-Holland.

Buob, S. and Stephan, G. (2011). To mitigate or to adapt: How to confront global climate change. *European Journal of Political Economy*, 27(1):1 – 16.

Calero, C., Bedi, A. S., and Sparrow, R. (2009). Remittances, Liquidity Constraints and Human Capital Investments in Ecuador. *World Development*, 37(6):1143 – 1154.

Carré, J., Gatimel, N., Moreau, J., Parinaud, J., and Léandri, R. (2017). Does air pollution play a role in infertility?: a systematic review. *Environmental Health*, 16(1):82.

Cashman, A. and Nagdee, M. R. (2017). Impacts of climate change on settlements and infrastructure in the coastal and marine environments of Caribbean small island developing states (SIDS). *Caribbean Marine Climate Change Report Card: Science Review*, 2017:23–30.

Cashman, A., Nurse, L., and John, C. (2010). Climate Change in the Caribbean: The Water Management Implications. *The Journal of Environment & Development*, 19(1):42–67.

Catalano, M., Forni, L., and Pezzolla, E. (2019). Climate-Change Adaptation: The Role of Fiscal Policy. *Resource and Energy Economics*.

Chakraborty, S. (2004). Endogenous lifetime and economic growth. *Journal of Economic Theory*, 116(1):119 – 137.

Chambwera, M., Heal, G., Dubeux, C., Hallegatte, S., Leclerc, L., Markandya, A., McCarl, B., Mechler, R., and Neumann, J. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Chowdhury, M. B. (2011). Remittances flow and financial development in Bangladesh. *Economic Modelling*, 28(6):2600–2608.

Christiano, L. and Fitzgerald, T. (1998). The business cycle: it's still a puzzle. *Economic Perspectives*, (Q IV):56–83.

Clemens, M. A. (2017). Migration is a form of development: The need for innovation to regulate migration for mutual benefit. Technical Report 2017/8, Population Division, United Nations Department of Economic and Social Affairs.

Cloos, P. and Ridde, V. (2018). Research on climate change, health inequities, and migration in the Caribbean. *The Lancet Planetary Health*, 2(1):e4 – e5.

Combes, J.-L. and Ebeke, C. (2011). Remittances and Household Consumption Instability in Developing Countries. *World Development*, 39(7):1076 – 1089. Special Section (pp. 1204-1270): Foreign Technology and Indigenous Innovation in the Emerging Economies.

Constant, K. (2018). Environmental policy and human capital inequality: A matter of life and death. *Journal of Environmental Economics and Management*.

Cooley, T. F. and Prescott, E. C. (1995). Economic growth and business cycles. *Frontiers of business cycle research*, 1.

Coon, M. (2014). Financial development and the end-use of migrants' remittances. *IZA Journal of Labor & Development*, 3(1):7.

Coulibaly, D. (2015). Remittances and financial development in Sub-Saharan African countries: A system approach. *Economic Modelling*, 45:249 – 258.

Cox-Edwards, A. and Rodríguez-Oreggia, E. (2009). Remittances and Labor Force Participation in Mexico: An Analysis Using Propensity Score Matching. *World Development*, 37(5):1004 – 1014.

Croes, R. (2011). Measuring and Explaining Competitiveness in the Context of Small Island Destinations. *Journal of Travel Research*, 50(4):431–442.

Currie, J., Zivin, J. G., Mullins, J., and Neidell, M. (2014). What Do We Know About Short- and Long-Term Effects of Early-Life Exposure to Pollution? *Annual Review of Resource Economics*, 6(1):217–247.

Dasgupta, P. (2008). Discounting climate change. *Journal of risk and uncertainty*, 37(2-3):141–169.

De Haas, H. (2010). Migration and Development: A Theoretical Perspective. *International Migration Review*, 44(1):227–264.

de la Croix, D. and Gobbi, P. E. (2017). Population density, fertility, and demographic convergence in developing countries. *Journal of Development Economics*, 127:13 – 24.

de la Croix, D. and Gosseries, A. (2012). The natalist bias of pollution control. *Journal of Environmental Economics and Management*, 63(2):271–287.

de la Croix, D. and Michel, P. (2002). *A theory of economic growth: dynamics and policy in overlapping generations*. Cambridge University Press.

Delogu, M., Docquier, F., and Machado, J. (2018). Globalizing labor and the world economy: the role of human capital. *Journal of Economic Growth*, pages 1–36.

Demirgüç-Kunt, A., Córdova, E. L., Pería, M. S. M., and Woodruff, C. (2011). Remittances and banking sector breadth and depth: Evidence from Mexico. *Journal of Development Economics*, 95(2):229 – 241.

Desai, M. A., Kapur, D., and McHale, J. (2004). Sharing the Spoils: Taxing International Human Capital Flows. *International Tax and Public Finance*, 11(5):663–693.

Docquier, F., Faye, O., and Pestieau, P. (2008). Is migration a good substitute for education subsidies? *Journal of Development Economics*, 86(2):263–276.

Docquier, F. and Marfouk, A. (2006). International migration by education attainment, 1990–2000. *International Migration, remittances and the brain drain*, pages 151–199.

Docquier, F. and Rapoport, H. (2012). Globalization, brain drain, and development. *Journal of Economic Literature*, 50(3):681–730.

Docquier, F., Rapoport, H., and Salomone, S. (2012). Remittances, migrants' education and immigration policy: Theory and evidence from bilateral data. *Regional Science and Urban Economics*, 42(5):817–828.

Durand, J., Kandel, W., Parrado, E. A., and Massey, D. S. (1996). International migration and development in Mexican communities. *Demography*, 33(2):249–264.

Dye, S., Buckley, P., and Pinnegar, J. (2017). Impacts of Climate Change on the Coastal and Marine Physical Environments of Caribbean Small Island Developing

States (SIDS). *Caribbean Marine Climate Change Report Card: Science Review*, 2017:23–30.

ECLAC (2017). Migration in the Caribbean: Current trends, opportunities and challenges. techreport, (Economic Comission for latin America and the Caribbean), Subregional Headquarters for the Caribbean Port of Spain.

ECLAC (2018). The Caribbean Outlook. techreport, Economic Commission for Latin America and the Caribbean, Subregional Headquarters for the Caribbean Port of Spain.

Evans, M. F. and Smith, V. K. (2005). Do new health conditions support mortality–air pollution effects? *Journal of Environmental Economics and Management*, 50(3):496 – 518.

Faist, T. (2008). Migrants as transnational development agents: an inquiry into the newest round of the migration-development nexus. *Popul. Space Place*, 14(1):21–42.

Farbotko, C. and Lazrus, H. (2012). The first climate refugees? Contesting global narratives of climate change in Tuvalu. *Global Environmental Change*, 22(2):382–390.

Feenstra, R. C., Inklaar, R., and Timmer, M. P. (2015). The Next Generation of the Penn World Table. *American Economic Review*, 105(10):3150–82.

Fromentin, V. (2017). The long-run and short-run impacts of remittances on financial development in developing countries. *The Quarterly Review of Economics and Finance*, 66:192 – 201.

Giuliano, P. and Ruiz-Arranz, M. (2009). Remittances, financial development, and growth. *Journal of Development Economics*, 90(1):144 – 152.

Gordon, B. A., Mackay, R., and Rehfuess, E. (2004). *Inheriting the world: the atlas of children's health and the environment*. World Health Organization.

Gray, C. and Mueller, V. (2012). Drought and Population Mobility in Rural Ethiopia. *World Development*, 40(1):134 – 145.

Greenidge, K., Drakes, L., and Craigwell, R. (2010). The external public debt in the Caribbean Community. *Journal of Policy Modeling*, 32(3):418 – 431.

Guha, P. (2013). Macroeconomic effects of international remittances: The case of developing economies. *Economic Modelling*, 33:292 – 305.

Guillaumont, P. (2010). Assessing the Economic Vulnerability of Small Island Developing States and the Least Developed Countries. *The Journal of Development Studies*, 46(5):828–854.

Gupta, S., Pattillo, C. A., and Wagh, S. (2009). Effect of Remittances on Poverty and Financial Development in Sub-Saharan Africa. *World Development*, 37(1):104 – 115.

Guzmán, J. M., Rodríguez, J., Martínez, J., Contreras, J. M., and González, D. (2006). The Demography of Latin America and the Caribbean since 1950. *Population (English Edition, 2002-)*, 61(5/6):519–620.

Hamada, K. and Bhagwati, J. (1975). Domestic distortions, imperfect information and the brain drain. *Journal of Development Economics*, 2(3):265 – 279.

Hatton, T. J. (2014). The economics of international migration: A short history of the debate. *Special Section articles on "What determined the dynamics of labour economics research in the past 25 years? edited by Joop Hartog and and European Association of Labour Economists 25th Annual Conference, Turin, Italy, 19-21 September 2013 Edited by Michele Pellizzari*, 30:43–50.

He, J., Liu, H., and Salvo, A. (2019). Severe Air Pollution and Labor Productivity: Evidence from Industrial Towns in China. *American Economic Journal: Applied Economics*, 11(1):173–201.

Heileman, S. and Walling, L. J. (2005). *Caribbean environment outlook*. UNEP/Earthprint.

Hugo, G. (2011). Future demographic change and its interactions with migration and climate change. *Global Environmental Change*, 21:S21–S33. Migration and Global Environmental Change-Review of Drivers of Migration.

Imai, K. S., Gaiha, R., Ali, A., and Kaicker, N. (2014). Remittances, growth and poverty: New evidence from Asian countries. *Journal of Policy Modeling*, 36(3):524 – 538.

Isen, A., Rossin-Slater, M., and Walker, W. R. (2017). Every Breath You Take—Every Dollar You'll Make: The Long-Term Consequences of the Clean Air Act of 1970. *Journal of Political Economy*, 125(3):848–902.

James, K. H. (2005). A simple synthesis of Caribbean geology. *Caribbean Journal of Earth Science*, 39:69–82.

John, A. and Pecchenino, R. (1994). An Overlapping Generations Model of Growth and the Environment. *The Economic Journal*, 104(427):1393–1410.

Julca, A. and Paddison, O. (2010). Vulnerabilities and migration in Small Island Developing States in the context of climate change. *Natural Hazards*, 55(3):717–728.

Kelman, I. and West, J. J. (2009). Climate change and small island developing states: a critical review. *Ecological and Environmental Anthropology*, 5(1):1–16.

King, R. G. and Rebelo, S. T. (1999). Resuscitating real business cycles. In Taylor, J. B. and Woodford, M., editors, *Handbook of Macroeconomics*, volume 1 of *Handbook of Macroeconomics*, chapter 14, pages 927–1007. Elsevier.

Klein, R. J., Schipper, E. L. F., and Dessai, S. (2005). Integrating mitigation and adaptation into climate and development policy: three research questions. *Environmental Science & Policy*, 8(6):579 – 588. Mitigation and Adaptation Strategies for Climate Change.

Klöck, C. and Nunn, P. D. (2019). Adaptation to Climate Change in Small Island Developing States: A Systematic Literature Review of Academic Research. *The Journal of Environment & Development*, 0(0):1070496519835895.

Kydland, F. E. and Prescott, E. C. (1991). The econometrics of the general equilibrium approach to business cycles. *The Scandinavian Journal of Economics*, 93(2):161–178.

Lai, W. (2017). Pesticide use and health outcomes : Evidence from agricultural water pollution in China. *Journal of Environmental Economics and Management*, 86:93–120.

Lalonde, R. J. and Topel, R. H. (1997). Chapter 14 Economic impact of international migration and the economic performance of migrants. volume 1 of *Handbook of Population and Family Economics*, pages 799 – 850. Elsevier.

Lammoglia, S.-k., Kennedy, M. C., Barriuso, E., Alletto, L., Justes, E., Munier-jolain, N., and Mamy, L. (2017). Assessing human health risks from pesticide use in conventional and innovative cropping systems with the BROWSE model. *Environment International*, 105(April):66–78.

Lauby, J. and Stark, O. (1988). Individual Migration as a Family Strategy: Young Women in the Philippines. *Population Studies*, 42(3):473–486.

Lett, L. A., Stingone, J. A., and Claudio, L. (2017). The Combined Influence of Air Pollution and Home Learning Environment on Early Cognitive Skills in Children. *International Journal of Environmental Research and Public Health*, 14(11).

Lewis, W. A. (1954). Economic development with unlimited supplies of labour. *The manchester school*, 22(2):139–191.

Li, X. and Zhou, Y. (2013). An economic analysis of remittance of unskilled migration on skilled-unskilled wage inequality in labor host region. *Economic Modelling*, 33:428–432.

Lilleor, H. B. and den Broeck, K. V. (2011). Economic drivers of migration and climate change in LDCs. *Global Environmental Change*, 21:S70 – S81. Migration and Global Environmental Change – Review of Drivers of Migration.

Liu, A., Qian, N., Yu, H., Chen, R., and Kan, H. (2017). Science of the Total Environment Estimation of disease burdens on preterm births and low birth weights attributable to maternal fi ne particulate matter exposure in. *Science of the Total Environment*, 609:815–821.

Mamun, M. A., Sohag, K., Uddin, G. S., and Shahbaz, M. (2015). Remittance and domestic labor productivity: Evidence from remittance recipient countries. *Economic Modelling*, 47:207 – 218.

Mandelman, F. S. (2013). Monetary and exchange rate policy under remittance fluctuations. *Journal of Development Economics*, 102:128 – 147. Migration and Development.

Marchiori, L., Maystadt, J.-F., and Schumacher, I. (2012). The impact of weather anomalies on migration in sub-Saharan Africa. *Journal of Environmental Economics and Management*, 63(3):355–374.

Marchiori, L., Pieretti, P., and Zou, B. (2008). Brain Drain, Remittances and Fertility. 115:9–42.

Marchiori, L., Pieretti, P., and Zou, B. (2010). Migration and Human Capital in an Endogenous Fertility Model. *Annals of Economics and Statistics*, (97/98):187–205.

Marchiori, L. and Schumacher, I. (2011). When nature rebels: international migration, climate change, and inequality. *Journal of Population Economics*, 24(2):569–600.

Marcotte, D. E. and Marcotte, D. E. (2017). Something in the air? Air quality and children's educational outcomes. *Economics of Education Review*, 56:141 – 151.

Mariani, F., Pérez-Barahona, A., and Raffin, N. (2010). Life expectancy and the environment. *Journal of Economic Dynamics and Control*, 34(4):798 – 815.

McField, M. (2017). Impacts of climate change on coral in the coastal and marine environments of Caribbean Small Island Developing States (SIDS). *Caribbean Marine Climate Change Report Card: Science Review*, 2017:52–59.

Melendez, M. and Salisbury, J. (2017). Impacts of ocean acidification in the coastal and marine environments of Caribbean small island developing states (SIDS). *Caribbean Climate Change Report Card: Science Review*, 2017:31–39.

Mercer, J., Kelman, I., Alfthan, B., and Kurvits, T. (2012). Ecosystem-Based Adaptation to Climate Change in Caribbean Small Island Developing States: Integrating Local and External Knowledge. *Sustainability*, 4(8):1908–1932.

Michael A. Taylor, K. A. S. (2017). Impacts of climate change on sea temperature in the coastal and marine environments of Caribbean Small Island Developing States (SIDS). *Caribbean Marine Climate Change Report Card: Science Review*, 2017:23–30.

Middelbeek, L., Kolle, K., and Verrest, H. (2014). Built to last? Local climate change adaptation and governance in the Caribbean - The case of an informal urban settlement in Trinidad and Tobago. *Urban Climate*, 8:138 – 154.

Mohee, R., Mauthoor, S., Bundhoo, Z. M. A., Somaroo, G., Soobhany, N., and Gunasee, S. (2015). Current status of solid waste management in small island developing states: A review. *Waste Management*, 43:539–549.

Monioudi, I. N., Asariotis, R., Becker, A., Bhat, C., Dowding-Gooden, D., Esteban, M., Feyen, L., Mentaschi, L., Nikolaou, A., Nurse, L., Phillips, W., Smith, D. A., Satoh, M., Trotz, U. O., Velegrakis, A. F., Voukouvalas, E., Vousdoukas, M. I., and Witkop, R. (2018). Climate change impacts on critical international transportation assets of Caribbean Small Island Developing States (SIDS): the case of Jamaica and Saint Lucia. *Regional Environmental Change*, 18(8):2211–2225.

Mountford, A. (1997). Can a brain drain be good for growth in the source economy? *Journal of Development Economics*, 53(2):287 – 303.

Mountford, A. and Rapoport, H. (2011). The brain drain and the world distribution of income. *Journal of Development Economics*, 95(1):4–17.

Mullings, B. (2012). Governmentality, Diaspora Assemblages and the Ongoing Challenge of 'Development'. *Antipode*, 44(2):406–427.

Murray, M. and Watson, P. K. (2019). Adoption of natural disaster preparedness and risk reduction measures by business organisations in Small Island Developing States - A Caribbean case study. *International Journal of Disaster Risk Reduction*, 39:101115.

Mycoo, M. A. (2017). A Caribbean New Urban Agenda post-Habitat III: Closing the gaps. *Habitat International*, 69:68–77.

Nawrotzki, R. J., Riosmena, F., Hunter, L. M., and Runfola, D. M. (2015). Amplification or suppression: Social networks and the climate change – migration association in rural Mexico. *Global Environmental Change*, 35:463 – 474.

Ng'ang'a, S. K., Bulte, E. H., Giller, K. E., McIntire, J. M., and Rufino, M. C. (2016). Migration and Self-Protection Against Climate Change: A Case Study of Samburu County, Kenya. *World Development*, 84:55 – 68.

Nordhaus, W. D. (2007). A review of the Stern review on the economics of climate change. *Journal of economic literature*, 45(3):686–702.

Nurse, L., McLean, R., Agard, J., Briguglio, L., Duvat-Magnan, V., Pelesikoti, N., Tompkins, E., and Webb, A. (2014). Small islands Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed VR Barros et al.

Nyamongo, E. M., Misati, R. N., Kipyegon, L., and Ndirangu, L. (2012). Remittances, financial development and economic growth in Africa. *Journal of Economics and Business*, 64(3):240 – 260.

OECD (2019). *Education at a Glance 2019*.

Omanbayev, B., Salahodjaev, R., and Lynn, R. (2018). Are greenhouse gas emissions and cognitive skills related? Cross-country evidence. *Environmental Research*, 160:322 – 330.

Opperman, P. and Adjasi, C. K. D. (2019). Remittance volatility and financial sector development in sub-Saharan African countries. *Journal of Policy Modeling*, 41(2):336 – 351.

Osili, U. O. (2007). Remittances and savings from international migration: Theory and evidence using a matched sample. *Journal of Development Economics*, 83(2):446 – 465. Papers from a Symposium: The Social Dimensions of Microeconomic Behaviour in Low-Income Communities.

Pautrel, X. (2009). Pollution and life expectancy: How environmental policy can promote growth. *Ecological Economics*, 68(4):1040–1051.

Pautrel, X. (2012). Pollution, Private Investment in Healthcare, and Environmental Policy. *The Scandinavian Journal of Economics*, 114(2):334–357.

Pope III, C. A., Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., and Thurston, G. D. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Jama*, 287(9):1132–1141.

Pope III, C. A., Burnett, R. T., Thurston, G. D., Thun, M. J., Calle, E. E., Krewski, D., and Godleski, J. J. (2004). Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. *Circulation*, 109(1):71–77.

Power, M. C., Adar, S. D., Yanosky, J. D., and Weuve, J. (2016). Exposure to air pollution as a potential contributor to cognitive function, cognitive decline, brain imaging, and dementia: A systematic review of epidemiologic research. *NeuroToxicology*, 56:235–253.

Pujol, J., Martínez-Vilavella, G., Macià, D., Fenoll, R., Alvarez-Pedrerol, M., Rivas, I., Forns, J., Blanco-Hinojo, L., Capellades, J., Querol, X., Deus, J., and Sunyer, J.

(2016). Traffic pollution exposure is associated with altered brain connectivity in school children. *NeuroImage*, 129:175–184.

Raffin, N. (2012). Children's environmental health, education, and economic development. *Canadian Journal of Economics/Revue canadienne d'économique*, 45(3):996–1022.

Ragazzi, F. (2014). A comparative analysis of diaspora policies. *Political Geography*, 41:74 – 89.

Rao, B. B. and Hassan, G. M. (2011). A panel data analysis of the growth effects of remittances. *Economic Modelling*, 28(1):701 – 709.

Rapoport, H. and Docquier, F. (2006). The economics of migrants' remittances. *Handbook of the economics of giving, altruism and reciprocity*, 2:1135–1198.

Rawlins, B., Ferguson, A., Chilton, P., Arthurton, R., Rees, J., and Baldock, J. (1998). Review of agricultural pollution in the Caribbean with particular emphasis on small island developing states. *Marine Pollution Bulletin*, 36(9):658 – 668.

Raza, S. A. and Jawaid, S. T. (2014). Foreign capital inflows, economic growth and stock market capitalization in Asian countries: an ARDL bound testing approach. *Quality & Quantity*, 48(1):375–385.

Robert B. Potter, David Barker, D. C. T. K. (2004). *The Contemporary Caribbean*. Routledge.

Robinson, S.-a. (2017). Climate change adaptation trends in small island developing states. *Mitigation and Adaptation Strategies for Global Change*, 22(4):669–691.

Rosa, M. J., Pajak, A., Just, A. C., Sheffield, P. E., Kloog, I., Schwartz, J., Coull, B., Enlow, M. B., Baccarelli, A. A., Huddleston, K., Niederhuber, J. E., Rojo, M. M. T., Wright, R. O., Gennings, C., and Wright, R. J. (2017). Prenatal exposure to PM2.5 and birth weight: A pooled analysis from three North American longitudinal pregnancy cohort studies. *Environment International*, 107:173 – 180.

Salas, V. B. (2014). International Remittances and Human Capital Formation. *World Development*, 59:224 – 237.

Sampson, T. (2013). Brain drain or brain gain ? Technology diffusion and learning on-the-job. *Journal of International Economics*, 90(1):162–176.

Scobie, M. (2016). Policy coherence in climate governance in Caribbean Small Island Developing States. *Environmental Science & Policy*, 58:16 – 28.

Shalizi, Z. and Lecocq, F. (2009). To Mitigate or to Adapt: Is that the Question? Observations on an Appropriate Response to the Climate Change Challenge to Development Strategies. *The World Bank Research Observer*, 25(2):295–321.

Sibly, R. M., Hone, J., Clutton-Brock, T. H., Lutz, W., and Qiang, R. (2002). Determinants of human population growth. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 357(1425):1197–1210.

Sjaastad, L. A. (1962). The Costs and Returns of Human Migration. *Journal of Political Economy*, 70(5, Part 2):80–93.

Smit, B., Burton, I., Klein, R. J., and Wandel, J. (2000). An anatomy of adaptation to climate change and variability. In *Societal Adaptation to Climate Variability and Change*, pages 223–251. Springer.

Sobiech, I. (2019). Remittances, finance and growth: Does financial development foster the impact of remittances on economic growth? *World Development*, 113:44 – 59.

Stark, O., Helmenstein, C., and Prskawetz, A. (1997). A brain gain with a brain drain. *Economics Letters*, 55(2):227 – 234.

Stark, O. and Lucas, R. E. B. (1988). Migration, Remittances, and the Family. *Economic Development and Cultural Change*, 36(3):465–481.

Stephenson, T. S. and Jones, J. J. (2017). Impacts of climate change on extreme events in the coastal and marine environments of Caribbean Small Island Developing States (SIDS). *Caribbean Marine Climate Change Report Card: Science Review*, 2017:10–22.

Thiede, B., Gray, C., and Mueller, V. (2016). Climate variability and inter-provincial migration in South America, 1970–2011. *Global Environmental Change*, 41:228 – 240.

Thomas, A. and Benjamin, L. (2018). Policies and mechanisms to address climate-induced migration and displacement in pacific and caribbean small island developing states. *International Journal of Climate Change Strategies and Management*, 10(1):86–104.

Thomas-Hope, E. (2002). Skilled labour migration from developing countries: study of the Caribbean region. Technical Report 50, International Migration Programme, International Labour Office, Geneva.

Thomas-Hope, E. M. (1992). *Caribbean migration*. University of West Indies Press.

Thonart Philippe, Diabaté Sory Ibrahim, Hiligsmann Serge, and Lardinois Mathias (2005). *Guide pratique sur la gestion des déchets ménagers et des sites d'enfouissement technique dans les pays du Sud*.

Todaro, M. P. (1969). A model of labor migration and urban unemployment in less developed countries. *The American economic review*, 59(1):138–148.

Tol, R. S. (2005). Adaptation and mitigation: trade-offs in substance and methods. *Environmental Science & Policy*, 8(6):572 – 578. Mitigation and Adaptation Strategies for Climate Change.

Tol, R. S., Fankhauser, S., and Smith, J. B. (1998). The scope for adaptation to climate change: what can we learn from the impact literature? *Global Environmental Change*, 8(2):109 – 123.

Tol, R. S. J. (2006). The Stern Review of the Economics of Climate Change: A Comment. *Energy & Environment*, 17(6):977–981.

Tsur, Y. and Withagen, C. (2013). Preparing for catastrophic climate change. *Journal of Economics*, 110(3):225–239.

Tzivian, L., Winkler, A., Dlugaj, M., Schikowski, T., Vossoughi, M., Fuks, K., Weinmayr, G., and Hoffmann, B. (2015). Effect of long-term outdoor air pollution and noise on cognitive and psychological functions in adults. *International Journal of Hygiene and Environmental Health*, 218(1):1–11.

UN-OHRLLS (2015). Small Island Developing States in Numbers. Technical report, Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS).

UN-OHRLLS (2017). Small island developing states in numbers: Updated climate change. Technical report, Office of the High Representative for the Least Developed Countries, Land locked Developing Countries and Small Island Developing States.

UNEP (2016). *GEO-6 Regional Assessment for Latin America and the Caribbean.* United Nations Environment Programme, Nairobi, Kenya.

Valcke, M., Bourgault, M.-h., Rochette, L., Normandin, L., Samuel, O., Belleville, D., Blanchet, C., and Phaneuf, D. (2017). Human health risk assessment on the consumption of fruits and vegetables containing residual pesticides : A cancer and non-cancer risk / bene fi t perspective. *Environment International*, 108(August):63–74.

van der Velde, M., Green, S., Vanclooster, M., and Clothier, B. (2007). Sustainable development in small island developing states: Agricultural intensification, economic development, and freshwater resources management on the coral atoll of Tongatapu. *Ecological Economics*, 61(2):456 – 468.

Varvarigos, D. (2010). Environmental Degradation, Longevity, and the Dynamics of Economic Development. *Environmental and Resource Economics*, 46(1):59–73.

Varvarigos, D. (2013). Environmental dynamics and the links between growth, volatility and mortality. *Bulletin of Economic Research*, 65(4):314–331.

Varvarigos, D. (2014). Endogenous longevity and the joint dynamics of pollution and capital accumulation. *Environment and Development Economics*, 19(4):393–416.

Vergara, W., Rios, A. R., Galindo, L. M., and Samaniego, J. (2015). Physical damages associated with climate change impacts and the need for adaptation actions in latin america and the caribbean. *Handbook of climate change adaptation*, pages 479–491.

Vizcaíno, C., Miguel, A., González-Comadran, M., and Jacquemin, B. (2016). Outdoor air pollution and human infertility: a systematic review. *Fertility and Sterility*, 106(4):897–904.e1.

Wade, C., Otero, E., Poon-Kwong, B., Rozier, R., and Bachoon, D. (2015). Detection of human-derived fecal contamination in Puerto Rico using carbamazepine, HF183 Bacteroides, and fecal indicator bacteria. *Marine Pollution Bulletin*, 101(2):872 – 877.

Wang, M., Zhao, J., and Bhattacharya, J. (2015). Optimal health and environmental policies in a pollution-growth nexus. *Journal of Environmental Economics and Management*, 71:160 – 179.

Wege, D., Ryan, D., Varty, N., Anadón-Irizarry, V., and Pérez-Leroux, A. (2010). Ecosystem profile: The caribbean islands biodiversity hotspot. Technical report.

WHO, W. h. O. (2016). *World health statistics 2016: monitoring health for the SDGs sustainable development goals*. WHO, World health Organization.

Wilson, D. C., Velis, C., and Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. *Habitat International*, 30(4):797 – 808. Solid Waste Management as if People Matter.

Wilson, R. (2017). Impacts of climate change on mangrove ecosystems in the coastal and marine environments of caribbean small island developing states (SIDS). *Caribbean Climate Change Report Card: Science Review*, 2017:61–82.

Woodruff, C. and Zenteno, R. (2007). Migration networks and microenterprises in Mexico. *Journal of Development Economics*, 82(2):509 – 528.

Yang, D. (2008). International migration, remittances and household investment: Evidence from Philippine migrants' exchange rate shocks. *The Economic Journal*, 118(528):591–630.

Zemel, A. (2015). Adaptation, mitigation and risk: An analytic approach. *Journal of Economic Dynamics and Control*, 51:133 – 147.

Zhang, J. and Nishimura, K. (1993). The old-age security hypothesis revisited. *Journal of Development Economics*, 41(1):191 – 202.

List of Figures

List of Tables