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ESSAYS ON ECONOMIC GROWTH, ENERGY USE AND BIODIVERSITY LOSS

Thèse nouveau régime

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Résumé

L'impact de l'activité économique et de l'augmentation de la population sur l'environnement soulève de profondes questions sur l'avenir des sociétés humaines et des ressources environnementales. En ceci, les "Limites de la Croissance" ("Limits to Growth", Meadows, Meadows, Behrens et Randers, 1974) mettent en garde les sociétés humaines contre la possibilité d'un effondrement social si les tendances actuelles d'exploitation de ressources naturelles et de dégradation de l'environnement suivent leur court. La richesse de la nature étant primordiale 'a la richesse des nations, cette thèse en sciences économiques au travers de quatre contributions théoriques et empiriques traite de la possibilité d'une cohabitation pacifique des sociétés humaines avec la nature et discute des politiques de conservation de la nature. Nos résultats théoriques et empiriques montrent d'une part que l'expansion de l'habitat humain se fait au détriment des autres espèces biologiques (animales et végétales). D'autre part, nous montrons que les efforts actuels de conservation des espèces biologiques sont fortement orientés vers des forets dont la richesse en biodiversité s'avère douteuse. Finalement, nous montrons qu'une utilisation de plus en plus croissante des énergies primaires, donc à forts impacts écologiques, est encore à attendre des pays en développement.

En termes de politiques environnementales, nos travaux appellent davantage à la réduction de l'empreinte écologique des sociétés humaines. Ceci inclut: Une exploitation favorisant la régénération des forêts et non la réduction des aires déjà couvertes; L'élargissement des aires protégées surtout dans les pays en développement ; Une incitation des individus à orienter les préférences vers la demande de biens à faibles empreintes écologiques.

Mots clés : Habitat humain; croissance économique et démographique; énergie fossiles; extinction des espèces; dégradation environnementale.

Abstract

The impact of economic activities and increasing population on the environment raise profound interrogations towards the future of human societies and environmental resources. In this, the "Limits to Growth" (Meadows, Meadows, Behrens and Randers, 1974) warn human societies about the possibility of social collapse if current trends of exploitation of natural resources and environmental degradation remain unchanged. The wealth of nature being essential to the wealth of nations, this thesis in economics through four theoretical and empirical contributions addresses the possibility of a peaceful cohabitation between human and nature and discusses conservation policies of nature. Our theoretical and empirical results show on the one hand that human habitat is being expanded to the detriment of other biological species (animal and plant). On the other hand, we show that current efforts to conserve biological species are strongly oriented towards forests whose richness in biodiversity is doubtful. Finally, we show that an increasingly growing consumption of primary energies, therefore with strong ecological impacts, is still to be expected from developing countries.

In terms of environmental policies, our work advocates for a reduction of the ecological footprint of human societies. This includes policies promoting forest regeneration and not the reduction of covered areas, expansion of protected areas, especially in developing countries and incentives for individuals to orient preferences towards the demand for goods with low ecological impacts.

Keywords: Human habitat; economic and demographic growth, fossil fuels; extinction of species; environmental degradation

La Faculté n'entend donner aucune approbation ni improbation aux opinions émises dans les thèses. Ces opinions doivent être considérées comme propres à leurs auteurs.

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to Kokoè, Mawussé and Violeta

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1. Chapitre introductif

(Introductory Chapter - English version below)

"Human beings and the natural world are on a collision course. Human activities inflict harsh and often irreversible damage on the environment and on critical resources."

— *The Limits to Growth*, Meadows et al., 2004, pp. 15

"The wealth of nature is essential to the wealth of nations. All aspects of the global economy, from raw materials to manufacturing to trade and commerce depend on biodiversity and ecosystems."

— The International Union for Conservation of Nature (IUCN)

1.1 Motivation

Les "Limites de la Croissance" ("Limits to Growth", Meadows, Meadows, Behrens et Randers, 1974) mettent en garde les sociétés humaines contre la possibilité d'un effondrement social si les tendances actuelles d'exploitation de ressources naturelles et de dégradation de l'environnement suivent leur court. Cette dégradation se caractérisant essentiellement par des émissions de gaz à effet de serre, la déforestation, la destruction des complexes écologiques ainsi que par le changement climatique, est de plus en plus considérée par les chercheurs dans plusieurs disciplines comme une menace pour l'avenir des sociétés humaines. La richesse de la nature étant primordiale à la richesse des nations, la problématique soulève de profondes questions sur les causes, les conséquences et les approches ou politiques de préservation des ressources environnementales.

Globalement, la question de la dégradation des ressources environnementales peut être posée en terme de cohabitation harmonieuse entre les sociétés humaines et la nature. En ceci, les travaux de recherche en sciences économiques, en biologie, aussi bien en sociologie qu'en biogéographie abordent le sujet en terme de développement durable et d'exploitation optimale des ressources naturelles. Quant à la biodiversité, comparativement à la problématique des émissions de gaz et de gestion des ressources naturelles, l'extinction des espèces fait l'objet de moins d'études économiques, alors que le sujet n'est point négligeable étant donné que ses conséquences sont tout aussi menaçantes pour la stabilité des sociétés humaines. L'observation de l'évolution de la population humaine et du nombre d'espèces éteintes ainsi que la classification de ces dernières dans les différentes classes biologiques (voir Figure 1.1) interpelle sur la question de la cohabitation pacifique.

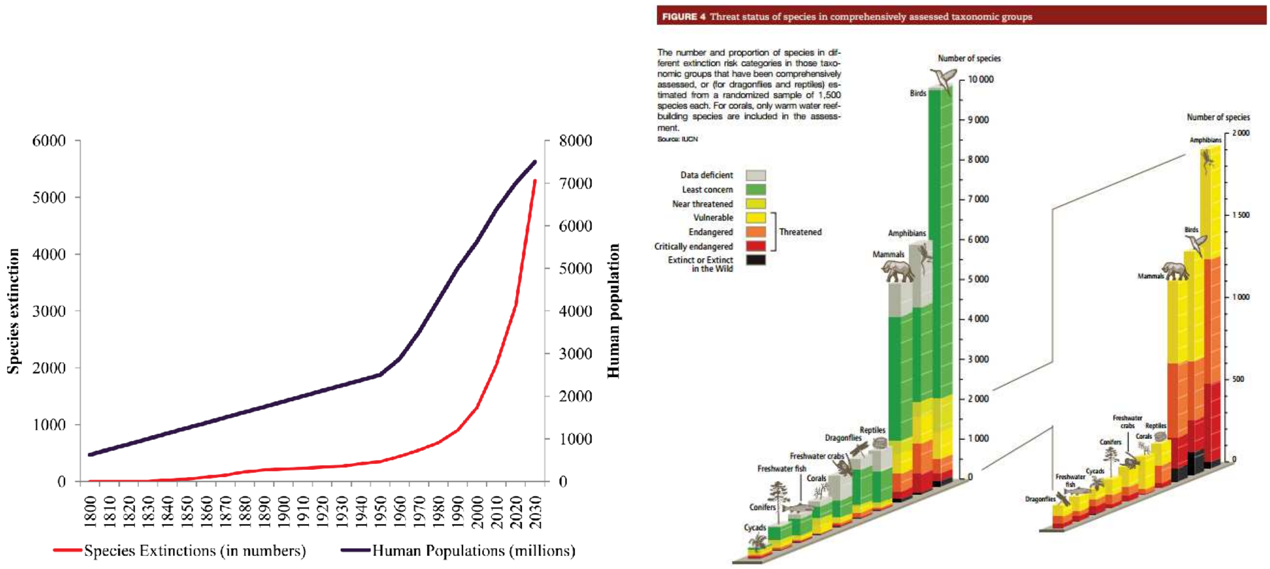


Figure 1.1: Population and species extinction

Source: International Union for Conservation of Nature, UICN

Sur le plan théorique (théorie de la croissance par exemple), il est moins rare de trouver des travaux traitant le sujet des émissions de gaz et de gestion des ressources que ceux traitant de la perte de la biodiversité. Les contributions à la question des ressources naturelles sont essentiellement au travers des modèles de prédateur-proie ou de population-ressources, où l'objet est d'étudier la dynamique de long-terme de la population et des ressources (Brander et Taylor, 1997, 1998; Finnoff et Tschirhart, 2008; Motesharrei et al., 2014; Roman et al., 2018). Cette littérature, malheureusement, résume la complexité des problèmes environnementaux (déforestation, destruction des écosystèmes, extinction) en l'étude de la dynamique d'une seule et unique variable, dont les fluctuations correspondraient à celle des ressources environnementales. Ainsi, une hausse des surfaces forestières est faussement à considérer comme une régénération des complexes écologiques et de la diversité biologique s'y afférente. Cette simplification à tort de la complexité du lien entre les activités économiques, la déforestation et l'extinction d'espèces animales et végétales requiert de nouvelles perspectives analytiques.

Quant aux études empiriques, peu de travaux traitent de la biodiversité en analyse économique et a fortiori discutent l'hypothèse de cohabitation pacifique. En effet, des travaux existant discutent de l'impact écologique de la croissance économique en analysant le cas des mammifères, des oiseaux, des amphibiens, des poissons, des reptiles menacées d'extinction (Dietz and Adger, 2003; Hoffmann, 2004; Mills and Waite, 2009; Halkos and Tzeremes, 2010). Des perspectives globales étudiant l'impact de l'activité économique et de la population sur l'habitat naturel, testant par conséquent l'hypothèse de cohabitation pacifique n'est pas identifiable dans cette littérature. Nos travaux de recherche dans le cadre de cette thèse sur la *Croissance Économique, Consommation d'Énergie et Perte de la Biodiversité* s'inscrivent globalement dans cette perspective et s'articulent autour des interrogations suivantes: Une cohabitation pacifique est-elle possible entre l'espèce humaine et la biodiversité? Quelle place pour la biodiversité en théorie de la croissance? Quelle orientation efficiente des politiques de conservation de la biodiversité? Quel est le rôle des facteurs géographiques et institutionnels dans l'exploitation des énergies fossiles? Cette thèse se propose donc d'apporter des éléments de réponses théoriques et empiriques à ces interrogations actuelles.

1.2 Aperçu et contribution

Cette thèse envisage quatre (4) contributions à la question de la dégradation de l'environnent, dont trois portent essentiellement sur la problématique de perte de la biodiversité. La première contribution (Chapitre 2) se propose d'analyser au niveau global les facteurs socio-économiques entrainant la destruction de l'habitat naturel (extinction des espèces animales et végétales), testant l'hypothèse de cohabitation pacifique entre l'homme et la nature. Le Chapitre 3, un modèle Ricardo-Malthusien de population, de déforestation et de biodiversité, introduit les questions de déforestation et d'extinction dans un modèle économique. La troisième contribution (Chapitre 4), "Income, biodiversity and forests in conservation policies", s'intéresse aux déterminants des politiques de conservation. La problématique de la dégradation de l'environnement étant unique mais avec de différentes facettes, nous introduisons dans cette thèse un Chapitre 5 essentiellement centré sur l'utilisation grandissante des énergies primaires. Outre le rôle de l'activité économique, de la démographie et des facteurs climatiques dans la perte de la biodiversité, ce Chapitre 4 met en exergue le rôle des institutions et des facteurs géographiques aussi bien dans les enjeux environnementaux que de développement comparé.

Chapitre 2: La question de la cohabitation (co-écrit avec Nguyen-Van P.).

Ce papier teste l'hypothèse d'une possible cohabitation entre l'espèce humaine et les espèces animales et végétales. Ce faisant, nous utilisons les données de comptage relatives aux espèces menacées de l'Union Internationale pour la Conservation de la Nature (UICN Red-List) avec les variables socio-économiques de la Banque Mondiale, les indicateurs du développement dans le monde. Globalement, nos résultats montrent qu'une cohabitation serait possible dans les pays à revenu élevé, alors que dans les pays à revenu faible une relation d'incompatibilité est observée (relation en U-inversé entre PIB par habitant et le nombre d'espèces). Une contextualisation de notre analyse dans la littérature critique sur l'existence de la courbe de Kuznets environnementale fournit des explications assez cohérentes à nos résultats. En effet, la "Ecological Modernization theory" et la "Ecologically Unequal Exchange theory" permettent de comprendre les facteurs qui sous-tendent la relation compatible entre l'activité économique et les espèces animales et végétales observée dans les pays industrialisés, contrairement aux pays en développement.

Chapitre 3: Déforestation et biodiversité en théorie de la croissance.

Dans ce Chapitre, nous proposons un modèle de population endogène qui, dans la logique de Brander et Taylor (1998), de Anderies (1998) et de la littérature existante en modèles de population-ressource, relie les problèmes de déforestation et de perte de biodiversité à l'activité économique ainsi qu'aux choix d'agents économiques représentatifs. A la différence des travaux théoriques existant, nous dissocions les questions de déforestation et de perte de biodiversité, en considérant les ressources forestières comme input dans l'activité de production. L'utilisation croissante des ressources forestières entraine la déforestation qui réduit ou détruit l'habitat des espèces biologiques, dont la population est fonction croissante de la taille de l'habitat naturel disponible. Un second facteur contribuant à la destruction de l'habitat est la croissance démographique. Les résultats de cette analyse théorique permettent de saisir comment l'empreinte écologique des sociétés humaines est cause de déforestation et d'extinction des espèces biologiques.

Chapitre 4: La biodiversité dans les politiques de conservation.

L'analyse de l'hypothèse de cohabitation pacifique des sociétés humaines avec les espèce animales et végétales soulève la question de l'efficacité des politiques de conservation, plus précisément de la localisation optimale des aires protégées dans la protection des espèces animales et végétales. La question de l'efficacité a largement été abordée dans la littérature pour déboucher sur la certitude selon laquelle les aires protégées permettent de réduire le taux de déforestation (Naughton-Treves et al. (2005), Joppa and Pfaff (2010) et Sims and Alix-Garcia (2017)). En ce qui est de la protection de la biodiversité, bien que les auteurs ne semblent pas unanimes sur le sujet, il se dégage que les espèces sont relativement mieux protégées à l'intérieur des aires protégées qu'à l'extérieur (Bruner et al. (2001) et Barnes et al. (2015)). Abordant le problème inversement, notre contribution interroge les motivations dans l'établissement des réserves naturelles ainsi que l'efficience de leur localisation géographique. L'objectif des aires protégées étant aussi la protection des espèces biologiques, on s'attendrait à ce que globalement, les aires protégées les plus larges se retrouvent dans les pays tropicaux, où la majeure partie des espèces est identifiée. Cette observation n'est forcément pas le cas. Des parts relativement égales d'aires protégées sont remarquées dans les zones tropicales et non-tropicales, alors qu'une large richesse en espèce biologique, un risque élevé d'extinction ainsi qu'une plus large couverture forestière sont observés dans les pays tropicaux. Sur la base de ces observations, nous proposons dans le chapitre 4 une analyse quantitative des déterminants des aires protégées afin de fournir une explication à l'in-efficiente localisation géographique soupçonnée des aires protégées. Concrètement, nos résultats montrent que les efforts de conservation des pays dépend fortement du niveau de revenu et la surface forestières mais pas systématiquement de la richesse en espèces biologiques.

Chapitre 5: Croissance et énergie primaires (co-écrit avec Nguyen-Van P.).

Ce dernier Chapitre postule sur la base du débat Institutions-Géographie (Acemoglu et al. (2001, 2005) et Sachs (2003) et Sachs et al. (1999, 2001)) que ces deux facteurs représentent les deux faces d'un même pièce de monnaie. Il se propose donc d'analyser leur rôle dans une étude spatiale des déterminants socio-économiques de la consommation des énergies primaires dans les pays en développement. Non seulement, ce papier montre que les énergies primaires constituent un moteur de croissance économique en Afrique Sub-Saharienne, mais il met aussi en exergue la dépendance spatiale dans la consommation d'énergie primaire. Par ailleurs, ce Chapitre permet d'introduire le débat Institutions-Géographie, donc des deux faces d'une même pièce de monnaie, dans les études portant sur le lien environnement-croissance ou encore plus précisément énergie-croissance. Quant à l'impact environnemental, nos résultats permettent de prédire une utilisation de plus en plus croissante des énergies primaires en Afrique Sub-Saharienne et par conséquent une augmentation des émissions de gaz.

Dans ce Chapitre introductif, nous avons présenté la problématique, les motivations ainsi que les contributions de nos travaux à la recherche en sciences économiques sur les questions de dégradation des ressources environnementales et d'extinction des espèces. Aussi, nous avons proposé un aperçu des différents Chapitres qui constituent cette thèse. Dans ce qui suit, les principales contributions présentées sous format d'articles et rédigées en Anglais.

Introductory Chapter

Motivation

The "Limits to Growth", (Meadows, Meadows, Behrens and Randers, 1974), observing that production activities inflict harsh and often irreversible damage to nature, warns human society on the possibility of collapse, if current trends in the exploitation of natural resources and more globally in environmental degradation follow their course. The latter, mainly characterized by greenhouse gas emissions, deforestation, destruction of ecological complex and climate change, is subject of studies in several disciplines and considered as a threat to the future of human societies. The richness of nature being primordial to the wealth of nations, environmental degradation raises profound interrogations towards its causes and consequences as well as possible conservation policies.

Globally, environmental harms due to production activities can be addressed as an issue of harmonious cohabitation between human societies and nature. In this, studies in economics, biology, sociology and biogeography assess the topic in terms of sustainability in natural resources use. Nevertheless, compared to deforestation and natural resource, relatively few attention is devoted to the extinction of biological species (even so in economics), though the subject is not negligible, its consequences being equally threatening (if not much more) for the stability of human societies.

Theoretically (growth theory for instance), it is less rare to find study dealing with gas emissions and deforestation than those dealing with species extinction. The theoretical contributions on natural and forest resources are mainly in predator and prey perspectives or population-resource models, where the purpose is to study the long-term dynamics of population and natural resources (Brander and Taylor 1997, 1998; Finnoff and Tschirhart, 2008; Motesharrei et al., 2014; Roman et al., 2018). These approaches, unfortunately, summarize more complex environmental issues (deforestation, ecosystem destruction, extinction) by studying the dynamics of a single indicator, whose fluctuations correspond to that of environment. Hence, an increase in forest cover is wrongly considered as a regeneration of ecological complexes and related biological diversity. This misguided simplification of the complexity of the relationship between economic activities, deforestation and the extinction of animal and plant species requires some new analytical perspectives.

Empirically, few are studies addressing biodiversity loss in economic analysis and scarcer are those discussing the peaceful cohabitation hypothesis. Indeed, the existing literature discusses the ecological impact of economic growth by analysing the case of mammals, birds, amphibians, fish, and endangered reptiles (Dietz and Adger 2003; Hoffmann 2004; Mills and Waite, 2009; Halkos and Tzeremes, 2010). However, global level perspectives investigating the ecological impact of economic activities and population growth, therefore testing the peaceful coexistence hypothesis, are not identifiable in this literature.

The present Thesis on *Economic Growth, Energy use and Biodiversity Loss* fits into these theoretical and empirical gaps and is structured around the following research questions: Is a peaceful cohabitation between human and biodiversity possible? How geographically efficient and species oriented are conservation policies? Do geographical and institutional characteristics matter in fossil energy use? We propose to provide theoretical and empirical response elements to these questions.

Overview and contribution

The Thesis consists of four (4) contributions on environmental degradation, three of which address biodiversity loss and the last one questions primary energy use.

The first essay (Chapter 2) discusses at global level the socio-economic factors leading to the destruction of natural habitat (extinction of animal and plant species), thereby testing the peaceful cohabitation hypothesis. The second essay (Chapter 3), a "Ricardo-Malthusian model of population, deforestation and biodiversity loss", assesses species extinction in an general equilibrium model. The third essay (Chapter 4), "Income, biodiversity and forests in conservation policies", focuses on the determinants of conservation efforts. Environmental degradation being a multi-facet issue, we introduce in this Thesis a fourth essay (Chapter 5) discussing the increasing primary energy use in developing countries (Sub-Saharan Africa) and related environmental consequences. In addition to the role of economic activity, demography and climate in biodiversity loss, this Chapter highlights the role of institutions and geographic factors. Hereafter, an insight into each of the Essays.

Chapter 2: Testing the peaceful cohabitation (with Nguyen-Van P.)

This first essay aims to test the hypothesis of a peaceful cohabitation between human and animal and plant species. Thereby, we use the IUCN Red-List data on endangered species along with World Bank socio-economic indicators (WDI). Overall, our results show an apparent peaceful cohabitation in high-income countries, while in low-income countries an incompatibility is observed (an inverted U-shaped relationship between GDP and the number of threatened species). A contextualization of our results in the critical literature on the existence of Environmental Kuznets Curve reveals some fair explanations. Moreover, the "Ecological Modernization Theory" and the "Ecologically Unequal Exchange Theory" help provide some descriptions of the forces underlying the decreasing trend observed in threatened animal and plant species in high-income countries.

Chapter 3: Deforestation and biodiversity loss in economic theory

This essay extends existing population-resource models (initiated by Brander and Taylor, 1998; Anderies, 1998) to biodiversity loss. Contrary to existing theoretical studies, we dissociate the issues of deforestation from biodiversity loss, considering forest resources as input in the productive process, while species stock is not. In this perspective, increase in forest resources harvest leads to deforestation and reduces habitat of biological species, whose population positively depends on the size of natural habitat. A second channel of habitat destruction is population growth. The results of this theoretical analysis make it possible to understand how human ecological footprint causes deforestation and extinction of biological species.

Chapter 4: Biodiversity, forest and income in conservation policies

Questioning the peaceful cohabitation between human and nature raises some interrogations towards the effectiveness of conservation policies, more specifically the optimal location of protected areas in the conservation of animal and plant species. Protecting areas (PAs) also aiming at protecting biological species, the largest PAs are expected in tropical countries, where the majority of species are identified. This observation is not necessarily the case, motivating this essay, the results of which show that conservation efforts are highly income level dependent rather than biological species richness.

Chapter 5: Economic growth and primary energy use (with Nguyen-Van P.)

This essay, based on the Institutions versus Geography debate (Acemoglu et al.,2001, 2005; and Sachs, 2003; and Sachs et al.,1999, 2001), argues that institutions and geography represent the "two sides of the same coin" and proposes to assess their role in a spatial analysis of the socio-economic determinants of primary energy use in Sub-Saharan Africa. Not only this essay shows that economic growth and demographic characteristics drive primary energy use, but it also highlights the spatial dependence in primary energies (energies directly harvested from natural resources). Regarding environmental impact, our results help predict a growing primary energies use in Sub-Saharan Africa and consequently increasing gas emissions.

This introductory chapter overviews the main issues, the motivations as well as the contributions of our work to economic research on environmental degradation, extinction of biological species, as well as conservation policies. In the following are the individual essays included in this Thesis.

2. Is there a peaceful cohabitation between human and natural habitats?*

Abstract: The ongoing ecological crisis has motivated systematic studies on biodiversity loss, mostly considering birds, mammals, fish, amphibians but disregarding large-scale perspectives on natural habitat. The present paper proposes to assess the case of animal and plant species, testing whether a peaceful cohabitation between economic expansion and biodiversity is possible. Thereby, controlling for initial conditions (total species identified) and inverse causality, we find that the count of species under threat of extinction depicts an inverted U-shaped curve with income per capita and also that the more biological species-rich a country is, the more threatened species it holds. Moreover, compared to developing countries, high-income countries definitely appear to be threatening fewer animal and plant species, suggesting a possible peaceful cohabitation. Relative species poverty, production sectors (mostly secondary and tertiary) and mainly ecologically unequal trade seem to be some of the forces behind the peaceful cohabitation observed in high-income countries.

*This Chapter is based on Lawson, L. and Nguyen-Van, P., 2018. "Is a peaceful cohabitation between living species possible? An empirical analysis on the drivers of threatened species," Working Papers of BETA N^o. 2018-19, UDS, Strasbourg.

2.1 Introduction

The current biodiversity crisis raises questions on the future of human society and for a wide range of researchers, biodiversity loss threatens human well-being. This impossible cohabitation perspective is animated in ecological economics by researchers such as Tisdell (2011) and Diaz et al. (2006), among others, and in environmental sociology by the treadmill of production theory (Schnaiberg, 1980; Schnaiberg et al., 2002). Furthermore, it has promoted systematic investigations on the potential for human society to destroy natural habitat through theoretical and empirical studies on deforestation and species loss (John and Pecchenino, 1997; Koop and Tole, 1999; Brock and Taylor, 2010; Chaudhary and Brooks, 2017; Damania et al., 2018). This paper offers a new insight into the empirical side by investigating whether a peaceful cohabitation is possible, analysing the determinants of animal and plant species loss and assessing the forces behind patterns observed in species loss.

The Living Planet Index (LPI) over the last 50 years shows an overall declining trend in low-income countries, while an upward trend suggesting prosperous conservation and a peaceful cohabitation is noticeable in high-income countries (Figure 2.3). In a global perspective however, this observation remains questionable, since recent studies on deforestation and biodiversity loss not only points out the role of local factors but also of trade and ecologically unequal exchanges in the observed patterns (Rudel and Roper, 1997; Sanderson, 2005; Lenzen et al., 2012; Jorgensen, 2016). Thereby, two main interrogations arise: What drives animal and plant species loss in high and low-income countries? Is there a peaceful cohabitation between human and natural habitats? Our paper provides some insights into these queries considering the main biotic components of ecosystems: Animal and plant species.

The existing literature solely focuses on the case of endemic species in the well-known taxonomic groups such mammals, birds, amphibians, fish, reptiles, among others, working out the role of human population and economic expansion. In this literature, contrary to global patterns observed in the LPI, results supporting a peaceful cohabitation, (known as Environmental Kuznets Curve (EKC) for threatened species or extinction risk) are very scarce. Moreover, this literature has let aside the case of endangered plant species notwithstanding the importance of plants in an ecosystem. Hence, the contribution of our paper is twofold. Firstly, globally targeting threatened animal and plant species while distinguishing high and low-income countries helps explore the peaceful cohabitation hypothesis, going beyond patterns suggested by the LPI. Secondly, contrary to existing studies on forest cover or deforestation (e.g. Jorgensen et al., 2010; Leblois et al., 2017), considering threatened plant species precisely tackles a further aspect of species loss and natural habitat destruction, which surprisingly has been less addressed by existing economic studies.

To the best of our knowledge, there are relatively very few studies investigating at a global scale the peaceful cohabitation between natural and human habitats, addressing initial conditions and income level heterogeneities. Aiming to fill that gap, this paper considers as proxy for the threat to natural habitat the total count of *critically endangered, endangered* and *vulnerable* animal and plant species, as the latter provide aggregate measures of the threat to the major biotic components of ecosystems.[1] Thereby, we address endogeneity for income by the control function approach, initial condition for biodiversity by the total species identified and non-linearity in the income-threatened species nexus by a non-parametric curve. Finally, our results suggest an apparent harmonious cohabitation in high-income countries. Separating high and low-income countries provides some hints about the mechanisms behind the observed patterns in biodiversity loss and habitat destruction.

Section 2 overviews the related literature. Section 3 presents the data and in Section 4 we discuss the income-threatened species nexus. Section 5 describes the econometric specification. Section 6 presents the results of our empirical analysis. In Sections 7, we discuss the results and finally Section 8 draws some conclusions.

2.2 Related literature

Broadly addressing species loss, we essentially focus on theoretical and empirical studies on the resources depletion, species loss and human habitat expansion nexus. Theoretical works on species loss as consequences of economic activities and population growth seem relatively few. Still, they permit an understanding of how

[1] It hides however the threat level in each taxonomic group e.g. birds, mammals, amphibians,...

economic expansion affects natural habitat. Tisdell (2011) holds aggregate economic activities responsible for biodiversity loss, while Lanz et al. (2018) point to intensive agriculture. Likewise, Cabo (1999), Polasky et al. (2005) and Alam and Quyen (2007) propose North-South models that highlight the role of global trade. Specifically, as introduced by Flam and Helpman (1987) and Copeland and Kotwal (1996), Alam and Quyen (2007) by assuming the South to be rich in forest land, outline how an unsustainable population growth in the South may have the same effects on biodiversity as trade openness.[2] Similar contributions to this literature led by Rosen et al. (1994), Farrow (1995), Carlos and Lewis (1999), and Taylor (2011) have been focused on the extinction of specific species.

Using economic theory to explain species loss actually traces back to the 1950s and even earlier. Gerhardsen (1952) and Scott (1954) followed by Schaefer (1957), Clark (1973) and Huang and Lee (1976), to cite a few, are some of the pioneers analysing species over-exploitation in economic frameworks. More recently, the question of ecosystem depletion has become whether nature will always be able to support human habitat, as the excessive demand of natural resources causes environmental issues. This treadmill of production and neo-Malthusian perspectives are discussed by Smith (1975), Schnaiberg and Kenneth (1994) and Brander and Taylor (1998), among others. For these researchers, ecosystem depletion and species loss threaten human societies and can lead to disastrous consequences.

Empirically, the scholarship explores the drivers of extinction, testing the EKC-hypothesis for threatened species.[3] Thereby, significant contributions are by researchers such as Asafu-Adjaye (2003), Freytag et al. (2012) and Polaina et al. (2015), among others. Despite the Fuentes' (2011) argument for the absence of conflicts between economic growth and biodiversity, results based on a wide range of indicators suggest that human population dynamics, urbanization and economic expansion harm biodiversity. Verboom et al. (2007) for instance project a decline of biodiversity, while McDonald et al. (2008), Leblois et al. (2017) and Damania

[2]Trade may impel the South to clear forests in order to satisfy the global demand for agricultural goods.

[3]The EKC hypothesis globally states that in the process of development, environmental depletion decreases after a certain level in GDP. Our focus being risks of species loss, we wish to abstract from the large literature on EKC for the diverse environmental indicators and the challenges or criticism surrounding its existence.

et al. (2018) stress the role of urbanization, trade and road infrastructure, as the latter shrink distances to parks and lead to habitat destruction.

It is to mention that investigating an EKC for biodiversity loss is a delicate exercise. Indeed, contrary to gas emissions where countries are supposed to reduce their gas emissions after a certain level of income, biological species cannot be as easily reconstituted once extinct. Nevertheless, focusing on the threat to biodiversity such an investigation is feasible since the indicators are stocks of endangered species. In so doing, Dietz and Adger (2003) and Mills and Waite (2009) using a species richness index, Hoffmann (2004) and McPherson and Nieswiadomy (2005) using a calculated endangering rate for mammal and bird species whereas Halkos and Tzeremes (2010) using a biodiversity performance measure, find results indicating that economic growth is not neutral in biodiversity loss. Relying solely on the count of threatened species classified into seven taxonomic groups, Kerr and Currie (1995), Naidoo and Adamowicz (2001), Majumder et al.(2006), Perrings and Halkos (2010), and Freytag et al. (2012) provide results stating that economic growth harms biodiversity by increasing the number of endangered species.

It is noticeable that the existing literature, with few exceptions, do not permit to claim neither an EKC for threatened mammals, amphibians, birds, among others, nor a peaceful cohabitation between economic activities and the latter species groups. Moreover, plants being the main biotic components of ecosystems, more attention should be given to the drivers of threatened plant species, in identifying the ecological impacts of human habitat. This unfortunately has been less regarded in existing empirical studies. Based on this literature review, most recurrent drivers of species loss are economic expansion (per capita GDP, industrial and agricultural production), urbanization, population growth and trade openness. The following Section discusses the data exploited in our study.

2.3 Data and descriptive statistics

2.3.1 The data

Indicators of biodiversity: To assess the drivers of habitat destruction, this paper exploits count of animal and plant species classified by the IUCN Red List as being threatened. Precisely, these are species known as vulnerable, endangered and critically endangered, since facing an extremely high risk of extinction (see Table 2.4 for more details on the species classification criteria). This includes all taxonomic categories (among others mammals, birds, reptiles for animals and algae, mushrooms for plants) and seems highly heterogeneous. However, when assessing the peaceful cohabitation hypothesis, these counts serve as aggregate proxies for the threats to natural habitat. Substantive contributions separating classes can be found in the existing literature (see e.g. Naidoo and Adamowicz, 2001; Perrings and Halkos, 2010; Freytag et al., 2012).

Explanatory variables: With regard to threats to natural habitat, the UICN lists habitat disturbances, over-exploitation and pollution. In addition, the existing literature helps identify aggregate economic production, trade openness and intensive agricultural production (Cabo, 1999; Alam and Quyen, 2002; McPherson and Nieswiadomy, 2005; Mills and Waite, 2009); human population growth and urbanization (McDonald et al., 2008). Thus, to capture human activities, we use income per capita in purchasing power parity (PPP, in 2011 $), population density, imports and exports in GDP, industry and agriculture added values (share of GDP). Further control variables such as the share of forest land, net inflows of foreign direct investments, climate zones, institutional quality and government expenditures on goods and services are also included. Political institutions correspond to the index of control for corruption, whereas climate zones are measured by distance to Equator. These explanatory variables are drawn from the World Development Indicators.

Table 2.1: Descriptive statistics

Variables	Units	Mean	S.D.	Min.	Max.	Obs.
lnGDP per capita	\$, PPP 2011	9.10	1.24	6.34	11.82	1210
Threatened plant species	Counts	51.86	111.07	0	1839	1232
Total plant species	Counts	151.88	199.29	21	2542	1232
Threatened animal species	Counts	123.39	147.45	5	1009	1253
Total animal species	Counts	1131.61	929.15	18	5733	1253
Climate zone	Latitude	25.32	17.06	0.22	64.15	1253
Forest area	% area	32.54	23.88	0.00	98.46	1061
Agricultural land	% land area	40.291	21.69	0.453	84.642	1253
Rents of natural resources	% GDP	2.57	5.19	0.00	43.85	1011
Industry, added value	% GDP	28.52	13.06	4.00	78.20	1110
Agriculture, added value	% GDP	13.31	12.65	0	58.21	1103
Foreign direct investment	% GDP	5.586	11.910	-43.463	255.423	1253
Exports	% GDP	43.293	29.630	5.517	230.269	1253
Imports	% GDP	49.467	27.701	11.254	246.812	1253
Population density	$1000/km^2$	0.32	1.55	$1.69e-3$	19.07	1235
Control for corruption	Index	-0.08	0.99	-1.92	2.52	1253
Government expenditures on GS	% total GE	17.48	11.93	2.21	75.73	887
Africa						
lnGDP per capita	\$, PPP 2011	8.010	1.058	6.340	10.668	364
Threatened plant species	Counts	47.372	79.652	0	496	363
Total plant species identified	Counts	155.647	154.836	2	1066	363
Threatened animal species	Counts	98.964	91.836	10	550	364
Total animal species identified	Counts	1195.39	686.359	101	3666	364
America						
lnGDP per capita	\$, PPP 2011	9.314	.752	7.315	10.861	214
Threatened plant species	Counts	92.257	160.308	1	1839	217
Total plant species identified	Counts	205.244	267.171	108	2542	217
Threatened animal species	Counts	174.811	205.911	33	1009	217
Total animal species identified	Counts	1600.77	1268.853	19	5358	217
Asia						
lnGDP per capita	\$, PPP 2011	9.231	1.172	7.197	11.821	392
Threatened plant species	Counts	62.066	129.022	0	706	377
Total plant species identified	Counts	155.566	227.030	1	1522	377
Threatened animal species	Counts	156.497	174.761	7	806	392
Total animal species identified	Counts	1133.959	1046.448	28	5733	392
Europe						
lnGDP per capita	\$, PPP 2011	10.119	.646	8.205	11.208	280
Threatened plant species	Counts	11.924	29.711	0	214	275
Total plant species identified	Counts	99.764	121.431	1	738	275
Threatened animal species	Counts	68.925	60.088	5	334	280
Total animal species identified	Counts	681.807	317.022	18	2363	280

Notes: Counts of countries = 179; period: 2008-2014; number of observations: 1253. The counts of animal and plant species have been taken from "Red List Category Summary" and include for animals the number of identified vertebrates (amphibians, birds, fish, mammals, reptiles) and invertebrates (insects, molluscs, crustaceans, corals and others). For plants, the counts include mosses, algae, mushrooms among others.

Overall, the dataset includes 179 countries and covers the period between 2008-2014. Table 2.1 reports descriptive statistics of the main variables involved in our study. Thereby, one notices high standard deviations (S.D.) in the counts of animal and plant species, signalizing a high dispersion sample. The highest levels in per capita GDP are observed in Macau, Qatar and Luxembourg. Regarding threatened species, the highest values are observed in the USA and in Ecuador; the fastest population growth rates are observed in Qatar (2008-2010) and Oman (2010-2013). By focusing only on regional data on average, European countries show relatively low animal and plant species richness (total species) followed by Asia, Africa and America. Observed counts of threatened animal and plant species follow similar classification. Considering income level however, the highest GDP per capita are observed in Europe.

2.3.2 Data on threatened species

Eppink et al. (2007) and Bartkowski et al. (2015) discussed the complexity and the multidimensionality of the concept of biological diversity which justifies the existence of several proxies. In our case, using counts of threatened species as indicator of natural habitat destruction seems suitable but implies non-standard modelling, since the key distributional assumptions (normality and homoscedasticity) are not fulfilled for applying standard linear techniques (Hoffmann, 2004 and Cunningham and Lindenmayer, 2005). Therefore, it becomes important to preliminary have an insight into the count data (i.e. the number of threatened animal and plant species).

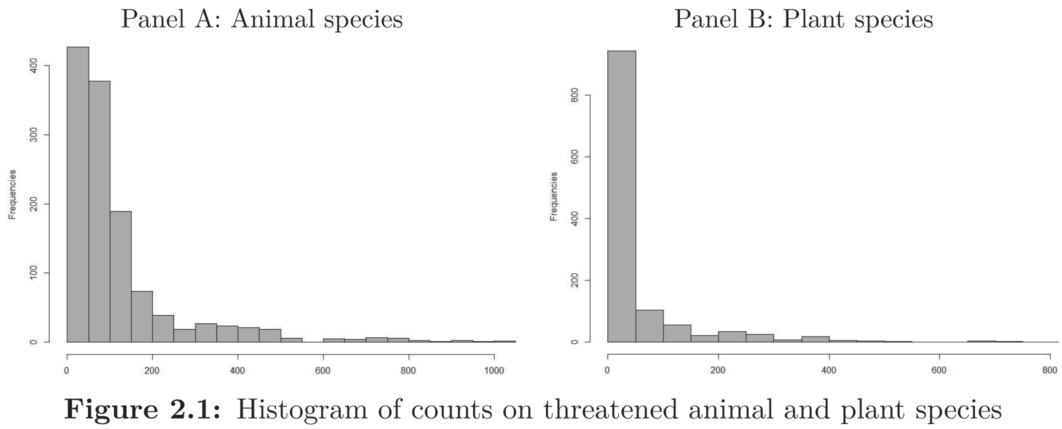


Figure 2.1: Histogram of counts on threatened animal and plant species

For this purpose, in addition to Table 2.1, we propose a histogram of our series on threatened animal and plant species which provides some relevant details regarding the symmetry or skewness of the distribution. Figure 2.1 indicates that the series on our response variables, counts of threatened animal and plant species, are strongly right-skewed. Appropriate techniques to model these data are discussed in the next two Sections.

As a parametric specification could be misleading in investigating the shape of a complex relationship, the following proposes a prior non-parametric analysis uniquely focused on the relationship between our variables of interest, per capita GDP and the number of threatened animal and plant species.

Data transformations for regression models in exponential families are often used to modify count data, making non-parametric regression procedures easily feasible (Brown et al., 2010).[4] In empirical studies and using data on threatened species, Dietz and Adger (2003) and Mills and Waite (2009) divide the number of species by the country size, Hoffmannn (2004) by the total number of species whereas Perrings and Halkos (2010) for instance use a log-transformation. Following the latter authors, we modify our data using a $\log(y_{it} + k)$ operator as proposed by Anscombe (1948), with $0 \leq k \leq 1$.[5] Thereby, the negative binomial (NB) mean-variance relation, $\sigma_y^2 = \mu_y + \frac{1}{k}\mu_y^2$, is used to compute k.[6] Exploiting the log-transformed counts, the Nadayara-Watson (local constant kernel) estimator is applied to the non-parametric regression of $\log(y_{it} + \hat{k})$ on log-income per capita (x_{it}).

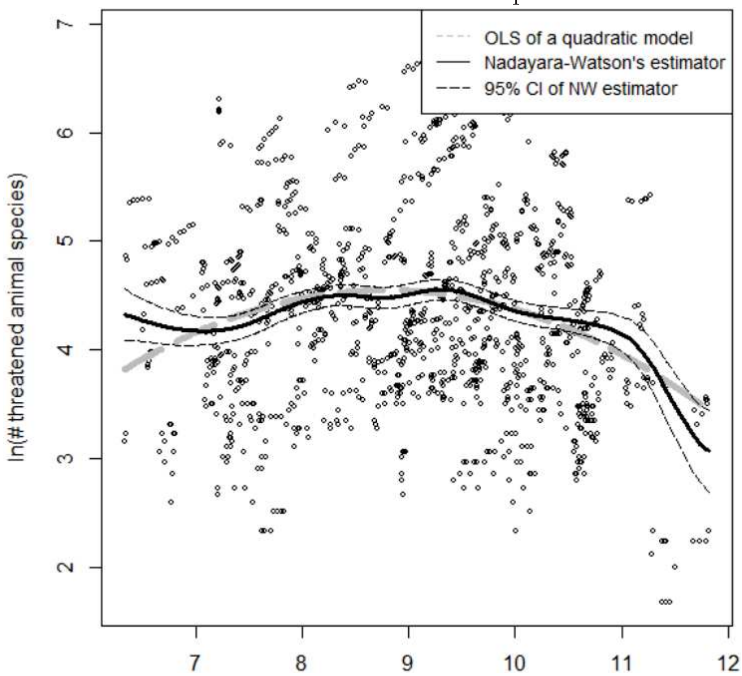
The main objective is to directly estimate $m(x_{it}) \equiv E[\ln(y_{it} + \hat{k}|x_{it})]$. Moreover, as the ecological modernization theory predicts that environmental harms will slow down and even be compatible along economic development, using for response variable log-modified or time-averaged counts should permit to appropriately investigate the income-threatened species nexus. The results of the local constant kernel estimation are displayed in Figure 2.2.

[4]See for contributions to the topic Anscombe (1948), Hoyle (1973) and Brown et al. (2010).

[5]Lambert et al. (2010) and Cameron and Trivedi (1998) proposed different approaches in estimating k.

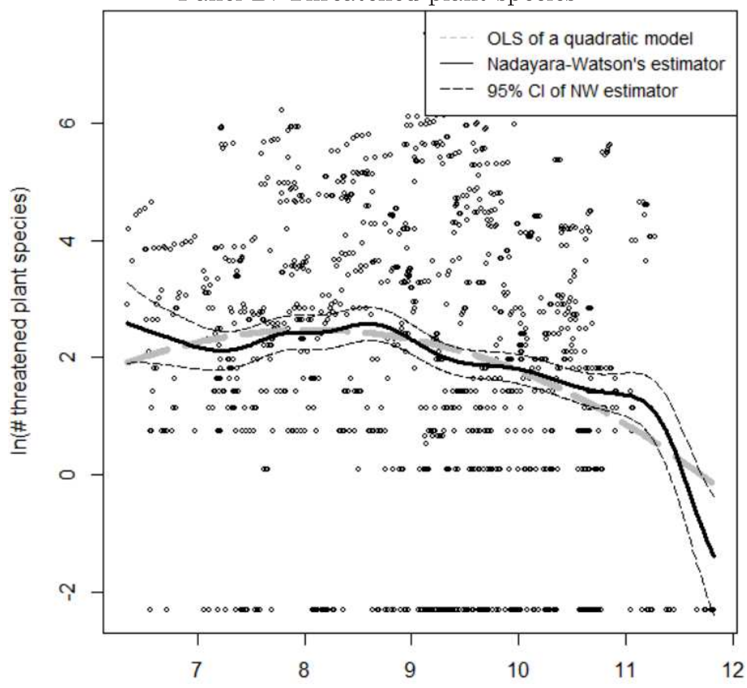
[6]It is to mention that σ_y^2 and μ_y respectively stand for variance and mean of the dependent variable.

Panel A: Threatened animal species



lnGDP per capita

Panel B: Threatened plant species



lnGDP per capita

Figure 2.2: Non-parametric model of log-modified count on threatened species and lnGDP per capita.

Note: The black curves are the NW-estimator and its 95% confidence interval. The grey curve corresponds to the OLS regression of a quadratic model. As Bandwidth parameter, we rely on Silverman's rule of thumb, since the latter works well for approximately normal densities.

In the case of animal species, a slight upward trend in the number of threatened species for low-income levels is noticeable. This trend is reversed after a certain level in log-income per capita, the turning point being around the mean of the sample. Hence, low-income levels are positively linked to increasing threatened species, while the situation reveals to be more optimistic in high-income countries. Regarding threatened plant species, the regression lines show similar patterns. For low-income levels, no clear conclusion can be made, as the confidence interval is quite large. After the sample's mean of lnGDP per capita, circa 9.10 $, the results are analogous to those obtained in the case of animal species. This suggests that in high-income countries, economic activities do not conflict with plant species, confirming theoretical predictions of the EKC literature.

The previous results however suffer two major drawbacks. Indeed, the initial condition of species richness (total species) was not controlled for. In addition, the optimistic patterns observed in high-income countries may correspond to the fact that large species were exhausted in the past (by economic activities) so that the number of threatened species observed is much lower than in low-income countries. Our analysis will appropriately address these two issues (initial condition and endogeneity of income) in order to deliver consistent estimations. Thus, the results can be interpreted as causal link between income and species loss. Nevertheless, the patterns observed (Figure 2.2) motivates the use of a quadratic function of income in our parametric econometric modelling. The following Section discusses regression models for count data.

2.4 Econometric specification

2.4.1 The count model

To assess the determinants of animal and plant species loss while testing the peaceful cohabitation hypothesis, we use parametric count data regression methods. Exploring count data, the econometric literature (Cameron and Trivedi, 2013; Hilbe, 2011) argues for the use of Poisson-gamma mixture models. Considering the number of threatened species (y_{it}) to be Poisson distributed, $f(y|x) = \frac{e^{-\mu}\mu^y}{y!}$, and assuming independence between the vector of exploratory variables (x_{it}) and the error term (ε_{it}), we start from the following model.[7]

$$\mu_{it} \equiv E\left[y_{it}|x_{it}\right] = \exp(x'_{it}\beta),\ i = 0, 1, \cdots, N;\ t = 0, 1, \cdots, T. \tag{2.1}$$

We note that x_{it} contains, among others, variables such as population density, share of forest and agricultural land, exports and imports. Species richness (measured by total species identified) is also included into the model to control for the initial condition. Moreover, lnGDP per capita enters non-linearities in the model via a quadratic function, as identified in the previous Section. Model (1) can suffer from two major issues. Firstly, patterns of overdispersion in the data on threatened species are observed (Table 2.1). Therefore, a NB distribution releasing the mean-variance equality assumption should be considered. Secondly, the model assumes independence between the unobserved errors ε_{it} and the regressors x_{it}. Indeed, there might be a reverse causality between GDP per capita and biodiversity indicators, as production activities can be reversely explained by exploitation of natural resources and ecosystem services. This corresponds to our discussion above regarding income and the initial condition. Such an endogeneity issue leads to biased estimation (Cameron and Trivedi, 2013). A very straightforward and novel way to deal with that issue is by the control function approach (CFA) for non-linear models discussed in Winkelmann (2008) and Wooldridge (2014, 2015).

2.4.2 Endogeneity

Let x_1 be an endogenous regressor (GDP per capita for instance) and also a set of valid excluded instruments Z. The CFA proposes a first-stage regression whose residuals are introduced back into the conditional mean equation of the second stage estimation (i.e. Equation(1)). It is to mention that the first stage regression model includes all explanatory variables except x_1 in addition to the excluded instruments Z. That is:

[7] Our dataset having a very small T, associated with low time variability in the response variable for a relatively high number of individuals (N=179), we assume homogeneity of the slope coefficients over time and pool the data. Econometric tests (see Baltagi and Griffin, 1997; Pesaran and Smith, 1995; Baltagi et al., 2008) indicates that in panel data with T very small, pooled estimators are also a viable choice.

$$x_1 = \rho Z + x'_{-1}\delta + v, \text{ where } v|x_i, Z \sim N(0, \sigma^2 I). \tag{2.2}$$

where x'_{-1} indicates the set of explanatory variables excluding x_1. The second stage regression considers the conditional mean (equation (1)) augmented by $\hat{v}_{it} \equiv x_1 - \hat{\rho}Z_1 - x'\hat{\delta}$ as an additional explanatory variable:

$$\mu_{it} \equiv E\left[y_{it}|x_{it}, x_{1,it}\right] = \exp(x'_{it}\beta + \lambda\hat{v}_{it}) \tag{2.3}$$

Wooldridge (2015) mentions that introducing the first-stage residuals in equation (3) controls for the endogeneity of x_1. Moreover, it serves the purpose of producing a heteroscedasticity robust endogeneity test.[8] Relying on the control function approach in NB regression models, parameters β and λ can be estimated using maximum likelihood.

2.5 Estimation results

2.5.1 Tests for overdispersion

Before any estimation, it seems important to test for overdispersion, which implies checking the mean-variance equality assumption of the Poisson distribution, as huge differences are observed between the mean and the variance of the series on threatened animal and plant species (Table 2.1). Dean and Lawless (1989) and Hilbe (2011) propose a Z-score test which seems straightforward. Applying the latter to the different model specifications, we find results suggesting overdispersion in the counts on threatened species (Table 2.2). Thus, modelling counts of threatened species, overdispersion should be considered as in NB model.

2.5.2 Determinants of biodiversity loss

Considering the counts of threatened species to be NB distributed, the econometric literature indicates that NB estimates are asymptotically normal, efficient and unbiased. However, this unbiasedness is violated in presence of regressor endogeneity, as

[8] The null hypothesis H_0: $\beta_v = 0$ corresponds to x_1 exogenous. See also Wooldridge (2014)

previously mentioned regarding GDP per capita. We tackle this issue by exploiting the CFA (Wooldridge, 2014, 2015) discussed above. To instrument for GDP per capita, we rely on political institutions and government expenditures, namely the index of control for corruption and the share of goods and services expenditure (% of total government expenditures). The latter seem to be good instruments since economic theory acknowledges government expenditures and good political institutions as driving macroeconomic performances. Also, they show high correlation with lnGDP per capita.

Since our dataset has a very small T characterized with low time-variability in the response variable for a relatively high number of individuals N, we rely on pooling the data. In addition to over-dispersion tests and first stage regressions, we report the results of estimating the parameters of different NB model specifications in Table 2.2. Observing the results for both animal and plant species, one notices that compared to a linear fit a quadratic specification in lnGDP per capita fits better the data. This corroborates the discussion in Section 3 which suggests a non-linear modelling for the economic growth and threatened species nexus. By comparing information criteria, Model 4 shows larger predictive power and therefore will be considered to discuss the peaceful cohabitation hypothesis.

- Animal species: Our results broadly indicate that the expansion of human habitat's characteristics is not neutral in biodiversity loss, as income per capita and human population dynamics significantly affect the number of threatened animal species. More precisely, our parametric estimations reveal a non-linear relationship between income per capita and threatened animal species implying that economic activities increasingly threaten biodiversity in low-income countries, while it decreasingly does in high-income countries. Such a result, largely known in the existing literature as the presence of an EKC relationship, seems to hold as the parameter of the quadratic term remains statistically significant throughout specifications 2, 3 and 4. This suggests an inverted U-shaped relationship for species, which indeed supports a peaceful cohabitation in high-income countries, as suggested by the patterns observed LPI's over 1970-2005.

Besides tests of the peaceful cohabitation hypothesis, controlling for species richness and climate zone by using the total number of animal species identified and distance from equator indicates that more threatened animal species lie in species-rich regions while less are found in countries far from the equator. These results imply that in tropical zones, where biodiversity mostly lies, relatively high species are threatened by extinction.

As Polasky et al. (2002) and by Alam and Quyen (2007) argue that trade openness and agricultural production lead to deforestation and species loss in the South, we include agricultural production, exports, imports and forest cover in the regression. It results that forest size is positively linked to the number of threatened animal species.

Forests largely serving as natural habitat for species, it is not surprising to observe that the larger forest size there is in a country, the more threatened species it shelters. Concerning agricultural land, its GDP share and exports, our results do not globally support conclusions by Alam and Quyen (2007). Agricultural production (share in GDP) and exports are not to blame for threatening animal species, at least when considering the whole sample. Additionally, FDI and exploitation of natural resources do not globally drive biodiversity loss. Countries of our sample being at different stages of development, separating countries according to income level and considering geographical subsamples will probably help more clearly apprehend the role of trade openness and agriculture in endangering species.

A final interesting result in the case of animal species is the role of human population growth. Population density is found to have a positively effect on the number of species at threat, meaning that the higher human population is, the more threatened animal species there are. Such a result underlines the existence of a possible competitive exclusion over habitat between human population and animal species, all other things being equal.

Table 2.2: Results of estimating negative binomial models for threatened species

				Second stage regressions				
	Panel A: Animal species				Panel B: Plant species			
Covariates / Models	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Intercept	10.20**(4.33)	10.89**(4.56)	−23.50 (31.58)	28.79 (35.49)	10.29(7.14)	12.25*(7.59)	−65.32 (61.31)	10.02 (7.49)
GDP per capita	.068 (.061)	2.034***(.479)	1.629***(.447)	.740* (.480)	−.363***(.090)	4.259***(.884)	2.274***(.836)	1.800* (.575)
Squared GDP p. c.		−.106***(.027)	−.078***(.024)	−.050**(.024)		−.247***(.048)	−.094**(.047)	−.088* (.055)
Total species identified			.064***(.004)	.056***(.005)			.045***(.008)	.003***(.001)
Climate zone			−.017***(.002)	−.015***(.003)			−.072***(.006)	−.074***(.008)
Forest area			.002* (.001)	.001 (.001)			.018***(.004)	.021***(.003)
Agricultural land			.004***(.001)	−.005 (.016)			.026***(.004)	.020***(.004)
Rents of resources				−.003 (.004)				−.013 (.009)
Industry				−.011**(.005)				−.007 (.008)
Agriculture				−.033***(.008)				−.024 (.020)
FDI, net inflows				−.007 (.033)				.001 (.007)
Exports				−.001 (.004)				.006 (.010)
Imports				−.011***(.004)				−.031***(.009)
Population density				.027**(.013)				.054* (.030)
Time trend	.053***(.021)	.052**(.023)	.010(.016)	.016 (.019)	.055*(.035)	.054(.037)	.027 (.067)	.048***(.016)
$\hat{v}_{GDP}$	.061 (.085)	−074(.076)	−075*(.044)	.481***(.116)	.745***(.160)	.347** (.139)	−303**(.147)	.045 (.361)
Number of obs.	872	872	739	625	855	855	726	631
AIC criterion	10148	10129	7790.3	6494	7355.7	7325.8	5635.8	4869.4
Log likelihood	-5069.136	-5058.556	-3885.137	-3229.977	-3656.883	-4255.516	-2807.878	-2419.708
				First stage regressions for GDP per capita				
	Model 1 & 2		Model 3	Model 4	Model 1 & 2		Model 3	Model 4
Intercept	5.279 (.137)		4.708(3.091)	4.49 (18.75)	5.279 (.137)		5.412*(3.169)	8.662 (19.297)
Index of Corruption	.687***(.029)		.528***(.031)	.273***(.023)	.687***(.029)		.521***(.030)	.275***(.023)
Government expenses	−.024***(.002)		−.016***(.003)	−.004**(.002)	−.024***(.002)		−.016***(.003)	−.004**(.002)
Total species identified			.012***(.003)	.005**(.002)			.080***(.016)	.004***(.001)
Climate zone			.022***(.002)	.012***(.001)			.023***(.002)	.012***(.001)
Forest area			−.002*(.001)	−.002*(.001)			−.001 (.001)	−.002*(.001)
Agricultural land			−.012***(.001)	−.005***(.001)			−.011***(.001)	−.004***(.001)
Rents of resources				−.004** (.002)				−.004*(.002)
Industry				.003 (.002)				.002 (.002)
Agriculture				−.047***(.002)				−.047***(.002)
FDI, net inflows				.001 (.001)				.001 (.001)
Exports				.016***(.002)				.015***(.001)
Imports				−.014***(.002)				−.014***(.002)
Population density				−.006 (.009)				−.006 (.009)
Time trend	.002 (.014)		−.019 (.015)	.007 (.009)	.002 (.014)		−.022 (.016)	.005 (.010)
F-stat. (p-value)	308.6 (.000)		187.8 (.000)	350.9 (.000)	308.6 (.000)		192.1 (.000)	355.3 (.000)
Adjusted R-squared	.514		.639	.887	.515		.649	.888
				Tests for overdispersion				
Z-score	123.49	123.64	32.953	31.932	173.48	152.21	63.286	48.076
p-value	.000	.000	.000	.000	.000	.000	.000	.000

Notes: Dependent variables are the counts of threatened animal and plant species. Bootstrapped standard errors in brackets. Unbalanced panel data, with $N = 179$ and $T = 7$. $\hat{v}_{GDP}$ stands for the control function relatively to GDP per capita. Regarding the first stage regressions, dependent variable is GDP per capita (in log). Robust (HAC) standard errors in brackets. For the overdispersion tests, the null hypothesis is equi-dispersion. Table 2.5 & 2.6 in Appendix reports results using mean-centered GDP per capita and controlling for country dummy. Significance level: "***" 1%, "**" 5% and "*" 10%.

- Plant species: The results in Table 2.2 Panel B are derived using the same methodology and instrumental variables as in the case of animal species. Here also, comparing information criteria indicates that NB models including GDP per capita and its quadratic form correspond much better to the data. Thus, results of the NB Model 4 strengthen conclusions regarding an inverted U-shaped relationship between the number of threatened plant species and income per capita, since the linear term of GDP per capita is positively related to the response variable, whilst its squared form shows a negative link. Likewise, the patterns observed in Figure 2.2 and the outcomes of this parametric analysis support a declining trend in the numbers of threatened species after a certain level of GDP per capita.

Controlling for the total number of species identified and climate zone, we find results revealing that more threatened plant species are located in tropical and species-rich countries. Furthermore, the positive and significant effects of forest observed here implies that the larger forest share countries have, the more plant species-rich they are and consequently the more threatened plant species they shelter. Also, increases in land devoted to agricultural production lead to plant species loss, likely through forest clearing. Once again, FDI, trade openness and rents of natural resources are globally not to blame for biological species. Human population dynamics, captured by population density, is positively and significantly linked to the number of threatened plant species, supporting our first argument regarding possible conflicts over habitat between human population and other biological species.

It is to notice that this parametric analysis globally supports the patterns observed in Figure 2.2, which hint that an apparent peaceful cohabitation between economic activities and biodiversity is underway in high-income countries. The results also identify that human population growth as driving biodiversity loss, providing evidence of a possible global competition between human population and biodiversity over habitat.

2.5.3 Regional heterogeneities

In order to investigate whether heterogeneities exist over regions, the same analysis is performed using data classified by continent (Table 2.3). Thereby, we further use the control function approach in solving for potential endogeneity with respect to income per capita.

- Africa: Being mostly in tropical zones and largely covered by forest, animal and plant species-rich African countries are also those sheltering relatively high numbers of species threatened by extinction. Besides these environmental factors, FDI, exports and population growth appear to be the main factors threatening biodiversity in Africa, supporting the conflicting cohabitation argument. Exports, mostly of primary goods and raw material, threaten species in Africa.

- America: A non-linear relationship is observed between the number of threatened animal and plant species and income. Besides climate zones, our results show that larger forest covered American countries also shelter more threatened animal and plant species. Increasing agricultural land and exports enhance the threat to biological species. However, no conflict is observed between population dynamics and others biological species in America.

- Asia: The results suggest an inverted U-shaped curve between the number of threatened species and income per capita, similar to those observed in Figure 2.2 for the whole sample. In addition, species-rich and large forest covered Asian countries shelter relatively high threatened animal and plant species. Human population dynamics are not significantly harmful to biodiversity in Asia.

- Europe: Regarding animal species, the results also indicate that species-rich and large forest covered European countries shelter relative high threatened species. The share of agricultural land positively drives biodiversity loss, while population density has no impact on endangered species. Finally, relatively high plant species are at threat in European countries which larger share of industrial value-added in GDP.

This regional analysis has revealed the divergent role played by FDI, exports and population dynamics in driving species loss. While FDI, human population dynamics and exports promote biodiversity loss in Africa, they are found to be insignificant to species loss in Europe and Asia. In complement, we disentangle countries according to income levels using the sample median of GDP per capita (in log) to distinguish high and low-income countries.

- High-income countries: An inverted U-shaped relationship appears between GDP per capita and threatened species, supporting a possible harmonious cohabitation between biological species and human economic activities. However, the initial condition for biodiversity (species richness) matters as well, since the more species-rich high-income countries are, the more threatened animal species they shelter. Among our control variables, it is to observe that exports, industrial production and population dynamics do not harm biological species in developed countries.

- Low-income countries: Focusing on threatened plant species, our results signal a upward trend which implies that more plant species are threatened by extinction with increasing income per capita. This contradicts the peaceful cohabitation hypothesis. Moreover, in contrast to developed countries, FDI, industrial production, exportation and human population growth positively drive species loss, enhancing conflicts between human and natural habitats in developing countries.

Table 2.3: Regional heterogeneities: Estimation of NB models for animal and plant species

Panel A: Animal species

Covariates / Models	Africa	America	Asia	Europe	High-income	Low-income
Intercept	6.351 (6.410)	5.607(4.801)	5.516 (4.120)	−12.360**(4.740)	−4.19 (3.479)	4.466 (4.910)
GDP per capita	−.538 (1.530)	−8.465***(2.010)	3.492***(.767)	.465 (1.081)	1.056***(.163)	−.340 (1.240)
Squared GDP per capita	.001 (.093)	.387***(.102)	−.155***(.035)	−.015 (.050)	−.530***(.079)	.030 (.073)
Total animal species	.006***(.001)	.005***(.000)	.041***(.005)	.058***(.023)	.057***(.004)	.046***(.008)
Climate zone	.051***(.013)	.020* (.010)	−.045***(.006)	−.066***(.007)	−.023***(.004)	−.011**(.005)
Forest area	−.003 (.005)	.008* (.005)	.003 (.002)	.005* (.003)	−.005***(.002)	.003 (.002)
Agricultural land	−.002 (.004)	.009***(.003)	.006**(.003)	.008** (.003)	−.008 (.022)	−.005 (.003)
Rents of natural resources	.010 (.011)	.001 (.011)	−.003 (.004)	.017* (.009)	.002 (.004)	−.019**(.007)
Industry, value added	−.043***(.010)	−.014 (.009)	−.023***(.005)	.004 (.005)	−.022***(.006)	.004 (.009)
Agriculture, value added	−.027**(.011)	−.120***(.023)	.022 (.019)	.008 (.012)	−.020 (.019)	−.006 (.007)
FDI, net inflows	.026**(.012)	.017 (.014)	−.006 (.009)	−.002 (.003)	−.003 (.003)	.026**(.010)
Exports	.038** (.016)	.012*(.007)	−.004 (.004)	.004 (.007)	.003 (.006)	.008 (.059)
Imports	−.025**(.011)	−.023***(.007)	−.014***(.00)	−.021**(.009)	−.014**(.007)	−.007* (.004)
Population density	.003***(.001)	−.003 (.005)	−.004* (.002)	−.027 (.023)	−.006 (.020)	.013**(.005)
Time trend	.036 (.031)	−.003 (.025)	−.034* (.020)	.063***(.024)	−.002 (.017)	.025 (.025)
$\hat{v}_{GDP}$	.712**(.370)	.624* (.376)	−.725***(.256)	−.120 (.190)	.742***(.263)	.103 (.218)
Number of countries	52	31	56	40	92	92
Number of obs.	135	118	151	228	363	269
AIC Criterion	1326.8	1193.8	1592	1919.6	3646.9	2267.1
Log Likelihood	-646.396	-579.905	-778.983	-510.833	-1806.434	-1116.539

Panel B: Plant species

Covariates / Models	Africa	America	Asia	Europe	High-income	Low-income
Intercept	8.410***(1.133)	10.26(9.024)	−7.602 (10.80)	−2.849**(1.090)	−2.689***(1.022)	8.799(19.03)
GDP per capita	−2.254(2.406)	−6.152*(3.760)	4.428* (2.378)	1.009 (3.825)	3.434***(.637)	−1.014 (0.914)
Squared GDP per capita	.079 (.146)	.156 (.200)	−.190* (.114)	−.044 (.179)	−1.679***(.305)	.047***(.005)
Total plant species	.014***(.002)	.004***(.001)	.009**(.004)	.006**(.001)	.003***(.001)	.005*(.003)
Climate zone	.045* (.025)	.042* (.027)	−.109***(.012)	−.104***(.014)	−.091***(.010)	−.053*** (.002)
Forest area	.012* (.007)	.025**(.012)	.029***(.007)	−.005 (.007)	.004 (.004)	.020*** (.004)
Agricultural land	−.004 (.008)	.014*(.008)	.062***(.007)	.019***(.006)	.015***(.005)	.009**(.004)
Rents of natural resources	−.039**(.018)	.016 (.028)	−.037*** (.013)	.048**(.021)	−.024* (.014)	−.056***(.009)
Industry, value added	.021 (.014)	−.037*(.023)	.006 (.013)	.047***(.014)	−.016 (.004)	.027***(.001)
Agriculture, value added	.016 (.017)	−.286***(.047)	.073 (.052)	−.304 (.049)	−.039 (.056)	−.012 (.022)
FDI, net inflows	.019 (.014)	−.022 (.032)	−.084**(.033)	.006 (.0302)	−.003 (.009)	.041***(.011)
Exports	.073***(.028)	−.001 (.015)	.035***(.012)	−.033*(.018)	.022 (.019)	.039**(.012)
Imports	−.041***(.016)	−.016 (.014)	−.067***(.011)	.021 (.001)	−.052***(.021)	−.031***(.002)
Population density	.005***(.001)	−.003***(.001)	−.002**(.001)	−.002** (.023)	−.005 (.008)	.003**(.001)
Time trend	−.413***(.055)	.019 (.045)	.028 (.053)	.142***(.053)	.051 (.048)	−.040 (.091)
$\hat{v}_{GDP}$	1.312*(.704)	2.087**(.849)	−1.94***(.688)	−.326 (.574)	.183 (.752)	.368 (.764)
Number of countries	52	31	56	40	92	92
Number of obs.	135	118	148	224	356	269
AIC Criterion	1030.8	1161.7	1160.3	1055.7	2467.7	2267.1
Log Likelihood	-498.389	-563.862	-563.138	-510.833	-1216.86	-1116.539

Notes: Dependent variables are counts of threatened animal and plant species. Bootstrapped standard errors in brackets. Significance level: "***" 1%, "**" 5% and "*" 10%. See Table 2.2 for further comments..

The income level analysis points out further heterogeneities, which globally support disparities observed in the regional assessment. For both species group, after controlling for initial condition and endogeneity, a peaceful cohabitation with economic expansion is noticeable in high-income countries. Also, human population growth and exports enhance species loss only in low-income countries. Finally, contrasting results appear between regions regarding the role of exports, FDI and industrial production activities.

2.6 Discussion: Beyond the peaceful cohabitation

Our analysis globally reveals non-linearities in the income and threatened species nexus, which overall associates threats to animal and plant species with income levels by an inverted u-shaped curve. In addition, it provides hints on the opposite role played by population growth, FDI, industrial production and exports. While these variables negatively affect the number of endangered species indicating a possible peaceful cohabitation in developed countries, they drive biodiversity loss in low-income countries. Such findings enlighten some of the mechanisms behind the patterns depicted by Figure 2.2.

Regarding species richness, it is to notice that high-income countries, mostly non-tropical countries, shelter relatively few animal and plant species compared to low-income countries, mostly tropical countries (Polasky et al., 2005 and Giam, 2017). Furthermore, our analysis controlling for species richness show that the more species-rich countries are, the more threatened species they shelter. This implies that compared to developing countries, high-income countries also hold relatively few threatened animal and plant species. However, it is to underline that species extinct during the first stages of economic development cannot be recovered, making ecological modernization theory-based projections somewhat fragile, when it comes to biodiversity.[9] With regard to the peaceful cohabitation hypothesis, these arguments point to a relative species poverty in high-income countries, providing first

[9]This theory hypothesizes that "while the most challenging environmental problems have been caused by modernization and industrialization, their solutions must necessary lie in more – rather than less – modernization and super-industrialization" (see Lippert, 2007).

explanations to the declining counts of threatened animal and plant species with income level.

Concerning international trade, the recent critical EKC literature (Wagner, 2008, 2010; Kaika and Zervas, 2013; Rodriguez et al., 2016) and works by sociologists on the treadmill of production (Schnaiberg, 1980; Gould et al., 2004) as well as on ecologically unequal exchange theory (Jorgensen, 2016 and Jorgenson and Dick, 2010) go a step ahead by shedding light on the mechanisms behind the observed trends. The treadmill of production theory discusses the existence of perpetual conflicts between economic expansion and nature while the ecologically unequal exchange theory points out the role of trade in externalizing environmental degradation. As human habitat endlessly uses natural resources to produce consumption goods and generates wastes, it continually destroys natural habitat, making cohabitation between natural and human habitats hardly peaceful. In this context, a strategic externalization of ecosystem damaging production activities (environmental unfriendly manufactures) to developing countries may lead to EKC relationships in high income countries in the sense that environmental harms and issues related to habitat destruction are displaced to low income countries. Similar results are noted in the theoretical analyses by the North-South model by Polasky et al. (2002) and Alam and Quyen (2007). Empirically, the results by Jorgenson and Dick (2009) and Hornborg (2012) show that trade's structure (mainly flow of primary sector goods) may help high-income countries to partly pass their demand-based ecological impact to developing ones. Our analysis distinguishing low and high-income countries leads to conclusions fairly supporting the ecologically unequal exchange theory and the results by Lenzen et al. (2012) and Chaudhary and Brooks (2017), since industrial production, FDI and exports endanger biological species. Based on these findings, one can legitimately argue that industrial production in poor countries (mostly in the primary sector and exports of raw materials) threatens animal and plant species, whereas both tertiary sectors production and trade appear to be ecosystem friendly in high-income countries.

In addition to the disparate role of human population growth in threatening biodiversity only in low-income countries, relative species richness and international trade are some of the mechanisms allowing a decreasing link between species loss with income, suggesting that a peaceful cohabitation between habitats is possible in high-income countries.

2.7 Concluding remarks

Existing studies on biodiversity loss strongly underlines conflicts between livings species, a competitive exclusion. In relation to economic and population growth, this implies that human society and economic activities (human habitat) grow at the expense of non-human species.[10] In this perspective, human habitat seems to be a predator to natural habitat and biodiversity.

Applying count data regression and control function approach, the paper supports the idea that economic activities have an impact on natural habitat destruction. However, this impact is non-linear, similarly to an inverted U-shape. The latter globally indicates that species loss tends to slow down with economic development, suggesting a possible peaceful cohabitation between habitats in high-income countries. Such a result can be linked to the patterns in the Living Planet Index (LPI), observed between 1970 and 2005 (see Figure 2.3). In tropical climate zones, where developing countries mostly lie, a rapidly decreasing trend in LPI is observed, contrary to temperate climate countries where an upward trend is noticed. Human population (population density) globally conflicts with biodiversity.

Furthermore, distinguishing high from low-income countries reveals the distinct roles of trade, FDI and industrial production, providing hints about the forces behind the peaceful cohabitation. While exports, FDI and industrial production are biodiversity-friendly in high-income countries, they are found to be enhancing species loss in developing countries.

Our study on the peaceful cohabitation between natural and human habitats can be extended in different ways. A promising extension could be in proposing a population-resource model for resources-based economies (Africa for instance) and then using available data on biodiversity and population growth to simulate the joint evolution of population, deforestation and animal and plant species stock.

[10] The concept is known as *Gause's law* and can be found in Czech (2004, 2008).

Appendix

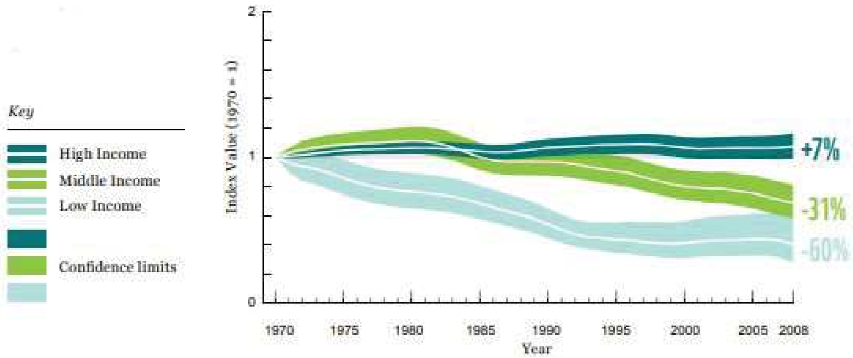


Figure 2.3: Living Planet Index by country income group The index shows a 7% increase in high-income countries, a 31% decline in middle-income countries and a 60% decline in lowincome countries between 1970 and 2008 (Source: WWF/ZSL, 2012).

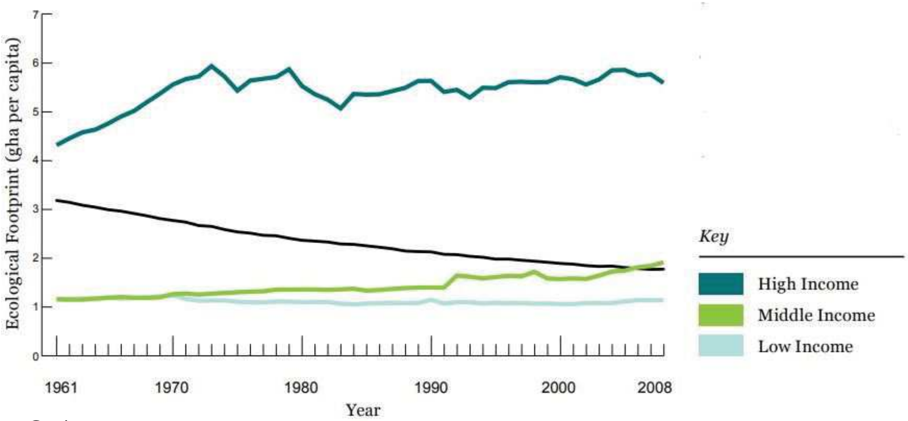


Figure 2.4: Ecological Footprint per person in high-, middle- and low-income countries between 1961 and 2008. The black line represents world average biocapacity (Source: Global Footprint Network, 2011).

SUMMARY OF THE FIVE CRITERIA (A-E) USED TO EVALUATE IF A TAXON BELONGS IN AN IUCN RED LIST THREATENED CATEGORY (CRITICALLY ENDANGERED, ENDANGERED OR VULNERABLE).[1]

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

- **A1** Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.
- **A2** Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.
- **A3** Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3]*.
- **A4** An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

- **(a)** direct observation *[except A3]*
- **(b)** an index of abundance appropriate to the taxon
- **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- **(d)** actual or potential levels of exploitation
- **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)

	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km²	< 5,000 km²	< 20,000 km²
B2. Area of occupancy (AOO)	< 10 km²	< 500 km²	< 2,000 km²
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented **OR** Number of locations	= 1	≤ 5	≤ 10

(b) Continuing decline observed, estimated, inferred or projected in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals

(c) Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals

C. Small population size and decline

	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) **(i)** Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(ii) % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population

	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	**D1.** < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	**D2.** typically: AOO < 20 km² or number of locations ≤ 5

E. Quantitative Analysis

	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

1 Use of this summary sheet requires full understanding of the *IUCN Red List Categories and Criteria* and *Guidelines for Using the IUCN Red List Categories and Criteria*. Please refer to both documents for explanations of terms and concepts used here.

Table 2.4: Species classification criteria (Source: IUCN)

(a) Animal species **(b) Plant species**

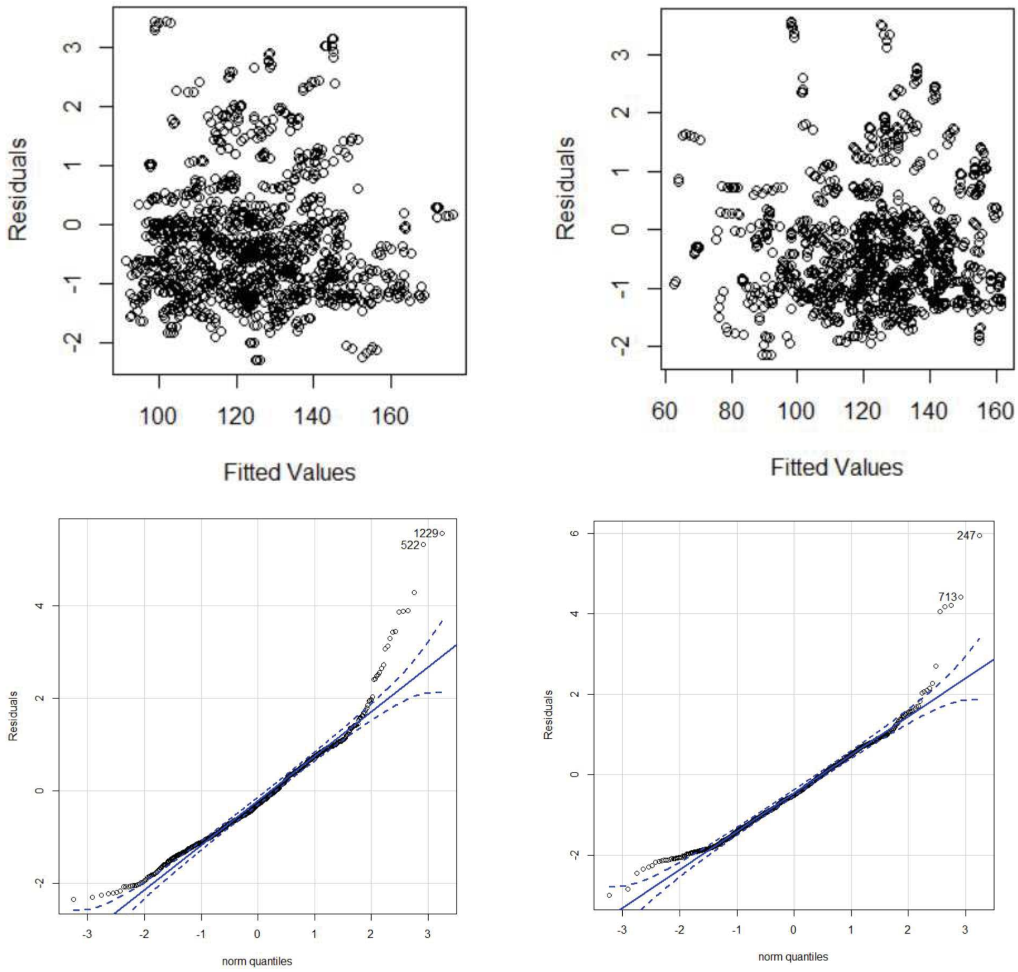


Figure 2.5: Residuals diagnostics Model 4, Table 2.2

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

Table 2.5: Results of NB estimation controlling for country-dummies

	(a) Animal species			(b) Plant species		
Covariates / Models	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Intercept	4.924***(.485)	−2.338(1.851)	2.498 (2.223)	8.751***(.649)	−3.488 (2.925)	−8.639*(4.812)
lnGDP per capita	−.029 (.054)	1.557***(.418)	.643* (.409)	−.548***(.068)	2.097***(.638)	2.781***(.908)
Squared lnGDP per capita		−.085***(.023)	−.041**(.018)		−.141***(.034)	−.162***(.045)
Total species identified			.577***(.033)			.438***(.039)
Climate zone			−.013***(.002)			−.045***(.007)
Forest area			.002* (.001)			.012*** (.002)
Mean years of schooling			.007 (.012)			.089**(.039)
Rents of natural resources			−.002 (.003)			−.013(.014)
Foreign direct investment			−.016 (.273)			.102 (.535)
Agriculture, value added			−.027***(.007)			−.028* (.015)
Industry, value added			−.006 (.004)			.010 (.017)
Trade			−.005***(.001)			−.009***(.003)
Population density			.302*(.128)			.272(.471)
$\hat{v}_{GDP\text{p.c.}}$	.138**(.067)	.014 (.068)	.188** (.092)	.876***(.112)	.632*** (.120)	.123 (.194)
Country dummy	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Number of obs.	1210	1210	846	1190	1190	837
AIC criterion	14050	14034	8856.2	10484	10473	6774.5
Log likelihood	-7020.228	-7010.922	-4412.087	-5236.816	-5230.418	-3371.229

Note: See Table 2.6 below for comments

Table 2.6: NB Estimation using mean-centered per capita GDP

	Animal species			Plant species		
Covariates / Models	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Intercept	4.658*** .080)	4.771***(.092)	4.939***(.021)	−.705***(.167)	4.064***(.072)	4.373***(.470)
lnGDP per capita	−.029 (.053)	.004 (.053)	−.106 (.087)	−.275***(.065)	−.457***(.056)	−.206 (.181)
Squared lnGDP per capita		−.085***(.023)	−.042**(.019)		−.138***(.031)	−.146***(.045)
Total species identified			.577***(.035)			.443***(.039)
Climate zone			−.013***(.002)			−.043***(.008)
Forest area			.002*(.001)			.012***(.002)
Mean years of schooling			.007 (.013)			.010 (.020)
Rents of natural resources			−.002(.003)			−.013(.014)
Foreign direct investment			−.157 (3.259)			.096 (.514)
Agriculture, value added			−.027***(.008)			−.029**(.014)
Industry, value added			−.006* (.004)			.011 (.017)
Trade			−.005***(.001)			−.010***(.002)
Population density			.302**(.138)			.443(.466)
$\hat{v}_{GDP\text{ p.c.}}$	.139**(.067)	.014 (.066)	.188** (.099)	.100**(.042)	.621 (.061)	.184 (.195)
Country dummy	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Number of obs.	1210	1210	846	1190	1190	837
AIC criterion	14059	14044	8663.2	10483	10437	6790.3
Log likelihood	-7025.521	-7017.044	-4416.592	-5237.518	-5231.509	-3380.159

Notes: Dependent variable is the counts of threatened animal and plant species. Bootstrapped standard errors in brackets. Unbalanced panel data, with n=179 and T=7. "***", "**" and "*" respectively stand for significance level at 1, 5 and %.

3. A simple Ricardo-Malthusian model of population, forest and biodiversity

Abstract: This paper assesses the interactions between human and nature, arguing that population growth and forest resources use cause natural habitat conversion, which resolves into biodiversity loss. Relying on profit and utility maximization behaviours, we describe the joint evolution of population, forest and species stock by a dynamic system characterized by a locally stable steady state. Compared to existing studies, we enlighten the possibility of total extinction of biological species. Furthermore, our analysis supports an impossible peaceful cohabitation, as in the presence of human population growth, forest resources and species stock diverge from their carrying capacity. Finally, scenarios analyses associated with high fertility and preference for the resource-based good globally indicate rapid population growth followed by a sudden drop.

3.1 Introduction

The Limit to Growth (Meadows et al., 1974) is among first global level reports, discussing the ecological constraints faced by human societies and predicting population overshoot. In the same perspective, environmental degradation and unsustainable resource extraction, which translate into deforestation, habitat destruction, climate change and biodiversity loss, have provoked systematic inquiries towards understanding the cohabitation between human and nature, as well as their long-run dynamics. Thereby, several studies have been devoted to how biodiversity loss occurs and affects biogeochemical cycles and human societies.

About the causes of species loss, empirical studies largely mention economic expansion and population growth (Fuentes, 2011; Chaudhary and Brooks, 2019), while the International Union for Conservation of Nature (IUCN) mainly blames natural habitat destruction. Theoretically, existing studies in ecological economics predominantly discussed resources depletion within economic and bioeconomics frameworks, capturing such complex environmental issues using a single parameter or indicator (Brander and Taylor, 1998; D'Alessandro, 2007). Moreover, it is noticeable that compared to gas emissions and energy use, biodiversity loss has received relatively few attention in the existing literature, though scientist acknowledge it impacts to rival those of many other environmental issues (Edwards and Abivardi, 1998; MEA, 2005). Extending existing studies, this paper proposes a population, forest and biodiversity model, arguing that the latter occurs through forest degradation and conflicts with human population over habitat.

Two main approaches are observed in modelling population-resources dynamics: Ecologically inspired models and Economic-type models (Nagase and Uehara, 2011; Roman et al., 2018). In contrast to ecological models, economic models provide the microeconomic foundations, (agents' decisions), which evidently drive the dynamics of population and resources. This is the case in Brander and Taylor (1998), Dalton and Coats (2000), D'Alessandro (2007) and Nagase and Uehara (2011), among others. The present paper proposes, in addition to the well-known population-forest nexus, to discuss species loss. Doing so, contrary to the common theoretical perspective, where the production technology directly uses natural resources as input, our approach considers that species richness is not a direct input in the production process, while forest resources are.

Prior Predator-Prey and human-nature dynamical models (Brander and Taylor, 1998; Motesharrei et al., 2014) provide basic foundations to the specifications used in this paper. The first component of our model is a Malthusian population dynamics, where birth and death rates drive population growth in addition to a resource-dependent fertility function. The second component describes the evolution of forest stock, specified as the difference between its regeneration and harvest. Microeconomic foundations on individual behaviours provide insights into how preferences shape the joint evolution of population and resources. The third component, the evolution of species stock, is driven by forest clearing and population growth induced species loss.

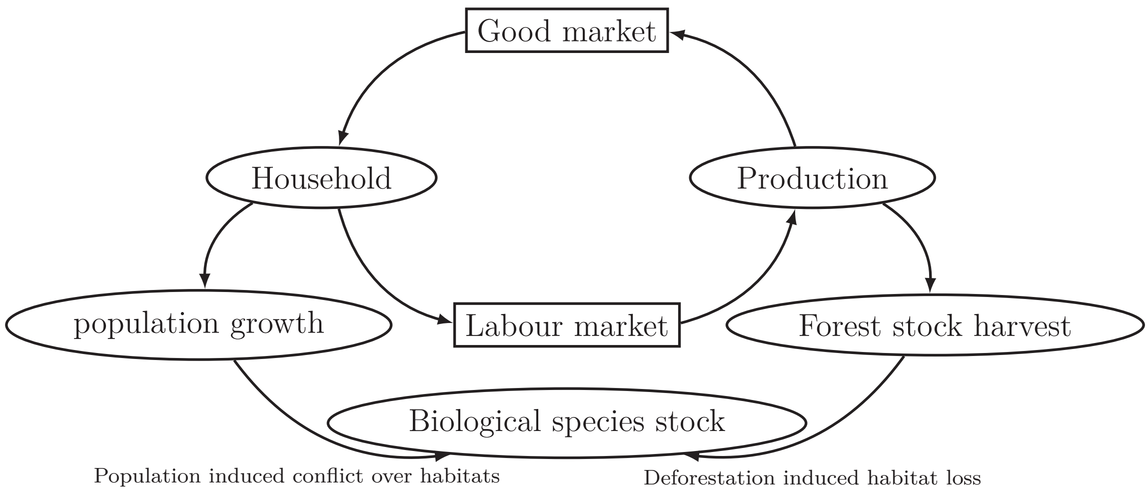


Figure 3.1: Synopsis of the population-forest-biodiversity model

Biodiversity, the number and variability of living organisms, reveals to be complex but can be seen as a stock.[1] Our purpose being neither estimating species population nor valuing species, we employ a single indicator of species stock. Such a perspective deliberately disregards the width and complexity of the concept of biodiversity. However, similar to physical capital, a unique indicator helps end-up with a broad and tractable model for species loss.

[1]Cambridge Dictionary. It includes several different species, more than a million according to the most pessimistic estimates, ranging from bird and mammal species to bacteria and microscopic.

Section 2 presents a brief literature overview. Sections 3 and 4 respectively describe the basis structure of the model and discuss the population and resources dynamics. Section 5 analyses stability of the population-forest-biodiversity model and Section 6 assesses some scenarios. In Section 7, we discuss our results and draw some conclusions.

3.2 A brief literature review

Founding works on human-resources interactions and concerns over societal collapses are the predator-prey models and "The Limit to Growth" perspectives discussed, among others, by Levin, (1974), Meadows et al., (1974) and Weitzman (1998). On the one hand, the literature on economic expansion, population growth and resources scarcity is animated by ecological-type models, where mostly numerical methods are exploited. On the other hand, researchers rely on microeconomic grounded models to assess how preferences affect wealth, population and resources dynamics. Both analytical frameworks and discussions about endogenous population growth and collapse of past societies seem relevant to the present paper.

Ecological-type models. This generation of studies largely derives from the Lotka-Volterra model describing the joint-evolution of two competing species (wolves and rabbits) and apply the latter to human and nature dynamics. This has been the case in Anderies (1998, 2003), Turchin (2003) and Janssen et Scheffer (2004), to cite a few. Thereby, Anderies (1998, 2000) exploits ritual lash-and-burn cycles to explain human-ecosystem interactions in the Tsembaga of New Guinea and the rise and fall of Easter Island. Turchin (2003), noting that population is historically characterized by oscillations, discusses and applies several population models to empirical data.

In a different perspective, computable general equilibrium models are exploited to analyse the human and nature dynamics in the works among others by Tschirhart (2000), Basener and al., (2008), Finnoff and Tschirhart (2008), Motesharrei et al., (2014) and Brandt and Merico (2015). Globally, these authors exploit mathematical tools to address more specific societal concerns within the Predator-Prey perspective. Thus, Finnoff and Tschirhart (2008), for instance, associate dynamic economic and ecological models to investigate how changes in price affect population, resources harvest and tourism. While Basener and al. (2008) and Brandt and Merico (2015) introduce rat infestations and epidemic in population-resources models for Easter Island, Motesharrei et al. (2014) discussed the role of social stratification (elites and commoners) in wealth accumulation and resource dynamics. Although this ecological literature provides us with tools to access population-resources dynamics, it lacks insights into individual behaviour and preferences that shape the global dynamics.

Economic type models. Contrary to ecological models, economic models propose a framework inspired by neoclassical theories, using assumption with regard to utility and profit maximization. Although being restrictive due to its microeconomic foundation, this approach has received relatively large attention, at least in the economic literature. Among the most recent works on boom and bust cycles, the seminal paper by Brander and Taylor (1998) on the historical case of Easter Island has inspired a sequence of studies about environmental resources and economic systems. This has been the case in Dalton and Coats (2000), Bologna and Flores (2008) and Roman et al. (2017), to cite few.

Population-resources models associate Lotka-Volterra ecological perspectives to economic models to assess how endogenous population growth and resource degradation can lead to collapse. In the same vein as Brander and Taylor (1998), Dalton and Coats (2000), Erickson and Gowdy (2000) and Reuveny and Decker (2000) discuss how institutional settings, technological progress and fertility management affect the population and resource dynamics. Furthermore, while Pezzey and Anderies (2003) extend Brander and Taylor (1998) to assess how subsistence level of resource consumption and institutional settings can prevent a collapse, Dalton et al. (2005) discuss the role of property-rights regimes and technological changes in slowing down (or amplifying) boom and bust cycles. In more recent literature, D'Alessandro (2007), Bologna and Flores (2008), Zhou and Liu (2010) and Roman et al. (2017) propose more general frameworks, relaxing standard assumption of the Brander and Taylor's (1998) model, as there seems to be no-perfect specification of population-resources model (Basener et al., 2008). This has given insight into non-linearity, hopf-bifurcation in the conditions leading to collapse in population-resources models. A final aspect of these models has been investigating historical collapses such as the Mayan and Mesopotamian civilizations as well as Ancient Egypt and the Roman empire. Thereby, arguments such as cultural-historical factors, trade characteristics and war (Demerest et al., 2004), diseases and environmental degradations (Acuna-Soto et al., 2005; Roman et al., 2017) are noticed.

Globally, whether the focus is on biological-type or economic-type models, it is noticeable that issues related to species loss have not been specifically targeted. Indeed, Brander and Taylor (1998) and related contributions have discussed forest resource depletion. Nevertheless, these population-resources studies did not consider informative to dissociate deforestation from biological species loss. The present paper aims to fill that gap by introducing issues relative to species loss into population-forest models.

3.3 The basic structure of the model

As in population-resources models, this paper considers a two production sectors economy: A manufacture and a forest resource harvest sector. The manufactured good is produced by a representative firm using only labour, L_M, while the resource-harvest sector employs labour, L_H, and forest resources, F. Labour is freely mobile across sectors, implying wage equality between sectors ($w_H = w_M = w$). The structure of the model described hereafter closely follow resource-population discussions in Brander and Taylor (1998), Dalton and Coats (2000), Nagase and Uehara (2011), among others.

3.3.1 Firms' behaviour

Manufactures: They are considered as numeraire using a Ricardian production function $Y_{M,t} = L_{M,t}$, where L_M stands for the quantity of labour used in sector M. Assuming the price of the good to equal one, the optimal behaviour of the representative firm is:

$$\underset{L_{M,t}}{Max}\, \Pi_{M,t} \; with \;\; \Pi_{M,t} = Y_{M,t} - w_t L_{M,t} \equiv L_{M,t} - w_t L_{M,t} \tag{3.1}$$

Profit maximization yields $w_{M,t} \equiv w_t = 1$.

Harvest sector: Forest resources use is governed by the supply of good, H, using the well-known Schaefer (1957) production function, $Y_{H,t} \equiv H(F_t) = qE_tF_t$, where E_t is the harvest effort (labour) and q a positive parameter to be seen a scaling parameter or level of technological knowledge. Since there are no property rights over land, the firm i hires a quantity of labour, $L_{H,t} \equiv E_t$, to maximize the following function:

$$\underset{L_{H,t}}{Max}\,\Pi_{H,t} \; with \;\; \Pi_{H,t} = p_H Y_{H,t} - w_{H,t}L_{H,t} \equiv p_H q L_{H,t} F_t - w_{H,t}L_{H,t} \tag{3.2}$$

First order condition of profit maximization yields: $p_H q F_t = w_{H,t}$ which implies:

$$p_{H,t} = \frac{w_{H,t}}{qF_t} \tag{3.3}$$

(3) expresses the supply price of the harvest good, $p_{H,t}$, as positively dependent on the wage rate and negatively on forest resources harvested in the production process.

3.3.2 Preference and budget constraints

At each period t, a new generation of agents is born and lives 2 periods, childhood and adulthood. Adult individuals in t (born in $t-1$) are endowed with one unit of time which they supply inelastically to labour force participation to earn w_t. By definition, children consume a fraction of their parents' time endowment and do not make any economic decision. Thus, adult individuals (N_t) choose the optimal mixture of M and H to maximize their utility function. Such formulations of individuals' behaviour are intensely described in De La Croix and Michel (2002) and Galor (2011).

The utility function of the representative agent is defined over consumption of the resources and harvest goods H_t and M_t, respectively $c_{H,t} \equiv C_{H,t}/N_t$ and $c_{M,t} \equiv C_{M,t}/N_t$. The problem of the representative individual is:

$$\underset{h_t,m_t}{Max}\, U(c_{H,t}, c_{M,t}) \text{ with } U(c_{H,t}, c_{M,t}) = (c_{H,t})^{\gamma}\,(c_{M,t})^{1-\gamma} \;\text{ where }\; \gamma \in (0,1) \tag{3.4}$$

$$\text{subject to } w_t = p_{H,t}c_{H,t} + c_{M,t} \;\text{ and }\; c_{H,t}, c_{M,t} > 0$$

Solving the maximization problem for a representative agent delivers $c^*_{H,t} = w_t\gamma/p_{H,t}$ and $c^*_{M,t} = w_t(1-\gamma)$, which for N individuals correspond to:

$$C^*_{H,t} = \gamma w_t N_t / p_{H,t} \quad \text{and} \quad C^*_{M,t} = (1-\gamma) w_t N_t \tag{3.5}$$

C^*_H and C^*_M are the aggregate demand for the resources and the manufactured goods.

3.3.3 Competitive equilibrium and market clearing

A competitive equilibrium is a sequence of allocations $\{Y_{H,t}, Y_{M,t}, F_t, L_{H,t}, L_{M,t}\}_{t=1}^{\infty}$ and prices $\{w_t, p_{H,t}\}_{t=1}^{\infty}$ given initial values F_0 and N_0 such that consumers and firms maximize their objective functions and markets clear. As there are two consumption goods in the economy, the market clearing conditions for the goods and labour markets respectively are:

- Labour market: $N_t = L_{M,t} + L_{H,t}$
- Good markets
  - Manufactured good M: $$L_{M,t} = (1-\gamma)w_t N_t \equiv C^*_{M,t} \tag{3.6}$$
  - Resources harvest good H: $$H(F_t) = \gamma w_t N_t / p_{H,t} \equiv C^*_{H,t} \tag{3.7}$$

Using FOC of profit maximization, $p_H q F_t = w_{H,t}$, $w_t = 1$, (7) becomes:

$$H(F_t) = \gamma q N_t F_t \tag{3.8}$$

Definition 1. *Considering q and γ, an equilibrium is an infinite sequence of prices $\{w_t, p_{H,t}\}_{t=1}^{\infty}$, allocation $\{C_{H,t}, C_{M,t}\}_{t=1}^{\infty}$ and $\{L_{H,t}, L_{M,t}\}_{t=1}^{\infty}$ such that:*
– Households maximize their utility function;
– Firms maximize their profit;
– Markets clear for all generations.

3.4 Dynamics of population, forest and species

3.4.1 Population dynamics

As biologists describe the Malthusian population growth as depending on the birth and death rates, human population growth is observed when the birth rate, (b), exceeds the death rate, (d). In addition to these two parameters, the literature in a predator-prey perspective argues that natural resources availability and harvest increase fertility and specifies population dynamics as positively depending on $\phi(F_t) \equiv H(F_t)/N_t$.

$$N_{t+1} = N_t + N_t(b - d + \alpha\phi(F_t)) \tag{3.9}$$

where b, d and α are positive parameters, $b - d$ is likely negative, $\alpha\phi(F_t)$ being the so-called "fertility function". Exploiting (8), the dynamical evolution of population becomes:

$$N_{t+1} = N_t + N_t(b - d + \alpha\gamma q F_t) \tag{3.10}$$

3.4.2 Forest dynamics

Forest resources in period t, besides being used in production H, regenerate over time. Therefore, forest clearing is essentially governed by the demand, respectively supply of the resources dependent good, thus the harvest function (8). Considering $G(F_t)$ to be the regeneration function, the evolution of forest stock is given by: $\Delta F = G(F_t) - \gamma q N_t F_t$.

Regarding regeneration of forest, bio-economists (Clark, 1974; Chasnov, 2009) discuss population models for renewable resources. The most common approach is the logistic model, satisfying the conditions: $G(0) = 0$ and $G(\overline{F}) = 0$, where $\overline{F}$ is the carrying capacity. Using a logistic population model for forest resources and assuming g to be the regeneration rate, the dynamics of forest cover is given by:

$$F_{t+1} = F_t + gF_t(1 - F_t/\overline{F}) - \gamma q N_t F_t \tag{3.11}$$

3.4.3 Dynamics of species stock

Forest cover, providing a number of ecosystem services, is also considered to be natural habitat for biodiversity, hosting a variety of biological species, B_t. In this perspective, harvest of forest resources drives biodiversity loss, $E(B_t)$. Since extinct species cannot be recovered, we assume that identification or discovery of new species essentially governs regeneration of biodiversity, $I(B_t)$. The dynamics of species stock can be specified as:

$$B_{t+1} = B_t + I(B_t) - E(B_t) \tag{3.12}$$

Biodiversity loss: Existing studies present harvest of resources as a function of labour force employed in resource sector. Regarding biodiversity however, the stock of species is not a direct input in the production function and our approach considers that species loss occurs through habitat destruction or forest resources harvest, H_t.

Since habitat conversion also occurs through human settlements (McDonald et al., 2008; Mills and Waite, 2009; Freytag et al., 2012), population growth is considered as a second cause of species loss. Accounting for both forest resources harvest and human population growth as driving species loss implies: $E(B_t) \equiv E(F_t, N_t, B_t) = \delta_1 \gamma q N_t F_t B_t + \delta_2(b - d + \alpha\gamma q F_t) N_t B_t$, where $0 < \delta_1, \delta_2 < 1$.

Species identification: Recovering extinct species being impossible, we consider new species identification as the main source of regeneration. Using a logistic growth function for biological entities (Brown, 2000; De Vries et al., 2006; Hannon and Ruth, 2014), species regeneration is given by $I(B_t) = g\left(B_t - B_t^2/\overline{B_t}\right)$, where $\overline{B_t}$ is the maximum possible species stock.

Introducing species loss and regeneration functions in (12) delivers the dynamics of biodiversity as depending on F_t and N_t. This is:

$$B_{t+1} = B_t + g\left(B_t - B_t^2/\overline{B_t}\right) - \delta_1 \gamma q N_t F_t B_t - \delta_2(b - d + \alpha\gamma q F_t) N_t B_t \tag{3.13}$$

3.5 Steady state and linear stability analysis

3.5.1 Steady state

The model is characterized by the joint evolution of population, forest resources and species stock. Combining equations (9), (11) and (13), the dynamic system is given by the following equations, assuming a positive regeneration rate:

$$\Delta N = N_t(b - d + \alpha\gamma q F_t) \tag{3.14}$$

$$\Delta F = g F_t(1 - F_t/\overline{F}) - \gamma q N_t F_t \tag{3.15}$$

$$\Delta B = g\left(B_t - B_t^2/\overline{B_t}\right) - \delta_1 \gamma q N_t F_t B_t - \delta_2(b - d + \alpha\gamma q F_t) N_t B_t \tag{3.16}$$

This system reaches a steady-state, if simultaneously $F_{t+1} = F_t$, $N_{t+1} = N_t$ and $B_{t+1} = B_t$. Thereby, one realises that the evolution of F_t and N_t is independent on B_t. Analysing steady-state, it is sufficient to observe the joint evolution of F_t and N_t, which actually is similar to the in-death bivariate steady-state analysis proposed in Brander and Taylor (1997, 1998), Dalton and Coats (2000) and Bologna and Flores (2008).

Proposition 1 *The dynamic system described by equations (14), (15) and (16) exhibits four feasible steady-states. Steady states 1, 2 and 3 are corner solutions, while steady state 4 is an internal solution, respectively represented by the following threesomes.*[2]

ss1. $N^* = 0,\ F^* = 0,\ B^* = 0$

ss2. $N^* = 0,\ F^* = \overline{F},\ B^* = \overline{B}$

ss3. $N^* = \frac{g}{\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q \overline{F}}\right),\ F^* = \frac{d-b}{\alpha\gamma q},\ B^* = 0.$

ss4. $N^* = \frac{g}{\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q \overline{F}}\right),\ F^* = \frac{d-b}{\alpha\gamma q},\ B^* = \overline{B}\left[1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q \overline{F}}\right)\right]$

It is to note that $N^* = \frac{g}{\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q \overline{F}}\right) \equiv \frac{g}{\gamma q}\left(1 - F^*/\overline{F}\right)$. Positivity conditions for N^*, F^* and B^* at steady-state 3 and 4 require $0 < d - b < 1$ and imply the following:

$$0 < F^* = \frac{d-b}{\alpha\gamma q} < \overline{F} \tag{3.17}$$

$$0 < \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q \overline{F}}\right) < 1 \tag{3.18}$$

$$0 < B^* = \overline{B}\left[1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q \overline{F}}\right)\right] < \overline{B} \tag{3.19}$$

Our aim being the joint evolution of population, forest and species stocks, we focus on *ss*.4 and assess how changes in the model's parameters affect N^*, F^* and B^* by differentiating the latter with respect to (d), (b), (α), (γ) and (q).

Proposition 2 *1. The steady-state stock of forests F^**

– *rises if the mortality rate (d) rises and birth rate (b) falls;*

– *rises if the fertility responsiveness to resources abundance falls (α) and preference for the resources-based good (γ) rises;*

– *falls with technological progress in the resources harvest sector (q).*

2. The state state adult population level N^*

– *falls if mortality rate (d) rises and the birth rate (b) falls;*

– *rises if the fertility responsiveness rises (α) and carrying capacity $\overline{F}$ rises;*

– *falls if there is technological progress in the resources harvest sector (q) and*

[2] Further steady states such as $N^* = 0, F^* = \overline{F}, B^* = 0$ and $N^* = 0, F^* = 0, B^* = \overline{B}$ exist but are unrealistic, since the first implies that even in the absence of population, resource stocks can reach 0 and the second that in absence of forest, species stock reaches its carrying capacity.

$F^* < \overline{F}/2$.

– falls if preference for the resources-based good (γ) rises and $F^* < \overline{F}/2$.

3. The steady-state stock of biological species B^*

– rises with increasing mortality rate (d) if $F^* > \overline{F}/2$;

– falls with increasing birth rate (b) if $F^* > \overline{F}/2$;

– falls with increasing fertility responsiveness to resources abundance (α) if $F^* > \overline{F}/2$;

– falls with increasing preference for the resources-based good (γ) if $F^* < 2\overline{F}/3$;

– falls with technological progress in the resources harvest sector (q) if $F^* < 2\overline{F}/3$.

Proof: See Appendix A-2 for proof elements.

3.5.2 Linear stability analysis

The stability of fixed points involves observing the eigenvalue of the corresponding Jacobian Matrix (Galor, 2007; Anishchenko et al., 2014). Let D be a vector of deviations from the steady state, $D = (N_t - N^*, F_t - F^*, B_t - B^*)$. Small changes in D over time, using Taylor expansion, can be expressed as: $dD/dt \simeq J(N^*, F^*, B^*)D + Z(N, F, B)$, where J is the Jacobian Matrix of the first-order partial derivatives with respect to N_t, F_t and B_t. $Z(N, F, B)$ stands for higher-order derivatives of the Taylor expansion, which near the steady-state can be ignored. J is:

$$J \equiv \begin{pmatrix} J_{1,1} & J_{12} & J_{1,3} \\ J_{2,1} & J_{22} & J_{2,3} \\ J_{3,1} & J_{3,2} & J_{3,3} \end{pmatrix} = \begin{pmatrix} \frac{d(\Delta N)}{dN} & \frac{d(\Delta N)}{dF} & \frac{d(\Delta N)}{dB} \\ \frac{d(\Delta F)}{dN} & \frac{d(\Delta F)}{dF} & \frac{d(\Delta F)}{dB} \\ \frac{d(\Delta B)}{dN} & \frac{d(\Delta B)}{dF} & \frac{d(\Delta B)}{dB} \end{pmatrix}$$

$$= \begin{pmatrix} b - d + \alpha\gamma q F_t & \alpha\gamma q N_t & 0 \\ -\gamma q F_t & g - 2gF_t/\overline{F} - \gamma q N_t & 0 \\ -\delta_1\gamma q F_t B_t - \delta_2(b - d + \alpha\gamma q F_t)B_t & -\delta_1\gamma q N_t B_t - \delta_2\alpha\gamma q N_t B_t & g - 2gB_t/\overline{B} - \delta_1\gamma q N_t F_t - \delta_2(b - d + \alpha\gamma q F_t)N_t \end{pmatrix}$$

where it is to recall that ΔN, ΔF and ΔB are given by (14), (15) and (16). Finally, the behaviour of the system almost entirely depends on the eigenvalues of matrix J evaluated at the corresponding steady state.

Proposition 3 *Assuming the positivity conditions (17), (18) and (19) to hold, the behaviour of the system is the following:*

$-ss1.$, characterized by $N^* = 0$, $F^* = 0$ and $B^* = 0$, is a saddlepoint.

$-ss2.$, characterized by $N^* = 0$, $F^* = \overline{F}$ and $B^* = \overline{B}$ is a saddlepoint.

$-ss3.$, characterized by $N^* = \frac{g}{\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)$, $F^* = \frac{d-b}{\alpha\gamma q}$ and $B^* = 0$ is stable

$-ss4.$, characterized by $N^* = \frac{g}{\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)$, $F^* = \frac{d-b}{\alpha\gamma q}$ and $B^* = \overline{B}\left[1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)\right]$ is a stable node allowing for monotonic convergence, when the following holds:

$$g\frac{d-b}{\alpha\gamma q\overline{F}} > 4\left[\alpha\gamma q\overline{F} - (d-b)\right] \tag{3.20}$$

Reciprocally, when $g\frac{d-b}{\alpha\gamma q\overline{F}} < 4\left[\alpha\gamma q\overline{F} - (d-b)\right]$, both eigenvalues have imaginary parts associated with negative real parts, thus, ss4 is a stable focus-node converging to equilibrium with damped oscillations.

Proof: See Appendix A-3 for proof elements.

3.5.3 Population, forest cover and species stock interactions

Our specification showing population growth and preferences as driving both forest harvest and species loss, an analysis of resources (F_t and B_t) dynamics conditional on population seems interesting.

Starting from (14) and (15), we first observe that in the absence of forest resources, $F^* = 0$, population also reaches a steady state $N^* = 0$ (ss1). However, in the absence of population, $N^* = 0$, forest stock reaches its carrying capacity, $\overline{F}$ (ss2). Population growth rate, $b - d + \alpha\gamma q F_t$, and forest harvest, $\gamma q N_t F_t$, positively depending on forest stock, the system reaches an interior steady state $\{N^*, F^*\} > 0$, when there is no growth in population and forest resources harvest exactly equals its extrinsic growth (Figure 3.2. 2, Panel A & B).

For any forest stock below F^* (Figure 3.2), there is a decrease in population (negative population growth rate) and respectively in forest resources harvest. This process reduces resources-use pressure and favours net stock regeneration. Reciprocally, for any stock larger than F^*, increasing forest resources harvest (positive population growth rate) is observed, exceeds resources regeneration and leads to forest depletion. Hence, the higher forest stock, respectively the higher is resources harvest, the larger human population grows.

In addition to this Predator-Prey system, equation (16) expresses biodiversity loss as driven by both forest resources harvest and population growth. Starting from the internal steady state for the forest-population couple $\{N^*, F^*\} > 0$, Figure 3.2 (Panel C) helps identify two possible steady states of species stock: $B^* = 0$ and $B^* > 0$. Technically, solving $B_t\left[g\left(1 - B_t/\overline{B_t}\right) - \delta_1\gamma q N_t F_t - \delta_2(b - d + \alpha\gamma q F_t)N_t\right] = 0$, given $\{N^*, F^*\} > 0$ delivers these solutions. The couple $\{N^* > 0, F^* > 0, B^* = 0\}$ and $\{N^* > 0, F^* > 0, B^* > 0\}$ represent further steady states of the population-forest-biodiversity model.

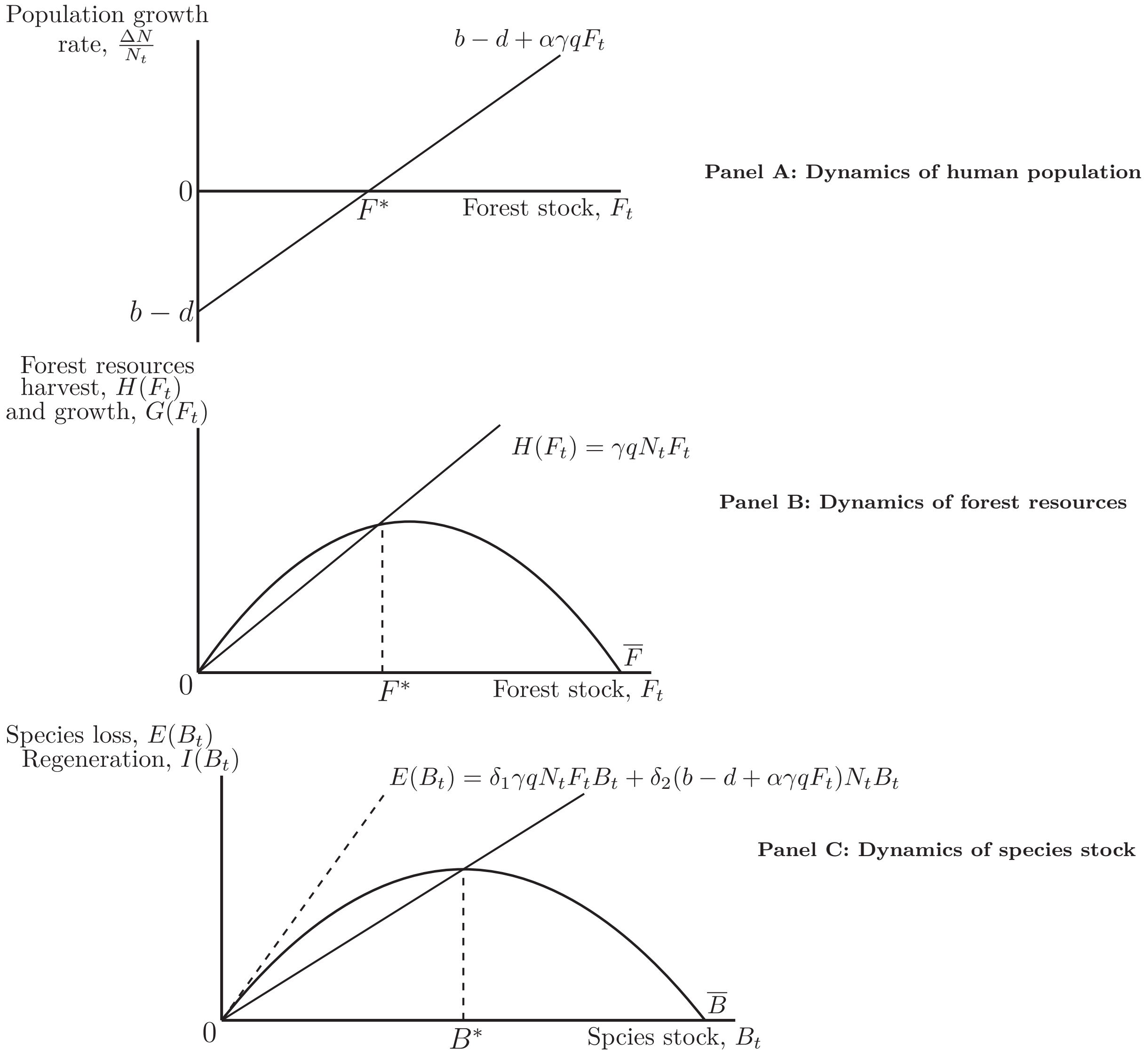


Figure 3.2: Illustration of the dynamics of population-forest-species stock

Compared to the referential works by Brander and Taylor (1998), Dalton and Coats (2000), D'Alessandro (2007), and related studies, this paper points out the possibility of a long run equilibrium characterized by total extinction of biological species. This is, contrary to biological species stock which cannot reach a steady state $B^* > 0$, when there are no forest resources, $F^* = 0$, forest stock however can reach a steady state $F^* > 0$ while there is no biodiversity $B^* = 0$. Such a property of our model precisely enlightens the possibility of an empty forest equilibrium (ss.3).

3.6 Scenarios analysis

Starting from an interior solution for population and forests, there are two locally stable steady states ($ss3$ and $ss4$), as demonstrated above. Thereby, by increasing the slope of the extinction line, $E(B_t)$ (higher ecological footprint), $ss4$ collapses to $ss3$ (Figure 3.2).

3.6.1 Applying the population-forest-biodiversity model to Easter Island

Parameter choice

This paper exploring the evolution of species stock, the dynamics of the system can be investigated in a paradigm similar to Brander and Taylor (1998), Dalton and Coats (2000) and Bologna and Flores (2010), among others. The Easter Island economic literature use the following values for carrying capacity of forest $\overline{F}$, intrinsic regeneration rate g, net birth rate $b-d$, labour harvesting productivity q, preference for the harvest good γ and the fertility parameter α: $\overline{F} = 12000$, $g = 0.04$, $b - d = -0.10$, $q = 0.00001$, $\alpha = 4$ and $\gamma = 0.4$. The latter parameter, γ, implies that consumers prefer the manufactured good to the resource-based one.

Equation (16) includes the carrying capacity of biodiversity ($\overline{B}$) and ecological footprint parameters δ_1 and δ_2. Values for these parameters can be identified using the same intuition as the Schaefer's production function. Similar to the harvest function, where an effort L_H is used to a harvest $H = qL_HF$, lost of forests $\gamma q N_t F_t$ and increase of population $(b-d+\alpha\gamma q F_t)N_t$ cause biological species lost respectively given by $\delta_1(\gamma q N_t F_t)B_t$ and $\delta_2(b - d + \alpha\gamma q F_t)N_t B_t$. Therefore, values given to the parameters q, δ_1 and δ_2 are to be of comparable ranges. Moreover, δ_1 and δ_2 should take values lower than the intrinsic regeneration rate g, to allow an assessment of the role of preferences, fertility and other parameters in species loss.

Regarding $\overline{B}$, similar to $\overline{F}$ where researchers consider the starting value of forest resources as being equal to the carrying capacity, we argue that $\overline{B} = B_0$ and choose a value for biodiversity carrying capacity in the range of forest stock: $\overline{B} = 10000$.[3]

Impact of intensive harvest, preference and fertility

Impact of population growth and intensive harvest. The evolution of the couple population-forest being largely discussed in existing study, we focus here on their interaction with species stock, given the amplitude of forest clearing and population growth. Thereby, we start from a perspective where there is no ecological footprint with regard to biodiversity, which remains equal to its carrying capacity or starting value (Figure 3.3 (Panel A)).

Firstly, with a significant ecological footprint or impact of human activities ($\{\delta_1, \delta_2\} \neq 0$), species stock diverges from its carrying capacity to converge to a new steady state below $\overline{B}$ (ss4). Secondly, since both population growth and forest clearing enhance biodiversity loss, relatively rapid decline in species stock is observed. It is also noticeable in every scenarios assessed that species stock reaches its minimum for the whole period, when human population reaches its peak. The system leading to two locally stable steady states with positive human population, Figure 3.3 helps notice that for relatively high ecological footprint, ss4 becomes ss3, as species stock reaches zero.

[3] Carrying capacities are defined as equalling starting values, since forest on Easter Island has "been in place for approximately 37000 years before first colonizations" (Brander and Taylor, 1998, pp.128).

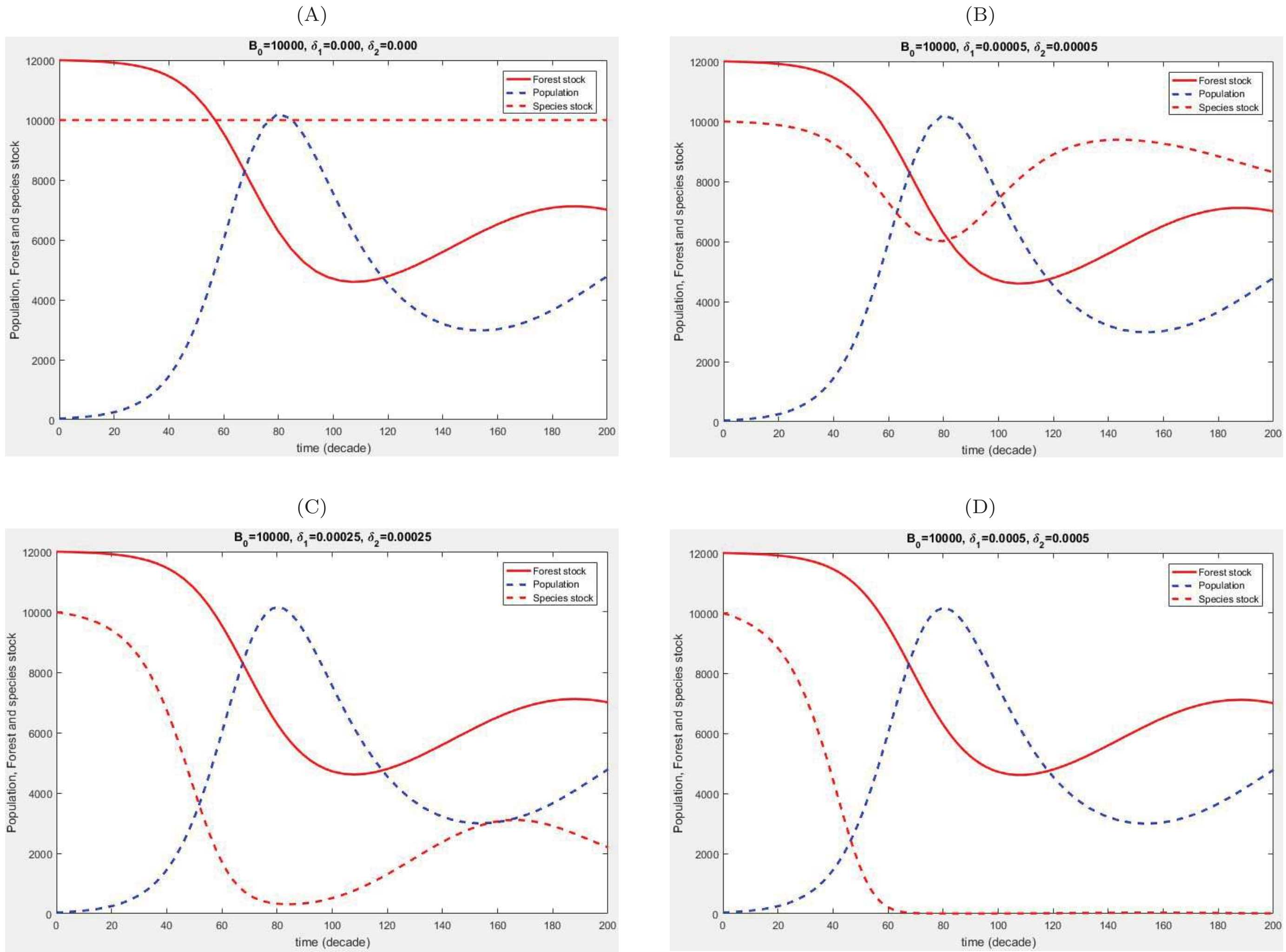


Figure 3.3: Scenario 1: Species loss in the Easter-Island framework

Applying the population-forest-biodiversity model to Easter-Island reveals two interesting teachings. Foremost, the combined impact of population growth and deforestation overwhelms natural regeneration of biological species, even when the rates of species loss due to population and deforestation $\{\delta_1, \delta_2\} \neq 0$ are quite inconsequential compared to the intrinsic regeneration rate g. Hence, as far as economic activities exploit forest or natural resources and there are conflicts over habitats between human and biological species, ecological destruction (deviations from $\overline{B}$ and $\overline{F}$) will increase until a societal collapse occurs. After a population collapse, forest and species stocks regeneration overcomes the ecological impact of human activities and stocks finally converge oscillatory to a long-run steady state. Nevertheless, when high ecological footprint lead to extinction, a significant species stock regeneration becomes impossible ($ss3$), supporting the so-called empty forest hypothesis.

Impact of changes in the preference for the resource-based good. The benchmark model and parameter choice as specified above assume that individuals prefer the manufactured goods to resource-based ones, since $\gamma = 0.4$. Starting from the case where the couple $\{\delta_1, \delta_2\}$ allows for an interior steady state with relatively low ecological impact oh human activities (Figure 3.3), we investigate how changes in preferences affect the long-run behaviour of the system. It is then obvious that an equal preference for both goods or a higher preference for the harvest good will amplify human ecological impact, leading to rapid forest clearing and species loss. Thereby however, it is to observe that the rapid resource depletion occurs, the sooner population collapses (Figure 3.2 (Panel B)). Reciprocally, disfavouring resource-based goods delays (and even dampens) the occurrence of the population overshoot (Figure 3.4 (Panel A)).

(A) (B)

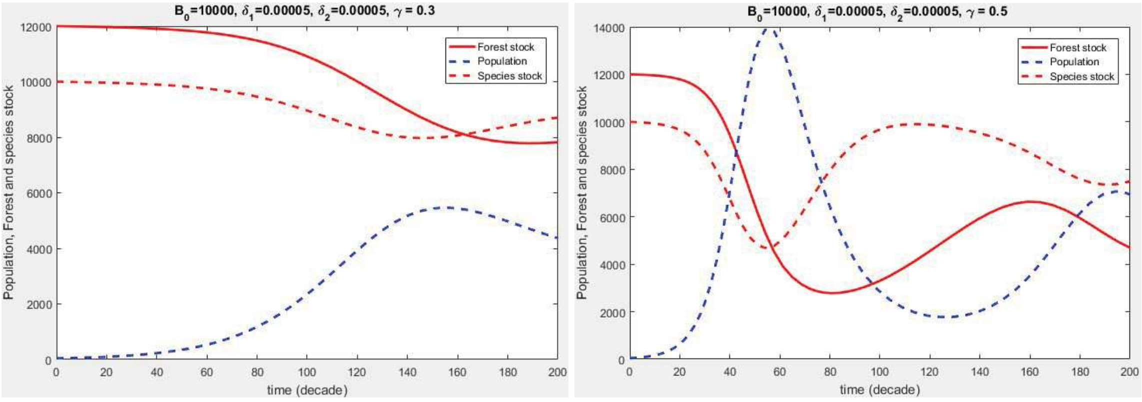


Figure 3.4: Impact of changes in preference for the resource-based good

Impact of changes in fertility α. Besides the preference for manufactured and resource-based good, individual decisions over fertility affect demands, thus resources harvest and population dynamics. Compared to the starting model, where the fertility parameter $\alpha = 4$ (Figure 3.3 (Panel B)), we simulate two scenarios considering $\alpha = 3$ and $\alpha = 5$, in order to assess how changes in fertility impact the long-run equilibrium. Using the parametrization of the benchmark model (Figure 3.3 (Panel B)) and changing the fertility parameter produces results comparable to change in individual's preference.

(A) (B)

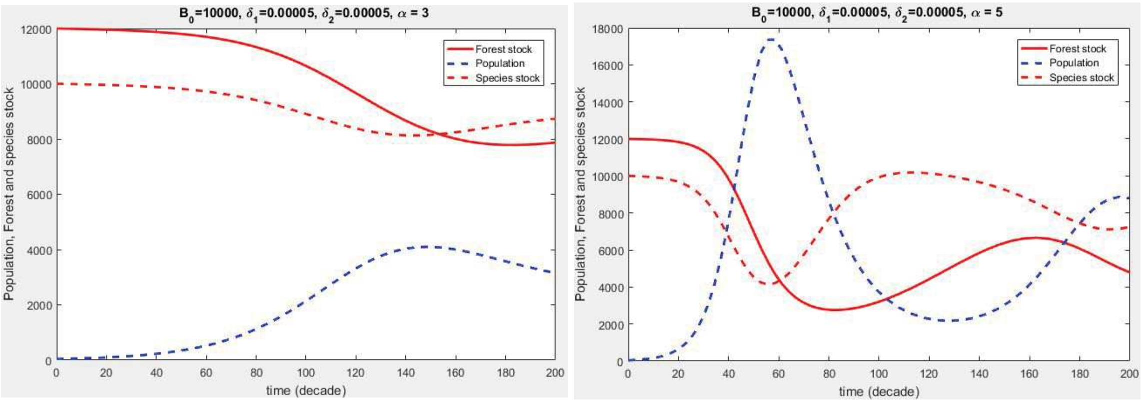


Figure 3.5: Impact of changes in human fertility

Reducing the fertility parameter by 25% slows population growth (which reaches a peak of 4000 after 1400 year) and mitigate societal collapse, as a very smooth decrease in population is observed after its peak. Thereby, a very slow environmental depletion (deforestation and species loss) is noticeable. Respectively, a 25% increase in α leads to rapid population growth producing a collapse after 60 decades associated with rapid resource depletion and a relatively low steady state values for forest and species stocks.

3.6.2 Population-forest-biodiversity in a developing resource-intensive economy

Developing economies, mostly characterized by relatively high population growth, intensive resource harvest, represent a group a countries the scenarios discussed above can be associated with. A feasible parametrization for resource-intensive economies should concurrently consider higher net birth rate or fertility parameter α, preference for the harvest good and human impact $\{\delta_1, \delta_2\}$. Thereby, compared to Figure 3.3 (Panel A), we increase α, γ, and $\{\delta_1, \delta_2\}$, combining the different experiments conducted above.

Our simulations (3.3 (A)) indicate a rapid growth in population, which reaches a size higher than those observed in previous scenarios. Reciprocally, a sudden drop in forest and species stocks is noticeable following human population growth. The latter falls dramatically after 40 decades of flourishment, allowing forest and species stocks to smoothly recover. A second case, increasing values of parameters, displays a more rapid increase in population (of about 35000) after 25 decades, associated with rapid decline in forest and species stock, which converge to zero. As expected, the collapse of population also occurs sooner.

(A) (B)

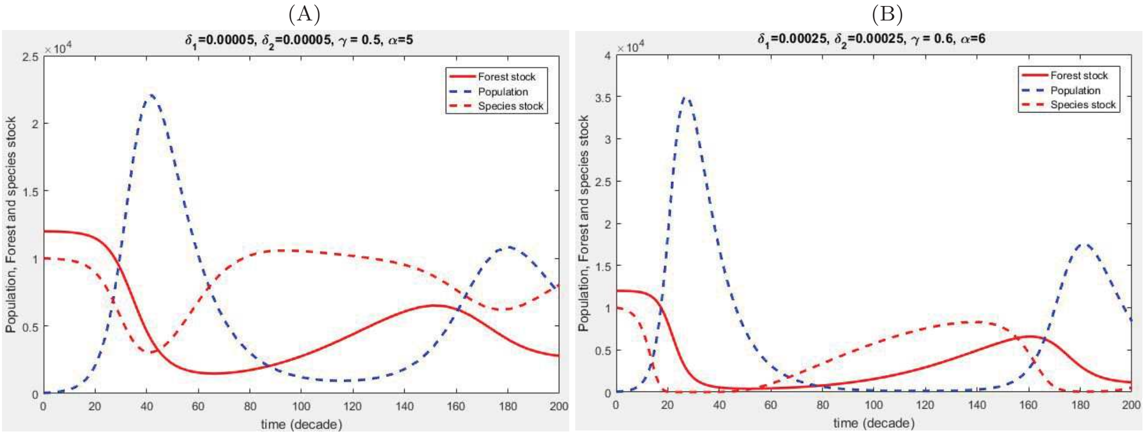


Figure 3.6: Population, forest and biodiversity in resource-intensive economies

Globally, applying the population-forest-biodiversity model to a resource-intensive economy provides explanations to the rapid population growth and ecological destruction currently observed in developing countries (for instance Sub-Saharan Africa). It also predicts a population overshoot at some point of time: The rapid human population and ecological destruction occur, the sooner and dramatic is the societal collapse. Finally, after a societal collapse, environmental resources do not return to their initial values, suggesting that as long as there is increase in human population and production activities exploit nature, environmental resources cannot converge to their carrying capacities.

3.7 Discussion and concluding remarks

3.7.1 Brander and Taylor, HANDY and the Population-Forest-Biodiversity model

Throughout this paper on a Ricardo-Malthusian economic model of population, forest and biodiversity, we mentioned the seminal paper by Brander and Taylor (1998) and its extensions, among others, by D'Alessandro (2007) and Bologna and Flores (2008). These studies discuss the predator-prey system in economics mostly relying on a set of two equations which stand for population and forest resources. Environmental issues being more complex, our extension dissociates forest clearing from species loss and offers a broader perspective into environmental considerations. Indeed, in existing studies, human population growth and resources extraction cause forest resources depletion which can be seen as equalling species loss. Nevertheless, separating forest and species stocks, as we did, provides some insights into the possibility of species-empty forests. Thus, compared to the Brander and Taylor's long-run equilibrium for the so-called ecological complex and human population, our specification underlines two corresponding equilibria with regard to biodiversity: A zero species stock (species-empty forests) and a positive stock equilibria (species-poor forests).

Extension of Brander and Taylor (1998) investigated how institutional setting could have saved Easter Island, while the HANDY model discusses interconnections between social stratification, wealth and nature. Also, in these studies, issues relative to ecological complex are assessed using a unique indicator, reducing more diversiform environmental issues to a homogeneous phenomenon. Therefore, in contrast to existing works on the topic, this paper can be considered as an extension of population-forest studies to biodiversity, which is not to consider as systematically flourishing when forests recover.

3.7.2 Concluding remarks

Theoretical efforts to assess environmental depletions and the role of economic activities and population has led, among others, to population-resources model exploiting economic and dynamic system analysis tools. The present paper proposes to introduce biodiversity loss within population-resources framework, exploiting predator-prey perspectives developed in the exiting literature.

Grounded on utility and profit maximization behaviours, the model described the joint evolution of human population, forest resources and biological species stocks by a system of three first-order dynamic equations. Steady states and local stability analysis show that an interior and locally stable equilibrium is feasible $\{N^* > 0, F^* > 0, B^* > 0\}$, besides a corner solution characterized by positive human population and forest stocks and where biodiversity has gone completely extinct $\{N^* > 0, F^* > 0, B^* = 0\}$. The latter solution appears to be a fallback solution, when the biodiversity impacts of population and deforestation $\{\delta_1, \delta_2\}$ are beyond a certain threshold (high ecological footprint).

Applying the population-forest-biodiversity model to economies characterized by relatively high fertility, preference for resource harvest goods, and more generally to resource-intensive economies reveals that endogenous population growth and forest clearing cause rapid extinction of biological species. Moreover, as fertility depends on forest resources stock, a societal collapse seems almost inevitable. Observing the different scenarios (Figures 3.3, 3.4, 3.5, 3.6) suggests the following description of the population and forest stock interaction: *i*. The higher economic production exploits forest resources (reciprocally deforestation), the larger are fertility and population growth; *ii*. The higher fertility and preference for harvest good, the sooner human population reaches its peak and collapses. Nevertheless, considering biological species, not only their stock takes positive values in the long-run, it can also converge to a zero level in presence of large ecological footprint, leading to a steady state equilibrium with total species extinction.

These numerical exercises on the case of resource-intensive economies provide some explanations to current rapid population growth and ecological destruction observed in developing countries. Our assessment, however, does not help answer the question whether (and when) a collapse will occur, as the parameters' values are essentially those used in the Easter Island case studies. Nevertheless, the population-forest-biodiversity model presented in this paper supports population-resources and HANDY perspectives on the impossibility of an infinite increase in human population and natural resource use.

Appendix A

A-1: Proof of Proposition 1.

Proof elements involve setting $N_t(b - d + \alpha\gamma q F_t) = 0$, $gF_t(1 - F_t/\overline{F}) - \gamma q N_t F_t = 0$ and also $g\left(B_t - B_t^2/\overline{B_t}\right) - \delta_1 \gamma q N_t F_t B_t - \delta_2(b - d + \alpha\gamma q F_t)N_t B_t = 0$ and directly observe that steady-states 1 and 2 satisfy these conditions. Regarding steady state 3 and 4, first we solve for F^* in $(b - d + \alpha\gamma q F_t = 0)$, then introduce its value into $gF_t(1 - F_t/\overline{F}) - \gamma q N_t F_t = 0$, finding N^*. The two possible values of B^* directly derive by substituting N^* and F^* into $g\left(1 - B_t/\overline{B_t}\right) - \delta_1 \gamma q N_t F_t - \delta_2(b - d + \alpha\gamma q F_t)N_t = 0$.

A-2: Proof of Proposition 2.

Let recall the steady-state values of forest cover, population and species stock:

$F^* = \frac{d-b}{\alpha\gamma q} > 0$

$N^* = \frac{g}{\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q \overline{F}}\right) > 0$

and $B^* = \overline{B}\left[1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)\right] \equiv \overline{B}\left[1 - \frac{\delta_1\gamma q}{g} N^* F^*\right] > 0.$

Proposition 2 follows by differentiating B^* with respect to the parameters.

(i) $\frac{\partial B^*}{\partial \overline{B}} = \left[1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)\right] > 0;$

(ii) $\frac{\partial B^*}{\partial \overline{F}} = -\frac{\delta_1\gamma q\overline{B}F^*}{g}\frac{\partial N^*}{\partial \overline{F}} \equiv -\frac{\delta_1\overline{B}F^*(d-b)}{\alpha\gamma q\overline{F}^2} < 0;$

(iii) $\frac{\partial B^*}{\partial d} = -\frac{\delta_1\gamma q\overline{B}}{g}\left[F^*\frac{\partial N^*}{\partial d} + N^*\frac{\partial F^*}{\partial d}\right] = -\frac{\delta_1\overline{B}}{\alpha\gamma q}\left[1 - 2\frac{d-b}{\alpha\gamma q\overline{F}}\right] \equiv -\frac{\delta_1\overline{B}}{\alpha\gamma q}\left[1 - 2\frac{F^*}{\overline{F}}\right];$

(iv) Similar to the previous case, $\frac{\partial B^*}{\partial b} = \frac{\delta_1\overline{B}}{\alpha\gamma q}\left[1 - 2\frac{F^*}{\overline{F}}\right];$

(v) $\frac{\partial B^*}{\partial \alpha} = -\frac{\delta_1\gamma q\overline{B}}{g}\left[F^*\frac{\partial N^*}{\partial \alpha} + N^*\frac{\partial F^*}{\partial \alpha}\right] = \frac{\delta_1(d-b)\overline{B}}{\alpha^2\gamma q}\left[1 - 2\frac{d-b}{\alpha\gamma q\overline{F}}\right] \equiv \frac{\delta_1(d-b)\overline{B}}{\alpha^2\gamma q}\left[1 - 2\frac{F^*}{\overline{F}}\right];$

(vi) $\frac{\partial B^*}{\partial \gamma} = \overline{B}\left[-\frac{\delta_1 q N^* F^*}{g} - \frac{\delta_1 q\gamma}{g}\left(F^*\frac{\partial N^*}{\partial \gamma} + N^*\frac{\partial F^*}{\partial \gamma}\right)\right] = \overline{B}\left[-\frac{\delta_1(d-b)}{\alpha\gamma^2 q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right) - \frac{\delta_1(d-b)}{\alpha\gamma^2 q}\left(1 - 2\frac{d-b}{\alpha\gamma q\overline{F}}\right)\right]$ and is equivalent to $-\overline{B}\frac{\delta_1(d-b)}{\alpha\gamma^2 q}\left(2 - 3\frac{d-b}{\alpha\gamma q\overline{F}}\right) = -\overline{B}\frac{\delta_1(d-b)}{\alpha\gamma^2 q}\left(2 - 3\frac{F^*}{\overline{F}}\right);$

(vii) Similar to $\frac{\partial B^*}{\partial \gamma}$, one can directly deduce $\frac{\partial B^*}{\partial q} = -\overline{B}\frac{\delta_1(d-b)}{\alpha\gamma q^2}\left(2 - 3\frac{F^*}{\overline{F}}\right).$

A-3: Proof of Proposition 3.

– **Stability of ss1:** Evaluating the J-Matrix at ss1 delivers:

$$J_{ss1}(N^*, F^*, B^*) = \begin{pmatrix} b-d & 0 & 0 \\ 0 & g & 0 \\ 0 & 0 & g \end{pmatrix} \tag{3.21}$$

The corresponding three eigenvalues are respectively $\lambda_1 = b - d < 0$ and $\lambda_2 = \lambda_3 = g > 0$. Thus, ss1 is a saddle point.

– **Stability of ss2:** Evaluating the J-Matrix at ss2 delivers:

$$J_{ss2}(N^*, F^*, B^*) = \begin{pmatrix} b-d+\alpha\gamma q\overline{F} & 0 & 0 \\ -\gamma q\overline{F} & -g & 0 \\ -\delta_1\gamma q\overline{F}\overline{B} - \delta_2(b-d+\alpha\gamma q\overline{F})\overline{B} & 0 & -g \end{pmatrix} \tag{3.22}$$

Finding the corresponding eigenvalues requires solving the equation $(b-d+\alpha\gamma q\overline{F} - \lambda)(-g-\lambda)^2 = 0$. The latter yields $\lambda_1 = b - d + \alpha\gamma q\overline{F}$ and $\lambda_2 = \lambda_3 = -g$. We can see that $-1 < \lambda_2 = \lambda_3 < 0$ and further that $0 < \lambda_1 = b - d + \alpha\gamma q\overline{F} < \alpha\gamma q\overline{F}$. Thus, similar to ss1, ss2 is a saddlepoint.

– **Stability of ss3:** Evaluating the J-Matrix at ss3 delivers:

$$J_3^* = \begin{pmatrix} J_{11}^* & J_{12}^* & J_{13}^* \\ J_{21}^* & J_{22}^* & J_{23}^* \\ J_{31}^* & J_{32}^* & J_{33}^* \end{pmatrix} \text{ where } \begin{cases} J_{11}^* = 0 \\ J_{12}^* = \alpha g\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right) \equiv \alpha\gamma q N^* \\ J_{13}^* = 0 \\ \\ J_{21}^* = -\frac{d-b}{\alpha} \equiv -\gamma q F^* \\ J_{22}^* = -g\frac{d-b}{\alpha\gamma q\overline{F}} \equiv -g\frac{F^*}{\overline{F}} \\ J_{23}^* = 0 \\ \\ J_{31}^* = 0 \\ J_{32}^* = 0 \\ J_{33}^* = g - g\delta_1\frac{d-b}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right) \equiv g - \delta_1 g F^*\left(1 - F^*/\overline{F}\right) \end{cases} \tag{3.23}$$

A corresponding characteristic equation is: $(J_{11}^* - \lambda)\left[(J_{22}^* - \lambda)(J_{33}^* - \lambda) - J_{32}^* J_{23}^*\right] = 0$ which delivers: $\lambda_1 = J_{11}^* = 0$, $\lambda_2 = J_{22}^* = -g\frac{F^*}{\overline{F}}$ and $\lambda_3 = J_{33}^* = g\left(1 - \delta_1\frac{d-b}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)\right)$. $B^* = 0$ implies the equality $1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right) = 0$ holds (from (19)). Therefore, the corner steady state ss3 is stable.

– **Stability of ss4:** Evaluating the J-Matrix at ss4 delivers:

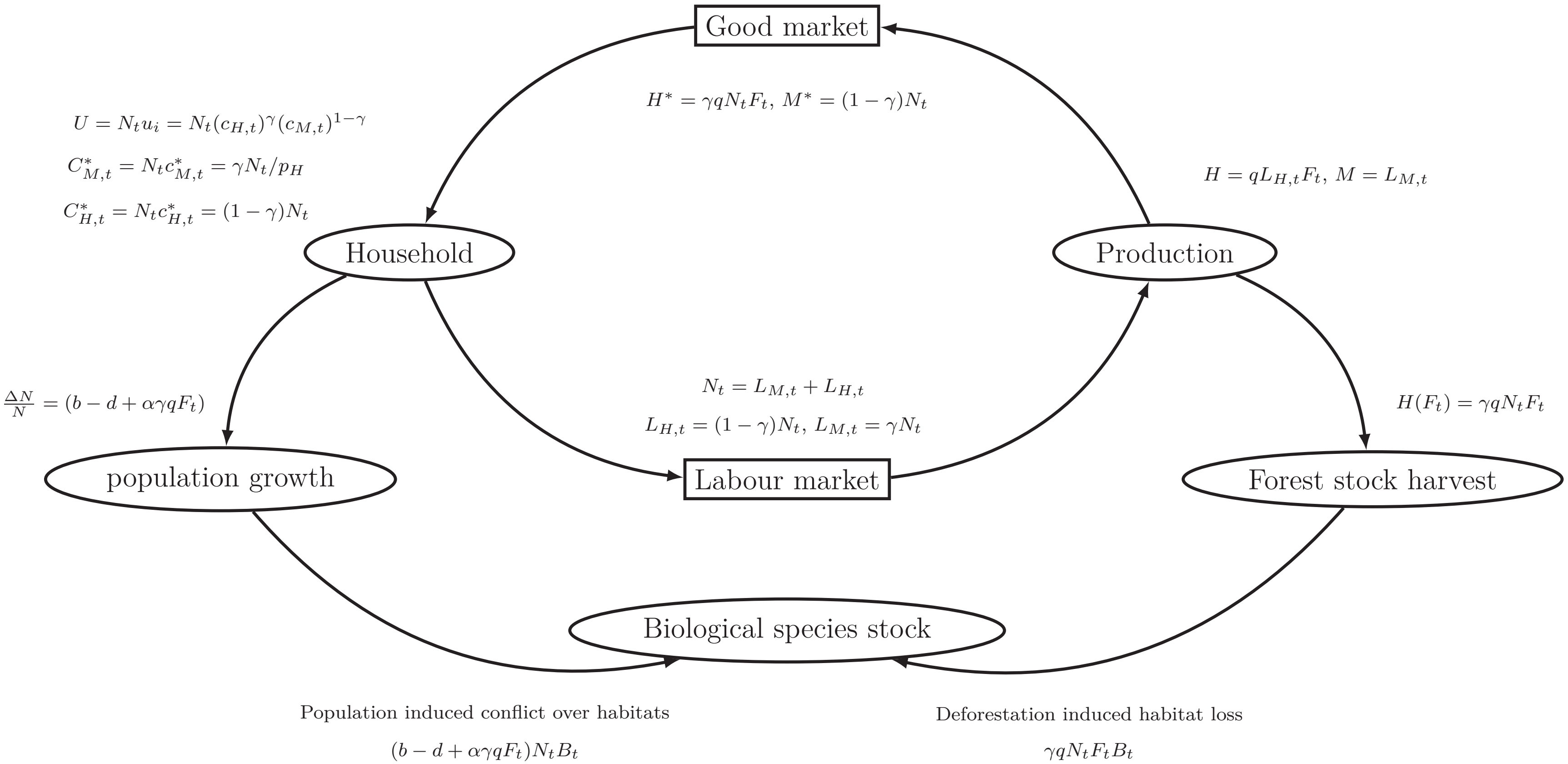
$$J_4^* = \begin{pmatrix} J_{11}^* & J_{12}^* & J_{13}^* \\ J_{21}^* & J_{22}^* & J_{23}^* \\ J_{31}^* & J_{32}^* & J_{33}^* \end{pmatrix} \text{ where } \begin{cases} J_{11}^* = 0 \\ J_{12}^* = \alpha g \left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right) \equiv \alpha\gamma q N^* \\ J_{13}^* = 0 \\ J_{21}^* = -\frac{d-b}{\alpha} \equiv -\gamma q F^* \\ J_{22}^* = -g\frac{d-b}{\alpha\gamma q\overline{F}} \equiv -g\frac{F^*}{\overline{F}} \\ J_{23}^* = 0 \\ J_{31}^* = -\delta_1 \frac{d-b}{\alpha}\overline{B}\left[1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)\right] \\ J_{32}^* = g\overline{B}(-\delta_1 - \delta_2\alpha)\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)\left[1 - \frac{\delta_1(d-b)}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right)\right] \\ J_{33}^* = g\delta_1\frac{d-b}{\alpha\gamma q}\left(1 - \frac{d-b}{\alpha\gamma q\overline{F}}\right) - g \equiv -g + g\delta_1 F^*\left(1 - F^*/\overline{F}\right) \end{cases} \quad (3.24)$$

Finding the corresponding eigenvalues requires finding solution to the characteristic equation

$(J_{33}^* - \lambda)\left[(J_{11}^* - \lambda)(J_{22}^* - \lambda) - J_{12}^* J_{21}^*\right] = 0$ which after some algebra corresponds to $\left(-g + g\delta_1 F^*(1 - F^*/\overline{F}) - \lambda\right)\left(\lambda^2 + \lambda g F^*/\overline{F} + g(d-b)(1 - F^*/\overline{F})\right) = 0$. The latter implies that the first eigenvalue $\lambda_1 = -g + g\delta_1 F^*(1 - F^*/\overline{F})$ and exploiting the positivity condition (19), it appears that $-1 < -g < \lambda_1 < 0$. Regarding the second part of the characteristic equation, its discriminant is $\Delta = (gF^*/\overline{F})^2 - 4g(d-b)(1 - F^*/\overline{F})$.

Case 1.: When $\Delta > 0$, thus $g\frac{d-b}{\alpha\gamma q\overline{F}} > 4\left[\alpha\gamma q\overline{F} - (d-b)\right]$, one can easily show that both eigenvalues $\lambda_2 = \frac{1}{2}(-gF^*/\overline{F} - \Delta^{\frac{1}{2}})$ and $\lambda_3 = \frac{1}{2}(-gF^*/\overline{F} + \Delta^{\frac{1}{2}})$ are negative real numbers. In this case, ss4 is stable with monotonic convergence.

Case 2.: When $\Delta < 0$, thus $g\frac{d-b}{\alpha\gamma q\overline{F}} < 4\left[\alpha\gamma q\overline{F} - (d-b)\right]$, the eigenvalues λ_2 and λ_3 are complex conjugate with negative real part and SS4 can be characterized as a stable focus.



$$\Delta N \equiv N_{t+1} - N_t = N_t(b - d + \alpha\gamma q F_t)$$

$$\Delta F \equiv F_{t+1} - F_t = gF_t(1 - F_t/\overline{F}) - \gamma q N_t F_t$$

$$\Delta B \equiv B_{t+1} - B_t = g\left(B_t - B_t^2/\overline{B_t}\right) - \delta_1 \gamma q N_t F_t B_t - \delta_2 (b - d + \alpha\gamma q F_t) N_t B_t$$

Figure 3.7: Graphical abstract: Overview of the population-forest-biodiversity model

Table 3.1: Parameter choice in the different scenarios

		Fig. 3				**Fig. 4**		**Fig. 5**		**Fig. 6**	
		A	B	C	D	A	B	A	B	A	B
g	Intrinsic regeneration rate	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04
$b-d$	Net birth rate	$-.10$	$-.10$	$-.10$	$-.10$	$-.10$	$-.10$	$-.10$	$-.10$	$-.10$	$-.10$
q	Labour harvesting productivity	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001
α	Fertility parameter	4	4	4	4	4	4	3	5	5	6
γ	preference for the harvest good	.4	.4	.4	.4	.3	.5	.4	.4	.5	.6
δ_1	Forest-induced Ecological footprint	.00	.00005	.00025	.0005	.00005	.00005	.00005	.00005	.00005	.00025
δ_1	Human habitat-induced Ecological footprint	.00	.00005	.00025	.0005	.00005	.00005	.00005	.00005	.00005	.00025
$\overline{F}$	Forest carrying capacity	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
F_0	Forests' initial value	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
$\overline{B}$	Species stock carrying capacity	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
B_0	Species stock's initial value	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
$N_{t=0}$	Species stock starting value	40	40	40	40	40	40	40	40	40	40

4. Do Species-poor forests fool conservation policies?*

Abstract: This paper exploits World Development Indicators and IUCN Red-List data to empirically assess the socio-economic and environmental drivers of conservation efforts. In addition to spatial spillovers, our results firstly indicate that forest cover, income level along with good political institutions positively drive protected areas (PAs), while human population growth conflicts with nature conservation efforts. Secondly, indicators of biodiversity (species richness and extinction risk) are found to be non-significant predictors of PAs share, suggesting that species-rich countries are not predominantly the ones sheltering the largest PAs share. Although species-poor forests matter as well, in addition to ecosystem centered approaches, our results encourage conservation practitioners to further account for species richness and extinction risks in global conservation policies.

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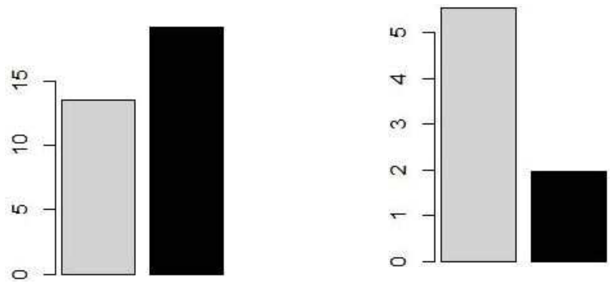
4.1 Introduction

Existing works in ecological modernization theory predict large demands for environmental quality in high-income countries, suggesting that conservation efforts are likely development level driven (Mol and Spaargaren, 1993; Mol, 2000). Hence, Protected Areas (PAs), known as the core instrument of nature conservation policies, might be income level dependent. Such an observation raises questions on factors enhancing conservation efforts and whether income-level relevant conservation actions will help achieve global ecosystem preservation goals. Addressing these questions, the present paper proposes to assess the socio-economic and environmental factors influencing conservation policies worldwide, using the share of PAs in surface area as a proxy for conservation efforts.

First, on their importance, PAs are of main hope for meeting the ambitious global conservation targets (Le Saout et al., 2013). Furthermore, being the core-unit of nature conservation policies, PAs will be of major importance in facing challenges such as water security, human health and climate change (Chape et al., 2005; Hartley et al.,2007; Joppa and Pfaff, 2011). Largely, the existing studies on the importance of PAs definitely agree on their role in slowing deforestation and protecting species (Naughton-Treves et al., 2005; Sims and Alix-Garcia, 2017; Bruner et al., 2001). Secondly, the PAs downgrading and downsizing literature (Symes et al., 2016; Pack et al., 2016; Cook et al., 2017) discusses the causes and consequences of PAs loss to argue that the latter weakens PAs' performance in ecosystem preservation. However, considering topics related to PAs' environmental drivers, the role of development level as well as efficiency in their geographical distribution, surprisingly very few research papers can be identified. Therefore, in addition to globally assessing environmental and socio-economic drivers of PAs, This study aims at questioning efficiency in PAs' geographical distribution by distinguishing low- and high-income countries as well as geographical blocks such as Africa, America, Asia and Europe.



PAs share, %

Species richness, ‰km^2

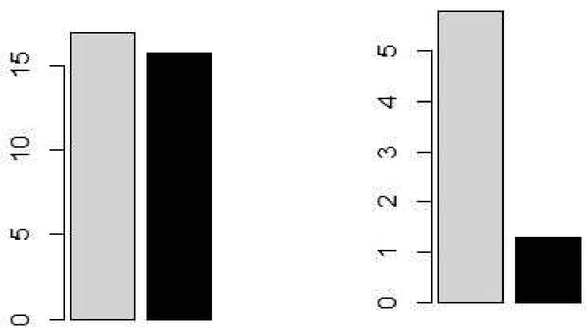
Figure 4.1: Mean PAs share in surface area and species richness

■ **High-income countries**
■ **Low-income countries**

Notes: Mean PAs share in surface area and species richness (animal and plant species density) for a sample of 156 high- and low-income countries. Sample median of lnGDP per capita is used to identified low- and high-income countries. More details on the data in Descriptive Statistics.

By comparing mean PAs share in surface area in low- and high-income countries (Figure 4.1), it appears that larger PAs are sheltered by high-income countries. On the contrary, considering a proxy for species richness (species density), fairly larger shares are observed in low-income countries.

Dissociating tropical from temperate climate countries, comparable PAs share in tropical and non-tropical areas are observable, whereas much larger species richness is noticed in tropical areas (Figure 4.2). Since biological species mostly lie in tropical countries, which predominantly are low-income countries associated with relatively high deforestation and species extinction rate (Asafu-Adjaye, 2003; Polasky et al., 2005), significantly larger PAs shares are also expected to be located in those areas. The charts analysis suggests a different perspective and this study aims to assess the reasons species-rich tropical areas appear to be poorly covered by PAs.



PAs share, %

Species richness, ‰km^2

Figure 4.2: Mean PAs share in surface area and species richness

■ **Temperate countries**
■ **Tropical countries**

Notes: Mean PAs share and species richness (species density) for a sample of 156 countries. Areas between latitude ±30° are considered as being (sub-) tropical zones. More details on the data in Descriptive Statistics.

Assessing the role of environmental and socio-economic factors in nature conservation efforts, this paper uses as indicator of the latter the share of PAs in surface area, without any distinction between management categories. We are aware that proceeding this way is questionable, as it treats PAs with different management categories equally.[1] Nevertheless, contrary to PAs effectiveness analyses, our study aiming at globally assessing the determinants of protected areas, such an approach appears to be reasonable. Moreover, considering total PAs share in surface area serves as a good proxy for country-level relative demand for nature conservation.

We believe the added value of this study is twofold. Firstly, as PAs management requires huge funds, our analysis considering income level helps test whether development level significantly affects ecosystem conservation efforts. Secondly, with regard to the well-known ecosystem-centered and species-centered debate in conservation, our analysis helps assess the role of environmental determinants such as forest cover, species richness and extinction risk in influencing conservation policies.

Section 2 overviews the related literature. Sections 3 and 4 respectively present the data and propose an insight into the PAs-income and PAs-forest cover nexuses, among others. The econometric specification is briefly discussed in Section 5. Our results are reported and discussed in Section 6 and 7. In Section 8, we conclude the study.

4.2 Related literature

The existing literature on conservation policies, among others, discusses species versus ecosystem centered approaches (Betts et al., 2014; Santos-Filho et al., 2016), proactive versus reactive approaches in biodiversity management (Heller and Zavaleta, 2009; Drechsler et al., 2011) and questions the effects of PAs on local communities (Sims, 2010; Richardson et al. 2012). Furthermore, it is characterized by PAs effectiveness analysis and also assesses the drivers of PAs withdrawal. The present paper dealing with factors influencing conservation efforts, this literature overview focuses on effectiveness and PAs withdrawal analyses.

[1] These categories are: "Strict Nature Reserve", "Wilderness Area", "National Park", "Habitat/Species Management Area", "Protected Landscape" and "Protected area with sustainable use of natural resources".

Regarding PAs effectiveness, the literature is animated by Bruner et al. (2001), Naughton-Treves et al. (2005), Andam et al. (2008), Butchart et al. (2012), Barnes et al (2015), Sims and Alix-Garcia (2017), to cite few. Addressing deforestation, Naughton-Treves et al. (2005) survey the expansion of PAs to conclude that relatively low deforestation rates are definitely observed within PAs. On the same topic, the empirical results by Joppa and Pfaff (2010) are supported by the recent findings by Sims and Alix-Garcia (2017) and Blankespoor et al. (2017). Also, Joppa and Pfaff (2010) conclude that PAs reduce the clearing of natural forest land. Similarly, exploiting data on 64 countries, Blankespoor et al. (2017) find results strengthening the effectiveness of parks in slowing deforestation. Andam et al. (2008) reach alike conclusions in Costa Rica. In the Indonesian case, Gaveau et al. (2009) stress that relatively low deforestation rates are observed within PAs. Inter-alia, Adeney et al. (2009) and Soares-Filho et al. (2010) in the case of the Brazilian Amazon and Bray et al (2008), Songer et al. (2009) and Southworth et al. (2004) respectively in the case of Guatemala, Myanmar and Honduras show that establishing PAs reduces human impacts on existing forests. In Mexico, Sims and Alix-Garcia (2017) comparing PAs and Payments for Ecosystem Services (PES) argue that both policies help fight forests clearing.[2] In Europe, the European Environment Agency globally notes increases in forest cover since 1990, associated with more than 21% of territories under protection (MacSharry, 2012). Although, PAs do not always guarantee a zero forest loss and PAs size in Europe is not to be considered as an indicator of its biological species richness, they help effectively protect endemic species and reduce infrastructure development and urbanisation related human pressure (Heino et al., 2015; Hoffman et al., 2018).

Considering biodiversity, Bruner et al. (2001) assess 93 PAs in 22 tropical countries to argue that even in situations of underfunding and of significant local land-use pressure, tropical PAs effectively protect ecosystem and species richness within their borders. Targeting specific groups of species, Butchart et al. (2012) and Barnes et al. (2015) find results suggesting that PAs reduce extinction risk. In addition, Barnes et al. (2015) point out the existence of very important sites poorly covered by PAs. Nevertheless, birds in PAs are not significantly better protected

[2]Blankespoor et al. (2017) propose an exhaustive review on such country-level analyses.

than those outside, as long as there are forests and ecosystem outside PAs. Recent contributions by Watson et al. (2016), Hiley et al. (2016) and Polak et al. (2016) among others lead to comparable results. A further aspect of this literature led by Badalamenti et al. (2000), Sims (2010), Richardson et al. (2012) and Canavire-Bacarreza and Hanauer (2013) focuses on the effects of PAs on local communities. Its conclusions though remain somewhat controversial.

A recent aspect of the literature has been investigating PAs downgrading, downsizing, and degazettement (PADDD), the aim being to assess the patterns, the drivers and consequences of PAs withdrawal. Thereby, works by Mascia et al. (2014), Symes et al. (2016), Pack et al. (2016) and Cook et al. (2017), to cite few, identify factors such as industrial-scale commodity production and resources extraction, energy production, corruption, land claims and human settlements as being the main causes of PADDD. Besides the effectiveness analysis, this literature provides evidence of PAs losses, which likely undermine the performances of PAs. Overall, researchers agree on the role of PAs in slowing deforestation and in protecting endemic species, at least within PAs. However, empirical economics works questioning the role of income level and environmental factors in driving PAs appear to be less regarded, motivating this paper.

4.3 The data

Similar to the large existing empirical literature on environmental issues, where environmental indicators are explained by per capita GDP and other potential determinants (e.g. Dietz and Adger, 2003; Richardson et al., 2012), this paper explains PAs share in surface area by income per capita, forest cover, proxies for species richness and extinction risk. To this end, our dataset includes series on forest cover, number of animal and plant species (total species identified and count of threatened) along with economic and social indicators such as income per capita, population dynamics among others. Due to few variabilities in PAs shares and series on biological species over time, in addition to missing values, the dataset is restricted to 156 countries observed in 2012. The data are mostly extracted from the World Development Indicators (WDI) except the counts of biological species, which are drawn from the IUCN Red-List of threatened species (category summary of country totals for animal and plants).

4.3.1 Descriptive statistics

Conservation efforts. As proxy for countries' efforts of conservation, we consider the share of terrestrial PAs in total land area.[3] The latter being "any site designated by countries under legislation primarily aiming at nature conservation" (EEA, 2012), disregarding management categories for the whole sample still reflects ecosystems maintenance measures taken by countries.

Environmental factors: PAs aiming at long-run nature preservation, some of their potential environmental determinants are forest cover and biodiversity indicators. Forests cover is the share of land under natural or planted stands of trees of at least 5 meters in situ (WDI, 2014). Regarding biodiversity indicators, we mainly use a proxy for extinction risk and species richness (species density). Extinction risk is computed as the share of threatened animal and plants species in total species identified. Our proxy for species richness somewhat follows the species-area relationship discussed in Dietz and Adger (2003) and Mills and Waite (2009). Thereby, we simply divided the total number of animal and plant species identified by surface area.

Socio-economic factors. Drawing upon existing works, this study considers socio-economic characteristics such as GDP per capita, population dynamics (population density, and total and rural population growth), agricultural land and forest rents. Regarding the influence of income level, on one hand, Mascia et al. (2014) and Symes et al. (2016) discussed the role of poverty in PAs withdrawal. On the other hand, the ecological modernization and ecologically unequal exchange theories (Mol and Spaargaren, 1993; Mol, 2000) predict large demand for conservation in high income level, suggesting that PAs share is income level dependent. Concerning population dynamics, McDonald et al. (2008) and Songer et al. (2009) argue that increasing population reduces distance of cities to natural reserves and Symes et al. (2016) conclude that the latter leads to PAs loss. As agricultural expansion

[3] It is to recall regarding European countries that the data include Natura 2000 network of PAs.

and forests resources exploitation are proven to be promoting habitat loss (Koh and Ghazoul, 2010), we account for this using the share of agricultural land in total land area and forest rents in GDP.

Finally, we control for educational level and institutional characteristics as done in the existing literature (e.g. Bhattarai and Hammig, 2001; Nguyen-Van, 2003; Beevers, 2015; Schulze et al. 2018), by exploiting the mean years of schooling and index of control for corruption. The latter Worldwide Governance Indicator (WGI) captures the "extent to which public power is exercised for private gain" (The World Bank Group).

Descriptive Statistics of the variables mentioned above are reported in Table 4.1. Thereby, it appears that on average, PAs and forests respectively cover circa 16% and 31,4% of national territories. However, it is to signal that countries such as Djibouti and Libya have less than 0.15% of their national territories as PAs, while 0.0% of forest shares are observed in Qatar and Oman. Overall, the data show for our sample of 156 countries a mean species richness of circa 37 species per 1000 square kilometre for a mean extinction risk of circa 11.82%.

Table 4.1: Descriptive statistics

Variables	Units	Mean	S.D.	Min	Max
Terrestrial PAs	% area	16.348	11.594	.080	54.508
Forest area	% area	31.413	22.729	0	98.355
LnGDP per capita	$, ppp	9.108	1.229	6.462	11.798
Species richness	$10^3/\text{km}^2$	37.469	252.236	.106	3144.966
Extinction risk	%	11.820	10.273	0.283	69.517
Forest rents	% GDP	2.764	5.361	0	31.278
Agricultural land	% area	41.246	21.599	0.469	81.305
Mean years of schooling	years	7.999	3.081	1.300	12.900
Population growth	%	1.489	1.393	-1.691	9.932
Rural population growth	%	0.412	1.858	-7.967	7.799
Population density	$10^3/\text{km}^2$	0.108	0.139	0.002	1.193
Control for corruption	Index	-0.138	1.001	-1.561	2.391

Notes: The sample includes 156 countries observed in 2012. In Appendix, a list of countries.

4.3.2 An Insight into the data on forest and PAs cover

As the descriptive statistics do not provide sufficient information regarding the geographical distribution of forest share and most importantly of PAs, we propose maps reflecting countries share of PAs and forest cover (Figure 4.4, in Appendix). Observing the maps, we notice that countries with relatively large PAs share also seem to show high shares of forest cover. Focusing on Sub-Saharan Africa, South America and Western Europe on both maps, relatively dark colourings are observed in the same areas. Reciprocally, in North America, Russia and Asia both maps display relatively lightened colourings. Moreover, compared to tropical countries, lower shares of PAs and forest cover are observed in countries located far from the equator. Although very insightful, these interpretations should be carefully considered, since a map analysis seems considerably short in quantitatively addressing the role of forest cover in driving conservation policies.

4.4 The PAs-income, forest and species richness

Before any parametric analysis of the determinants of PAs, we propose a non-parametric insight into the PAs-income, PAs-forest, PAs-species richness and PAs-institutions nexuses. Thereby, we rely on the Nadayara-Watson estimator for models with a single explanatory variable.

The regression lines (Figure 4.3) indicate that income and forest cover are positively linked to PAs share, while biological species richness shows a seemingly non-significant effect. Regarding the latter relationship, no clear upward or downward trend can be claimed as the confidence intervals are quite large. Finally, political institutions (control for corruption) show an upward trend to PAs share, suggesting that good political institutions might be enhancing conservation efforts.

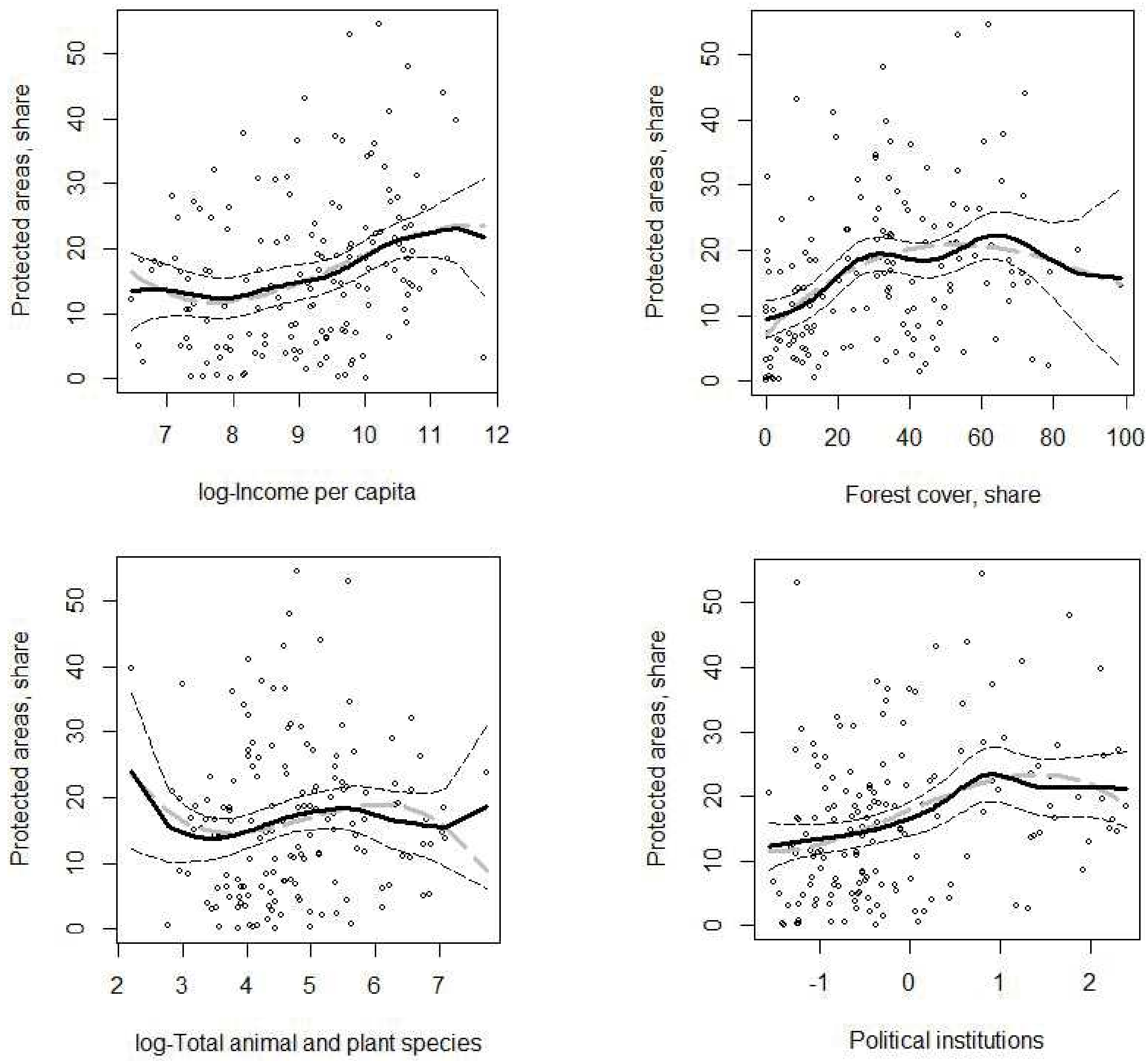


Figure 4.3: Kernel regression-lines with confidence intervals. The grey line corresponds to a quadratic model.

4.5 Econometric model

PAs being geographical spaces dedicated to nature conservation goals, countries located in the same geographical areas likely show similar patterns in PAs share: Spatial spillovers. Therefore, we hypothesize the existence of spatial dependence (regional networks) in PAs share and consider an econometric specification that accounts for geographical spillovers using a geography-based connectivity weighting system. Countries involved in our analysis and details about the geographical links employed in building the weighting matrix, $W_{n \times n}$ are reported in Figures 4.5 and

4.6. Thereby, our study exploiting country-level data, contiguous countries (nearest countries for islands) are considers as neighbours by the matrix entries, generating a network matrix of dimension 156×156.

As we believe PAs to be globally subject to spatial dependence, the independence assumption underlying standard linear regression models (relating PAs share to potential drivers) are likely not fulfilled, leading to biased least square estimators. Therefore, econometric texts (Anselin 2013; Arbia, 2014; LeSage and Pace, 2009) argue for exploiting spatial inference techniques, the latter considering geographical links between observations.

Starting from the following standard regression model $y = X\beta + \varepsilon$ with $\varepsilon|X \sim iid(0, \sigma^2 I)$, the corresponding spatial regression model in case of spatial dependence in the dependent variable (y), in the vector of explanatory variables (X) and in the residuals (ε) is:

$$y = \rho W y + W X \beta_w + X\beta + \varepsilon \qquad \text{with } |\rho| < 1 \tag{4.1}$$

$$\varepsilon = \delta W \varepsilon + \mu \quad \text{with } \mu|X \sim iid(0, \sigma_\mu^2 I) \text{ and } |\delta| < 1 \tag{4.2}$$

where ρ, β_w, β and δ are the model's parameters. This general form subsumes several models depending on whether the parameters of the spatial terms, ρ, β_w and δ, equal 0 or not. Thus, in absence of residuals spatial autocorrelation ($H_0 : \hat{\delta} = 0$) and when Wald tests indicate that including the spatial lag of the regressors, WX, does not statistically improve the quality of the regression ($H_0 : \hat{\beta}_w = 0$), the model is finally restricted to:

$$y = \rho W y + X\beta + \varepsilon, \quad \text{assuming} \quad \varepsilon|X \sim iid(0, \sigma^2 I) \tag{4.3}$$

The regression model (3) is the final specification this empirical study uses in analysing the environmental and socio-economic drivers of PAs.[4] Regarding the model's parameters, β stands for the effects of explanatory variables, while ρ captures the amplitude of spatial dependence in PAs, given that Wy represents average PAs in neighbouring countries. The weighting matrix W being common border-based, the estimated parameter of vector Wy can been as how changes in PAs share in neighbouring countries affect PAs in a considered country i, ceteris paribus. Econometric literature suggests Maximum Likelihood (ML) procedures (see Anselin,

[4]The final form of the regression model is actually suggested by specification tests. See Table 4.2

2013; LeSage and Pace, 2009; Bivand et al., 2015) which help estimate the parameters of (3).

4.6 Estimation results

4.6.1 Some tests: Evidence of spatial dependence in PAs

Before estimating the parameters, we test for spatial dependence in PAs share as well as in the residuals, using $W_{n\times n}$ by exploiting Moran-I tests under randomization and Monte-Carlo permutation tests. The tests results (Table 4.2) support our assumption regarding the presence of geographical spillovers in PAs, justifying the specification of the spatial regression model (3). Based on these first results, the spatial lag of PAs, Wy, is introduced into the model.

Next, four different models (Model 1-4) are estimated using ML techniques, whose respective residuals are exploited in testing for residuals spatial autocorrelation ($H_0 : \hat{\delta} = 0$). Observing the latter test results, we fail to reject H_0, suggesting no residuals spatial autocorrelation. Finally, we test whether the spatial lag of the regressors, WX, should be introduced into the model by exploiting Wald tests, which actually compares models without WX to augmented ones ($H_0 : \hat{\beta}_w = 0$). The results at 1% and 5% significance-levels indicate that introducing WX does not significantly improve the quality of the model. Overall, the preliminary tests recommend models including only the spatial lag of PAs, Wy, thus equation (3).

4.6.2 Estimating spatial lag models of PAs

Addressing endogeneity. Next to specification tests, the parameters of (3) are estimated addressing endogeneity. Indeed, the presence among regressors of variables such as per capita GDP, forest rents, agricultural land and forest cover as well as biodiversity indicators raises endogeneity issues. Regarding production activities for instance, the literature has proven conservation actions to be income level dependent (Mol and Spaargaren, 1993; Mol, 2000). Reversely, as production process exploits ecosystem services and natural resources, per capita GDP, forest rents and agricultural land can be explained by PAs share. Hence, there appears to be inverse

causality between economic and environmental indicators. Similar observations hold for forest cover and biodiversity. Precisely, since PAs help reduce forest clearing and protect species, observed forest cover, species richness and extinction risk can also be expressed as depending on conservation efforts.
To address these endogeneity issues, we rely on instrumental variables technique, using as instrument for each of the variable listed above its one year-lag. In doing so, the predicted values of the first stage regressions are next used in estimating the parameters of the second stage model.
Results of estimation. The outcomes of estimating the spatial lag model of PAs and corresponding average direct impacts are reported in Table 4.2. First, the results support the existence of positive spatial spillovers in PAs share. The weighting system being geography-based, a positive $\hat{\rho}$ suggests that increases of PAs share in the neighbouring countries enhance conservation policies in a considered country, all other things being equal. In addition to geographical spillovers, the results fairly endorse claims regarding the non-randomness of establishing PAs. Comparing information criteria, it is to signal that the following results interpretation is essentially based on Model 4.

As the ecological modernization theory predicts the extent of conservation policy to increase with development level, income per capita is expected to be encouraging conservation efforts. As predicted, per capita GDP positively drives PAs, implying that the higher income level, the larger nature preservation efforts (PAs share in surface area). The same result is noted in Dietz and Adger (2003) and is consistent with the recent study by Hoffman et al. (2018).

Table 4.2: Results of estimating SLM of PAs and average direct impacts

Covariates, X	Model 1	Model 2	Model 3	Model 4
Spatial effects in PAs, $\hat{\rho}$	.239***(.093)	.221**(.093)	.244***(.091)	.202**(.091)
Intercept	−12.405** (6.161)	−12.721* (7.584)	−14.194* (8.379)	−4.149 (12.929)
LnGDP per capita	2.212***(.684)	3.169***(.899)	3.799***(.949)	2.889**(1.233)
Forest area	.146***(.036)	.126***(.038)	.098**(.041)	.107**(.047)
Climate zone		−.114* (.065)	−.173** (.077)	−.246***(.081)
Extinction risk		−42.952 (37.0)	−41.80 (36.772)	−43.782 (35.992)
Species richness		18.873 (33.0)	23.612 (33.222)	11.0 (32.812)
Population density			−.004 (.006)	−.005 (.006)
Population growth			−1.714* (.892)	−1.852** (.928)
Rural population growth			1.218** (.610)	1.514** (.606)
Agricultural land				.047 (.045)
Forest rent				−.079 (.204)
Mean year of education				.039 (.254)
Institution				3.188***(1.175)
Number of obs.	156	156	156	156
Log likelihood	-583.908	-581.521	-578.696	-574.598
AIC	1182.5	1182.7	1184.4	1181.9
Average direct impacts	(1)	(2)	(3)	(4)
LnGDP per capita	2.245***(.696)	3.210***(.887)	3.860***(.945)	2.920**(1.264)
Forest area	.148***(.037)	.128***(.037)	.099***(.042)	.108***(.049)
Climate zone		−.115** (.064)	−.175**(.076)	−.248***(.083)
Extinction risk		−42.509 (37.471)	−42.47 (37.343)	−44.251 (36.334)
Species richness		18.118 (34.02)	23.99 (34.204)	11.12 (33.664)
Population density			−.004 (.006)	−.005 (.006)
Population growth			−1.714* (.898)	−1.530* (.962)
Rural population growth			1.237* (.642)	1.514***(.634)
Agricultural land				.048 (.049)
Forest rent				−.081 (.197)
Mean year of education				.039 (.255)
Institution				3.222***(1.172)
	a. Tests for presence of spatial autocorrelation in PAs			
	Global Moran-I test under random.		Monte-Carlo permutation test	
	Test-stat.	0.232	Test-stat.	0.233
	p-value	2.853e-05	p-value	0.001
Moran test	*b.* Test for residuals spatial autocorrelation, (Based on Model 1-4)			
Moran-I	.007	.004	.016	.022
p-value	.407	.427	.355	.313
Wald test	*c.* Test comparing models without and with WX, (Based on Model 1-4)			
L. ratio	2.876	2.901	13.741	19.847
p-value	.237	.715	.088	.070

Notes: Dependent variable is the share of PAs. In brackets are asymptotic standard errors. We use the one-year lag of the series on GDP per cap., forest rents, agricultural land, forest area, species richness and extinction risk as instruments. "***", "**" and "*" respectively indicate significance at 1%, 5% and 10% levels. In *b* and *c* results of tests performed on the residuals of the corresponding model 1-4 and Wald tests.

Concerning forest cover, our results show that relatively large PAs shares are observed in countries with high forest cover, since decelerating deforestation is among the objectives of conservation policies. This means that implementing PAs, conservationists specifically target locations with large natural habitats for animal and plants species, Forests. Similar conclusions appear in the PAs effectiveness literature and also in Brockett and Gottfried (2002) and Sierra and Russman (2006) in the case of PES. The latter observations suggest that, besides regional network effects in PAs, forest cover and income level definitely promote conservation efforts.

Controlling for geographical location, we introduce a proxy for climate zone into the regression model. Climate zone, measured by the distance of the capital city from Equator, shows a significant negative effect on PAs share. This indicates that compared to the Poles, larger natural reserves are observed in countries located close to the Equator. Reciprocally, fewer terrestrial PAs are located far from the equator. Biological species mostly lying in tropical rainforests, such a result seems not surprising, as conservation efforts aim not only to reduce deforestation but also species loss.

Regarding the indicators of biodiversity, namely species richness and extinction risk, less conclusive outcomes are observed. Both variables show no significant effects on PAs share, implying that biological species density and the risk of extinction are not genuinely accounted for, when it comes to establish PAs. The latter results remain unchanged, when further factors are controlled for, suggesting that conservation efforts are mainly income and forest cover driven. How does forest cover drives PAs, whereas species density does not? The "empty forests" hypothesis (Redford, 1992; Wilkie et al., 2011; Antunes et al., 2016) provides some reasonable explanations to our results. Concretely, the latter argues that as large species have already gone ecologically extinct in several forests, when implementing conservation policies "we must not let a forest full of trees fool us" into believing in its biological species richness (Redford, 1992). Moreover, recent observations by Hoffman et al. (2018) strengthen our results by showing that in Europe PAs size is not a predictor of biological species richness, since containing considerably fewer species than expected from their size. Nevertheless, because naturalness and ecosystem services of forests matter as well, focusing on forests when establishing PAs seems to be the most common approach, even in case of species-poor forests.

Demographic pressure, captured by population density and population growth, shows negative links to PAs, denoting possible conflicts over habitat between human population and natural reserves. The latter result suggests the existence of an unfriendly cohabitation between nature conservation efforts and human population growth. Similar results on the consequences of human population are discussed by McDonald et al. (2008) and Songer et al. (2009). Specifically, shrinking distances of cities to natural reserve, population growth and cities enlargement lead to withdrawal of PAs. Moreover, by controlling for rural population, we find results indicating that rural population growth is not globally to blame for conflicting with conservation actions. Hence, the adverse effects of population on conservation efforts are likely global level effects rather than being only imputed to rural populations.

Agricultural land and forest rents show no significant effects on PAs size. Controlling for education and political institutions, by using the mean years of schooling and control for corruption index, our results show a positive role of political institutions in empowering nature conservation measures. The latter corroborates the existing literature suggesting that improving political institutions, reducing corruption, may help strengthen environmental policies and reach nature conservation goals (Clements et al., 2010; Beevers, 2015; Schulze et al., 2018).

Overall, our regression analysis helps identify forest cover as the main environmental driver of PAs share, since indicators of biodiversity are found to be neutral. This implies that even when species-poor or containing fewer species, forest cover is a good predictor of PAs. In the upcoming section, we question the robustness of our results and propose a regional analysis.

4.7 Robustness and heterogeneity analysis

4.7.1 Robustness check

The main criticism of spatial analyses being whether the weighting system suits the actual scale of the geographical interactions, we check our results for robustness by employing two different weighting matrices, built using the *k*-nearest neighbours principle considering $k = 1$ and $k = 2$. The latter are used to test for spatial dependence in PAs, following the same procedures as above. Since, the tests using both weighting systems show results supporting the presence of spatial dependence in PAs, we proceed by estimating the same model. The data remaining unchanged, using different weighting systems should not grossly affect the parameters, but only the amplitude of the spatial effects. The results presented in Table 4.4 broadly support our findings regarding the role of income level, forest and good political institutions in positively driving conservation efforts. This robustness analysis also indicates that species richness and extinction risk do not significantly drive PAs, likely suggesting the lack of systematic targeting toward biological species richness and extinction risks when establishing PAs. Consequently, countries with the highest animal and plant species richness coupled with the highest extinction risk are not predominantly those sheltering the largest PAs, regardless of management categories. Considering population dynamics, their conflicting links to PAs remain significant.

Finally, our first discussions regarding spatial spillovers in PAS as well as factors promoting conservation efforts globally hold, since this robustness analysis relying on different weighting systems leads to very comparable results. Forest cover remains the main environmental predictor of PAs.

4.7.2 Regional analysis

Globally assessing the determinants of PAs likely hides some regional disparities. To address that, we propose heterogeneity analyses based on income levels and regional blocks.[5] Thereby, we distinguish low- and high-income countries and consider the following three regional blocks: Africa, South & North America, Europe and Asia. The latter geographical blocks respectively include 46, 28 and 82 countries. Additionally, we address endogeneity by employing instrumental variables method as above, which amounts to introducing the fitted-values of the first stage regressions into the second stage model. The results of this heterogeneity analysis are reported in Table 4.3.

[5] To classify countries according to income level, we use the sample median of lnGDP per capita.

Income level. Per capita GDP has significant effects on PAs share only in high-income countries, supporting the increasing demand for environmental quality with development level hypothesis. Reciprocally, forest cover significantly drives conservation efforts only in low-income countries. Climate zone shows comparable results, indicating that independently of income level larger PAs shares are observed in countries close to the Equator. The indicator of extinction risk has no significant effects, while even relatively fewer PAs shares are identified in developing countries characterized by high species density, providing statistical supports to Figure 4.1. Finally, this income level analysis shows that good political institutions strengthen nature preservation policies in low-income countries.

Table 4.3: Results of robust linear models of PAs

	Income level		Regional blocks			
Covariates, X	Low-income	High-income	Africa	America	Europe	Asia/Pacific
Intercept	5.076 (24.284)	−5.149* (3.202)	8.003 (21.622)	9.404 (10.099)	−9.363*(5.806)	−10.41 (42.060)
LnGDP p. c.	3.137 (2.294)	7.691***(3.215)	.869 (2.065)	5.260 (7.092)	13.759***(4.801)	2.917* (2.001)
Forest area	.154***(.062)	.102 (.070)	.227***(.069)	−.554**(.235)	.026 (.179)	.076 (.102)
Climate zone	−.256**(.123)	−.284**(.104)	−.106 (.189)	−.803**(.344)	−.290 (.620)	−.326* (.187)
Extinction risk	−.697 (.548)	−.331 (.348)	−.164 (.529)	.122 (.623)	−.107 (2.071)	−.412 (.691)
Species richness	−1.942**(.772)	.537(.351)	−.242***(.093)	−.434 (.378)	.187 (.161)	.028 (.091)
Population density	−.002 (.007)	.003 (.011)	.013 (.021)	−.065* (.040)	.025 (.033)	−.009 (.008)
Population growth	2.702 (2.302)	−3.306***(1.181)	.164 (3.309)	6.243 (5.940)	−1.394***(.633)	−.690 (1.791)
Rural pop. growth	−0.438 (1.532)	1.331**(.656)	3.742 (2.450)	−2.054 (2.218)	3.054 (2.212)	.457 (1.791)
Agricultural land	.015 (.066)	.093 (.060)	−.004 (.081)	−.512** (.211)	−.122 (.149)	.147 (.096)
Forest rent	−.198 (.221)	−2.166 (2.057)	−.402 (.278)	.662 (3.514)	−8.024 (8.277)	.079 (.988)
Mean year of edu.	.172 (.334)	2.096 (1.462)	−0.176 (.445)	−1.329 (.923)	−.551 (.589)	.613 (.517)
Institution	4.342** (2.515)	2.097 (1.462)	4.727* (2.772)	−5.441 (4.586)	.292 (3.121)	3.492* (2.115)
Number of countries	78	78	46	24	41	43
Adj. R-squared	.241	.295	.264	.387	.516	309
F-stat. (P-value)	3.045 (.00)	3.680 (.00)	2.342 (.02)	2.315 (.07)	4.56 (.00)	2.567 (.01)

Notes: Dependent variable is the share of PAs in land area. Estimates are obtained using 2SLS methods. In bracket are bootstrapped standard errors. See Table 4.2 for further comments.

Regional blocks. Per capita GDP significantly drives conservation policies only in Europe (mostly high-income countries) and Asia, while it appears to be neutral in Africa and America. The latter outcomes also strengthen observations based on Figure 4.1, indicating that relatively large PAs share are located in high-income countries. Contrary to income, a positive role of forests in driving PAs in Africa seems predictable. Being mostly low-income countries, comparatively low demands for nature conservation could be theoretically foreseen in African countries. Therefore, forest cover might be the main drivers of PAs in Africa. In America however, countries with the largest forest share in surface area seem to shelter relatively fewer PAs along with conflicts between natural parks and land devoted to agricultural production. This is, increases in agricultural land lead to PAs loss in America, underlining a possible competition between agricultural production and conservation efforts. Political institutions encourage PAs establishing in Africa and Asia.

Overall, this robustness analysis supports the discussions in Section 6, highlighting the role of income and forest cover in driving nature conservation efforts. Additionally, we find that income is the main PAs driver in high-income countries (Europe), while forest cover significantly drives PAs in low-income countries (Africa). Moreover, PAs share appears to be neutral to biological species richness and extinction risks in both high and low-income countries. In America, there appears to be conflicts between land devoted to agricultural production and natural reserves.

4.8 Concluding Remarks

Conservation practitioners acknowledge PAs as the main instrument of conservation policies and the existing literature discusses the effectiveness of PAs in decelerating deforestation and protecting endemic species. Moreover, the PAs downgrading, downsizing, and degazettement (PADDD) literature points out factors driving PAs loss. However, questions regarding global efficiency of PAs in covering forests and species hotspots appear much less regarded. As the ecological modernization theory predicts high demands for environmental quality, thus large conservation efforts in high-income countries, large PAs shares are expected to be located in high-income countries, where relatively low species richness and extinction risks are actually observed. Therefore, besides PAs effectiveness and PADDD analyses, this paper proposes to assess the environmental and socio-economic predictors of conservation efforts worldwide.

To address factors influencing conservation efforts (measured by the share of PAs in surface areas), this paper exploits spatial econometrics techniques to analyse data drawn from the World Development Indicator (WDI) and UICN Red-List.

Firstly, our results support the presence of spatial spillovers in PAs share, indicating that conservation efforts or increases in PAs share in the neighbouring countries positively affect PAs sheltered by a considered country. Secondly, per capita GDP and good political institutions are found to be driving PAs, while population growth globally conflicts with conservation efforts. These results suggest that high-income countries, which also show relatively good political institutions allocate funds and devote larger shares of their surface area to nature conservation goals. In low-income countries however, low demands for environmental quality and weak funding capacities do not fundamentally promote nature conservation actions. Regarding environmental indicators, while the proxies for species richness and extinction risk are neutral, forest cover positively drives PAs. How do forests drive conservation efforts, whereas species richness does not? The species poor argument discussed in the literature seems to be a consistent explanation of such observations.

Considering geographical blocks (Africa, America, Europe and Asia) and dissociating low- from high-income countries reveals some disparities with regard to the role of income and forest in driving conservation efforts. In brief, income level primarily drives PAs only in high-income countries (Europe), whereas in low-income countries (Africa) forest cover does. It remains questionable whether forests and income driven conservation policies will help meet global biodiversity conservation targets. In case of species-poor forests, forest cover is likely to drive conservation policies, while indicators of biodiversity would not. Our results precisely support the latter hypothesis.

Finally, providing a number of ecosystem services, forests and their naturalness matter as well. Therefore, in addition to ecosystem centered approaches, our study identifying forests as main environmental drivers of conservation efforts urges practitioners to further focus on species richness and endemic species hotspots, when implementing conservation policies.

Appendix

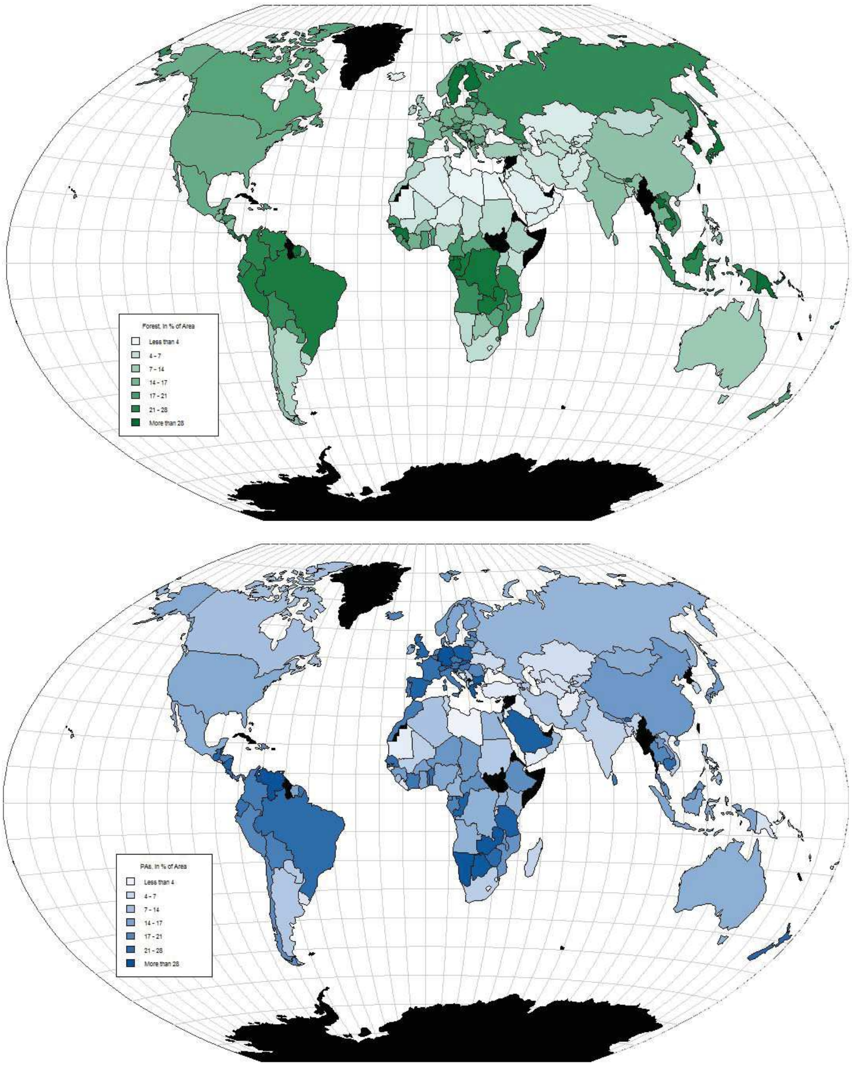


Figure 4.4: Map of forest cover ■ and PAs share in surface area ■.

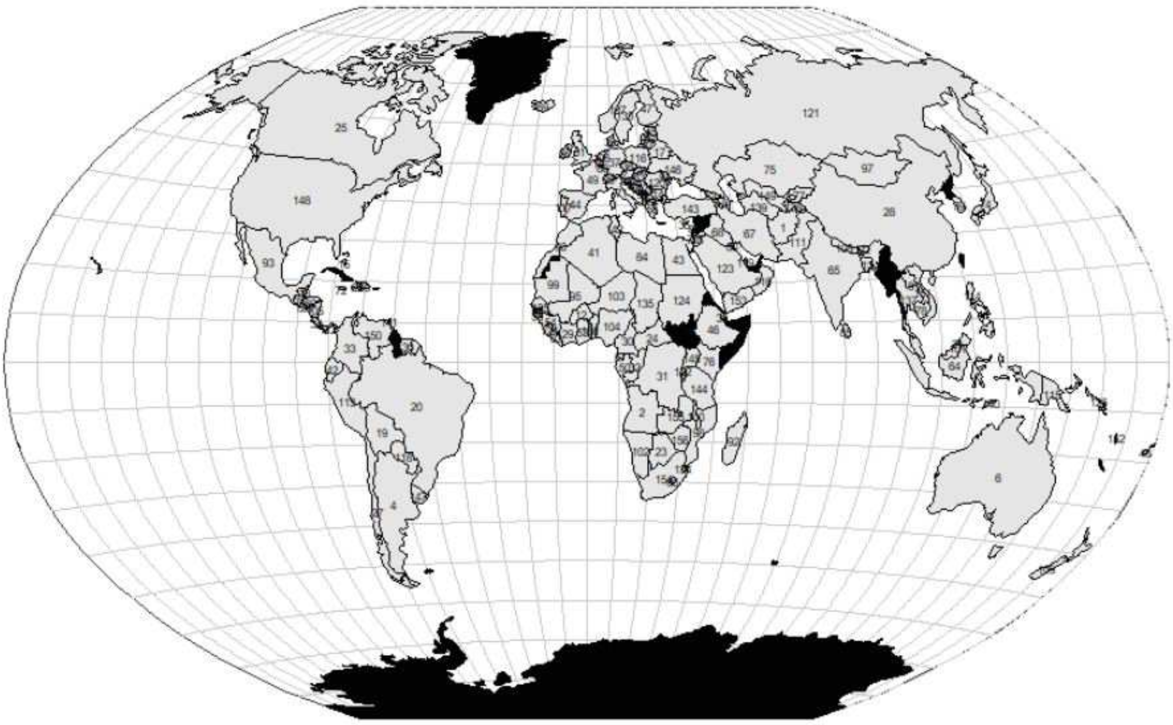


Figure 4.5: Countries involved in the analysis

Notes: Afghanistan 1, Angola 2, Albania 3, Argentina 4, Armenia 5, Australia 6, Austria 7,Azerbaijan 8, Burundi 9, Belgium 10, Benin 11, Burkina Faso 12, Bangladesh 13, Bulgaria 14, Bahamas 15, Bosnia and Herzeg. 16, Belarus 17, Belize 18, Bolivia 19, Brazil 20, Brunei Darussalam 21, Bhutan 22, Botswana 23, Central African Republic 24, Canada 25, Switzerland 26, Chile 27, China 28, Cote d'Ivoire 29, Cameroon 30, Congo, Dem. Rep. 31, Congo, Rep. 32, Colombia 33, Costa Rica 34, Cyprus 35, Czech Republic 36, Germany 37, Djibouti 38, Denmark 39, Dominican Rep. 40, Algeria 41, Ecuador 42, Egypt, Arab Rep. 43, Spain 44, Estonia 45, Ethiopia 46, Finland 47, Fiji 48, France 49, Gabon 50, United Kingdom 51, Georgia 52, Ghana 53, Guinea-Bissau 54, Guatemala 55, Gambia, The 56, Equatorial Guinea 57, Greece 58, Guinea 59, Honduras 60, Croatia 61, Haiti 62, Hungary 63, Indonesia 64, India 65, Ireland 66, Iran, Islamic Rep. 67, Iraq 68, Iceland 69, Israel 70, Italy 71, Jamaica 72, Jordan 73, Japan 74, Kazakhsta 75, Kenya 76, Kyrgyz Republic 77, Cambodia 78, Korea, Rep. 79, Kuwait 80, Lao PDR 81, Lebanon 82, Liberia 83, Libya 84, Sri Lanka 85, Lesotho 86, Lithuania 87, Luxembourg 88, Latvia 89, Morocco 90, Moldova 91, Madagascar 92, Mexico 93, Macedonia 94, Mali 95, Montenegro 96, Mongolia 97, Mozambique 98, Mauritania 99, Malawi 100, Malaysia 101, Namibia 102, Niger 103, Nigeria 104, Nicaragua 105, Netherlands 106, Norway 107, Nepal 108, New Zealand 109, Oman 110, Pakistan 111, Panama 112, Peru 113, Philippines 114, Papua New Guinea 115, Poland 116, Portugal 117, Paraguay 118, Qatar 119, Romania 120, Russian Federation 121, Rwanda 122, Saudi Arabia 123, Sudan 124, Senegal 125, Solomon Isl. 126, Sierra Leone 127, El Salvador 128, Serbia 129, Suriname 130, Slovak Republic 131, Slovenia 132, Sweden 133, Swaziland 134, Chad 135, Togo 136, Thailand 137, Tajikistan 138, Turkmenistan 139, Timor-Leste 140, Trinidad and Tobago 141, Tunisia 142, Turkey 143, Tanzania 144, Uganda 145, Ukraine 146, Uruguay 147, United States 148, Uzbekistan 149, Venezuela 150, Vietnam 151, Vanuatu 152, Yemen, Rep. 153, South Africa 154, Zambia 155, Zimbabwe 156.

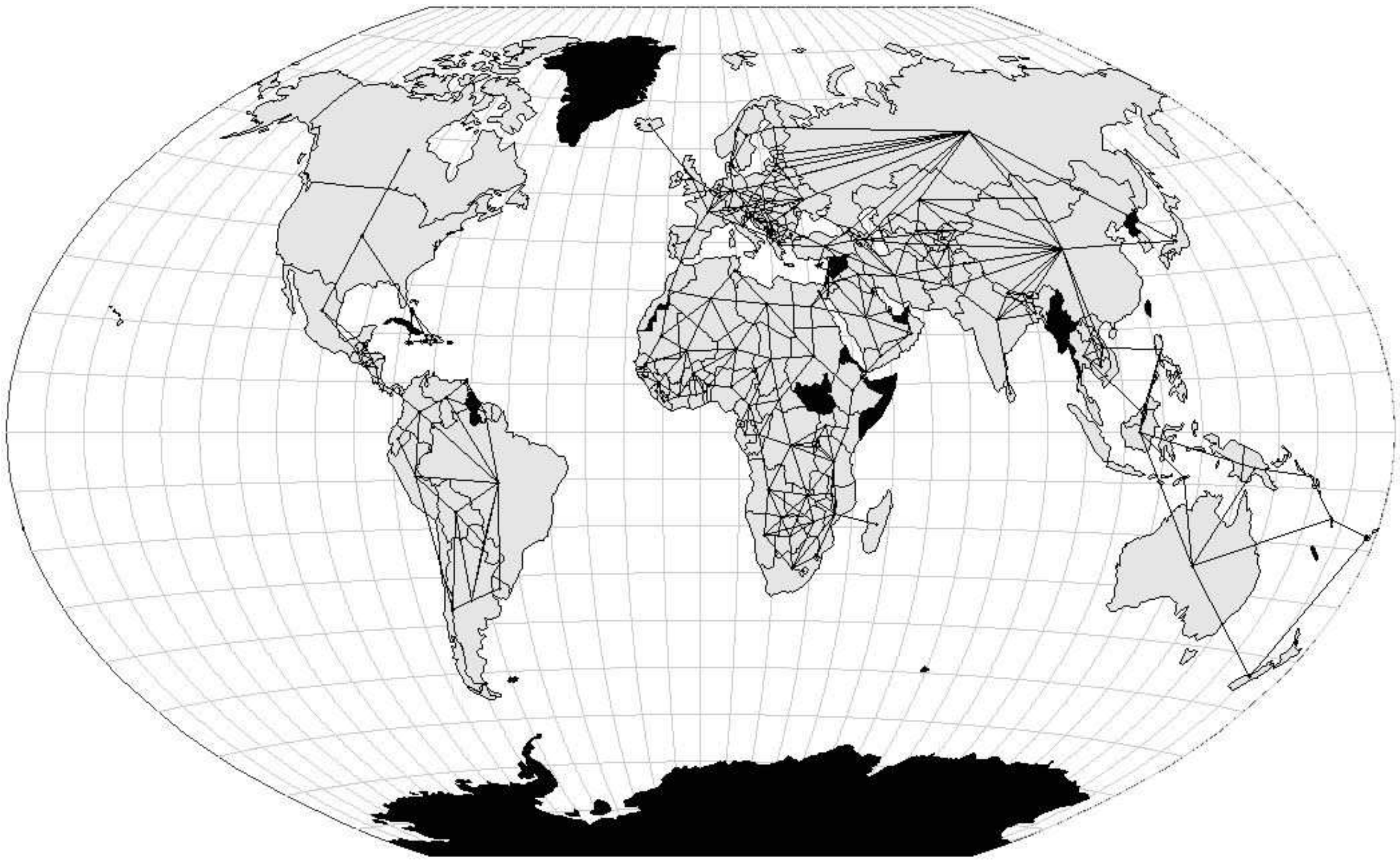


Figure 4.6: Borders based links used in building the connectivity matrix, $W_{(156\times156)}$

Notes: Common borders links (nearest neighbour for islands) exploited in building our main row-standardized weighting matrix characterized by 156 regions, 645 non-zero links with circa 4.135 average number of links and 2.651% non-zero weights.

Table 4.4: Results of estimating SLM of PAs using different weighting systems

	$k = 1$		$k = 2$	
Covariates, X	Model 1	Model 4	Model 1	Model 4
Spatial effects in PAs $\hat{\rho}$	.399**(.141)	.298* (.148)	.356* (.182)	.189 (.197)
Intercept	−16.574***(6.187)	−9.369 (13.397)	−17.050*** (6.423)	−7.579 (13.772)
LnGDP per capita	2.394*** (.692)	3.196*** (1.235)	2.486*** (.692)	3.206** (1.248)
Forest area	.145*** (.036)	.117** (1.235)	.157*** (.037)	.127** (.048)
Climate zone		−.237*** (.082)		−.251*** (.048)
Extinction risk		4.667 (3.625)		−4.793 (3.662)
Species richness		7.591 (3.303)		5.955 (33.371)
Population density		−.004 (.006)		−.004 (.006)
Population growth		−1.401* (.905)		−1.621* (.959)
Rural population growth		1.429* (.611)		1.477** (.617)
Agricultural land		.0511 (.046)		.059 (.047)
Forest rent		−.065 (.206)		−.076 (.208)
Mean year of education		.024 (.256)		.049 (.259)
Institution		3.156** (1.205)		3.407*** (1.213)
Number of obs.	156	156	156	156
AIC criterion	1182.5	1181.9	1181.7	1181.1

Notes: Notes: Dependent variable is the share of PAs in land area. As proxy for institution, we use the series *control for corruption* from the WGI. In bracket are asymptotic standard errors. The models 1 & 4 have been estimated using an international panel dataset, with n=41 and T=14. $\hat{\rho}$ stands for the spatial effects in PAs. "***" when $p < 0.01$, "**" $p < 0.05$, and "*" when $p < 0.1$.

5. Institutions and geography: A "two sides of the same coin" story of primary energy use*

Abstract: Why do coastal Sub-Saharan African (SSA) countries appear to be more energy consuming than inland ones? Do institutional and geographical factors matter for energy consumption, similar to the case of economic development? To answer these questions, surprisingly rarely addressed in the existing literature, we empirically assess the determinants of primary energy use across SSA, exploiting spatial analysis methods. Our results highlight the existence of positive geographical spillovers in primary energy use. We also derive factors (income, exports, population dynamics and urbanization) explaining the reasons coastal countries are more energy intensive. Furthermore, good political institutions and geographical location enhance primary energy use, connoting a "two sides of the same coin" role played by both factors. Our results impel SSA countries to develop alternative energy strategies and deploy energy resources management policies, since adverse environmental consequences associated to increasing fossil energies use are to expect in the near future.

*This Chapter is based on Lawson L. and Nguyen-Van P., 2018. "Institutions and geography: A "two sides of the same coin" story of primary energy use in Sub-Saharan Africa," Working Papers of BETA $N^o.2018-27$, UDS, Strasbourg.

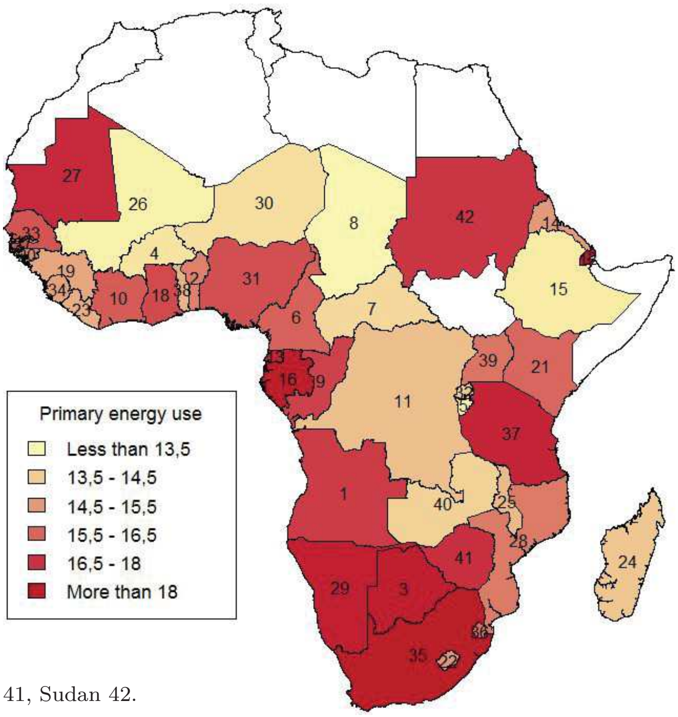
5.1 Introduction

Recent acceleration of ecosystem depletion and gas emissions has motivated systematic studies on the socio-economic drivers of natural resources and fossil energy use. This is the case in recent studies by Medlock and Soligo (2001), Wolde-Rufael (2009), Benthem and Romani (2009), Özokcu and Özdemir (2017) and Antonakakis et al. (2017), among others, on the energy use and economic development nexus. The present paper offers a new perspective on the primary energy use characteristics of SSA countries by investigating an issue which has surprisingly received few attention from the literature so far: The role of political institutions and geographical spillovers in primary energy use.

Existing works on energy use predominantly focus on the income-energy link, analysing causality, long-run dynamics and the so-called Environmental Kuznets Curve hypothesis for energy use. Further aspects question the drivers of energy demand and the channels through which energy availability enhances economic development. In this scholarship, relatively rare mentions of the role of institutional and geographical characteristics of countries (location, weather differentials and spatial spillovers) can be identified. Aiming to fill that gap, our paper analyses how institutions and geography influence energy consumption in Sub-Saharan Africa, accounting for usual socio-economic characteristics such as income and urbanization level, imports, exports and population dynamics, among others.

SSA countries being pre-industrial and highly resources-dependant economies, investigating topics relative to endowments in energy resources and primary energy use as well as related environmental consequences seems pertinent. Moreover, the "Geography versus Institutions" debate mainly animated by Acemoglu et al. (2001, 2005, 2008) and Sachs (2003) and Sachs et al. (1999, 2001), to cite a few, points out the importance of both factors in economic development. Hence, institutions and geography being among factors explaining economic growth, they likely play a similar role in energy consumption. In this perspective, introducing geographical factors and political institutions in a study of the determinants of primary energy use in SSA appears promising.

The contribution of our spatial analysis of primary energy use is twofold. Firstly, observing Figure 5.1, we can claim that location matters to endowments in fossil energies as well as in primary energy use, since high energy use is mostly observed in coastal located countries. Additionally, looking from South to the North, it appears that countries with lower energy use such as Chad, the Democratic Republic of Congo, Mali, and Ethiopia are mostly surrounded by countries with higher levels of energy consumption. As coastal and geographically contiguous SSA countries show comparable energy consumption levels, there might be some geographical spillovers in primary energy use and this analysis intends to consider that. Secondly, since SSA countries are being classified among the fastest growing economies, institutional and geographical factors seemingly play a significant role in their economic performances and therefore in energy use. Thus, our analysis proposes to account for institutions and geography, arguing that both factors also affect primary energy consumption, acting as the "two sides of the same coin".



List of countries: Angola 1, Benin 2, Botswana 3, Burkina Faso 4, Burundi 5, Cameroon 6, Central African Rep. 7, Chad 8, Congo Rep. 9, Cote d'Ivoire 10, Congo D. Rep. 11, Djibouti 12, Equatorial Guinea 13, Eritrea 14, Ethiopia 15, Gabon 16, The Gambia 17, Ghana 18, Guinea 19, Guinea-Bissau 20, Kenya 21, Lesotho 22, Liberia 23, Madagascar 24, Malawi 25, Mali 26, Mauritania 27, Mozambique 28, Namibia 29, Niger 30, Nigeria 31, Rwanda 32, Senegal 33, Sierra Leone 34, South Africa 35, Swaziland 36, Tanzania 37, Togo 38, Uganda 39, Zambia 40, Zimbabwe 41, Sudan 42.

Figure 5.1: Mean primary energy use per capita observed between 1990-2013, in thousandth of Kj.

The outline of the paper is as follows. Sections 2 and 3 present the related literature and the data. Section 4 comprehensively describes our econometric approach. Section 5 presents and discusses the estimation results. In Section 6, we provide some robustness check. Section 7 concludes the paper.

5.2 Related literature

The empirical literature on energy demand and economic development seems large in terms of contribution and methodological approach. Our paper broadly addressing the determinants of energy use, this literature review focuses on causality and long-run dynamics analyses, the energy-income nexus as well as the socio-economic drivers of energy use.

Being input in production activities, energy use reversely depends on income level. In addition to investigating the direction of causality, a first group of authors contributes by estimating the long-run relationship between energy and income. This is the case in Glasure and Lee (1998), Asafu-Adjaye (2000), Soytas and Sari (2003), Altinay and Karagol (2004), Lee (2005, 2006), Huang et al. (2008), Joyeux and Ripple (2011), Tang et al. (2012) and Omri (2015) among others. Reviewing this literature, a lack of unanimity regarding the direction of the causality is noticeable (Ozturk, 2010), motivating systematic meta-analyses (Menegaki, 2014; Bruns et al., 2014; Sebri, 2015), which lead to even ambiguous conclusions.

In the SSA context, the empirical results do not contrast with the previous ones. At country level, the results by Odhiambo (2009a) point to a stable long-run relationship with a unilateral causality running from energy to GDP in Tanzania, while in South Africa there is a bidirectional causality (Odhiambo, 2009b). The conclusions by Ebohon (1996), Wolde-Rufael (2009) and Esso (2010) partly support this bidirectional causality. Akinlo (2008) provides country level analyses to find a bidirectional causality in Gambia, Ghana and Senegal, while no causality is observed in Cameroon, Cote d'Ivoire, Nigeria, Kenya and Togo, similarly to Dogan (2014) in Benin, Congo and Zimbabwe. In the West African Economic Community, Ouedraogo (2013) claims a causality running from GDP to energy, while Kebede et al. (2010) point out regional disparities in energy demand and Wesseh and Lin (2016) work out the role of capital, labor, renewable and non-renewable energies in driving economic performance in Africa. It is to observed that these works on SSA countries are characterized by very limited samples in addition to providing less evidence of an EKC.

In a slightly different perspective, researchers analysed the energy-income relationship, challenging the existence of an Environmental Kuznets Curve (EKC) for energy.[1] This is the case in empirical works by Akarca and Long (1979), Gallet and List (1999), Nguyen-Van (2010), Antonakakis et al. (2017), among others. While conflicting, this literature largely does not support the EKC hypothesis.[2] Thus, in thorough discussions of stylised facts on the energy-income nexus from 1971 to 2010, Csereklyei et al. (2014, 2015) find a stable increasing relationship over the last four decades coupled with a decreasing energy intensity of GDP (Rühl et al., 2012). Definitely, besides global convergence in energy intensity, there seems to be no doubt that increase in energy consumption is largely economic growth driven.

Further relevant aspects of the literature concern drivers of energy use and the channels through which energy availability enhances GDP growth. On the latter point, Toman and Jemelkova (2003) and Birol (2007) argue that energy availability supports improvement of health and education system and also increases productivity in industry and agriculture.

Regarding further drivers of energy use, Medlock and Soligo (2001) explore the role of economic sectors to conclude that industrial, transportation and residential energy demand substantially increases in early stage of economic development. Metcalf (2008) and Van Benthem and Romani (2009) note end-use prices, the latter authors pointing out the role of agricultural and residential sectors in increasing energy demand in developing countries. Liddle (2013) assesses the relationship between economic growth, urbanization and energy consumption and finds results supporting a long-run relationship between these phenomena. Similar results are observed in the recent study by Dogan and Turkekul (2016), where a cointegration relationship appears between energy, urbanization and trade openness. Finally, in a systematic analysis of the determinants of energy consumption, Azam et al. (2016) mention the significant role played by income level, trade, urbanization, population growth and foreign direct investment.[3] Besides the latter socio-economic drivers, it is to notice that very few research papers address the role of institutional and geographical characteristics in energy consumption.

Based on this literature review, recurrent determinants such as per capita GDP,

[1] The EKC suggesting that environmental issues reverse their trend along with development.
[2] See the work by Tiba and Omri (2017) for a recent literature review on the EKC for energy.
[3] See Samuel et al. (2013) for a literature review on the drivers of energy demand.

industrial and agricultural production, urbanization, population growth, trade openness and foreign direct investments (FDI) should be accounted for in our empirical analysis.[4]

5.3 Data and descriptive statistics

Assessing how political institutions and geographical characteristics affect primary energy use, we intend to control for the most recurrent energy drivers identified in existing studies along with some SSA contextual elements derived from the comparative development literature. For this purpose, we drawn socio-economic variables from the World Development Indicators, data on primary energy use from the U.S. Energy Information Administration and indicators of political institutions from the Worldwide Governance Indicators (WGI). Due to missing values, the sample is reduced to 42 countries observed between 1990 and 2013.[5]

Dependent variable: As indicator of energy consumption, this study exploits the total primary energy use expressed in kilo-joules (Kj) per capita. It is to admit that such a synthetic measure of primary energy consumption does not provide any information concerning its composition or renewable structure. However, it serves as a good proxy for fossil and biomass energy use across SSA.

Explanatory variables: Considering socio-economic indicators, almost every peace of empirical study on energy consumption mentioned per capita GDP, trade, population dynamics and urbanization as driving energy demand. Therefore, our study accounts for per capita GDP (in purchasing power parity, PPP in 2011 $), the shares of imports and exports in GDP, as well as population density and urban population share. Following existing studies on the role of economic sectors in energy demand, the shares of agriculture, industry and FDI (net inflows) in GDP are additionally considered. Also, our dataset includes indicators of political institutions, (index of "governance effectiveness" and "regulatory quality"), poverty levels differentiation (poverty gap and Gini index), social conflicts (violent events and fatalities) and weather differentials (rainfalls and average temperatures) across SSA

[4]Series of end-use prices are hardly available for SSA for the considered period.

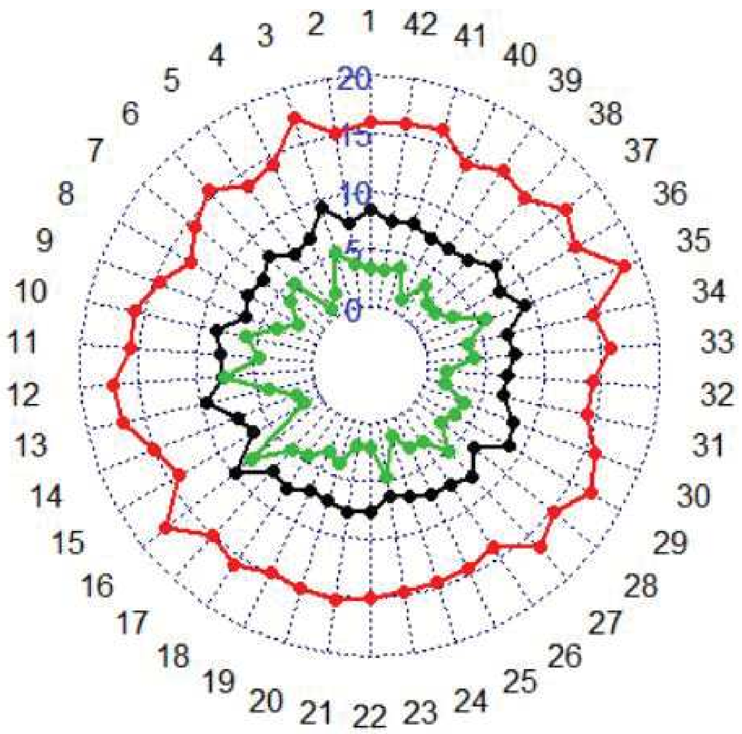
[5]Regarding South Sudan and Somalia, the data are not available for the considered period.

countries.

Table 5.1: Descriptive statistics

Variables	Units	Mean	S.D	Min	Max	Obs.
lnEnergy use per capita	kilojoule	15.353	1.206	12.616	18.622	1008
lnGDP per capita	In $	7.602	0.889	5.508	10.832	1008
Institutions (Governance eff.)	index	-.773	.569	-1.982	.876	1008
Institutions (Reg. quality)	index	-.711	.603	-2.412	.791	1008
Agriculture, added value	% GDP	28.062	17.021	.892	78.654	1008
Industry, added value	% GDP	27.267	15.804	3.329	84.283	1008
FDI, net inflows	% GDP	4.249	10.582	-82892	161.823	1008
Imports	% gdp	44.247	36.059	7.066	424.817	1008
Exports	% gdp	30.834	19.733	3.335	124.393	1008
Population density	count/km^2	57.257	70.442	1.719	449.051	1008
Population growth	%	2.600	1.040	-6.343	7.989	1008
Urban population share	in %	34.887	16.142	5.416	86.658	1008
Mean years of education	years	3.905	1.903	.700	10.100	965
Conflicts Fatalities	in 1000	.645	4.593	0	77.035	714
Violent Events	in 1000	.057	.127	0	1.321	714
Rainfalls, yearly	in dm	10.259	6.018	.704	32.822	966
Average temperatures	°C	24.731	3.286	12.628	29.541	966
Gini index	index	43.963	7.314	29.8	65.8	567
Poverty gap at 1.9$ a day	% of P.L.	19.604	12.046	1.8	63.6	639
Pop. with electricity access	in %	24.705	2.075	.010	89.30	995
Urban Pop access to electricity	in %	51.604	25.211	.010	100	1006
Government final consumption	% gdp	85.661	24.870	7.693	241.974	1008
Gross fixed capital formation	% gdp	20.132	8.774	-2.424	59.723	1008
Natural resources rents	% gdp	14.851	14.571	.374	89.002	1008

Notes: The sample includes $N = 42$ SSA countries. Number of periods, $T = 24$. N*T= 1008.



Notes: See Figure 5.1 for the list of corresponding countries 1-42

lnPrimary energy
lnGDP per capita
Urban population, $^o/_{oo}$

Source: The authors using data from the WDI and US-EIA observed between 1990-2013.

Figure 5.2: Mean Income, primary energy use and urban population in SSA.

Besides Figure 5.1 which helps identify Gabon, South-Africa and Nigeria as countries with the highest intensities of primary energy use per capita and respectively Chad, Mali and Ethiopia with the lowest levels, Table 5.1 reports descriptive statistics of our data for the entire sample. In addition to the series reported in Table 5.1, the dataset includes further variables such a coastal location dummy, the origin of the colonizer and the year of independence.[6]

Although very insightful, Figure 5.1 and Table 5.1 do not provide any information about the geographical distribution of income and urban population across SSA. To fill that gap, we jointly compares income, energy use and urban population share for the 42 countries of our sample (Figure 5.2). Therein, peaks (respectively low points) in urban population, per capita GDP and energy use are simultaneously observed in the same countries, giving hints on possible links between these phenomena. For instance, peaks are jointly observed in Botswana, Cameroon, Rep. Congo, Gabon, Nigeria, South Africa and Zimbabwe and reciprocally in Benin, Burundi, Chad, Gambia, Mozambique, Niger, Swaziland, Togo and Zambia where the lowest levels in energy, income and urban population are concurrently noticed. If there is a statistical relationship between these phenomena across SSA, a genuine data analysis will help assess it. For this purpose, we next present our spatial econometric specification.

5.4 Econometric model

Primary energies being essentially fossil energies (oil, coal and natural gas), we argue that observations on country-level primary energy use are likely subject to geographical spillovers. Moreover, Figure 5.1 indicates that location matters to energy use in SSA along with the fact that countries with low intensities are mostly surrounded by energy intensive ones. This suggests to account for time-invariant spatial effects in primary energy use.

Modelling spatial spillovers, econometric texts (Anselin, 2013; Anselin and Arribas-Bel, 2013; Arbia, 2014) discuss convenient methods that exploit different

[6] The origin of the colonizers and the years of independence will serve as instrument for current institutions.

geographical links and weighting systems. Let $\omega_{(n\times n)}$ be a connectivity matrix (row standardized), the component of which are w_{ij} with $i, j = 1, 2 \dots n$, a general form of the spatial panel data model is:[7]

$$y_{it} = \mu_i + \rho \sum_{j=1}^{n} w_{ij} y'_{jt} + \sum_{j=1}^{n} w_{ij} x'_{jt} \beta_w + x'_{it}\beta + u_{it}, \text{ with } |\rho| < 1 \tag{5.1}$$

$$u_{it} = \delta \sum_{j=1}^{n} w_{ij} u_{jt} + \varepsilon_{it}, \text{ with } \varepsilon_{it}|x_{it} \sim iid(0, \sigma^2) \text{ and } |\delta| < 1 \tag{5.2}$$

where ρ, δ, β_w and β are the parameters to estimate, μ_i being the individuals time-invariant characteristics.[8] The term $\sum_{j=1}^{n} w_{ij} y_{jt}$ stands for the spatial lag of the dependent variable and technically represents the average primary energy use in the neighbouring countries, while $\sum_{j=1}^{n} w_{ij} u_{jt}$ and $\sum_{j=1}^{n} w_{ij} x_{jt}$ respectively stand for residuals spatial heterogeneity and the spatial lag of the vector of regressors. The parameter ρ captures the strength of the spatial dependence on the neighbouring countries, if spatial spillovers there are in primary energy use. When specification tests (spatial dependence and Robust LM tests) suggest including $\sum_{j=1}^{n} w_{ij} y_{jt}$ and $\sum_{j=1}^{n} w_{ij} u_{jt}$ into the model, equations (1) and (2) become a model combining a spatial autoregressive model with spatially autocorrelated disturbances (SARAR). In that case, the regression model is reduced to:

$$y_{it} = \mu_i + \rho \sum_{j=1}^{n} w_{ij} y'_{jt} + x'_{it}\beta + u_{it} \text{ and } u_{it} = \delta \sum_{j=1}^{n} w_{ij} u_{jt} + \varepsilon_{it}, \tag{5.3}$$

$$\text{with } |\rho| < 1, \quad |\delta| < 1 \text{ and } \varepsilon_{it}|x_{it} \sim iid(0, \sigma^2)$$

The regression model (3) is the specification we use relating primary energy use to an index of political institutions, income per capita and other determinants.[9] Estimating ρ, δ, and the vector of parameters β, econometric texts (Elhorst, 2010; Baltagi et al., 2007; Kelejian and Prucha, 1999) discuss a two steps maximum likelihood (ML) approach, which are proven to provide consistent estimates (Yu et al., 2008; Debarsy and Ertur, 2010).[10]

[7] Different types of weighting systems can used. We rely in our estimations on a common border principle and on the k-nearest algorithm to build $\omega_{(n\times n)}$. See Tables AM-2 and AM-3 for more details.

[8] This is the most general model. (1) and (2) assume spatial autocorrelations only in the idiosyncratic term. Models where both, u_{it} and μ_i are spatially correlated are also feasible. See Kapoor et al. (2007).

[9] (3) is actually derived from specification tests, see Tables 5.6 & 5.7 for more details on the tests. Moreover, the condition $|\rho| < 1$ is known as the stationarity condition.

[10] A very comprehensive presentation of these estimation procedures is presented by Millo and Piras (2012).

5.5 Results and discussion

5.5.1 Modelling primary energy use: Preliminary tests

Fixed effects versus random effects models: To begin, we perform a standard Hausman test to compare fixed effects (FE) to random effects (RE) models using six (6) different specifications. The test results (Table 5.4) mostly indicate that FE models consistently match the data generating process. Next, we address endogeneity issues related to the presence of per capita GDP, institutional characteristics and electricity access among regressors.

Addressing endogeneity: Existing studies, also in the African context, largely suggest a bidirectional causality between GDP and energy use. The latter being input in production activities (Wolde-Rufael, 2009; Esso, 2010), income level reversely depends on energy use, leading to inverse causality. Regarding institutions, the comparative development literature shows that in former colonies and resource-rich countries such as SSA, current institutions directly derive from colonial institutions, which in Africa mainly appear to be resource extractive institutions (Acemoglu et al., 2001, 2012). Thus, current political institutions in former colonies are linked to the origin of the colonizers and highly reflect natural resources extraction strategies.

Solving for endogeneity, we rely on instrumental variables technique. Doing so, as instruments for lnGDP per capita, we use its one year lag, the gross domestic fixed investment and the government final consumption in GDP. Reciprocally as instruments for current institutions, we use a categorical variable for the origin of the colonizers, the year of independence and the one year lag of resources rents in GDP (proxy for richness in resources). Finally, as instrument for electricity access, we exploit the one year lag of urban population share.

Concretely, this consists of using predicted values of the endogenous regressors from the first stage regressions in the second stage model. The results of the first stage regressions as well as those of estimating standard FE models are reported in the Appendix (Table 5.5 and A-3) and give first insights into the role of political institutions, geographical factors and income among others in primary energy use in SSA. In the remaining, arguing that primary energy use is subject to spatial interactions, we test for spatial correlation and propose a spatial regression analysis.

Evidence of spatial dependence in primary energy use: Firstly, tests for spatial dependence are performed in each of the 24 yearly waves of the dataset using as weighting system a common borders-based connectivity matrix ω^* (see in Additional Materials, Table AM-2). The tests results show evidence of spatial dependence in primary energy use (Table 5.6). Secondly, we consider the six (6) different model specifications, testing for spatial dependence in energy use and in the residuals applying robust LM tests (Baltagi et al., 2007, Anselin et al., 2013). The latter tests support the presence of spatial spillovers in primary energy use as well as some residuals spatial autocorrelation (Table 5.7). Finally, modelling primary energy use in SSA, both spatial lag and residuals spatial autocorrelation should be considered.

Spatial Hausman tests: Accounting for the previous results, we perform in addition to the standard case spatial Hausman tests. The spatial Hausman tests strengthen the accuracy of the fixed-effects (FE) modelling largely suggested by early results. The latter test results are also reported in 5.7.

5.5.2 Results of estimating spatial FE models for primary energy use

Subsequent to the preliminary tests, we estimate the parameters of spatial regression models of primary energy use, combining ML and instrumental variables method for regressors' endogeneity, mainly per capita GDP and institutions. Thereby, at the first stage, we regress per capita GDP and the indicator of political institutions on their respective instrument, as mentioned above, in addition to the remaining set of explanatory variables. Exploiting the predicted values at the second stage, a two-step ML approach following Baltagi et al. (2007) and Millo and Piras (2012) is applied to estimate the model' parameters. Due to spatial interactions, the estimated parameters reported are no exact marginal effects. Therefore, we compute the corresponding average direct and total impacts (Table 5.2).

Comparing information criteria (AIC), our results interpretation is mainly based on the FE SARAR specification VI. The parameter $\hat{\rho}$ reflects spillovers from the neighbouring countries in energy use. However, as the amplitude of spatial spillovers depends on the weighting system, it should be carefully interpreted. Since the weighting matrix ω^* simply indicates whether countries share a common boundary or not, $\hat{\rho}$ then tells us how on average a country's own level of energy use depends on primary energy consumption in the neighbouring countries, all things being equal. This indication of positive geographical spillovers supports our assertion relatively to the role of geography in primary energy use.[11]

Apart from geographical spillovers in primary energy use, the regression model delivers further interesting results concerning the role of political institutions, per capita GDP and openness to trade among others. Regarding political institutions, known in the existing literature as a fundamental cause of long-run economic growth (Acemoglu et al. 2005, 2008), they are expected to be positively driving energy use. By encouraging investments in technology, physical capital and by driving economic outcomes, political institutions enhance energy demand. Accordingly, our estimates show positive and significant effects, implying that governance effectiveness, a good policy formulation and implementation enhances the demand for primary energy. Obviously, not only good political institutions shape economic production, they also appear to be enhancing the energy use in SSA countries.

Concerning income, the existing literature on SSA (Akinlo, 2008; Wolde-Rufael, 2009) consistently mentions a positive link to energy. Our standard FE (Table 5.4) and the FE-SARAR specifications (Table 5.2) support this finding. Considering the structure of the economy, agricultural and industrial production in GDP appear to be positively linked to primary energy use (Soligo, 2001). These results definitely indicate that despite being at early stages of development, aggregate production activities in SSA drives primary energy use.

[11] Possible explanations for spatial spillovers in energy use across SSA countries are through regional integration of electricity markets as well as cooperation in energy sectors. See Oseni and Pollitt (2016) for discussions regarding Western and Southern African cases.

Table 5.2: ML estimation of FE SARAR models of primary energy use (using ω^*)

Covariates	**I**	**II**	**III**	**IV**	**V**	**VI**
$\hat{\rho}$	.047 (.073)	.108* (.067)	.181***(.062)	.211**(.087)	.249***(.091)	.254** (.121)
$\hat{\delta}$	.027 (.086)	−.054 (.083)	−.172**(.082)	−.253**(.113)	−.309***(.116)	−.253*(.158)
lnGDP per capita	.765***(.032)	.779***(.033)	.676***(.038)	.732***(.063)	.730***(.067)	.488***(.093)
Institutions	.256***(.070)	.341***(.068)	.285***(.085)	.389***(.077)	.408***(.082)	.968***(.096)
Agriculture, GDP share		.010***(.002)	.008***(.002)	.005* (.003)	.002 (.003)	.012** (.003)
Industry, GDP share		.011***(.002)	.010***(.002)	.009***(.003)	.005* (.003)	.005 (.003)
FDI, GDP share			−.002**(.001)	−.002* (.001)	−.001(.002)	−.001 (.002)
Imports, GDP share			−.003***(.000)	−.003***(.001)	−.003***(.001)	−.005** (.002)
Exports, GDP share			.001 (.001)	−.001 (.002)	.001 (.002)	.012***(.002)
Population density				−.005***(.001)	−.006***(.001)	−.005***(.001)
Population growth				.001 (.017)	.017 (.018)	−.013 (.016)
Urban population share				.005 (.005)	.006 (.005)	.004 (.007)
Mean years of education				.017 (.029)	.013 (.029)	−.050 (.038)
Conflicts fatalities					.024 (.021)	−.076** (.027)
Violent events					.273**(.113)	.927***(.136)
Rainfalls, yearly					.121* (.065)	.238* (.071)
Average temperature					.023 (.029)	−.010 (.027)
Gini index						−.013* (.003)
PGap1.9						.009** (.002)
Access to electricity						.011*** (.004)
Number of Obs.	1008	1008	1008	756	714	429
Number of countries	42	42	42	42	42	39
AIC Criterion	3546.276	3510.416	3467.312	2291.08	2100.623	779.704
Log Likelihood	-1726.138	-1706.208	-1681.656	-1089.540	-990.312	-329.852
			Average direct impacts			
lnGDP per capita	.765***(.030)	.779***(.031)	.677***(.037)	.733***(.061)	.731***(.006)	.489***(.087)
Institutions	.273***(.074)	.341***(.069)	.286***(.071)	.389***(.079)	.408***(.041)	.970***(.099)
Agriculture, GDP share		.010***(.002)	.008***(.002)	.005* (.003)	.002(.002)	.013** (.003)
Industry, GDP share		.011***(.002)	.011***(.002)	.009***(.003)	.005* (.003)	.005** (.002)
FDI, GDP share			−.002**(.001)	−.002* (.001)	−.001(.001)	−.001 (.002)
Imports, GDP share			−.003***(.001)	−.003***(.001)	−.003***(.001)	−.005***(.001)
Exports, GDP share			.001 (.001)	−.001 (.002)	.001 (.001)	.012** (.002)
Population density				−.005***(.001)	−.006***(.001)	−.005***(.001)
Population growth				.001 (.018)	.018 (.017)	−.013 (.017)
Urban population share				.005 (.005)	.006 (.005)	.004 (.007)
Mean years of education				.017 (.029)	.013 (.030)	−.051 (.038)
Conflicts fatalities					.024 (.022)	−.077** (.027)
Violent events					.274**(.118)	.929***(.136)
Rainfalls, yearly					.121* (.064)	.239** (.068)
Average temperature					.023 (.029)	−.010 (.028)
Gini index						−.013** (.003)
PGap1.9						.009** (.002)
Access to electricity						.011** (.004)
			Total impacts			
lnGDP per capita	.803***(.072)	.873***(.076)	.826***(.080)	.928***(.135)	.971***(.142)	.654***(.157)
Institutions	.270***(.081)	.382***(.082)	.349***(.091)	.494***(.117)	.543***(.128)	1.298***(.246)
Agriculture, GDP share		.011***(.003)	.009***(.003)	.006* (.004)	.003 (.003)	.017*** (.005)
Industry, GDP share		.012***(.002)	.013***(.002)	.012***(.004)	.007*(.004)	.007* (.004)
FDI, GDP share			−.002** (.001)	−.003* (.001)	−.002(.002)	−.002 (.003)
Imports, GDP share			−.004***(.001)	−.003***(.001)	−.004***(.001)	−.007** (.002)
Exports, GDP share			.002 (.002)	−.001 (.002)	.001 (.002)	.016** (.004)
Population density				−.007***(.001)	−.007***(.001)	−.006***(.002)
Population growth				.001 (.024)	.024 (.026)	−.017 (.024)
Urban population share				.007 (.006)	.007 (.007)	.006 (.010)
Mean years of education				.021 (.037)	.018 (.041)	−.068 (.054)
Conflicts fatalities					.032(.029)	−.103** (.040)
Violent events					.364**(.164)	1.243***(.268)
Rainfalls, yearly					.161* (.089)	.319* (.104)
Average temperature					.030 (.039)	−.013 (.038)
Gini index						−.017* (.005)
Poverty Gap, 1.9$ a day						.012** (.003)
Access to electricity						.015** (.006)

Notes: Dependent variable is log primary energy use per capita. As proxy for "Institutions", we use the "Governance effectiveness index" (WGI). For the estimated parameters, bootstrapped standard errors in brackets. Regarding impact measures, Monte Carlo simulations based impacts and corresponding standard deviations are reported. $\hat{\rho}$ and $\hat{\delta}$ respectively stand for the spatial effects in primary energy use and in residuals. "***", "**" and "*" respectively indicate significance at 1%, 5% and 10% levels.

Controlling for population dynamics, we rely on population growth, urban population share and population density, the latter showing a negative link to energy consumption. This negative link of population density, previously suggested by the standard FE models, seems understandable as increases in total population, translated by positive changes in population density, should also dilute primary energy use measured in per capita terms. However, such an observation is not necessarily true when country level dynamics of energy demand and population are considered. Indeed, increases in total population, thereby in population density, lead to increases in the demand for energy. Energy consumption essentially being a urban phenomena in SSA (Mkhwanazi, 2003), the urban population parameter sheds some light on the role of urbanization and population dynamics by indicating a positive link to energy use. Population growth, migration towards urban areas and city enlargement likely intensify the energy demand and consequently primary energy use. A focus on the energy and urban population (and its access to electricity) nexus will help be more conclusive on the role of urbanization. Moreover, openness to international trade assessed using exports, imports and net inflows FDI share in GDP shows that foreign direct investments do not fundamentally promote energy consumption, while exports are found to be driving primary energy use. The latter result, in the context of SSA countries, can probably be extended to other natural resources to mean that SSA economies rely on extracting and exporting natural resources.

The regression model includes further control variables such as weather differentials (temperatures and rainfalls), social conflicts indicators (counts of conflict fatalities and violent events) and indicators of poverty level differentiation (Gini index and poverty gap). In contrast to average temperatures and yearly rainfalls, conflicts fatalities and more largely conflicts severity and civil wars appear to be negatively linked to the energy use per capita. Accounting for poverty incidence and income distribution (Gini index), our analysis shows that the higher income inequalities, the lower primary energy use per capita. Finally, population access to electricity positively drives primary energy use. Such a result seems predictable, since electricity production in SSA largely exploits oil, gas and coal sources (primary energies), the latter sources representing more than 65% of total electricity production in SSA between 1990 and 2013.[12]

Conclusively, after controlling for aggregate production, population dynamics, income distribution, poverty incidence, weather differentials and conflicts severity among others, our spatial analysis so far shows that besides geographical spillovers, institutions drive energy use. Indeed, geography and institutions seem not only driving economic development, they also affect energy demand.

5.6 Robustness, role of geographical location and functional forms

5.6.1 Robustness check

To check our results for robustness, we apply the same procedures as above by exploiting a different weighting system, a different proxy for political institutions and introducing the same control variables into the model. Thus, this section considers a distance-based weighting system, ω^{**}, which exploits the k-nearest neighbouring algorithm and implies that even not directly contiguous countries could be considered as neighbours by the matrix entries (see Table AM-3). As proxy for institutions, we now use the *"Regulatory Quality index"*. Moreover, as above control variables relatively to aggregate economic production, demographics, income distribution, conflicts and access to electricity are considered.

The preliminary test results exploiting the weighting matrix ω^{**}, tests for geographical dependence in each of the 24 waves of the panel dataset, are largely compatible with the previous ones in stressing the importance of accounting for spatial dependences when modelling primary energy use. Given these test results, we estimate the parameter of the regression model (3), with ω^{**} as weighting system, by combining ML and instrumental variable method as above. The results of estimating the different specifications of spatial models of primary energy use are reported in Table 5.3.

[12]See the World Bank Data on electricity production in SSA from oil, gas and coal sources.)

Table 5.3: Estimation of FE SARAR models of primary energy use using ω^{**}

Covariates	I	II	III	IV	V	VI
$\hat{\rho}$	.220***(.064)	.205** (.067)	.272***(.064)	.269***(.082)	.294***(.083)	.320***(.135)
$\hat{\delta}$	−.165* (.102)	−.117 (.102)	−.219* (.106)	−.261*(.133)	−.323***(.139)	−.286 (.216)
lnGDP per capita	.737***(.034)	.755***(.033)	.640***(.040)	.660***(.059)	.668***(.065)	.520***(.095)
Institutions	.234***(.080)	.512***(.071)	.451***(.069)	.650***(.077)	.759***(.090)	.861***(.091)
Agriculture, GDP share		.010***(.002)	.007***(.002)	.005** (.002)	.001 (.003)	.011***(.003)
Industry, GDP share		.011***(.002)	.011***(.002)	.014***(.002)	.010**(.003)	.009***(.003)
FDI, GDP share			−.003* (.001)	−.002* (.001)	−.001 (.001)	−.001 (.002)
Imports, GDP share			−.002***(.001)	−.002***(.001)	−.003***(.001)	−.002 (.001)
Exports, GDP share			.001 (.001)	.001 (.001)	.002 (.002)	.008***(.002)
Population density				−.006***(.001)	−.006***(.001)	−.005***(.001)
Population growth				−.035 (.017)	−.030* (.018)	−.043** (.017)
Urban population share				.006 (.005)	.007 (.005)	.002 (.008)
Pop. mean years of edu.				−.022 (.027)	−.039 (.029)	−.086** (.041)
Conflicts fatalities					.040* (.022)	.027 (.029)
Violent events					.429**(.111)	.555***(.124)
Rainfalls, yearly					.177** (.063)	.205***(.072)
Average temperature					.020 (.026)	−.002 (.028)
Gini index						−.011*** (.003)
PGap1.9						.003* (.002)
Access to electricity						.013*** (.004)
Number of Obs.	1008	1008	1008	756	714	429
Number of countries	42	42	42	42	42	39
AIC Criterion	3522.478	3473.778	3428.418	238.830	2040.929	788.195
Log Likelihood	-1714.239	-1687.889	-1662.209	-1063.415	-960.4647	-334.097
			Average direct impacts			
lnGDP per capita	.731***(.032)	.755***(.031)	.641***(.037)	.661***(.061)	.668***(.062)	.521***(.089)
Institutions	.430***(.079)	.512***(.070)	.451***(.069)	.650***(.081)	.759***(.086)	.862***(.091)
Agriculture, GDP share		.010***(.002)	.007***(.002)	.005 (.003)	.001 (.002)	.011**(.003)
Industry, GDP share		.011***(.002)	.011***(.002)	.014***(.003)	.010* (.002)	.009***(.003)
FDI, GDP share			−.003* (.001)	−.002* (.001)	−.001(.001)	−.001 (.002)
Imports, GDP share			−.002***(.001)	−.003***(.001)	−.003***(.001)	−.002*(.001)
Exports, GDP share			.001 (.001)	.001 (.002)	.002 (.002)	.009***(.002)
Population density				−.006***(.001)	−.006***(.001)	−.005**(.002)
Population growth				−.035 (.018)	−.030 (.018)	−.043**(.018)
Urban population share				.006 (.005)	.007 (.005)	.002 (.008)
Pop. mean years of edu.				.022 (.027)	−.039 (.029)	−.086**(.041)
Conflicts fatalities					.041* (.022)	.027 (.028)
Violent events					.430**(.110)	.556***(.121)
Rainfalls, yearly					.177 (.062)	.206***(.072)
Average temperature					.020 (.028)	−.002 (.029)
Gini index						−.011* (.003)
PGap1.9						.003* (.002)
Access to electricity						.013*** (.004)
			Total impacts			
lnGDP per capita	.938***(.089)	.950***(.092)	.879***(.093)	.904***(.143)	.946***(.146)	.765***(.200)
Institutions	.546***(.114)	.644***(.103)	.619***(.112)	.889***(.158)	1.075***(.184)	1.266***(.280)
Agriculture, GDP share		.012***(.003)	.011***(.003)	.007 (.004)	.002 (.003)	.016***(.005)
Industry, GDP share		.013***(.002)	.015***(.003)	.020***(.004)	.015** (.004)	.013**(.005)
FDI, GDP share			−.004* (.002)	−.003* (.002)	−.002* (.002)	−.002 (.004)
Imports, GDP share			−.003***(.001)	−.003***(.001)	−.005***(.001)	−.003*(.002)
Exports, GDP share			.001 (.002)	.002 (.002)	.003 (.002)	.013***(.004)
Population density				−.008***(.001)	−.009***(.002)	−.008***(.002)
Population growth				−.048 (.027)	−.030 (.026)	.063***(.031)
Urban population share				.008 (.007)	.007 (.007)	.003 (.012)
Pop. mean years of edu.				.031 (.039)	−.039 (.042)	−.126***(.067)
Conflicts fatalities					.048(.033)	.039 (.045)
Violent events					.430** (.176)	.816***(.243)
Rainfalls, yearly					.177 (.097)	.302***(.128)
Average temperature					.020 (.040)	−.003 (.045)
Gini index						−.016* (.006)
PGap1.9						.005** (.003)
Access to electricity						.019* (.007)

Notes: Dependent variable is log primary energy use per capita. As proxy for "Institution", we use the "Regulatory Quality Index" (WGI). ω^{**} is displayed in Table AM-3. See Table 5.2 for further comments.

The outcomes of the regression analysis using ω^{**} are quite consistent with the primary results, observing the sign, the amplitude and the statistical significance of the parameters of interest. Concerning the ω^{**}-based geographical spillovers, slightly higher amplitudes are noticeable. This is understandable, given its characteristics (higher average number of links) and since the two weighting matrices ω^{**} and ω^{*} are different. In addition to the geographical effects, political institutions and income per capita, positively and significantly effect energy use, supporting once more our claim on the two sides of the same coin role played by institutions and geography in primary energy use.

Observing the estimated parameters of the control variables, one can definitely argue that FDI, conflicts severity (fatalities) and inequalities in income distribution do not systematically enhance primary do energy use in SSA, while exports and population access to electricity significantly do. Globally, the robustness check of our spatial regression analysis relying on a different weighting system and a different indicator of political institutions, namely the regulatory quality index, yields results supporting our primary conclusions.

5.6.2 Does location matter to primary energy use?

The evidence of spatial spillovers in primary energy use partly answers the question concerning the role of geographical characteristics. Observing that coastal countries appear more energy intensive and further show relatively high income levels (Figure 5.1 & 5.2), we argue that location might not be neutral in natural resources endowments and extraction, especially in primary energy use. Therefore, we explore the role of location, employing a dummy variable relative to coastal location (1 if coastal located, 0 otherwise) using a standard random panel data model, as the latter does not apply prior individuals time-demeaning transformation to the data.

The results (Table 5.5) show that compared to inland countries, being a coastal located country fosters primary energy use per capita. Such a result is not surprising, since in average coastal located countries are also the one with intensive agricultural, mining and manufacturing activities. As economic activities appear intensive in coastal located SSA countries, so does energy demand. Based on this, we can fairly state that location matters not only in comparative development but also in energy consumption, supporting that geography matters.

In conclusion, this robustness analysis supports our leading results regarding the potential for good political institutions and geographical characteristics in driving primary energy use. Furthermore, it helps fully highlight the role of aggregate economic production, income inequalities, access to electricity, conflicts severity and exports in energy consumption.

5.6.3 The primary energy use, income and urbanization nexus

Supplementary to the robustness analysis, we test for linearity in the relationship between income, urban population and primary energy use in SSA. The purpose of this exercise is to provide general patterns of the links between these phenomena. Consequently, we rely on the local constant or Nadayara-Watson kernel estimator. This approach clarifies the details by indicating an overall upward functional form between income per capita and primary energy use. Such a result helps indeed draw conclusions regarding the non-existence of an EKC for primary energy use in SSA (Figure **??**).

To closely investigate the general pattern of the link between population dynamics, urbanization and primary energy consumption, it is quite informative to focus on urban population share in total population and its access to electricity. This not only because parametric specification could be misleading but also because energy consumption being mainly an urban phenomenon in Africa (Mkhwanazi, 2003 and IEA, 2014), considering urban population share and its access to electricity should provide mostly informative outcomes.

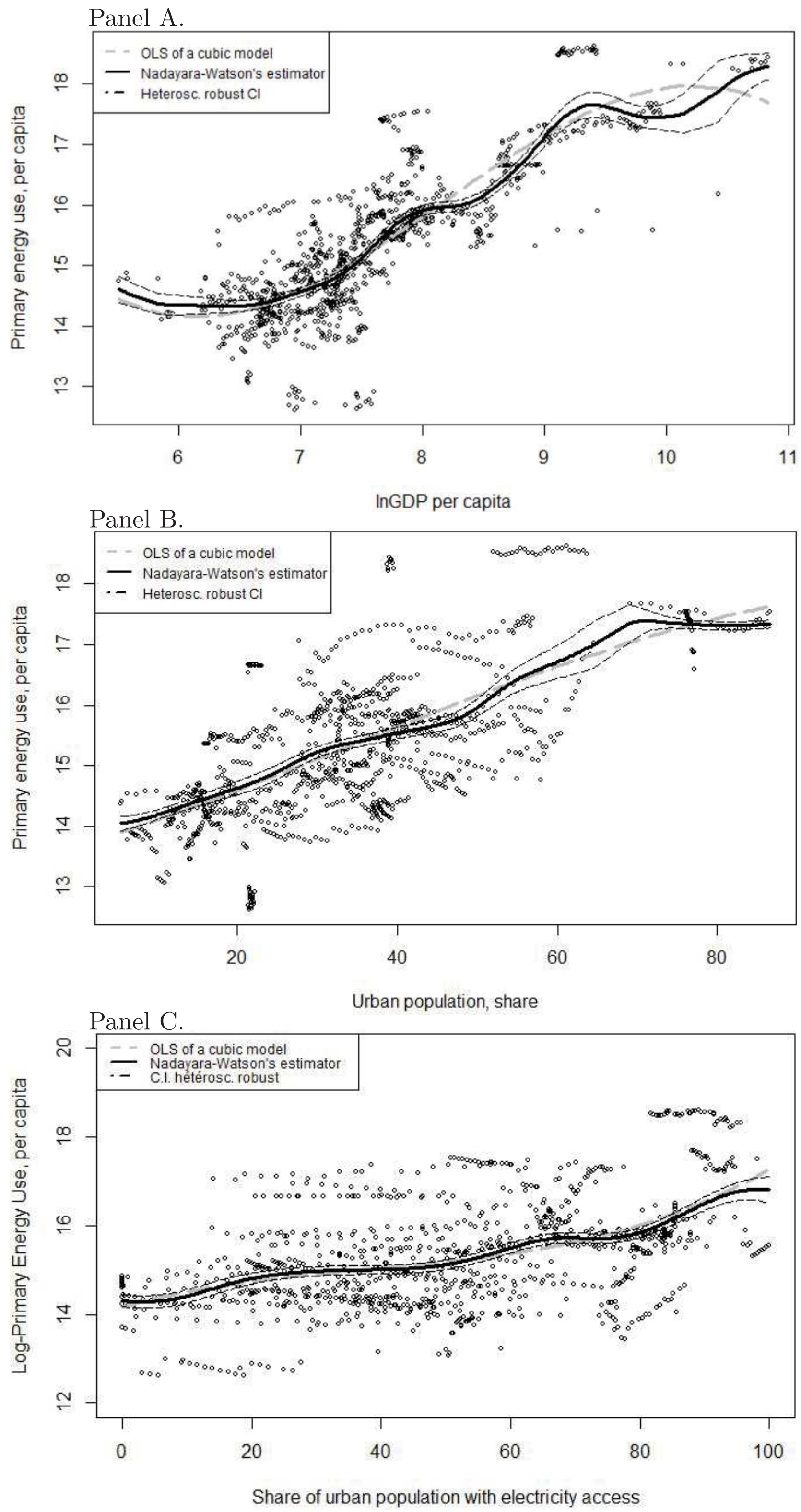


Figure 5.3: Functional forms of income per capita, urban population and electricity access of urban population

Note: The black curves are the NW-estimator and its 95% confidence interval. As bandwidth parameter, we rely on Silverman's rule of thumb, since the latter works well for approximately normal densities.

The results of the local constant kernel estimator (Figure 5.2, Panel B & C) showing increasing patterns in primary energy use to urban population share and its access to electricity. Accurately, while access to electricity overall positively drives primary energy use, for a share of urban population up to 60% a significantly clear upward trend appears. These results indicate that urban population growth and related phenomena (city enlargement and growing electrification) in SSA lead to higher demand for energy. Consequently, increases in primary energy use are to foresee in SSA countries where rapid urban population growth and economic growth are being observed.

5.7 Concluding remarks

The existing literature on energy consumption has essentially focused on direction of the causality between energy and income, the existence of an EKC for energy use, and further on the social and economic drivers of energy consumption. In SSA, where population and economic activities are rapidly growing, the existing studies have raised questions regarding the determinants of fossil energy use and future energy demand. However, contrary to the comparative development literature, questions related to spatial spillovers, institutional and geographical factors in energy use are much less investigated, whereas observations point to relative intensification of economic activities and energy consumption in coastal countries.

Aiming to fill this gap by focusing on primary energy use, this paper argues that in SSA countries geography and institutions, reciprocally to economic growth, matter for energy use. The latter seems highly related to economic activities, to demographic and social changes as well as to regional cooperation, motivating a spatial analysis. By drawing upon the well-known Institutions versus Geography debate with regard to their role in economic development, we identify both of these factors as important determinants in primary energy use.

The results of our empirical analysis support the existence of spatial spillovers in primary energy use among SSA countries, probably induced by cooperation in energy sectors. This somewhat highlights the role of geography in energy use, by suggesting that in SSA a country's own level in energy use is positively affected by energy use in the neighbouring countries. In addition to the spatial interactions, SSA coastal countries mostly showing higher income level also appear to be relatively more energy intensive than inland ones. Similar to geographical location, good political institutions are also found to be enhancing primary energy demand in SSA, illustrating a "two sides of the same coin" role by institutions and geography.

Furthermore, our results show that income per capita and urban population positively drive primary energy use, implying that future economic performances and urbanization in SSA will to lead to higher demands for energy. This is currently the case in South-Africa, Gabon, Nigeria, Equatorial Guinea and Ghana where economic performances and urbanization coincide with intensive primary energy use. As our sample is constituted by pre-industrial countries, thus low income countries, growing fossil energy consumption and related environmental consequences such as pollutants emission are to expect in the near future. On the role of population dynamics in SSA countries, as projections point to a fast population growth over the next 50 years, increases in the demand and growth of fossil energy use are also to expect, making Sustainable Development Goals more difficult to attain in Africa.

This study on the role of institutions and geography in primary energy use across SSA exploiting spatial regression approach has let some important points open to discussion and to possible improvements, especially concerning the environmental consequences of fossil and biomass energy use in pre-industrial economies. A further very insightful extension of this paper could be to purely investigate the primary energy consumption and carbon dynamics at early stages of development, by focusing on Sub-Saharan African countries. This can be a task for a future research.

Appendix

Table 5.4: Standard Hausman test

Hausman-test Stat.	χ^2	p-value	Number of regressors	NT
Model I	29.458	4.0e-07	2	1008
Model II	28.119	1.1e-05	4	1008
Model III	27.800	2.4e-04	7	1008
Model IV	5.792	.887	11	756
Model V	36.266	.002	15	714
Model VI	61.177	1.4e-0 6	18	429

Notes: See Table 5.5 below for the variables involved in Models I-VII.

Table 5.5: Result of standard instrumental variables models of primary energies use

Covariates/Models	**FE-I**	**FE-II**	**FE-III**	**RE-IV**	**FE-VI**	**FE-VI**	**RE-VI+location**
lnGDP per capita	.769***(.037)	.788***(.037)	.694***(.036)	.737***(.382)	.781***(.092)	.512***(.124)	.511***(.072)
Institutions	.259***(.109)	.334***(.116)	.272***(.105)	.410***(.055)	.449***(.132)	.630***(.189)	.646***(.159)
Agriculture, GDP share		.009***(.003)	.007**(.003)	.006** (.003)	.004 (.003)	.009** (.004)	.006** (.003)
Industry, GDP share		.010***(.002)	.010***(.002)	.010***(.002)	.006** (.003)	.004 (.004)	.002 (.003)
FDI, GDP share			−.002 (.002)	−.002 (.002)	−.001 (.002)	−.001 (.003)	−.002 (.003)
Imports, GDP share			−.003***(.001)	−.003***(.001)	−.003***(.001)	−.004**(.002)	−.003* (.002)
Exports, GDP share			.001(.001)	−.001 (.002)	.001 (.002)	.006**(.003)	.006** (.003)
Population density				−.004***(.001)	−.006***(.001)	−.004***(.001)	−.004***(.001)
Population growth				−.004 (.017)	.026 (.019)	.001 (.019)	−.005 (.020)
Urban population share				.010***(.002)	.007 (.005)	−.004 (.007)	.008** (.003)
Mean years of education				.027***(.016)	.032 (.024)	−.012 (.039)	−.016 (.023)
Conflicts fatalities					.023 (.039)	−.080** (.040)	−.076* (.045)
Violent events					.297**(.144)	.697***(.169)	.741***(.175)
Rainfalls, yearly					.134 (.088)	.150* (.084)	.069 (.070)
Average temperature					.034 (.030)	.007 (.032)	−.059***(.010)
Gini index						−.009**(.004)	−.008** (.003)
PGap1.9						.007***(.002)	.007** (.002)
Access to electricity						.013***(.005)	.012***(.003)
Coastal location dummy							.467***(.065)
Intercept	−−	−−	−−	9.602***(.402)	−−	−−	12.629***(.577)
Observations	1008	1008	1008	1008	756	429	429
Number of countries	42	42	42	42	42	39	39
F-stat (p-value)	301.963 (.000)	166.198 (.000)	105.390 (.000)	59.229 (.000)	30.003 (.000)	7.826 (.000)	15.027 .000
Adjusted R^2	.358	.381	.406	.459	.356	274	.384

Notes: Dependent variable is log primary energy use per capita. As proxy for "Institutions", we use the "Governance effectiveness index" (WGI). Bootstrapped standard errors are in brackets. "***", "**" and "*" respectively indicate significance at 1%, 5% and 10% levels. As instrument for lnGDP per capita and institutions, we respectively use one year lag lnGDP per capita and share of resource rents in GDP. The location dummy takes 1 if coastal located, 0 otherwise.

Table A-3: Results of first stage regressions surrounding Table 2 & 3

Panel A: First stage for GDP per Capita, used in Table 2 & 3

Covariates	I	II	III	IV	V	VI
Intercept	.029 (.026)	.104***(.036)	.109***(.037)	.068* (.039)	.097**(.046)	.126** (.059)
lag.lnGDP p. c.	.997***(.003)	.985***(.004)	.989***(.004)	.995***(.005)	.990***(.005)	.978***(.000)
Gross fixed Cap. form.	.001***(.000)	.001***(.000)	.002 (.003)	−.001*(.000)	−.001*(.000)	.007* (.004)
Gov. final consumption	−.002*(.001)	.001(.001)	−.004***(.001)	−.001***(.000)	−.001**(.000)	−.002(.002)
Agriculture, GDP share		−.003(.002)	−.004**(.002)	−.002 (.002)	−.007 (.027)	−.001 (.002)
Industry, GDP share		.008***(.002)	−.001 (.002)	.008 (.028)	.002 (.003)	.001* (.00)
FDI, GDP share			.001***(.000)	.004 (.025)	−.005 (.003)	.005 (.005)
Imports, GDP share			.003***(.001)	.001***(.000)	.001***(.000)	−.003 (.002)
Exports, GDP share			.002 (.002)	−.005**(.002)	−.004 (.003)	.004 (.003)
Population density				.023 (.032)	.036 (.035)	.000 (.003)
Population growth				.018***(.003)	.018***(.003)	.004 (.003)
Urban population share				−.088 (.175)	−.037 (.021)	−.005**(.002)
Pop. mean years of education				.004**(.002)	.005**(.002)	.001 (.002)
Conflicts fatalities					−.001 (.001)	−.002 (.006)
Violent events					−.056**(.021)	−.061***(.024)
Rainfalls, yearly					−.004 (.005)	−.001 (.006)
Average temperature					.009 (.101)	−.006 (.011)
Gini Index						.002***(.000)
PGap1.9						−.007** (.003)
Number of obs.	1008	1008	1008	756	714	429
Number of countries	42	42	42	42	42	39
Adjusted R-squared	.993	.993	.994	.996	.996	.997
F-Stat (p-value.)	4.9e4 (.000)	2.9e4 (.000)	2.0e4 (.000)	1.4e4 (.000)	1.0e4 (.000)	8093 (.000)

Panel C: First stage for "Share of population with electricity access", used in Table 2 & 3

Covariates	I	II	III	IV	V	VI
Intercept						−33.655***(6.529)
Lag. Share of Urban with Population with Elec. access						.465***(.022)
Agriculture, GDP share						−.167***(.038)
Industry, GDP share						−.061 (.064)
FDI, GDP share						−.052(.067)
Imports, GDP share						−.004 (.025)
Exports, GDP share						−.043 (.035)
Population density						.011** (.005)
Population growth						−.354 (.424)
Urban population share						.539***(.032)
Pop. mean years of education						1.179***(.273)
Conflicts fatalities						2.117***(.841)
Violent events						−9.173***(3.085)
Rainfalls, yearly						−.419 (.753)
Average temperature						.428***(.148)
PGap1.9						.228***(.062)
Gini index						.028 (.037)
Number of obs.						429
Number of countries	42	42	42	42	42	39
Adjusted R-squared						.904
F-Stat (p-value.)						251.9 (.000)

Panel B: Political institutions: First stage for "Governance effectiveness" (used in Table 2)

Intercept	2.349 (1.588)	12.806***(1.481)	13.233***(1.517)	9.442***(1.796)	10.930***(1.694)	21.199***(3.031)
lag.Resources rents in GDP	−.018***(.001)	−.019***(.001)	−.018***(.001)	−.020***(.002)	−.019***(.002)	−.018***(.002)
Year of Independence	−.001* (.000)	−.007***(.001)	−.007***(.001)	−.005***(.001)	−.006***(.000)	−.011***(.002)
Origin of the colonial power (categorical, ref. = not colonized):						
Belgian	−.412***(.076)	−.317***(.066)	−.345***(.068)	−.598***(.088)	−.404***(.091)	−.699***(.129)
British	.167** (.056)	.010 (.051)	.005 (.051)	−.162**(.056)	−.108*(.053)	−.558***(.080)
French	−.006 (.056)	−.119**(.050)	−.121**(.051)	−.002 (.057)	.030 (.054)	−.471***(.082)
Portuguese	.081 (.079)	.079 (.069)	.079 (.069)	.132* (.076)	.210***(.071)	−.190***(.092)
Spanish	.072 (.119)	−.447***(.114)	−.435***(.120)	−.399***(.128)	−.061 (.125)	−−
Agriculture, GDP share		−.016***(.001)	−.017***(.001)	−.011***(.002)	−.002 (.002)	−.005**(.002)
Industry, GDP share		.001 (.002)	.002 (.002)	.005**(.002)	.011***(.002)	.012***(.002)
FDI, GDP share			−.001 (.002)	−.003*(.002)	−.003 (.002)	−.008**(.003)
Imports, GDP share			.003 (.005)	.002**(.001)	.002**(.001)	.006***(.001)
Exports, GDP share			−.002* (.001)	−.004**(.001)	−.005***(.001)	−.009***(.002)
Population density				.002***(.000)	.002***(.000)	.002***(.001)
Population growth				.041**(.020)	.021 (.027)	.056**(.021)
Urban population share				−.001 (.001)	.002 (.002)	−.003 (.002)
Pop. mean years of education				.091***(.011)	.101***(.011)	.107***(.014)
Conflicts fatalities					.001 (.003)	.022 (.042)
Violent events					−.001**(.000)	−.809***(.164)
Rainfalls, yearly					−.031***(.003)	−.173***(.039)
Average temperature					−.007 (.006)	.037***(.008)
Gini index						−.014***(.003)
PGap1.9						−.006***(.002)
Number of obs.	1008	1008	1008	756	714	429
Number of countries	42	42	42	42	42	39
Adjusted R-squared	.294	.475	.476	.529	.617	.711
F-Stat (p-value.)	60.88 (.000)	102.10 (.000)	77.08 (.000)	54.03 (.000)	58.36 (.000)	51.13 (.000)

Panel D: Political institutions: First sate for "Regulatory Quality" (used in Table 3)

Intercept	.687 (1.663)	7.869***(1.697)	8.205***(1.735)	3.508*(1.990)	4.822**(1.998)	8.621**(3.439)
lag.Resources rents in GDP	−.016***(.001)	−.018***(.002)	−.018***(.001)	−.022***(.002)	−.21***(.002)	−.021***(.002)
Year of Independence	−.001 (.001)	−.004***(.001)	−.004***(.001)	−.003**(.001)	−.003**(.001)	−.006***(.002)
Origin of the colonial power (categorical, ref. = not colonized):						
Belgian	−.275***(.080)	−.220***(.075)	−.221***(.078)	−.393***(.098)	−.226**(.107)	−.951***(.145)
British	.403** (.059)	.270***(.058)	.257 (.059)	.103 (.062)	.154* (.063)	−.460***(.091)
French	.307 (.058)	.212***(.056)	.189**(.058)	.419***(.064)	.453***(.064)	−.173* (.093)
Portuguese	.172 (.083)	.152* (.079)	.143 (.079)	.317* (.084)	.395***(.084)	−.159 (.105)
Spanish	.023 (.126)	−.405***(.130)	−.329**(.137)	−.132 (.141)	.140 (.147)	−−
Agriculture, GDP share		−.009***(.001)	−.009***(.002)	−.003* (.002)	.003 (.002)	−.001 (.002)
Industry, GDP share		.004** (.002)	.003 (.002)	.001 (.002)	.005* (.003)	.011***(.002)
FDI, GDP share			.001 (.002)	−.001 (.002)	.001 (.002)	−.004 (.003)
Imports, GDP share			−.001* (.000)	−.001 (.006)	−.003 (.007)	.002 (.001)
Exports, GDP share			.002* (.001)	−.003**(.001)	.003* (.002)	−.004**(.002)
Population density				.002***(.000)	.002***(.000)	.002***(.000)
Population growth				.087***(.022)	.078***(.023)	.111***(.024)
Urban population share				−.001 (.001)	.001 (.002)	−.002 (.002)
Pop. mean years of education				.138***(.012)	.142***(.014)	.147***(.016)
Conflicts fatalities					−.039 (.037)	−.133***(.048)
Violent events					−.614**(.151)	−.325* (.186)
Rainfalls, yearly					−.249***(.036)	−.175***(.045)
Average temperature					−.008 (.007)	.031***(.010)
Gini index						.014***(.004)
PGap1.9						.001 (.002)
Number of obs.	1008	1008	1008	756	714	429
Number of countries	42	42	42	42	42	39
Adjusted R-squared	.308	.385	.393	.495	.539	.652
F-Stat (p-value.)	65.05 (.000)	70.92 (.000)	53.73 (.000)	47.35 (.000)	42.61 (.000)	39.20 (.000)

Notes: Share of population access to electricity appears only in specification VI and has been treated for inverse causality. Furthermore in specification VI, countries colonized by Spain (Equatorial Guinea) are excluded due to missing values. Robust standard errors are in brackets. "***", "**" and "*" respectively indicate significance at 1%, 5% and 10% levels.

Table 5.6: Test for spatial dependence in primary energy use considering yearly waves

	using ω^*		using ω^{**}	
Wave	Moran I	p-value	Moran I	p-value
Wave 1990	.087	.155	.091	.059
Wave 1991	.065	.206	.074	.091
Wave 1992	.054	.237	.065	.113
Wave 1993	.052	.241	.062	.120
Wave 1994	.039	.279	.042	.156
Wave 1995	.049	.250	.048	.164
Wave 1996	.025	.326	.035	.210
Wave 1997	.029	.314	.043	.180
Wave 1998	.061	.217	.050	.158
Wave 1999	.083	.164	.064	.115
Wave 2000	.100	.128	.081	.076
Wave 2001	.122	.090	.113	.031
Wave 2002	.179	.031	.109	.036
Wave 2003	.182	.029	.106	.039
Wave 2004	.154	.051	.119	.026
Wave 2005	.216	.014	.138	.014
Wave 2006	.219	.013	.145	.011
Wave 2007	.247	.007	.161	.006
Wave 2008	.276	.003	.196	.001
Wave 2009	.275	.003	.196	.002
Wave 2010	.301	.001	.219	.000
Wave 2011	.275	.003	.198	.001
Wave 2012	.276	.003	.198	.001
Wave 2013	.277	.003	.234	.000

Notes: Moran-I test under randomisation for primary energy use. H_0 is no spatial dependence. Each yearly wave consists of 42 observations. See Table AM-2 & AM-3 for details regarding the weighting systems ω^* and ω^{**}.

Table 5.7: Results of preliminary tests

Models specification	I	II	III	IV	V	VI
	Robust LM tests for spatial dependence$^{(1)}$					
In primary energy	12.168	16.148	14.483	20.173	25.694	4.807
	(.001)	(.000)	(.000)	(.000)	(.000)	(.028)
In residuals	8.272	7.115	8.322	19.287	17.794	3.448
	(.004)	(.008)	(.004)	(.000)	(.000)	(.063)
FE vs. RE	Spatial Hausman test$^{(2)}$					
χ^2	42.016	88.605	32.817	74.179	32.749	63.385
p-value	.000	.000	.000	.000	.000	.000

Notes: The test results reported here exploit the borders-based weighting matrix ω^*. $^{(1)}$Based on the results of standard Hausman tests, we perform locally robust LM tests for spatial lag and spatial error dependences. The statistics are LM-stat and in brackets the corresponding p-values. $^{(2)}$Based on the the spatial LM test results, we perform Hausman test comparing FE vs. RE SARAR models. The latter test defines the type of spatial panel data model (FE or RE) to estimate.

Additional Materials

Table 5.8: SSA: Colonizers, year of independence and coastal dummy as used in the paper

ID	Countries	Origin of colonizers	Year of independence	Coastal location dummy
1	Angola	Portuguese	1975	1
2	Benin	French	1960	1
3	Botswana	British	1966	0
4	Burkina Faso	French	1960	0
5	Burundi	Belgian	1962	0
6	Cameroon	French	1960	1
7	Central African Rep.	French	1960	0
8	Chad	French	1960	0
9	Congo, Rep.	French	1960	1
10	Cote d'Ivoire	French	1960	1
11	Congo, Dem. Rep.	Belgian	1960	1
12	Djibouti	French	1977	1
13	Equatorial Guinea	Spanish	1968	1
14	Eritrea	Others	1993	1
15	Ethiopia	Others	1947	0
16	Gabon	French	1960	1
17	Gambia, The	British	1965	1
18	Ghana	British	1957	1
19	Guinea	French	1958	1
20	Guinea-Bissau	Portuguese	1974	1
21	Kenya	British	1963	1
22	Lesotho	British	1966	0
23	Liberia	Others	1874	1
24	Madagascar	French	1960	1
25	Malawi	British	1964	0
26	Mali	French	1960	0
27	Mauritania	French	1960	1
28	Mozambique	Portuguese	1975	1
29	Namibia	Others	1990	1
30	Niger	French	1960	0
31	Nigeria	British	1960	1
32	Rwanda	French	1962	0
33	Senegal	French	1960	1
34	Sierra Leone	British	1961	1
35	South Africa	British	1910	1
36	Swaziland	British	1968	0
37	Tanzania	British	1961	1
38	Togo	French	1960	1
39	Uganda	British	1962	0
40	Zambia	British	1964	0
41	Zimbabwe	British	1965	0
42	Sudan	British	1956	1

Table AM-2: The border-based connectivity matrix 1, ω^*

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]	[,9]	[,10]	[,11]	[,12]	[,13]	[,14]	[,15]	[,16]	[,17]	[,18]	[,19]	[,20]	[,21]	[,22]	[,23]	[,24]	[,25]	[,26]	[,27]	[,28]	[,29]	[,30]	[,31]	[,32]	[,33]	[,34]	[,35]	[,36]	[,37]	[,38]	[,39]	[,40]	[,41]	[,42]
[1,]	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000
[2,]	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.250	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000
[3,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.250	.250	.000
[4,]	.000	.167	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000
[5,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000
[6,]	.000	.000	.000	.000	.000	.000	.200	.200	.200	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[7,]	.000	.000	.000	.000	.000	.167	.000	.167	.167	.000	.167	.000	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.167
[8,]	.000	.000	.000	.000	.000	.250	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250
[9,]	.200	.000	.000	.000	.000	.200	.200	.000	.000	.000	.200	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[10,]	.00	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.200	.000	.000	.000	.200	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
[11,]	.125	.000	.000	.000	.125	.000	.125	.000	.125	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.000	.000	.125	.000	.125	.125	.000	.00
[12,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.500	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[13,]	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[14,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00	.333
[15,]	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.200	.000	.200	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00	.200
[16,]	.000	.000	.000	.000	.000	.333	.000	.000	.333	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[17,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	1.00	.000	.000	.000	.000	.000	.000	.000	.000	.00
[18,]	.000	.000	.000	.333	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.00
[19,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.167	.000	.000	.167	.000	.000	.000	.000	.000	.000	.167	.167	.000	.000	.000	.000	.000	.000	.000	.00
[20,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.00
[21,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.333	.000	.000	.00
[22,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.500	.000	.000	.000	.000	.000	.00
[23,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.00
[24,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	1.00	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[25,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.333	.000	.00
[26,]	.000	.000	.000	.167	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.167	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.000	.00
[27,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.00
[28,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.143	.143	.000	.000	.000	.000	.000	.000	.000	.000	.000	.143	.143	.143	.000	.000	.143	.143	.00
[29,]	.250	.000	.250	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.250	.000	.00
[30,]	.000	.200	.000	.200	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[31,]	.000	.250	.000	.000	.000	.250	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[32,]	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[33,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.200	.200	.000	.000	.000	.000	.000	.200	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.250	.000	.000	.00
[34,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.500	.000	.000	.000	.500	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[35,]	.000	.000	.167	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.000	.167	.167	.000	.000	.000	.000	.000	.000	.167	.000	.000	.000	.000	.167	.00
[36,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.00
[37,]	.000	.000	.000	.000	.125	.000	.000	.000	.000	.000	.125	.000	.000	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.000	.125	.000	.000	.125	.000	.000	.000	.125	.000	.000	.000	.000	.000	.000	.125	.125	.000	.00
[38,]	.000	.333	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.00
[39,]	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.000	.000	.000	.200	.000	.000	.000	.00	.200
[40,]	.125	.000	.125	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.125	.125	.000	.000	.000	.000	.000	.000	.000	.125	.000	.000	.000	.125	.00
[41,]	.000	.000	.250	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.000	.000	.250	.000	.000	.000	.000	.250	.000	.00
[42,]	.000	.000	.000	.000	.000	.000	.200	.200	.000	.000	.000	.000	.000	.200	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.200	.000	.000	.00

Notes: This matrix is based on common borders principle and is of dimension 42×42. Number of non-zero links: 173. Percentage non-zero weights: 9.807. Average number of links: 4.119.

Table AM-3: The k-nearest algorithm based connectivity matrix 2, ω^{**}

1.	0.00	0.000	0.17	0.000	0.00	0.000	0.000	0.000	0.167	0.000	0.17	0.00	0.000	0.00	0.00	0.167	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.17	0.000	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.17	0.00	0.00
2.	0.00	0.000	0.00	0.091	0.00	0.091	0.000	0.000	0.000	0.091	0.00	0.00	0.091	0.00	0.00	0.000	0.000	0.091	0.091	0.000	0.00	0.00	0.091	0.00	0.00	0.091	0.000	0.00	0.00	0.091	0.091	0.00	0.000	0.000	0.00	0.00	0.00	0.091	0.00	0.00	0.00	0.00
3.	0.12	0.000	0.00	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.12	0.000	0.00	0.00	0.000	0.000	0.12	0.12	0.000	0.000	0.00	0.000	0.000	0.12	0.12	0.00	0.000	0.00	0.12	0.12	0.00
4.	0.00	0.071	0.00	0.000	0.00	0.000	0.000	0.000	0.000	0.071	0.00	0.00	0.000	0.00	0.00	0.000	0.071	0.071	0.071	0.071	0.00	0.00	0.071	0.00	0.00	0.071	0.071	0.00	0.00	0.071	0.071	0.00	0.071	0.071	0.00	0.00	0.00	0.071	0.00	0.00	0.00	0.00
5.	0.00	0.000	0.00	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.14	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.14	0.00	0.000	0.00	0.14	0.000	0.000	0.00	0.00	0.000	0.000	0.14	0.000	0.000	0.00	0.00	0.14	0.000	0.14	0.14	0.00	0.00
6.	0.00	0.111	0.00	0.000	0.00	0.000	0.111	0.111	0.111	0.000	0.00	0.00	0.111	0.00	0.00	0.111	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.111	0.111	0.00	0.000	0.000	0.00	0.00	0.00	0.111	0.00	0.00	0.00	0.00
7.	0.00	0.000	0.00	0.000	0.00	0.100	0.000	0.100	0.100	0.000	0.10	0.00	0.100	0.00	0.00	0.100	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.100	0.10	0.000	0.000	0.00	0.00	0.00	0.000	0.10	0.00	0.00	0.10
8.	0.00	0.000	0.00	0.000	0.00	0.200	0.200	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.200	0.200	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.20
9.	0.14	0.000	0.00	0.000	0.00	0.143	0.143	0.000	0.000	0.000	0.14	0.00	0.143	0.00	0.00	0.143	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.143	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
10.	0.00	0.091	0.00	0.091	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.091	0.091	0.091	0.091	0.00	0.00	0.091	0.00	0.00	0.091	0.000	0.00	0.00	0.000	0.000	0.00	0.091	0.091	0.00	0.00	0.00	0.091	0.00	0.00	0.00	0.00
11.	0.11	0.000	0.00	0.000	0.11	0.000	0.111	0.000	0.111	0.000	0.00	0.00	0.000	0.00	0.00	0.111	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.11	0.000	0.000	0.00	0.00	0.11	0.000	0.11	0.11	0.00	0.00
12.	0.00	0.000	0.00	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.25	0.25	0.000	0.000	0.000	0.000	0.000	0.25	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.25
13.	0.00	0.125	0.00	0.000	0.00	0.125	0.125	0.000	0.125	0.000	0.00	0.00	0.000	0.00	0.00	0.125	0.000	0.125	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.125	0.00	0.000	0.000	0.00	0.00	0.00	0.125	0.00	0.00	0.00	0.00
14.	0.00	0.000	0.00	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.33	0.000	0.00	0.33	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.33
15.	0.00	0.000	0.00	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.20	0.000	0.20	0.00	0.000	0.000	0.000	0.000	0.000	0.20	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.20	0.00	0.00	0.20
16.	0.14	0.000	0.00	0.000	0.00	0.143	0.143	0.000	0.143	0.000	0.14	0.00	0.143	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.143	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
17.	0.00	0.000	0.00	0.111	0.00	0.000	0.000	0.000	0.000	0.111	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.111	0.111	0.00	0.00	0.111	0.00	0.00	0.111	0.111	0.00	0.00	0.000	0.000	0.00	0.111	0.111	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
18.	0.00	0.100	0.00	0.100	0.00	0.000	0.000	0.000	0.000	0.100	0.00	0.00	0.100	0.00	0.00	0.000	0.000	0.000	0.100	0.000	0.00	0.00	0.100	0.00	0.00	0.100	0.000	0.00	0.00	0.000	0.100	0.00	0.000	0.100	0.00	0.00	0.00	0.100	0.00	0.00	0.00	0.00
19.	0.00	0.083	0.00	0.083	0.00	0.000	0.000	0.000	0.000	0.083	0.00	0.00	0.000	0.00	0.00	0.000	0.083	0.083	0.000	0.083	0.00	0.00	0.083	0.00	0.00	0.083	0.083	0.00	0.00	0.000	0.000	0.00	0.083	0.083	0.00	0.00	0.00	0.083	0.00	0.00	0.00	0.00
20.	0.00	0.000	0.00	0.111	0.00	0.000	0.000	0.000	0.000	0.111	0.00	0.00	0.000	0.00	0.00	0.000	0.111	0.000	0.111	0.000	0.00	0.00	0.111	0.00	0.00	0.111	0.111	0.00	0.00	0.000	0.000	0.00	0.111	0.111	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
21.	0.00	0.000	0.00	0.000	0.17	0.000	0.000	0.000	0.000	0.000	0.00	0.17	0.000	0.00	0.17	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.17	0.000	0.000	0.00	0.00	0.17	0.000	0.17	0.00	0.00	0.00
22.	0.00	0.000	0.20	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.20	0.000	0.000	0.00	0.000	0.000	0.20	0.20	0.00	0.000	0.00	0.00	0.20	0.00
23.	0.00	0.091	0.00	0.091	0.00	0.000	0.000	0.000	0.000	0.091	0.00	0.00	0.000	0.00	0.00	0.000	0.091	0.091	0.091	0.091	0.00	0.00	0.000	0.00	0.00	0.091	0.000	0.00	0.00	0.000	0.000	0.00	0.091	0.091	0.00	0.00	0.00	0.091	0.00	0.00	0.00	0.00
24.	0.00	0.000	0.00	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.50	0.000	0.000	0.50	0.00	0.000	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
25.	0.00	0.000	0.00	0.000	0.14	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.14	0.00	0.000	0.000	0.14	0.00	0.000	0.000	0.14	0.000	0.000	0.00	0.00	0.14	0.000	0.00	0.14	0.14	0.00
26.	0.00	0.077	0.00	0.077	0.00	0.000	0.000	0.000	0.000	0.077	0.00	0.00	0.000	0.00	0.00	0.000	0.077	0.077	0.077	0.077	0.00	0.00	0.077	0.00	0.00	0.000	0.077	0.00	0.00	0.077	0.000	0.00	0.077	0.077	0.00	0.00	0.00	0.077	0.00	0.00	0.00	0.00
27.	0.00	0.000	0.00	0.143	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.143	0.000	0.143	0.143	0.00	0.00	0.000	0.00	0.00	0.143	0.000	0.00	0.00	0.000	0.000	0.00	0.143	0.143	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
28.	0.00	0.000	0.14	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.14	0.14	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.000	0.000	0.00	0.14	0.14	0.000	0.00	0.14	0.14	0.00
29.	0.17	0.000	0.17	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.17	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.000	0.000	0.17	0.00	0.00	0.000	0.00	0.17	0.17	0.00
30.	0.00	0.143	0.00	0.143	0.00	0.143	0.000	0.143	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.143	0.000	0.00	0.00	0.000	0.143	0.00	0.000	0.000	0.00	0.00	0.00	0.143	0.00	0.00	0.00	0.00
31.	0.00	0.091	0.00	0.091	0.00	0.091	0.091	0.091	0.091	0.000	0.00	0.00	0.091	0.00	0.00	0.091	0.000	0.091	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.091	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.091	0.00	0.00	0.00	0.00
32.	0.00	0.000	0.00	0.000	0.12	0.000	0.125	0.000	0.000	0.000	0.12	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.12	0.00	0.000	0.00	0.12	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.000	0.000	0.00	0.00	0.12	0.000	0.12	0.12	0.00	0.00
33.	0.00	0.000	0.00	0.111	0.00	0.000	0.000	0.000	0.000	0.111	0.00	0.00	0.000	0.00	0.00	0.000	0.111	0.000	0.111	0.111	0.00	0.00	0.111	0.00	0.00	0.111	0.111	0.00	0.00	0.000	0.000	0.00	0.000	0.111	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
34.	0.00	0.000	0.00	0.091	0.00	0.000	0.000	0.000	0.000	0.091	0.00	0.00	0.000	0.00	0.00	0.000	0.091	0.091	0.091	0.091	0.00	0.00	0.091	0.00	0.00	0.091	0.091	0.00	0.00	0.000	0.000	0.00	0.091	0.000	0.00	0.00	0.00	0.091	0.00	0.00	0.00	0.00
35.	0.00	0.000	0.20	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.20	0.000	0.00	0.00	0.000	0.000	0.00	0.20	0.000	0.000	0.00	0.000	0.000	0.00	0.20	0.00	0.000	0.00	0.00	0.20	0.00
36.	0.00	0.000	0.20	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.20	0.000	0.00	0.00	0.000	0.000	0.20	0.00	0.000	0.000	0.00	0.000	0.000	0.20	0.00	0.00	0.000	0.00	0.00	0.20	0.00
37.	0.00	0.000	0.00	0.000	0.12	0.000	0.000	0.000	0.000	0.000	0.12	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.12	0.00	0.000	0.00	0.12	0.000	0.000	0.12	0.00	0.000	0.000	0.12	0.000	0.000	0.00	0.00	0.00	0.000	0.12	0.12	0.00	0.00
38.	0.00	0.083	0.00	0.083	0.00	0.083	0.000	0.000	0.000	0.083	0.00	0.00	0.083	0.00	0.00	0.000	0.000	0.083	0.083	0.000	0.00	0.00	0.083	0.00	0.00	0.083	0.000	0.00	0.00	0.083	0.083	0.00	0.000	0.083	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
39.	0.00	0.000	0.00	0.000	0.14	0.000	0.143	0.000	0.000	0.000	0.14	0.00	0.000	0.00	0.14	0.000	0.000	0.000	0.000	0.000	0.14	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.14	0.000	0.000	0.00	0.00	0.14	0.000	0.00	0.00	0.00	0.00
40.	0.10	0.000	0.10	0.000	0.10	0.000	0.000	0.000	0.000	0.000	0.10	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.10	0.000	0.000	0.10	0.10	0.000	0.000	0.10	0.000	0.000	0.00	0.00	0.10	0.000	0.00	0.00	0.10	0.00
41.	0.00	0.000	0.12	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.00	0.12	0.000	0.00	0.12	0.000	0.000	0.12	0.12	0.000	0.000	0.00	0.000	0.000	0.12	0.12	0.00	0.000	0.00	0.12	0.00	0.00
42.	0.00	0.000	0.00	0.000	0.00	0.000	0.200	0.200	0.000	0.000	0.00	0.20	0.000	0.20	0.20	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.00	0.000	0.000	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00

Notes: This matrix is built considering the k-nearest neighbouring countries, with k=2. Number of countries = 42. Number of non-zero links: 334. Percentage non-zero weights: 18.93424. Average number of links: 7.952381

Map of primary energy use in SSA, in kj per capita **Map of Electricity access, in share of Urban population**

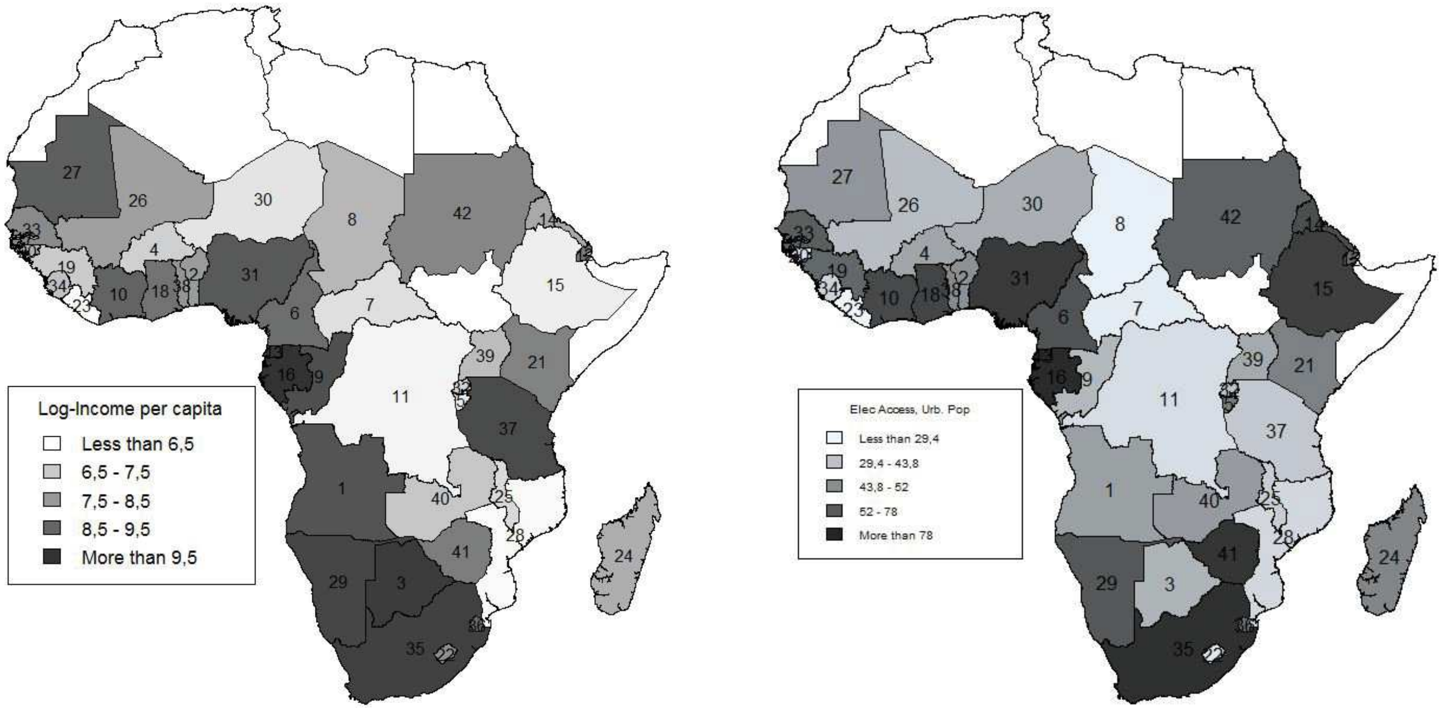


Figure AM-2: Primary energy use and Electricity access across SSA countries between 1990-2013

6. Conclusion générale

(Concluding Chapter - English version below)

Les objectifs de cette thèse sont d'abord de contribuer à l'analyse économique de la problématique de perte de la biodiversité sur le plan empirique, théorique que des politiques de conservation. Aussi, elle s'intéresse à la question de l'utilisation croissante des énergies primaires, qui en grande partie est responsable de pollution environnementale (émissions de gaz).

6.1 Contexte et motivation

L'impact de plus en plus inquiétant de l'activité économique et de la croissance démographique sur l'environnement soulève de profondes questions sur l'avenir des sociétés humaines et des ressources environnementales. En ceci, les capacités limitées de la planète à satisfaire les besoins d'une croissance qui se veut illimitée soutiennent les perspectives et prévisions des auteurs mettant en garde contre les possibilités d'un collapsus social, si la dégradation environnementale suit son court (Meadows et al., 1974). D'autres part, des travaux de recherche ont identifié et quantifié les besoins de la croissance et le nombre de Terre qu'il faudra pour satisfaire ces besoins et absorber les effets adverses de la croissance (Wackernagel et al., 1997). Une "success story" de réduction de l'impact écologique de l'homme ou de préservation globale de l'environnement n'est pas identifiable dans les études existantes que ce soit sur la question des émissions de gaz à effet de serre, de déforestation ou destruction écologique, de changement climatique ou de perte de biodiversité.

Dans ce contexte, des études en géographie, en biologie, en sociologie et en sciences économiques, entre autres, se concentrent sur la problématique de la dégradation de l'environnement, abordée sous différentes perspectives. Nos travaux portent aussi à la question de la destruction écologique, avec l'emphase sur la perte de la biodiversité. Comparativement à d'autres aspects de la question de la dégradation de l'environnement, la perte de biodiversité ayant été objet de moins d'études aussi bien sur le plan empirique que théorique, nous essayons dans cette thèse de contribuer à la littérature existante au travers des trois premiers Chapitres. L'exploitation et l'utilisation des énergies fossiles étant la cause primaires de pollutions ou émissions de gaz (qui elles même menacent la biodiversité), le dernier Chapitre fait ressortir les déterminants géographiques et institutionnels de l'utilisation des énergie primaires.

6.2 Principaux résultats

• Les résultats du Chapitre 2 globalement montrent que l'hypothèse de cohabitation pacifique entre l'homme et la nature est difficilement soutenable, puisqu'au travers des échanges commerciaux, des pays transmettent une partie de leurs propres impacts écologiques à d'autres pays. De plus, nous trouvons qu'il existe un conflit d'habitats entre la démographie humaine et les espèces animales et végétales.

• Le Chapitre 3 propose d'introduire la question de la perte de biodiversité dans un modèle de population-ressource, cette dernière étant objet de rares études en théorie de la croissance. Nos résultats supportent l'impossibilité d'une cohabitation entre l'homme et la nature, aussi longtemps qu'il y aura croissance démographique et exploitation de ressources forestières. Ainsi, en présence d'impact écologique très large, nos simulations soutiennent la possibilité d'aboutir à des forêts vide d'espèces mais aussi à des chutes drastiques de population dues à la dégradation de l'environnement.

• Chapitre 4: Les aires protégées étant les premiers instruments des politiques de conservation, nous faisons remarquer que les aires protégées les plus larges se localisent dans les pays à revenu élevés, alors que la richesse en biodiversité ainsi que des menaces d'extinction élevées sont observées dans les pays à faibles revenus. Les efforts de conservations étant dépendent du niveau de développement et non de la biodiversité, les résultats escomptés en termes de conservation d'espèces risquent ne pas être atteints.

• La consommation des énergies primaires étant la cause principale des émissions de gaz, le Chapitre 5 apporte des éléments empiriques sur le rôle des "deux faces d'une même pièce" que jouent les institutions et les facteurs géographiques dans l'exploitation ou l'utilisation des énergies primaires. En outre, l'activité économique, l'urbanisation et l'accès à l'électricité sont à tenir responsables de l'utilisation croissante des énergies primaires dans les pays en développement, et donc des conséquences environnementales associées.

6.3 Implication de politiques environnementales

Discutant des implications politiques de nos travaux, il faut faire remarquer que le Chapitre 2, en marge des déterminants de la perte de biodiversité, produit des résultats empiriques qui sont conformes aux conclusions théoriques du Chapitre 3. Dans ce Chapitre 3, presque toutes les expériences de simulations prédisent un collapsus, si l'impact écologique des sociétés humaines ne décroit pas.

Les politiques environnementales découlant des Chapitres 2 et 3 sont des mesures concourant à réduire l'empreinte écologique de l'activité économique et de la croissance démographique. L'activité de production exploitant les ressources environnementales et forestières, nos travaux appellent à une exploitation viable des ressources forestières, de manière à favoriser la régénération des forêts et non la réduction des aires déjà couvertes. Ensuite, l'urbanisation ou extension de l'habitat humain étant en conflit avec l'habitat naturel, nos résultats appellent à un renforcement des politiques de conservation dans les pays surtout en développement. Ceci afin de limiter d'une part la dégradation des forêts et aires protégées ainsi que leur conversion en habitat et d'assurer d'autre part une effectivité de la conservation des espèces biologiques. Finalement, au niveau micro-économique, des mesures d'information et de sensibilisation doivent être prises afin d'orienter les comportements et les préférences individuels vers la demande de biens à faible empreinte écologique.

Concernant les efforts de conservations au niveau global (Chapitre 4), nos résultats encouragent les pays tropicaux et à revenus faibles à intensifier les politiques de conservation par l'établissement et la gestion efficace des aires protégées et des payements pour services éco-systémiques, entre autres. L'établissement, la gestion des aires protégées et l'effectivité de la conservation étant une question de financement, les institutions ou organisations oeuvrant pour la préservation de la nature sont appelées à de plus en plus assister les pays tropicaux, à revenus faibles mais riche en biodiversité, dans leurs efforts de conservation.

Finalement, l'utilisation des énergies primaires étant une des premières sources d'émission de gaz à effet de serre, nos travaux permettent de prédire une dégradation croissante de l'environnement en Afrique Sub-Saharienne. Ces prédictions, non-louables par essence, attirent l'attention des acteurs socio-politiques sur l'impératif de passer à des énergies vertes afin d'assurer en Afrique un développement humain en harmonie avec la nature.

6.4 Limites et extensions possibles

Théoriquement et empiriquement, cette thèse remet en cause l'hypothèse d'une cohabitation pacifique entre l'homme et les espèces biologiques. Ensuite, elle discute la distribution inefficiente des aires protégées dans les efforts de conservation des espèces. Finalement, elle met en exergue le rôle des institutions et des facteurs géographiques dans la consommation croissante des énergies primaires. Ces apports souffrent cependant de certaines limitations aussi bien théoriques que empiriques qui méritent d'être relevées ici.

En testant l'hypothèse de cohabitation pacifique entre les habitats naturel et humain, une limitation du Chapitre 2 était d'exploiter uniquement les données sur les espèces menacées (animales et plantes). Une possible extension de l'étude sur l'hypothèse de cohabitation pacifique serait d'utiliser d'autres indicateurs de biodiversité ou plus globalement de dégradation de l'environnement.

Le Chapitre 3 étend les modèles de population-ressources à la problématique de la perte de la biodiversité. Deux critiques principales peuvent être formulées à l'égard de cet essai. (i) Les fonctions de production étant uniquement sur la base de ressources naturelles et du travail, il n'est pratiquement pas possible d'observer la dynamique du capital, qui en fait gouverne la croissance économique. (*ii*) La spécification utilisée se réfère au cas des pays en développement et sans ouverture commerciale. Une spécification plus économique, incluant les décisions individuelles comme d'éducation, le capital humain et l'accroissement technologique à la manière du modèle de croissance unifiée (Galor, 2011) devrait permettre d'aboutir à un modèle économique plus large qui permet de d'aborder la problématique de déforestation et de perte de biodiversité selon le niveau de développement.

Concernant les politiques de conservation et leurs déterminants, une extension de notre étude pourra se focaliser sur les données dites "*grid cell data*" afin de tester si finalement conserver les espaces vertes ou forêts n'est peut-être pas priorisé que la conservation des espèces biologiques.

Le dernier essai sur la consommation des énergies primaires prédit une demande de plus en plus croissante d'énergies dans les pays d'Afrique Sub-Sahélienne croissante mais ignore de relier cette problématique à celle des émissions de CO_2. Par ailleurs, comme la majorité des études existant sur le sujet, elle n'exploite aussi pas d'indicateurs qualitatifs (IDH) de développement qui, selon certains auteurs, seraient plus appropriés que les mesures quantitatives (PIB par habitant).

Les limites ci-dessus décrites donnent des possibilités d'extension de chacun de nos quatre essais. Nous nous proposons de continuer nos travaux de recherche sur la problématique de la dégradation de l'environnement, cette thèse nous offrant un (relatif) avantage comparatif sur le sujet.

Concluding Chapter

Increasing natural resources depletion, pollutant emissions and population growth raise some serious questions about the future of human societies and the nature. In this, the finite capacity of nature to satisfy increasing needs of natural resources supports the perspective and predictions of scientists arguing that human and nature are on a collision course. Moreover, scientists have classified the needs of human societies and estimated resources required to satisfy the latter (Wackernagel et al., 1997). A "success story" is hardly identifiable in these exercises regarding the environmental impact of human societies.

This Thesis discusses ecological destruction, putting some emphasis on biodiversity loss, since the latter theoretically and empirically has received relatively few attention in the existing literature on environmental degradation. It also addresses primary energy use, the latter primarily causing greenhouse gas emissions.

Main results

Theoretically and empirically, our analysis (Chapter 1 and 2) helps argue that compared to high-income countries, high ecological destruction occurs in low-income countries. Testing whether a peaceful cohabitation between human and natural habitats is possible, our results suggest that economic growth and animal and plant species are on a collusion course in developing countries, while an apparent peaceful cohabitation is observable in high-income countries. In addition to holding fewer species stock (initial conditions), trade appears to be among factors explaining the peaceful cohabitation patterns observed in rich countries. Exploiting the framework of population-resource models, we find results indicating larger ecological destruction in countries characterized by high fertility (population growth) and resources intensive production activities: Low-income countries. Furthermore, the outcomes of our scenario analysis imply concerning biodiversity the possibility of total extinction of biological species.

Discussing optimality and orientation of conservation efforts, Chapter 4 points out contrary to common expectations that larger protected areas are observed in geographical areas and countries characterized by low species richness. The focus of conservation policies being not only to protest forests but also biological species, the results of this essay underlines the lack of targeting towards biodiversity while establishing protected areas.

Fossil energy use being the main driver of CO_2 emissions, this Thesis also provides empirical evidences on the "two sides of the same coin" role played by institutional and geographical characteristics of Sub-Saharan African countries in primary energy use. Besides economic activities, population and access to electricity are among the main drivers of primary energy use. In light of these results, increasing fossil energy use associated with growing pollutant emissions are to expect in Sub-Saharan Africa.

Environmental policies implication

Discussing the policies implication of our results, it is to recall that besides socio-economic drivers of biodiversity loss, the results of testing the peaceful cohabitation hypothesis support our theoretical predictions in Chapter 3. In the latter Chapter, each of our scenario analysis predicts increasing ecological destruction and sudden drop in population, if the current trends of human ecological footprint remain unchanged.

In terms of policy implication, the results of Essays 2 & 3 globally suggest that a reduction in human ecological footprint is necessary and vital for environmental conservation. Such goals can be achieved through control of illegal mining activities, new population settlements and an optimal management of natural reserves. Economic activities exploiting natural resources, our results advocate for a viable resource harvest, allowing for resource regeneration. Cities enlargement being at conflict with natural habitats, our work impels political actors to closely control the development of new urban areas and to strengthen conservation action around urban areas. Finally, as our results indicate that individual preferences matter as well, environmental-friendly economic behaviours are to be promoted.

Exploiting the outcome of Chapter 4 about biodiversity in conservation policies, tropical and species-rich countries are invited to intensity conservation efforts. This not only by protecting their highly species-rich forests, but also with the adequate management strategies in order to achieve the assigned long-run conservation goals. As establishing and effectively managing protected areas require huge funds, international organization such IUCN and high-income countries are encouraged to financially support conservation efforts in low-income countries.

Finally, fossil energy consumption being the main cause of gas emissions, developing and industrialized countries are invited to seek for alternative and renewable energies, in order to reduce gas emissions and to promote a more peaceful cohabitation with nature.

Limitations and possible extensions

This thesis on economic growth, energy use and biodiversity loss tested the so-called peaceful cohabitation hypothesis between human and nature (theoretically and empirically) and discussed efficiency of conservation efforts. Finally, it pointed out the role of geographical and institutional characteristics in fossil energy use. Certainly, it has some shortcomings which need to be mentioned here.

Indeed, testing the peaceful cohabitation hypothesis can be done using the data on threatened animal and plant species, which are the main components of an ecosystem. A more larger perspective relying on diverse indicators of environmental degradation is also feasible and even sounds more suitable, given the ambition of such a study and the complexity of environmental issues.

Chapter 3, exploiting the framework of population and resources theory to address species loss, fails to assess the role of physical and human capital and technological progress. Moreover, it proposes a model non-applicable to different stages of economic development. A slightly different specification of agents' economic behaviours following the *Unified Growth Theory* paradigm should provide a broader economic model of biodiversity loss.

Regarding conservation policies and their determinants, our approach relies on country-level data and does not dissociate PAs management categories. A possible extension could be testing our results relying on micro-level or *grid cell data*. This should also help assess whether species-poor forests drive conservation efforts.

Finally, Chapter 5 discusses the socio-economic drivers of fossil energy use, pointing out the "two sides of the same coin" role played by institutions and geography. It does not specifically consider the consequences of fossil energy use and also disregards qualitative measures of human development (HDI), the latter having a larger emphasis on quality of life than GDP per capita.

These shortcomings actually represent extension possibilities of each of our four (4) essays, which we propose to address in future research project on environmental degradation, this thesis offering us a (relative) comparative advantage on the topic.

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