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RÉSUMÉ

Cette thèse se compose de trois essais ayant trait essentiellement à l'économie des ressources naturelles et de l'environnement. Elle porte sur la définition d'une qualité des institutions permettant l'exploitation optimale de ressources naturelles. Son principal objectif est d'étudier la qualité de droits de propriété permettant d'exploiter optimalement une ressource naturelle ou d'accumuler optimalement du capital physique.

Dans le premier essai qui s'intitule «The optimal quality of property rights in presence of externality and market power», nous considerons une économie avec une ressource naturelle renouvelable. Nous nous demandons s'il existe des circonstances dans lesquelles des droits de propriété partiels sur un stock de ressource naturelle peuvent permettre son exploitation optimale. Pour répondre à cette question, nous traitons la qualité (ou le degré de complétude) des droits de propriété sur un stock de ressource naturelle comme une variable endogène continue dans une économie où un nombre limité de firmes détient du pouvoir de marché. Sous des hypothèses standards, nous montrons qu'il existe toujours un degré de complétude des droits de propriété qui conduit à une exploitation optimale de premier rang de la ressource naturelle. Les droits de propriété optimaux ne sont ni complets, ni absents mais partiels. Un corollaire à ce résultat est que des droits complets ne constituent ni une condition suffisante, ni une condition nécessaire d'optimalité en présence de pouvoir de marché. Nous déterminons une expression analytique de la qualité optimale des droits de propriété et identifions les paramètres dont elle dépend.

Le deuxième essai s'intitule «Overlapping generations, natural resources and the optimal quality of property rights». Dans ce deuxième chapitre, nous considérons une économie avec générations imbriquées, qui est parfaitement compétitive, c'est à dire sans imperfections de marché, et dans laquelle une ressource naturelle est exploitée. Nous étudions la qualité optimale de droits de propriété portant sur le stock de ressource. La qualité des droits de propriété est définie comme la proportion du stock de ressource protégée, le reste étant en libre accès. Nous montrons que des droits complets ne sont pas toujours optimaux, des droits de propriété partiels sur le stock de ressource sont alors nécessaires pour exploiter la ressource optimalement. Nous montrons ainsi que des institutions parfaites ne sont pas toujours synonymes d'institutions complètes et ce même dans une économie parfaitement compétitive. Des institutions complètes peuvent être aussi dommageables que des institutions trop faibles quand une économie tend à suraccumuler du stock de ressource à l'équilibre.

Le troisième essai est une extension du deuxième et s'intitule «Overlapping generations, physical capital and the optimal quality of property rights». Dans cet essai, nous considérons une économie avec générations imbriquées, qui est parfaitement compétitive, dans laquelle le capital et le travail sont les deux facteurs de production. Le capital se distingue d'une ressource naturelle renouvelable par le fait que le stock entier de capital, et

non une quantité extraite de ce stock, est utilisé chaque période dans la production et par le fait que la dépréciation est une contribution négative au stock tandis que la croissance naturelle d'une ressource est une contribution positive au stock. Ces différences ont un impact sur la qualité optimale des droits de propriété. En effet, des droits partiels sur le stock de capital auraient pour effet de baisser le coût considéré du facteur capital lors des décisions d'utilisation de facteurs de production et donc d'accroitre la demande de capital. Ce qui aurait pour conséquence sous des hypothèses standards d'accroitre l'accumulation de capital. Contrairement aux résultats du deuxième essai, les droits de propriété sur le stock de capital doivent optimalement être complets. Cependant, nous montrons que des droits de propriété partiels sur le revenu de la génération active peuvent permettre d'atteindre l'optimum de premier rang. Comme des droits de propriété partiels sur le revenu des jeunes peuvent à tort être compris comme une forme de taxation car ils ont aussi pour conséquence de transférer des revenus, nous expliquons que des similitudes dans les effets cachent de profondes différences de nature et d'origine entre des droits de propriété partiels et un impôt sur le revenu.

ABSTRACT

This thesis consists of three essays related mainly to the economics of natural resources and the environment. We study the quality of institutions allowing an optimal exploitation of a natural resource. We focus on the determination of the quality of property rights allowing to optimally exploit a renewable resource or, as in the third essay, to optimally accumulate physical capital.

In the first essay, entitled "The optimal quality of property rights in presence of externality and market power", acknowledging the fact that there are many instances where property rights are neither perfectly defined nor perfectly enforced, we address the following question : could there be instances where partial property rights are economically efficient in a renewable resource economy? To address this question, we treat the quality (or level of completeness) of property rights as a continuous endogenous variable in a renewable resource economy where a finite number of firms exercises market power. We show that there exists a level of property rights completeness that leads to first-best resource exploitation in the presence of market power. This level is different from either absent or complete property rights. As a corollary, complete rights are neither necessary nor sufficient for efficiency in the presence of market power. We derive an analytic expression for the optimal level of property-right completeness and discuss its determinants. The optimal level depends on i) the number of firms; ii) the elasticity of input productivity and iii) the price elasticity of market demand.

The second essay is entitled "Overlapping generations, natural resources and the optimal quality of property rights". In this essay, we relax the assumption made in the first essay of the existence of a market imperfection (in the form of market power) and we investigate the merits for a perfectly competitive economy involving a renewable resource to have partial property rights. Can partial property rights be socially optimal in an otherwise perfect economy? If so, under which circumstances? In a decentralized perfectly competitive economy involving a renewable natural resource and overlapping generations, we show that optimal institutions should make it possible to infringe on a resource stock. The quality of property rights on the resource is defined as the proportion of the resource that can be appropriated rather than left under open access. With quasi-linear preferences and a strictly concave renewable resource growth function, we show that there always exists a quality of property rights leading to optimal steady-state extraction and resource stock levels. When the utility discount factor is too high, full appropriation of the resource stock leads to overaccumulation of the resource asset. The optimal quality of property rights involves some limitation to open access to counter the tragedy of the commons but not full private appropriation, because full appropriation would lead to an excessive amount of savings.

The third essay, entitled "Overlapping generations, physical capital and the optimal quality of property rights", builds on the second essay. In this essay, we explain how conventional capital differs from a renewable resource and how those differences impact the optimal quality of property rights. In fact, contrary to a resource stock, partial property rights on a capital stock does not prevent capital overaccumulation; they worsen the situation. We investigate the merits for an economy, using physical capital and labor as inputs in production, to have partial property rights and show that, in a perfectly competitive economy without market imperfections where agents live finite lives, optimal institutions should make it possible to appropriate a proportion of the young's income. The quality of property rights on the young's income is defined as the proportion of her labor income that the young can retain. We show that there always exists a quality of property rights on the young's income that leads to the first-best optimal steady-state. Partial property rights on income may wrongly be construed as a different name for an income tax because both have the effect of transferring income; we argue that similarities in effects hide significant differences in nature and origins.

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Chapitre 1

INTRODUCTION

L'objet de cette thèse est d'étudier les caractéristiques d'institutions permettant une exploitation économiquement optimale de ressources naturelles ou l'accumulation économiquement optimale d'un stock de capital. Par institutions, nous entendons ce que Douglass North (1991) a décrit comme les contraintes créées par les humains qui structurent les interactions politiques, économiques et sociales. Elles comprennent à la fois les contraintes informelles (sanctions, tabous, coutumes, traditions et codes de conduites) et les règles formelles (constitutions, lois, droits de propriété). Dans cette introduction, nous donnons d'abord un ensemble d'exemples de ressources naturelles surexploitées en raison d'institutions inadéquates, ce qui souligne la pertinence et l'importance de l'étude d'institutions optimales. Nous expliquons ensuite pourquoi parmi les institutions nous avons choisi de concentrer notre étude sur les droits de propriété. Puis, nous revoyons ce que la théorie économique traditionnelle nous apprend sur la qualité optimale des droits de propriété avant de présenter des exemples de situations dans lesquelles, en contradiction apparente avec les prescriptions de la théorie économique traditionnelle, des droits de propriété partiels sont en vigueur. Finalement, nous présentons les chapitres qui suivent et qui correspondent à chacun des trois essais composant cette thèse.

L'organisation des nations unies pour l'alimentation et l'agriculture (en anglais : Food and Agriculture Organization, "FAO") (2011) estime que 29.9% de l'ensemble des stocks de poissons faisant l'objet d'une pêche en mer sont écologiquement surexploités produisant de moins bons rendements que leurs potentiels biologiques et écologiques respectifs. 57.4% sont pleinement exploités au sens écologique. Nous savons qu'en présence de coûts d'exploitation, la surexploitation économique survient généralement à un niveau de stock plus élevé que la surexploitation écologique (Grafton *et al.*, 2007). Il est donc probable qu'en réalité, au delà des 29.9% de stocks surexploités écologiquement, une très grande majorité des stocks de poissons mondiaux sont économiquement surexploités. Certaines espèces sont particulièrement sujettes à la surexploitation incluant un tiers des espèces de thon, le flétan, l'espadon, le merlu, etc. La surexploitation de ressources naturelles renouvelables ne se limite malheureusement pas à la pêche. La FAO (2010) indique que la déforestation au niveau mondial bien qu'elle montre de légers signes de ralentissement se poursuit à un rythme alarmant. Des exemples de pays dans lesquels la déforestation, dont la cause est la surexploitation, est un problème majeur incluent Madagascar, la Cote d'Ivoire, le Vietnam, le Cambodge, la Colombie, le Brésil, etc. Enfin, de nombreuses espèces animales sont en danger en raison de chasses illégales parmi lesquelles les éléphants asiatiques, les tigres, les léopards, etc. Ce sont autant d'exemples de situations dans lesquelles les institutions se montrent inefficaces pour protéger des ressources naturelles. Cette inefficacité s'explique par la difficulté à définir et à protéger des droits de propriété sur des ressources naturelles renouvelables. Toute étude des institutions doit donc s'interroger sur les caractéristiques d'institutions optimales. Le propos de cette thèse est de contribuer à la compréhension de ce qui détermine des institutions optimales.

Parmi les différentes institutions, les droits de propriété sont sans doute l'institution la plus fondamentale. En effet, les droits de propriété servent d'incitatifs à la création d'autres institutions pour les définir et les protéger (North, 1990). Ils sont aussi une composante explicative majeure des comportements sociaux et économiques puisque leur distribution affecte les prises de décision concernant l'utilisation d'une ressource et donc les performances économiques (Libecap, 1989). Par ailleurs, en définissant les preneurs de décisions, la distribution des droits de propriété détermine les acteurs économiques et définit la distribution de la richesse dans la société. Nous concentrons donc notre étude des institutions sur les droits de propriété et étudions leur qualité optimale.

Nous reviendrons dans chacun des chapitres de cette thèse sur les avancées les plus récentes de la science économique dans l'étude des droits de propriété et situerons alors chacun des essais qui composent cette thèse dans la littérature économique pertinente. Nous indiquons seulement ici, dans une première approche, que la théorie économique traditionnelle nous apprend, avec le premier théorème du bien-être, que dans un cadre statique ou dans un cadre dynamique dans lequel les agents économiques ont une durée de vie infinie, une économie parfaitement compétitive, c'est à dire en particulier sans imperfections de marché et sans externalités, doit conduire à un équilibre décentralisé dans lequel l'exploitation d'une ressource est optimale et dans lequel l'accumulation de capital est également optimale. Une économie parfaitement compétitive s'entend comme une économie dans laquelle les droits de propriété sont parfaitement définis et protégés. La théorie économique traditionnelle nous apprend aussi que l'absence de droits de propriété sur une ressource naturelle peut conduire à sa surexploitation voire à son extinction, quand les agents économiques ne coopèrent pas entre eux. Il s'agit de ce qu'Hardin (1968) appelle la tragédie des ressources communes.

Dans la réalité, il existe cependant de nombreuses situations dans lesquelles les droits de propriété ne sont ni complets, ni absents, mais partiels. Ainsi, Dupont et Grafton (2001) fournissent un exemple d'un système de quota de pêche en Nouvelle-Ecosse dans lequel des quotas individuels transférables (ITQ) sont définis sur une partie seulement d'une prise totale permise (TAC), le reste demeurant en accès libre. Harrisson (2004) et Stavins (2011) fournissent d'autres exemples d'espèces de poissons qui migrent entre des zones où la pêche est réglementée et des zones non réglementées dans les eaux internationales. Grainger et Costello (2011) fournissent l'exemple de régimes de quotas de pêche en Nouvelle-Zélande qui sont partiellement protégés en raison de migrations et de pêches illégales. Les droits de propriété partiels ne concernent pas seulement les ressources naturelles renouvelables. Ainsi, le gisement de gaz de South Pars/North Dome, qui est le plus grand gisement de gaz au monde, se situe entre l'Iran et le Qatar et si chaque pays a en principe une réserve attribuée, les appropriations illégales ne sont pas rares. Enfin, comme nous l'indiquons dans le troisième essai de cette thèse, des droits de propriété partiels peuvent aussi concerner des revenus. Par exemple, les lois qui contraignent les enfants adultes à survenir aux besoins de leurs parents âgés, légitiment une appropriation partielle des revenus des enfants par leurs parents (Schoonbrodt et Tertilt, 2010). L'objet de cette thèse est de proposer une explication économique à la survenance fréquente de régimes de droits partiels. Ainsi, nous tentons de répondre spécifiquement à la question : est-ce que des droits de propriété partiels peuvent permettre une exploitation optimale d'une ressource naturelle (essais 1 et 2 qui correspondent aux chapitres 2 et

3 de cette thèse) ou permettre l'accumulation optimale d'un stock de capital (essai 3 qui correspond au chapitre 4 de cette thèse) ? Et, si oui, dans quelles circonstances ?

De nombreuses ressources naturelles sont surexploitées. Le message principal de cette thèse n'est donc pas de déconseiller le renforcement des droits de propriété mais de montrer formellement, dans différentes circonstances, que la distance jusqu'à des droits de propriété optimaux est parfois plus courte qu'on ne le croit généralement.

Le chapitre 2 s'intéresse à la qualité optimale de droits de propriété sur un stock de ressource en présence d'externalités et de pouvoir de marché. Le chapitre 3 relâche l'hypothèse de l'existence d'imperfection de marché sous la forme de pouvoir de marché et considère une économie à générations imbriquées, parfaitement compétitive. Dans ce contexte, nous y étudions la qualité optimale de droits de propriété sur un stock de ressource. Le chapitre 4 se base sur l'approche du chapitre 3 mais, après avoir spécifié les différences entre un stock de capital et un stock de ressource naturelle, nous y étudions la qualité optimale de droits de propriété dans une économie dans laquelle les facteurs de production sont le capital et le travail. Nous concluons dans le chapitre 5.

In this thesis, we study the characteristics of institutions necessary for an optimal exploitation of a natural resource or an optimal accumulation of a capital stock in an economy. Institutions are defined, following D. North (1991), as the humanly devised constraints that structure political, economic and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct), and formal rules (constitutions, laws, property rights). In this introduction, we first provide examples of over-harvested natural resources due to inadequate institutions; these examples underline the importance and the relevance of studying the characteristics of optimal institutions. We then explain, why among the different institutions, we focus on property rights and their optimal quality. We review the findings of traditional economic theory on the optimal quality of property rights before providing examples of situations where, in apparent contrast with the prescriptions of economic theory, partial property rights prevail. Finally, we introduce the different chapters of this thesis, each corresponding to one of our three essays.

According to the United Nations' Food and Agriculture Organization ("FAO") (2011), 57.4% of the fish stocks assessed were estimated to be fully exploited in 2009. These stocks produced catches that were already at or very close to their maximum sustainable production. 29.9% were overexploited. The overexploited stocks produced lower yields than their biological and ecological potential. The maximum economic yield, i.e., the biomass that produces the largest discounted economic profits from fishing, generally exceeds the maximum sustainable yield biomass (Grafton *et al.*, 2007) : due to positive fishing costs, it is generally not economically effcient to reduce the fishing stock down to the maximum sustainable yield biomass. It is therefore likely that a vast majority of fish stocks are in fact economically overexploited. Some species are particularly overfished including, but not limited to, one third of the tuna species, swordfish, halibut, cod, etc. The overharvesting of renewable resources is not limited to overfishing. According to the FAO (2010), the rate of deforestation shows signs of decreasing but remains alarmingly high. Countries facing dramatic deforestation include, but are not limited to, Madagascar, Ivory Coast, Vietnam, Cambodia, Colombia, Brazil, etc. Finally, numerous species are endangered by illegal hunting including asian elephants, tigers, leopards, etc. These are instances where institutions failed to protect natural resources adequately. Defining the characteristics of optimal institutions is therefore of primary importance. This thesis is a contribution to the understanding of what defines optimal institutions.

Among various institutions, property rights are perhaps the most fundamental as they act both as an incentive for the creation of other institutions in order to define and protect them (North, 1990), and as a key explanatory component of social and economic behaviors. In fact, as highlighted by Libecap (1989), property rights institutions critically affect decision making regarding resource use and hence affect economic behavior and performance. Besides, by allocating decision making authority, property rights also determine who are the economic actors in a system and define the distribution of wealth in a society. We therefore focus our study on property rights as an institution and, in particular, on what defines the optimal quality of property rights.

In the literature review in each chapter, we present the most recent and relevant advances in the economic theory upon which each chapter builds. Here, we simply present some of the fundamental findings of the economic theory on property rights. For infinitely lived agents, in a deterministic economy with complete property rights and no market failure, the competitive equilibrium is Pareto optimal provided that the number of agents is finite. Crucial to the definition of the competitive equilibrium is the condition that property rights be complete and perfectly defined. When the economy involves the extraction of a renewable resource, the dynamic path of that economy and its steady-state equilibrium are also optimal under perfect competition, given that perfect competition implies complete markets. However, property rights on the resource are often missing; open-access leads to overexploitation and the tragedy of the commons (Hardin, 1968).

In many situations, in apparent constrast with the prescriptions of the economic theory, property rights are neither complete nor absent, but partial. Dupont and Grafton (2001) provide an illustration of such a quality of property rights. The authors describe a rights-based fishery management system in Nova Scotia in which individual quotas ("ITQ") on a share of a total allowable catch ("TAC") co-exist with a non-ITQ competitive fishing pool on the remaining share of the TAC. Hannesson (2004) and Stavins (2011) provide other illustrations mentioning fish species that migrate between exclusive economic zones - 200 miles from coastlines - generally subject to well established rights based management systems, and open ocean - beyond the 200 miles limit - where that stock is in common-access. Grainger and Costello (2011) provide further examples of fishing ITQ regimes in New Zealand where property rights are insecure either because the species are migrating beyond territorial waters or because significant illegal harvesting occurs. The South Pars/North Dome gas field provides a non-renewable resource illustration of a combination of well-defined property rights and common-access. The South Pars/North Dome gas field is the world's largest gas field, it spans Iranian and Qatari territorial waters. Although each country has its own reserve, the field is in common-access and encroachments are frequent. Moreover, as discussed in the last essay of this thesis, property rights on income can also be partial. Schoonbroodt and Tertilt (2010) discuss how the common law system of the United States and England and the Roman-based legal system in France allocate a proportion of a child's income to her parents : mandatory parental support or filial responsibility law are instances of laws that affect parents' access to an offspring's labor income. Laws regarding child labour are also relevant as they allow (or prevent) parents' access to part of an offsprings' lifetime labor income. Laws that give parents control over other aspects of their children's lives might also allow parents to control their offspring income indirectly, e.g., by withdrawing consent to marriage unless monetary support is given, etc.

The object of this thesis is to specifically answer the following questions : can partial property rights be a necessary condition for a first-best optimal exploitation of a renewable resource (essays 1 and 2) or for a first-best optimal accumulation of a stock of capital (essay 3) ? If so, under which circumstances ?

Numerous natural resources are currently overexploited. When resources are overextracted due to too weak institutions, strengthening them is necessary but the distance to optimal institutions may be shorter than commonly believed. We show it formally under different circumstances.

Chapter 2 studies the optimal quality of property rights in the presence of externality and market power. Chapter 3 relaxes the assumption of the existence of a market imperfection in the form of market power and considers an overlapping generations, perfectly competitive, economy in which a renewable natural resource is exploited. We investigate the optimal quality of property rights in this context. In Chapter 4, which builds on Chapter 3, after having explained the main differences between conventional capital and a natural renewable resource, we investigate the optimal quality of property rights in an economy where capital and labor are used in production. We conclude in chapter 5.

Chapitre 2

THE OPTIMAL QUALITY OF PROPERTY RIGHTS IN PRESENCE OF EXTERNALITY AND MARKET POWER

2.1 Introduction

Among various institutions, property rights are perhaps the most fundamental as they act both as an incentive for the creation of other institutions (in order to define and protect them - North (1990)) and as a key explanatory component of social and economic behaviors. In fact, as highlighted by Libecap (1989), property rights institutions critically affect decision making regarding resource use and hence affect economic behavior and performance. Moreover, by allocating decision making authority, property rights also determine who are the economic actors in a system and define the distribution of wealth in a society.

There are many instances where property rights are neither perfectly defined nor perfectly enforced. Examples include but are not limited to aquifers or rivers, fisheries, hunting, forestry, underground reserves of crude oil, common pastures for cattle grazing, clean air, intellectual properties, etc. It is common wisdom among economists to consider those observed imperfections as either the economically efficient outcome from the consideration of definition/enforcement costs[1] by the government or from necessary, although economically inefficient, negotiated compromises between a multitude of economic and political forces pulling in different directions. The purpose of this paper is to further investigate that common wisdom. More specifically, this paper addresses the following question : could there, in fact, be instances where, absent any enforcement costs for the government, partial property rights are economically efficient ?

We answer this question for a renewable resource as they are frequently characterized by imperfect exclusion and by a limited number of firms permitted to enter the industry. Besides, they have exhibited monotonically increasing scarcity (Stavins, 2011) and therefore best illustrate the role of property rights ; similar rationale should apply to non-renewable resource.

We assume that some degree of market power may be present in the industry and that society determines the level of completeness of property rights. This could be done, as in Becker (1968), through investments in law enforcement, judicial systems, etc.

[1]In presence of definition/enforcement costs for the government, the first-order condition for optimality requires the equality of marginal costs and marginal benefits of definition/enforcement. The marginal costs being generally higher than the marginal benefits of full completion, the optimality condition is verified before definition/enforcement are complete (Nostbakken, 2008).

The basic model employed is one in which firms adopt a Cournot-Nash behavior when determining their own exploitation effort while considering the quality (or level of completeness) of property rights and their assignment to firms as given. We first address the existence of a level of completeness of property rights leading to first-best resource exploitation in presence of market power. Then, considering explicitly the quality of property rights as an endogenous variable, we seek to establish an analytic expression of that optimal quality under standard assumptions. To do so, we use a two stage Stackelberg game involving a social planner (the Stackelberg leader) and n profit maximizing firms (the Stackelberg followers). In stage one, the social planner chooses the quality of the property rights. In stage two, the firms adopt a Cournot-Nash behavior considering the quality of property rights as given.

We show, under standard assumptions, that complete rights are neither necessary nor sufficient for efficiency in a resource industry where a limited number of firms compete with each other. Partial property rights are found to be efficient in presence of market power as long as the number of firms is sufficiently high. We determine the relationship between the quality of property rights and the number of firms. We show that the optimal quality of property rights increases with the number of firms and that when the number of firms is reduced, property rights should optimally weaken. This explains what was already noted by Hotelling (1931) :

> "The government of the United States under the present administration has withdrawn oil lands from entry in order to conserve this asset, and has also taken steps toward prosecuting a group of California oil companies for conspiring to maintain unduly high prices, thus restricting production. Though these moves may at first sight appear contradictory in intent, they are really aimed at two distinct evils, a Scylla and

Charybdis between which public policy must be steered."

Our results suggest that the numerous instances of imperfectly enforced property rights are not necessarily signs of imperfect institutions; they may in fact reflect an adequate adjustment of the quality of property rights.

The remainder of the paper is organized as follows. In the next section, we examine the literature. Section 2.3 presents the baseline model. In section 2.4, we discuss the existence of an optimal level of property rights completeness in presence of market power. In section 2.5, we derive an analytic expression for that optimal quality of property rights under standard assumptions and interpret the results. We conclude in section 2.6.

2.2 Relation to the literature

A large portion of the economic literature considers complete property rights. There is a literature on the effects of market power in presence of complete property rights on the exploitation of renewable resource (Scott (1955) is a classical reference) as well as non renewable resource that include Salant (1976) and Loury (1986).

There is an extensive literature on situations where property rights are absent which includes : a literature related to the tragedy of the commons[2] that pertains mainly to renewable resource (e.g., Gordon (1954) and Hardin (1968)), a literature on the problem of common exploitation of a renewable resource when individual producers wield market power (e.g., Levhari and Mirman (1980) and Datta and Mirman (1999)). The latter consider for instance the coexistence of market power

[2] Consistent with this strand of the literature, the expression "open access" and "common access" are used interchangeably in this paper where the number of firms is fixed and finite.

and open access externalities in a model where two groups of countries, differing by the resource in open access to which they have access, compete through dynamic strategic price manipulation. In that paper, the focus is not on the quality of property rights as those are assumed absent. There is a literature on the problem of common exploitation of a non renewable resource (e.g., Dasgupta and Heal (1979)). More closely related to this paper is a literature looking for the optimal number of oligopoly firms in a common pool renewable resource (see Cornes, Mason et al. (1986) for a study in a static context and Mason and Polasky (1997) for a study in a dynamic context). In this paper, property rights are present but partial; the absence of property rights is only a polar case.

The rationale of this paper shares some common ground with Heintzelman *et al.* (2009) who show that there exists a specific organization of the fishing industry, partnerships, that can be socially optimal in a common pool resource. In our paper, we consider an oligopolistic market structure and show that a first-best social optimum can be achieved when a resource is partially protected. We show that the socially optimal quality of property rights is a function of technology, biology, preferences, and the number of firms in an industry.

There is also a literature in which property rights are partial with an exogenous degree of completeness : Bohn and Deacon (2000) is a classical reference which provides an empirical study of the effect of insecure ownership on ordinary investment and natural resource use.

There is finally a growing literature considering the interaction between trade and the quality of property rights in which the property rights are endogenously determined (see Hotte, Long and Tian (2000), Copeland and Taylor (2009) as well as Tajibaeva (2012)). Small, price taking, economies are generally considered. In this paper, we consider a closed economy in which the number of firms is finite. Firms have market power and can be both owners and poachers; poaching occurs at the equilibrium and its occurrence can lead to optimal exploitation in presence of market power.

Engel and Fisher (2008) consider how a government should contract with private firms to exploit a natural resource where an incentive to expropriate those firms may otherwise exist in the good state of the world where profits are high. Engel and Fisher consider three sources of potential inefficiencies : uncertainty, market power and an irreversible fixed cost. In this paper, we retain only market power. Costello and Kaffine (2008) study the dynamic harvest incentives faced by a renewable resource harvester with insecure property rights. A resource concession is granted for a fixed duration after which it is renewed with a known probability only if a target stock is achieved. They show that complete property rights are sufficient for economically efficient harvest but are not necessary. The idea is that if the target stock is set sufficiently high, then when the appropriator weights the extra benefit of harvesting now against the expected cost of loosing renewal, the appropriator may choose a similar path as with infinite tenure and complete rights. They further show that there exist a minimum length of tenure that is required to induce the infinite path and is a decreasing function of a renewal probability and growth rate. They conclude by saying : "Next steps in this vein could include combining the appropriator's incentives with the regulator's objective to design efficient incomplete property rights regimes." It is in fact what our simple model offers. This paper differs from Costello and Kaffine (2008) and Engel and Fisher (2008) in that the level of completeness is the result of benevolent government's decisions and complete rights are no longer a sufficient condition for efficiency : complete rights are inefficient in our model.

Grainger and Costello (2011) provide an empirical investigation of the impact of insecure property rights on the value of fishing quotas in Canada, New Zealand and the US. They illustrate the fact that different fishing ITQ regimes translate into different strengths of property rights. This paper investigates the impact of those different strengths of property rights on the exploitation of the resource in presence of market power.

The resource problem considered in this paper is a second best problem (Lipsey and Lancaster, 1956). In an economy where the number of firm is finite and firms exercise market power, property rights are established by a social planner that does not otherwise control firms. It is shown that the first best can be achieved by partial property rights provided some conditions on technology and preferences are satisfied.

2.3 The model

2.3.1 Resource, producers, technologies and consumers

We consider n firms $i = 1, ..., n$ having access to an homogeneous stock S of renewable resource. The rate of change of the stock $\dot{S}$ depends on total harvest H and, through a natural growth function $G(S)$, on the stock size :

$$\dot{S} = G(S) - H$$

We consider only steady state harvest equilibria, that is equilibria such that : $\dot{S} = 0$, implying

$$G(S) = H \tag{2.1}$$

which is the traditional bioeconomic equilibrium equation.

Harvesting by firm i , $h_i(e_i, S)$, depends on its own effort e_i, whose unit cost w is fixed and exogenous, and on the stock of resource. Total harvest is the sum of individual harvests : $H = \sum_{i=1}^{n} h_i(e_i, S)$. As total harvest is a function of individual efforts, equation (2.1) defines the equilibrium biomass as the implicit function S of $V = (e_1, ..., e_n)$ the vector of individual efforts :

$$S = S(V)$$

Noting $\frac{dh_i(e_i,S(V))}{de_i} \equiv \frac{\partial h_i(e_i,S(V))}{\partial e_i} + \frac{\partial S(V)}{\partial e_i}\frac{\partial h_i(e_i,S(V))}{\partial S}$, the individual harvest function is increasing in a firm's own effort $\left.\frac{dh_i}{de_i}\right|_{S>\tilde{S}} > 0$ as long as the resource stock is above the maximum sustainable yield level $\tilde{S}$ and decreasing otherwise. As a result, whatever the returns of the harvest functions $h_i\,(e_i, S)$ to effort and the resource stock, the equilibrium harvest functions $h_i(e_i, S(V))$ exhibit diminishing returns $\frac{d^2h_i}{de_i^2} < 0$. Both efforts and stock are essential to harvesting : $h_i(0, S) = 0\ \forall S$ and $h_i(e_i, 0) = 0\ \forall e_i$. All firms share the same harvesting technology with constant returns to effort given any resource stock level : $h_i(e_i, S) = h(e_i, S)$ and $\frac{\partial^2 h(e_i,S)}{\partial e_i^2} = 0$ $\forall\ i,\ S$.

Constant returns to efforts given any resource stock level means that $h(e_i, S) = e_i f(S)$ and $H = Ef(S)$ with $E = \sum_{i=1}^{n} e_i$ and $f(S) = h(1, S)$. At the steady state equilibrium, $S = S(E)$.

Equation (2.1) is not sufficient to uniquely define H and S. Consumer preferences, represented by an aggregate inverse demand function $P(H)$, determine which of the pairs (H, S) verifying this equation is economically efficient. In the next section, we define the economically efficient steady state, which under our standard assumptions, is unique.

2.3.2 Social optimum

Let the net consumer surplus be $C(H) = U(H) - P(H)H$. Let the net producer surplus be $\Pi(H) = P(H)H - w\sum_{i=1}^{n} e_i$. The social welfare $W(H)$ is the sum of the consumer and producer surpluses : $W(H) = U(H) - w\sum_{i=1}^{n} e_i$. The first-best problem is to maximize social welfare by choice of individual efforts :

$$\max_{e_1,\dots,e_n} \int_0^H P(u)du - w\sum_{i=1}^{n} e_i$$

subject to :

$$H = \sum_{i=1}^{n} h(e_i, S(E))$$

The n first-order conditions for effort are :

$$P(H)[\frac{\partial h}{\partial e_i} + \frac{\partial S}{\partial e_i}\sum_{j=1}^{n}\frac{\partial h}{\partial S}(e_j, S(E))] = w \ \ \forall i = 1, .., n. \tag{2.2}$$

At the steady-state equilibrium, this system uniquely defines the total level of efforts $E^* = \sum_{i=1}^{n} e_i^*(n)$ for all n. The individual level of efforts are undetermined[3]. A solution is $e_1^*(n) = e_2^*(n) = ... = e_n^*(n) = e^*(n)$ with $e^*(n) = \frac{E^*}{n}$. We have :

$$P(H^*)\frac{\partial H}{\partial e_i}(E^*, S(E^*)) = w$$

where :

$$\frac{\partial H}{\partial e_i}(E^*, S(E^*)) = \frac{\partial h}{\partial e_i}(e^*(n), S(E^*)) + \frac{\partial S}{\partial e_i}\sum_{j=1}^{n}\frac{\partial h}{\partial S}(e_j^*(n), S(E^*))$$

The Pareto optimum equilibrium resource stock and harvest are dependent on total effort : $E^* = ne^*(n)$ only and independent from the number of firms :

$$S^* = S(E^*) \ \ \forall n; \ H^* = E^* f(S(E^*)) \ \ \forall n$$

The pair (H^*, S^*) defines the socially optimal steady-state with $H^* = G(S^*)$.

[3]See G. Stevenson (2005) p. 38 on the classic indeterminacy of individual efforts in presence of constant returns to scale at the firm's level.

2.4 Existence of efficient property rights

2.4.1 Property rights

Property rights are an institution. For a renewable resource, they can be defined either on access to the resource or on harvest of the resource. In this section, the number of firms with access to the resource is given; we only consider the harvesting rights enjoyed by these firms. These rights may be interpreted as individual quotas. Imperfections in these rights may take the form of misreporting and/or harvest from open access stock as opposed to harvest from quotas.

Hotte *et al.* (2013) consider situations where both input exclusion and output appropriation are simultaneously present. They show that each of these types of property right tends to pull input use in opposite directions. Weak property rights on input encourages harvest while weak property rights on output discourages it. Indeed, the distinction between input and output rights, whenever possible, appears of primary importance. However, with most mixed regulatory regimes where rights on the input are enforced on the output, the distinction between weak individual quotas (generally considered output rights) and weak input exclusion may be blurred. To be more precise, in this paper, partial property rights on the output translates into partial property rights on labor as an input through a crowding effect : when individual quotas are partially enforced, they translate into partial self-appropriation of firms' efforts and, consistent with Hotte *et al.*'s conclusions, absent any market power, excessive efforts is encouraged and the resource is overharvested.

As we limit the analysis to steady state equilibria, total harvest, i.e., harvest from open access stock and harvest from quotas, must be equal to the natural growth of the resource. In other words, only the natural growth of the resource will be harvested at the steady state. For ease of reference, we will thereafter refer to the natural growth of the resource as simply "the resource to be harvested" or more simply "the resource", as the flow is proportional to the stock in steady-state equilibrium.

Complete property rights on the resource refer to rights that are defined on the entire resource to be harvested and to rights that are perfectly enforceable by the owner, secure from any seizure or encroachment. Complete property rights imply that firms can appropriate their individual quotas fully and can use them for production as they wish. Partial property rights may have different interpretations. Three of those interpretations are equivalent for the purpose of this paper. According to a first interpretation, partial property rights refer to rights that are defined on a share only of the resource to be harvested, the rest of the resource being in open access. According to a second interpretation, partial property rights are rights defined on the entire resource to be harvested but are not fully protected so that firms can secure only a share of their individual quotas. According to a third interpretation, risk-neutral firms harvest a renewable resource in an uncertain economy where the resource is either perfectly protected or in open access.

Hereafter, we will use the first interpretation as it relates to interesting observed situations. In fact, although our model is highly stylized and fits no specific resource industry, it provides a justification based on efficiency for rights-based resource management systems in which a share of a stock of resource is exploited under individual quotas whereas a remaining share is left to competitive common-access exploitation. Dupont and Grafton (2001) provide an illustration of such systems in Nova Scotia. The authors describe a rights-based fishery management system in which individual quotas ("ITQ") on a share of a total allowable catch ("TAC") coexist with a non-

ITQ competitive fishing pool on the remaining share of the TAC. Hannesson (2004) and Stavins (2011) provide other illustrations mentioning fish species that migrate between exclusive economic zones - 200 miles from coastlines - generally subject to well established rights based management systems, and open ocean - beyond the 200 miles limit - where that stock is in open access. Grainger and Costello (2011) provide further examples of fishing ITQ regimes in New Zealand where property rights are insecure either because the species are migrating beyond territorial waters or because significant illegal harvesting occurred. The South Pars/North Dome gas field provides a non-renewable resource illustration of a combination of well-defined property rights and open access. The South Pars/North Dome gas field is the world's largest gas field, it spans Iranian and Qatari territorial waters. Although each country has its own reserve, the field is in common-access and encroachments are frequent.

We call θ an indicator of the quality (or level of completeness) of property rights on the resource with $\theta \in [0,1]$. We consider that property rights are defined (i.e., quotas are attributed to the firm) on a share $(1-\theta)$ of the resource and that a share θ is in common access. Each firm is attributed a share β_i of the resource to be harvested. We have $\sum_{i=1}^{n} \beta_i = (1-\theta)$. The polar cases $\theta = 0$ and $\theta = 1$ can be interpreted as follows : $\theta = 0$ corresponds to a situation where property rights are complete; we have $\sum_{i=1}^{n} \beta_i = 1$ which means that the sum of all attributed and perfectly enforced quotas is equal to the total amount of resource harvested at the steady state (i.e., the natural growth of the resource). $\theta = 1$ corresponds to a situation where property rights are absent, no quotas are attributed : $\sum_{i=1}^{n} \beta_i = 0$ and the total amount of resource harvested is in common access. Interior values of θ mean that perfectly enforced property rights are defined on a share $(1-\theta)$ of the resource and that a share θ of the resource is in open access. The total resource in open access is then $\theta G(S)$. For the previously mentioned reasons, private or public costs of enforcement are ignored. If we were to adopt the second interpretation of the quality of property rights, we would assume that quotas are attributed on the entire resource so that each firm receives ρ_i of the resource with $\sum_{i=1}^{n} \rho_i = 1$ and that only a share $(1-\theta)$ of each quota is perfectly protected while a share θ is not protected. Then, as in the first interpretation, the total amount of resource protected would also be $(1-\theta)G(S)$ and the amount of resource in open access $\theta G(S)$. One may interpret $\rho_i G(S)$ as the legal, but not necessarily enforced or effective, property rights and $\beta_i G(S) = (1-\theta)\rho_i G(S)$ as the effective (or economic) property rights. They coincide and reflect the same reality when property rights are perfectly defined (i.e. $\theta = 0$). In any instances, rational economic agents' decisions are based on economic (or effective) property rights only.[4] If we were to adopt the third interpretation, θ would represent the probability that the resource falls in open access. As previously mentioned, we adopt thereafter the first interpretation.

The firms compete for the resource in common access. As in Gordon (1954) and subsequent literature, we assume that the share of the total resource in common access that each firm appropriates, is a positive function of its harvesting efforts and a negative function of the combined harvesting efforts from others. We call $\Psi(e_i, \sum_{j\neq i}^{n} e_j)$ this function. The literature endows it with the following properties : it is twice continuously differentiable, with $\Psi_1(e_i, \sum_{j\neq i}^{n} e_j) > 0$, $\Psi_2(e_i, \sum_{j\neq i}^{n} e_j) < 0$, $\Psi_{11}(e_i, \sum_{j\neq i}^{n} e_j) < 0$, $\Psi(0, \sum_{j\neq i}^{n} e_j) = 0$; individual shares in the common access

[4]As highlighted by Pande and Udry (2007), studies consistently show that there is a critical distinction between legal and effective security of property rights and that effective and individual economic behavior are jointly determined. A more in-depth discussion of the concept of effective property rights can be found in Grossman (2001).

resource must sum to unity, so that $\sum_{i=1}^{n}\Psi(e_i,\sum_{j\neq i}^{n}e_j)=1$. Hence, as in Gordon (1954) and subsequent literature, e_i serves both to harvest and appropriate the resource.

The harvest of firm i must verify $h(e_i,S(E))\leq\beta_i G(S)+\Psi(e_i,\sum_{j\neq i}^{n}e_j)\theta G(S)$. Substituting $H=G(S)$ at the steady-state equilibrium gives

$$h(e_i,S(E))=\beta_i H+\Psi(e_i,\sum_{j\neq i}^{n}e_j)\theta H \tag{2.3}$$

Summing across n, and recalling that $\sum_{i=1}^{n}\beta_i=(1-\theta)$ and $\sum_{i=1}^{n}\Psi(e_i,\sum_{j\neq i}^{n}e_j)=1$, shows that the condition $H=\sum_{i=1}^{n}h(e_i,S(E))$ is verified.

For the polar case of common access (i.e., $\theta=1$), firm i's harvest must be equal to $\Psi(e_i,\sum_{j\neq i}^{n}e_j)G(S)$. For the polar case of complete rights protection (i.e., $\theta=0$), firm i's harvest is limited to $\beta_i G(S)$, its individual quota. For the general case of incomplete rights $\theta\in[0,1]$, firm i's harvest is given by equation (2.3).

2.4.2 The firms' Cournot-Nash game

Each firm determines its harvesting effort considering as given the harvesting efforts of other firms, as well as the number of firms and the quality of property rights. Firm i's problem is :

$$\max_{e_i}\Pi_i=P(H)h(e_i,S(E))-we_i \tag{2.4}$$

subject to (2.3).

The polar cases $\theta=1$ and $\theta=0$ Assume that property rights are absent as in models of the commons. Then, $\theta=1$ leading to $\beta_i=0$ for all i. Equation (2.3) becomes :

$$h(e_i, S(E)) = \Psi(e_i, \sum_{j\neq i}^{n} e_j)H$$

and firm i's problem becomes :

$$\max_{e_i} \Pi_i = P(H)\Psi(e_i, \sum_{j\neq i}^{n} e_j)H - we_i \tag{2.5}$$

If $\Psi(e_i, \sum_{j\neq i}^{n} e_j)$ is given the standard functional form : $\Psi(e_i, \sum_{j\neq i}^{n} e_j) = \frac{e_i}{\sum_{j=1}^{n} e_j}$, then equation (2.5) is identical to equation (4) in Cornes *et al.* (1986). In that article, the authors determine the number of firms that equates the equilibrium harvest under oligopoly with the (unique) Pareto optimal harvest. We will refer to that number as $\bar{n}$ the "optimal number of firms in pure common-access".

Let $\theta = 0$; this corresponds to complete property rights, $\sum_{i=1}^{n} \beta_i = 1$. The objective (2.4) is unchanged, but constraint (2.3) becomes $h(e_i, S(E)) = \beta_i H$. The problem collapses to the traditional textbook version of the firm's problem in a Cournot oligopoly.

The general case $\theta \in [0, 1]$ With partial property rights, the first-order condition to the maximization of (2.4) subject to (2.3) is :

$$\frac{\partial H}{\partial e_i} P'(H)h(e_i, S(E)) + \beta_i \frac{\partial H}{\partial e_i} P(H) + \left[\Psi(e_i, \sum_{j\neq i}^{n} e_j)\theta \frac{\partial H}{\partial e_i} + \Psi'(e_i, \sum_{j\neq i}^{n} e_j)\theta H\right] P(H) = w \tag{2.6}$$

where :

$$\frac{\partial H}{\partial e_i} = \frac{\partial h}{\partial e_i} + \frac{\partial S}{\partial e_i} \sum_{j=1}^{n} \frac{\partial h}{\partial S}$$

We call $\Gamma(e_i; \theta, n)$ the left-hand side of equation (2.6) ; $\Gamma(e_i; \theta, n)$ is the marginal revenue in presence of partial property rights. The right-hand side of the equation is the marginal cost. Note that parameters θ and n are outside the control of individual firms. This problem is consistent with different vectors of β_i $i = 1, ..., n$; to each vector may correspond[5] different Nash equilibria. Consider the symmetric solution to system (2.6) when $\beta_i = \beta = \frac{1-\theta}{n}$ $\forall$ i. At the symmetric Nash equilibrium, the level of input extended by each firm is $\widehat{e}(\theta; n)$ implicitly defined by :

$$\Gamma(\widehat{e}; \theta, n) = w \quad \forall \theta \in [0, 1] \tag{2.7}$$

Proposition 2.1 *When the number of oligopolistic firms is strictly above the optimal number $\bar{n}$ of firms in pure common-access, there exists a quality of property rights θ^* with $1 > \theta^* > 0$ such that the harvesting efforts chosen by the oligopolistic firms at the Nash equilibrium sum up to the first-best industry level : $n\widehat{e}(\theta^*) = E^*$.*

Proof. Γ is a continuously differentiable function of $\widehat{e}$ and θ so that, applying the implicit function theorem to (2.7), there exists a continuous function $\widehat{e}(\theta; n)$ over the interval $[0, 1]$ such that :

$$\widehat{e} = \widehat{e}(\theta; n) \qquad \forall \theta \in [0, 1]$$

The Pareto-optimal number of firms $\bar{n}$ in pure common-access is defined by the condition $\bar{n}\widehat{e}(1; \bar{n}) = E^*$ which is a restatement of Cornes et al. (1986)'s findings in terms of property rights quality. From Cornes et al. (1986), we know that, for all n higher than $\bar{n}$, individual efforts from the oligopolistic firms in the absence of property rights will be higher than the optimal level of efforts : $\widehat{e}(1; n) > e^*(1; \bar{n}), \forall n > \bar{n}$. Hence :

$$n\widehat{e}(1; n) > E^*, \forall n > \bar{n}$$

[5] For additional assumptions on the inverse demand function ensuring the existence and the unicity of the Nash equilibrium, see Gaudet and Salant (1991).

For all n higher than $\bar{n}$, in presence of perfect property rights ($\theta = 0$), oligopolistic firms, competing à la Cournot, will provide a lower level of efforts than optimal :

$$n\widehat{e}(0; n) < E^*, \forall n > \bar{n}$$

As $\widehat{e}(\theta; n)$ is a continuous function of θ over $[0, 1]$, the intermediate value theorem implies that, when $n > \bar{n}$, there exists a value of θ, θ^*, such that $1 > \theta^* > 0$ and

$$n\widehat{e}(\theta^*; n) = E^*, \ \forall n > \bar{n}.$$

This is a fairly general result which does not rely on the particular functional form of Γ as long as a Nash equilibrium exists and as long as Γ is continuous in both $\widehat{e}$ and θ. ■

Corollary 2.1.1 *When the number of oligopolistic firms is strictly above the Pareto optimal number of firms in pure common-access, complete property rights $\theta = 0$ and the absence of property rights $\theta = 1$ both lead to socially inefficient levels of harvesting efforts.*

Proof. The result follows from $n\widehat{e}(1; n) > E^*$ and $n\widehat{e}(0; n) < E^*$, $\forall n > \bar{n}$. ■

2.5 Efficient property rights

Consider a social planner who seeks to establish adequate property rights in order to maximize welfare[6]. She cannot choose directly the efforts but she can choose, as

[6] In doing so, we do not imply that the quality of property rights is an handily available policy instrument to governments. The social planner is used as a conceptual tool to define the efficient quality of property rights. We do not address the question as to whether that quality is reached by society nor how. One may think that it may be reached by society through an evolution of negotiations and compromises, laws and regulations, public investments in the judiciary system and laws enforcement, etc.

Stackelberg leader, the quality of the property rights θ at no cost[7].

The situation is modelled as follows : given the property rights, it is assumed that firms compete in a Cournot-Nash game to determine their efforts. Each firm takes the efforts of others and the property rights quality as given when determining its own efforts. The social planner acts as a Stackelberg leader in choosing the quality of property rights taking into account the outcome of the firms' Nash-Cournot game. Firms act as Stackelberg followers with respect to property rights.

The solution must be subgame-perfect. The problem of input choice by the firms was shown to be a Nash equilibrium in the previous section. We now consider the problem of the social planner.

2.5.1 The social planner's problem as Stackelberg leader

The analysis of the previous section indicates that the first-best is attainable via an appropriate choice of property rights quality; the optimum property rights quality $\theta^* \in [0, 1]$ must be such that :

$$E^* = n\widehat{e}(\theta^*) \tag{2.8}$$

where E^* is implicitly defined by equation (2.2) and $\widehat{e}(\theta)$ is defined implicitly by equations (2.7). So θ^* must be solution to the following system :

$$\begin{cases} \Gamma(\widehat{e}; \theta, n) = P(H^*)\frac{\partial H}{\partial e_i}(E^*, S^*) \\ e^*(n) = \widehat{e}(\theta^*; n) \end{cases}$$

subject to $\theta^* \in [0, 1]$ and (2.3).

[7] As previously mentioned, the consideration of positive completion costs for the government would simply reinforce the argument.

Proposition 2.2 *The optimal quality of property rights is :*

$$\theta^* = \epsilon_c + \frac{1}{1-n}\frac{\epsilon_c}{\epsilon_D} \tag{2.9}$$

where ϵ_D *is the price elasticity of market demand at* (E^*, H^*)*,* ϵ_c *is the effort elasticity of harvest at* (E^*, H^*) *and* n *is the number of firms.*

Proof. See Appendix A ■

Interestingly, this result has an intuitive interpretation : as will be further explained thereafter, ϵ_c can be regarded as a measure of the common-access externality whereas $\frac{1}{\epsilon_D}$, i.e., the Lerner index, measures the extent of the inefficiency resulting from the presence of market power. Equation (2.9) provides that the optimal quality of property rights must be such that those two inefficiencies offset each other for any given number of firms. $\theta^*(n)$ is solution to the social planner's problem. We note that θ^* is a function of n and, as mentioned in Proposition 1, the constraint $\theta^* \in [0, 1]$ is binding for some values of n relative to technology and preferences. The analytic expression of the condition of existence is studied in the following paragraph.

2.5.2 Analytic expression of the condition of existence

We have to verify $1 \geq \theta^* = \epsilon_c + \frac{1}{1-n}\frac{\epsilon_c}{\epsilon_D} \geq 0$. $\theta^* \geq 0$ is always verified as $\epsilon_D(1-n) > 0$ and $\epsilon_c > 0$. On the other hand, as shown in Appendix B, $\theta^* \leq 1$ is verified if and only if :

$$n \geq \bar{n} = 1 + \frac{\epsilon_c}{(\epsilon_c - 1)\epsilon_D} \tag{2.10}$$

$\overline{n}$ is the Pareto optimal number of firms in pure common-access. It is identical to the optimal number of firms found in equation (4) of Cornes *et al.* (1986)'s article. It is the number of firms which, in the absence of property rights ($\theta = 1$) leads to the first-best level of harvesting effort for given technology (ϵ_c) and preferences (ϵ_D). In other words, equation (2.10) provides an analytic expression of the condition of existence in Proposition 1.

2.5.3 Interpretation of θ^*

As soon as $n \geq \bar{n} = 1 + \frac{\epsilon_c}{(\epsilon_c - 1)\epsilon_D}$, we have $1 > \theta^* > 0$. The result $\theta^* > 0$ means that complete property rights are inefficient. Partial property rights are efficient. Partial open access to the resource compensates in part for the under exploitation by the oligopoly. The result $\theta^* < 1$ means that partial property rights do better than no rights at all. It means that despite being weakly enforceable, the rights still attenuate the overexploitation of the resource.

Impact of the price elasticity of market demand ϵ_D

Proposition 2.3 *Everything else the same, the more price inelastic market demand, the more partial optimal property rights need to be.*

Proof. $\frac{\partial \theta^*}{\partial \epsilon_D} = \frac{\epsilon_c}{(n-1)[\epsilon_D]^2} > 0$ as $\epsilon_c > 0$ and $n > 1$. ■

It means that the lower the degree of buyers' responsiveness to price, the more oligopolistic firms can exercise their market power, the more partial optimal property rights must be to stimulate production. The more firms acquire market power, the less complete property rights should be to encourage production to optimal level.

Impact of the total effort elasticity of production ϵ_c

Proposition 2.4 *Everything else the same, the higher the total effort elasticity of production, the more partial optimal property rights need to be.*

Proof. $\frac{\partial\theta^*}{\partial\epsilon_c} = 1 + \frac{1}{(1-n)\epsilon_D} > 0.$ ■

Using the definition of ϵ_c, we can write $\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*} = \epsilon_c \left(\frac{H^*}{E^*}\right)$. Therefore, ϵ_c can be regarded as a measure of the distance between the average product $(\frac{H^*}{E^*})$ and marginal $(\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*})$ product. As $\epsilon_c < 1$, the higher ϵ_c, the closer the average and marginal products are, the weaker is the intensity of the commons problem and therefore the more partial property rights must be to stimulate production. The distance between average and marginal costs will be greater in industries with significant economies of scale. In those industries, our results suggest that stronger (although partial) property rights are sufficient to offset market power.

Impact of the relative value of input and output

Corollary 2.4.1 *Everything else the same, the greater the ratio between input costs and the market-value of output, the more partial optimal property rights need to be. Reciprocally, the lower the ratio between input costs and market-value of output, the more complete optimal property rights must be.*

Proof. We have $\epsilon_c = \frac{E^*}{H^*}\left(\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*}\right)$.Using equation (2.2), the total effort elasticity of production can be rewritten as $\epsilon_c = \frac{E^*}{H^*}\frac{w}{P(H^*)}$ and we recall that $\frac{\partial\theta^*}{\partial\epsilon_c} > 0$. ■

The rationale is the following : the lower the ratio between input costs and market-value of output, the more distant $P(H^*)H^*$ and wE^* are, the higher firms' profits from exploiting the resource, the greater the intensity of the commons problems[8], the more complete property rights must be; in other words, stronger (although partial) property rights suffice to optimally offset market power. According

[8] As the participation constraint is verified at the first-best equilibrium (i.e., firms profits are positive), we have $\frac{E^*}{H^*}\frac{w}{P(H^*)} < 1$, therefore the more distant $P(H^*)H^*$ and wE^* are, the lower is ϵ_c at (E^*, H^*) and stronger is the intensity of the commons problem.

to Demsetz (1967) : "property rights develop to internalize externalities when the gains of internalization become larger than the cost of internalization. Increased internalization results from changes in economic values, changes which stem from the development of new technology and the opening of new markets, changes to which the old property rights are poorly atuned." To support his theory, Demsetz discusses the close relationship between the development of private property rights in land among American Indians and the development of commercial fur trade. In this paper, we build on Demsetz's (1967) findings and explain how the outcome of the development of property rights, as a consequence of changes in economic values, is affected by the presence of market power : the more valuable is the output compared to the input, the greater the profits, the more intense is the commons problem and stronger partial property rights should be to offset market power.

Impact of biology and resource technology

Corollary 2.4.2 *Everything else the same, the lower the impact of efforts on stock level, the more partial optimal property rights must be and, the lower is the total efforts elasticity of resource stock, the more complete optimal property rights must be.*

Proof. $\epsilon_c = \frac{E^*}{H^*}\frac{\partial H}{\partial e_i}\Big|_{E^*,S^*}$ can be rewritten as

$$\epsilon_c = \frac{E^*}{H^*}\frac{\partial h}{\partial e_i}(e^*(n),S^*) + \left(\frac{E^*}{S^*}\frac{\partial S}{\partial e_i}(e^*(n),S^*)\right)\left(\frac{S^*}{H^*}\sum_{j=1}^{n}\frac{\partial h}{\partial S}(e_j^*(n),S^*)\right)$$

We call $\omega_c = \frac{E^*}{H^*}\frac{\partial h}{\partial e_i}(e^*(n),S^*)$ the partial effort elasticity of production at (E^*,H^*), $\eta_c = \frac{E^*}{S^*}\frac{\partial S}{\partial e_i}(e^*(n),S^*)$ the effort elasticity of the resource stock at (E^*,S^*) and $\varsigma_c = \frac{S^*}{H^*}\sum_{j=1}^{n}\frac{\partial h}{\partial S}(e_j^*(n),S^*)$ the resource stock elasticity of production at (S^*,H^*).

We have :

$$\epsilon_c = \omega_c + \eta_c \varsigma_c$$

and $\frac{\partial \epsilon_c}{\partial \eta_c} = \varsigma_c > 0$, $\frac{\partial \epsilon_c}{\partial \varsigma_c} = \eta_c < 0$. $\frac{\partial \theta^*}{\partial \epsilon_c} > 0$, therefore $\frac{\partial \theta^*}{\partial \eta_c} > 0$ and $\frac{\partial \theta^*}{\partial \varsigma_c} < 0$. ■

The lower is the impact of efforts on resource stock, the weaker is the intensity of the commons problem and therefore the more partial property rights must be to optimally offset market power. The greater is the resource stock elasticity of production, the more intense is the commons problem, the more complete optimal property rights must be to offset market power.

Impact of the number of firms n

Proposition 2.5 *The greater is the number of firms, the more complete optimal property rights should be. Reciprocally, a decrease in the number of firms must be compensated by more partial optimal property rights.*

Proof. $\frac{\partial \theta^*}{\partial n} = \frac{1}{(n-1)^2} \frac{\epsilon_c}{\epsilon_D} < 0$ as $\epsilon_D < 0$. ■

This is a formal illustration of the Hotelling's Scylla and Charybdis dilemma : a government that decreases the number of firms thereby increasing existing firms' market power must compensate that increase in market power by letting property rights become more partial (hence not letting oligopolistic firms act as oligopolists).

2.6 Conclusion

We have seen, under standard assumptions, that, even in the absence of completion and enforcement costs for the government, partial property rights can be efficient in presence of market power. This is consistent with the existence of mixed regulatory/property rights regimes such as in some Nova Scotia fisheries, in some New

Zealand ITQ regimes or in the South Pars/North Dome gas field. The determination of an analytic expression of that optimal quality of property rights has highlighted its main determinants. Greater buyer's responsiveness to price is consistent with more complete optimal property rights ; in other words, when consumers can police activities of oligopolistic firms through demand, the need for resource competition among firms is lower. Reciprocally, weaker protection of property rights by society can compensate weaker control of firms by consumers. Technology is an important determinant of the optimal quality of property rights. The dependence of the optimal quality of property rights to technology can also be regarded as a dependence to the relative price of output and input. The more valuable is output compared to input, the more complete property rights must be. Our results are consistent with Demsetz (1967)'s findings on the emergence of property rights : property rights develop to internalize externalities when the gains of internalization become larger than the cost of internalization. In fact, we build on Demsetz (1967)'s findings and explain how the outcome of the development of property rights, as a consequence of changes in economic values, is affected by the presence of market power : the more valuable is the output compared to the input, the greater the profits, the more intense is the commons problem and stronger partial property rights should be to offset market power.

Biology impacts the optimal quality of property rights : when the stock of resource is more sensitive to harvesting efforts, optimal property rights can be more complete. Our results also confirm Hotelling's intuition of the existence of a tension between the number of firms and the optimal quality of property rights.

Several additional extensions remain. An investigation of the first-best optimality of partial property rights with other market imperfections may be of interest.

The second-best optimality of partial property rights in presence of multiple market imperfections is also worth studying. Finally, a formal study of the dynamic trajectory of the quality of property rights leading to its optimal steady-state may complement fruitfully the findings of this paper.

Chapitre 3

OVERLAPPING GENERATIONS, NATURAL RESOURCES AND THE OPTIMAL QUALITY OF PROPERTY RIGHTS

3.1 Introduction

This paper investigates the merits for a renewable resource economy to have partial property rights. We show that, in a perfectly competitive economy where agents live finite lives, optimal institutions should make it possible to infringe on a resource stock. The quality of property rights on the resource is defined as the proportion of the resource that can be appropriated rather than left under open access. The answers are important for policy : when natural resources are overextracted as a result of too weak institutions, the distance to optimal institutions may be shorter than commonly believed.

For infinitely lived agents, in a deterministic economy with complete property rights and no market failure, the competitive equilibrium is Pareto optimal provided that the number of agents is finite. Crucial to the definition of the competitive equilibrium is the condition that property rights be complete and perfectly defined. When the economy involves the extraction of a renewable resource, the dynamic path of that economy and its steady-state equilibrium are also optimal under perfect competition, given that perfect competition implies complete markets. The optimal steady-state is stable. However property rights on the resource are often missing; open access leads to overexploitation and the tragedy of the commons.

With overlapping generations (OLG) models, the situation is different. Whether or not a renewable natural resource is exploited, the steady-state equilibrium of a perfectly competitive OLG economy need not be Pareto efficient. The first theorem of welfare may fail to apply because there is an infinite number of finitely lived agents. However, not every equilibrium is inefficient. Efficiency is linked to the marginal productivity of capital; the Cass criterion (Cass, 1972) gives necessary and sufficient conditions for efficiency. The possibility of inefficiency arises from the fact that the competitive growth equilibrium of an OLG economy may involve excessive savings. In an OLG economy using a renewable resource, excessive savings would take the form of insufficient harvesting and has been shown to be possible (Kemp and Long, 1979; Koskela *et al.*, 2002).

This paper formally investigates these Pareto inefficiencies in terms of the quality of property rights. In an overlapping generations model with quasi-linear preferences and a strictly concave renewable-resource growth function, we show that there always exists a quality of property rights that leads to optimal steady-state extraction and resource stock level. Under standard assumptions on preferences, technology, and resource dynamics, we establish the optimal steady-state quality of property rights and show that the steady-state is saddle stable. Our analytical results are illustrated by numerical calculations.

The paper is organized as follows. Section 3.2 examines the literature. Section 3.3 presents the basic structure of the model. Section 3.4 characterizes the competitive equilibrium. In section 3.5, the conditions of existence, the number of decentralized steady-states and the local stability properties of those equilibria are studied. Section 3.6 provides a characterization of the efficient steady-state. Section 3.7 studies the existence of an optimal quality of property rights and determines its expression as a function of technology, preferences and stock dynamics. Numerical calculations with parametric specifications and a graphic analysis are presented in section 3.8. We conclude in the last section of this chapter.

3.2 Relation to the literature

Our analysis builds on two major strands of the economics literature. One addresses the question of whether complete property rights are necessary to optimally exploit a natural resource (Engel and Fisher, 2008 ; Costello and Kaffine, 2008). The other strand considers the question of efficiency and/or equity in the exploitation of a natural resource when agents have finite lives and different generations coexist. In this latter strand, extensively reviewed by Farmer and Bednar-Friedl (2010), property rights are considered either complete (Kemp and Long, 1979 ; Mourmouras, 1991 ; Olson and Knapp, 1997 ; Koskela *et al.,* 2002, Brechet and Lambrecht, 2011), absent (Mirman and To, 2005 ; Karp and Rezai, 2013) or partial (Balestra *et al.*, 2010). Finally, in an OLG model with endogenous fertility and without a natural resource, Schoonbrodt and Tertilt (2010) and (2013) investigate whether children should have property rights on their entire labor income.

Engel and Fisher (2008) consider how a government should contract with private firms to exploit a natural resource where an incentive to expropriate those firms exists in the good state of the world where profits are high. Engel and Fisher consider three sources of potential inefficiencies : uncertainty, market power and an irreversible fixed cost. This paper considers a perfectly competitive economy with no market failure. Costello and Kaffine (2008) study the dynamic harvest incentives faced by a renewable resource harvester with insecure property rights. A resource concession is granted for a fixed duration after which it is renewed with a known probability only if a target stock is achieved. They show that complete property rights are sufficient for economically efficient harvest but are not necessary. The idea is that if the target stock is set sufficiently high, then when the appropriator weighs the extra benefit of harvesting now against the expected cost of losing renewal, the appropriator may choose a similar path to infinite tenure and complete rights. This paper differs from Engel and Fisher (2008) and Costello and Kaffine (2008) in that complete rights are no longer a sufficient condition for efficiency : complete rights can be inefficient. In chapter 2, we show that incomplete property rights can be optimal in the presence of market power : the optimal quality of property rights depend on the number of firms, on technology through the elasticity of input productivity and on preferences through the price elasticity of demand. That paper is in partial equilibrium and is essentially static. The present paper characterizes the steady-state equilibria of an OLG economy, studies its dynamic stability properties and compares competitive and efficient steady-state equilibria.

Using an OLG model with complete property rights, Kemp and Long (1979) demonstrate that a competitive economy with constant population may under-harvest a renewable resource as a consequence of the resource being inessential for production. They assume constant resource growth. Mourmouras (1991) considers interactions between capital accumulation and natural exploitation in Diamond's (1965) overlapping generations model. He shows that both a low rate of resource regeneration relative to population growth and a low level of savings may lead to the unsustainable use of a renewable resource, despite the existence of complete property rights. In this paper, complete property rights are not assumed ; property rights can be complete, absent or partial. The quality of property rights is an institutional parameter taken as given by individual agents. The natural resource is assumed to be essential for production and a strictly concave renewable resource-growth function is assumed. Kemp and Long (1979) and Mourmouras (1991) studied the steady-state without analyzing its dynamics and stability whereas this paper does study the dynamics of the system. Olson and Knapp (1997) analyze competitive allocations of an exhaustible resource in an OLG economy and characterize the behavior of resource extractions and prices when they are endogenously determined by preferences and technology.

Our model and methodology are similar to the renewable resource model and the approach of Koskela *et al.* (2002). However, in the paper by Koskela *et al.*, property rights are not the focus of the analysis and are assumed complete. Our model explicitly considers the role of the quality of the property rights in the dynamics of the economy : resource extraction and price paths evolve endogenously considering the quality of property rights at each date. Our model admits the model of Koskela *et al.* (2002) as a special case when property rights are assumed complete in each period. Brechet and Lambrecht (2011) consider an overlapping generations economy in which firms' technology is CES and combines labor, physical capital and a natural resource. They consider an economy in which households have a warm glow resource bequest motive. They shed light on the interplay between the resource bequest motive and the substitutability/complementarity relationship between capital and the natural resource in the determination of the use of the resource at the equilibrium. In this paper, consistent with the traditional walrasian representation of a perfectly competitive market, we do not assume intergenerational altruism nor a bequest motive : agents care only about their own lifetime welfare.

In contrast with the previous literature, Mirman and To (2005) consider an OLG model where property rights on the renewable resource are absent. Young agents use the extracted resource as a vehicle for savings and have market power on the resource market. Our model is also an OLG model and agents also use the non-extracted resource as savings vehicle; however, save for the possibility of incomplete property rights on the resource, the economy is perfectly competitive for all generations. Karp and Rezai (2013) use a two-sectors OLG model, with log linear additive intertemporal utility, to study the intergenerational effects of a tax that protects a renewable resource in open access. The old agents benefit from the environmental improvement (i.e., increase in the steady state level of stock and extraction) resulting from the tax. Absent a transfer, the tax harms the young agents by decreasing their real wages. They show that a Pareto improving tax can be implemented under various political economy settings. In this paper, there is only one sector, and property rights exist on the renewable resource but their quality is to be determined. The absence of property rights is only an extreme case of our model. Although our results with incomplete rights bear some similarity with those of Karp and Rezai (2013), incomplete property rights differ from Pigovian taxes in the sense that the quality of property rights, as an institution, is not a handily available policy instrument ; it is a durable, secular characteristic of an economy. Although, as underlined by Copeland and Taylor (2009), they are not an immutable characteristic of an economy, their dynamics may still be thought of as slow-motioned, short-term stationary ; the quality of property rights evolves as a result of long-term decisions such as public investments in the judiciary system, law enforcement, negotiations, compromises and cultural changes. Moreover, unlike the Pigovian tax, weak property rights do not involve the collection, management, or redistribution by the government of the share of goods that failed to be appropriated.

Balestra *et al.* (2010) investigate the optimal number of plots (or property rights) to maximize the stock of a natural resource whose evolution depends on both spatial spillovers amongst private owners (the higher the number of plots the less likely spatial spillovers occur) and maintenance cost of each plot (the higher the number of plots, the smaller the plots, the lower the maintenance cost of each plot). They consider an overlapping generations model with a renewable resource where a government decides the division of the resource in plots at each date. Each plot is assigned to a community that must manage it. Within each community, a representative young harvests and a representative old owns the capital (in the form of extracted resource). There are two sources of market power : as in Mirman and To (2005), within each community, the young has a form of market power as she decides how much to harvest taking into account the equilibrium of the production inputs market where she meets her contemporaneous old ; the second source of market power is the different communities playing a Cournot-Nash game. The authors compare the non-cooperative and cooperative outcomes and show that the gain from cooperation is remarkable. They study how a fiscal policy could decentralize the cooperative outcome. In this paper, the economy is perfectly competitive and the natural resource growth function meets standard assumptions (i.e., no biological spillovers are assumed) : for instance, a logistic growth function meets our assumptions on the resource growth.

Schoonbroodt and Tertilt (2013) question the economic rationale of pronatalist policies. They consider an OLG model where capital and labor are inputs in production, with fertility choice and parental altruism. When the cost of bearing children is positive, they show that parents' appropriation of children's income is rendered necessary to have a non-zero equilibrium fertility. This paper considers a renewable resource economy where property rights on the resource stock can be partial.

3.3 The model

We use a standard OLG model similar to the one used by Koskela *et al.* (2002). Our assumptions allow us to use Koskela *et al.*'s model as a benchmark when property rights are complete at all dates. We consider an overlapping generations economy without population growth where agents live for two periods and work only when young. We assume that agents maximize the intertemporally additive, quasi-linear lifetime utility function :

$$V = u(c_1^t) + \beta u_2(c_2^t) \tag{3.1}$$

with $u_2(c_2) = c_2$ where c_i^t denotes the period $i = 1, 2$ consumption of a consumer-worker born at time t and $\beta = \frac{1}{1+\delta}$ with δ being the exogenous rate of time preference. For the first-period utility function, $u' > 0$, $u'' < 0$, and $\lim_{c\to\infty} u'(c) = 0$ and $\lim_{c\to 0} u'(c) = \infty$. The young are endowed with one unit of labor, which they supply inelastically to firms in the consumption goods sector. Labor earns a competitive wage. The representative young consumer-worker uses the wage to buy the consumption good and to buy the stock of renewable resource that remains after production as savings to be used during her retirement. In addition to trading in the resource market, the young can also participate in the financial market by borrowing or lending[1]. The representative old rentier sells the stock of renewable resource and the financial assets bought when she was young to buy the consumption good during her retirement.

The representative firm produces the consumption good under a constant returns to scale technology that transforms the harvested resource H_t and labor L_t into output : $F(H_t, L_t)$. The technology can be expressed in factor-intensive form as $f(h_t) = \frac{F(H_t,L_t)}{L_t}$ with the standard properties $f' > 0$ and $f'' < 0$. Furthermore, we assume that the Inada conditions are verified : $\lim_{h\to 0} f'(h_t) = \infty$ and $\lim_{h\to\infty} f'(h_t) = 0$, where h_t is the *per capita* harvest. The assumption of a representative firm is not restrictive because with constant returns to scale, the number of firms does not matter and production is independent on the number of firms which use the same technology. Moreover, since the firm has constant returns to scale technology, profits are zero in equilibrium. Also, as noted by De la Croix and Michel (2002), we may assume that firms live forever. This would not change the results as the firm's problem in any case is a static one.

[1]The second vehicle for savings is not necessary for our demonstration. It is introduced to streamline the presentation and render explicit the underlying arbitrage condition between the resource and the financial assets.

The growth of the renewable resource is $g(x_t)$, where x_t denotes the beginning of period t *per capita* stock of the resource; $g(x_t)$ is strictly concave and there are two values $x = 0$ and $x = \tilde{x}$ for which $g(0) = g(\tilde{x}) = 0$. Consequently, there is a unique value $\hat{x}$ at which $g'(\hat{x}) = 0$, where $\hat{x}$ denotes the stock providing the maximum sustainable yield (MSY). A logistic growth function $g(x) = ax - \frac{1}{2}bx^2$ meets these assumptions.

The renewable resource in this model has two roles. It is both a savings vehicle between generations and an input in the production of a consumption good. The market for the resource operates in the following manner. At the beginning of period t the old agent owns the stock x_t; the stock increases by the current growth to $x_t + g(x_t)$. If property rights are complete, she sells the stock (growth included) to the firm, which then chooses the harvest h_t to be used as input in the production of the consumption good. The firm then sells the remaining resource stock x_{t+1} to the young, who becomes the old agent in the next period. The firm only plays the role of an intermediary between the generations; it does not extract any surplus from its activities. Surpluses are allocated between the generations by the price system.

With complete property rights, the natural growth of the resource yields a profit for its owner. The transition equation for the resource is :

$$x_{t+1} = x_t + g(x_t) - h_t \tag{3.2}$$

where h_t denotes the resource stock harvested by the firm for use as an input in production. The initial stock x_t and its growth, $g(x_t)$, can be put aside to feed into next period's stock or used to contribute to the current period's harvest.

Let $\theta_t \in [0, 1]$ be an indicator for the quality of property rights on the resource owned by the old agent at date t with $\theta_t = 1$ corresponding to complete rights and $\theta_t = 0$ corresponding to the absence of property rights. All other property rights in the economy are assumed complete. When property rights on the stock of resource are partial, the firm can harvest a proportion of the resource owned by the old agent without paying for it. At the beginning of period t the old agent owns the stock x_t; the stock increases by the current growth to $x_t + g(x_t)$. The firm appropriates for free a proportion $(1-\theta_t)$ of the quantity of resource h_t it harvests for production and buys the rest of the quantity it needs, θh_t, from its owner at the going resource price p_t. Then, the remaining resource stock, a quantity of $x_t - h_t + g(x_t)$, is transmitted to the next generation at price p_t. Altogether the old thus obtains the amount $p_t\left(x_t - (1-\theta)\, h_t + g(x_t)\right)$ from the resource; the firm harvests the quantity h_t at cost $p_t\theta_t h_t$; the young receives a quantity $x_{t+1} = x_t + g(x_t) - h_t$ which she pays to the old at the market price p_t out of her wage income w_t. θ_t is exogenous to individuals and firms.

The periodic budget constraints are thus :

$$c_1^t + p_t x_{t+1} + s_t = w_t \tag{3.3}$$

$$c_2^t = p_{t+1}\left[x_{t+1} + g(x_{t+1}) - (1-\theta_{t+1})h_{t+1}\right] + R_{t+1}s_t \tag{3.4}$$

where $R_{t+1} = 1 + r_{t+1}$ is the return factor on the financial asset and s_t represents savings by the young on the financial market. At the equilibrium, s_t will be zero so that the resource is the only savings vehicle. According to equation (3.4), the old agent consumes her savings, including the interest and the income she gets from selling the resource. From equations (3.3) and (3.4), the intertemporal budget constraint is :

$$c_1^t + \frac{c_2^t}{R_{t+1}} = w_t + \frac{p_{t+1}\left[x_{t+1} + g(x_{t+1}) - (1-\theta_{t+1})h_{t+1}\right] - R_{t+1}p_t x_{t+1}}{R_{t+1}} \tag{3.5}$$

3.4 Competitive equilibrium

To study the competitive equilibrium, we follow De la Croix and Michel (2002)'s approach and distinguish the temporary equilibrium and the inter-temporal equilibrium.

3.4.1 Temporary equilibrium

The temporary equilibrium of period t is a competitive equilibrium given price expectations. It is such that : (i) the representative agent optimizes her lifetime utility subject to both her budget constraint in each period and her price expectations, and, (ii) all markets clear at period t. The temporary equilibrium gives the equilibrium value of the current variables, including current prices as a function of the past and of the expectations about the future.

Consumptions at each period c_1^t and c_2^t by an individual of generation t and the demand for the resource stock as savings x_{t+1}, are determined as a solution to the following utility's maximization problem :

$$\max_{c_1^t, c_2^t, x_{t+1}} u(c_1^t) + \beta c_2^t$$

subject to the intertemporal budget constraint (3.5). It gives the following first-order conditions for c_1^t, c_2^t and x_{t+1} at the interior solution with λ a non-negative multiplier[2] :

$$u'(c_1^t) = \lambda$$
$$\beta = \frac{\lambda}{R_{t+1}}$$
$$\lambda p_{t+1} \frac{[(1 + g'(x_{t+1})) - (1 - \theta_{t+1})(1 + g'(x_{t+1}))]}{R_{t+1}} = \lambda p_t$$

Rearranging the system of first-order conditions leads to

$$u'(c_1^t) = \beta R_{t+1} \tag{3.6}$$
$$p_t u'(c_1^t) = \beta p_{t+1} \theta_{t+1} (1 + g'(x_{t+1})) \tag{3.7}$$

Recalling that $u_2' = 1$, equation (3.6) is the first Euler equation which provides that in an optimal plan the marginal utility cost of saving equals the marginal utility benefit obtained by doing that. More specifically, the opportunity cost (in terms of current utility) of saving one more unit in the current period in the form of financial assets must be equal to the benefit of having R_{t+1} more units in the next period. This benefit is the discounted additional utility that can be obtained next period through the increase in consumption by R_{t+1} units. Rearranging equation (3.6), an alternative interpretation follows from :

$$\frac{u'(c_1^t)}{\beta} = R_{t+1}$$

the utility marginal rate of intertemporal substitution $\frac{u'(c_1^t)}{\beta}$ should be equal to the marginal rate of transformation R_{t+1} which is the rate at which savings in the form of financial assets allow an agent to shift consumption from period t to $t+1$. Equation (3.7) is the second Euler equation which indicates that the opportunity cost (in terms

[2] To determine the third first-order condition, we first substituted the transition equation for the resource : $h_{t+1} = x_{t+1} + g(x_{t+1}) - x_{t+2}$.

of current utility) of saving the value of one more unit in the current period in the form of resource stock must be equal to the benefit of having $\theta_{t+1}(1+g'(x_{t+1}))$ more units valued p_{t+1} each in the next period. This benefit is the discounted additional utility that can be obtained next period through the increase in consumption by $\theta_{t+1}(1+g'(x_{t+1}))\frac{p_{t+1}}{p_t}$ units. Rearranging equation (3.7), an alternative interpretation follows from :

$$\frac{u'(c_1^t)}{\beta} = \theta_{t+1}(1 + g'(x_{t+1}))\frac{p_{t+1}}{p_t}$$

the utility marginal rate of intertemporal substitution should be equal to the marginal rate of transformation $\theta_{t+1}(1+g'(x_{t+1}))\frac{p_{t+1}}{p_t}$ which is the rate at which savings in the form of resource stock allow an agent to shift consumption from period t to $t+1$. Equations (3.6) and (3.7) together imply the arbitrage condition for the two assets at the equilibrium :

$$R_{t+1} = \theta_{t+1}(1 + g'(x_{t+1}))\frac{p_{t+1}}{p_t} \tag{3.8}$$

which provides that the interest factor should be equal to the resource price adjusted growth factor considering the quality of property rights. When savings behavior is optimized, we see from equation (3.8) that the price paths of the resource stock adjusts itself to the quality of the property rights. In other words, the firm and the young pay for the stock exactly what it is worth considering the quality of the property rights.

We now consider the market clearing conditions :

$$c_1^t + c_2^{t-1} = f(h_t) \tag{3.9}$$

is the consumption good market clearing condition.

$$x_{t+1} + \theta_t h_t = x_t + g(x_t) - (1 - \theta_t)h_t \tag{3.10}$$

is the renewable resource stock market clearing condition.

$$s_t = 0 \tag{3.11}$$

The fact that the arbitrage condition (equation (3.8)) is verified, that there is only one type of consumer per generation (i.e., no intragenerational heterogeneity) and no government debt, forces the asset market clearing condition to be such that saving is 0 for all t.

Firm's profits are

$$\pi(H_t, L_t) = F(H_t, L_t) - \theta_t p_t H_t - w_t L_t$$

The first-order conditions for the firm's profits maximization, expressed *per capita*, are

$$f'(h_t) = \theta_t p_t \tag{3.12}$$

$$f(h_t) - h_t f'(h_t) = w_t. \tag{3.13}$$

They determine the demand for the factors of production H_t and L_t[3] from their marginal costs $\theta_t p_t$ and w_t. With a constant returns to scale technology, the firm has zero profits at the optimum. The resource price is endogenous in this economy. However, in a partial equilibrium analysis, we note that, for a given resource price, the marginal cost of the resource is lowered as $(1 - \theta_t)$ is appropriated from the old at no cost by the firm. Equation (3.12) defines the quantity of resource harvested as an implicit function of the quality of property rights ; for a given price, the derivative of that implicit function[4] is negative as $f'' < 0$: the more partial the property rights on the resource stock, the higher the quantity harvested. When $\theta_t \to 0$, we have :

[3]The labor market also clears and we have : $L_t = L \; \forall t$ as there is no population growth.

[4]$\psi(h_t, \theta_t) = f'(h_t) - \theta_t p_t$ leading to $\frac{\partial h_t}{\partial \theta_t} = \frac{p_t}{f''(h_t)} < 0$

$h_t \to x_t + g(x_t)$: the resource is exhausted in period t. This is an illustration of the traditional tragedy of the commons when preferences are quasi linear and harvest costs are zero.[5]

Equation (3.13), on the other hand, defines the wage as an implicit function of the quality of the property rights; for a given resource price, the derivative of that implicit function is negative[6] : the more partial the property rights on the resource stock, the higher the wage. We define the intertemporal equilibrium in the next paragraph.

3.4.2 Intertemporal equilibrium

In this economy, the link between two periods t and $t+1$ is given by the resource dynamics and by the rational expectations on resource prices and property rights quality[7]. Using the transition equation for the renewable resource stock (3.10) and the first-order conditions for profit maximization (3.12) and (3.13) to eliminate input prices from the first-order condition for the resource stock (3.7), the intertemporal equilibrium is, for a given initial resource stock x_1, a sequence of temporary equilibria that satisfies for all $t \geq 0$ the following conditions :

$$x_{t+1} = x_t + g(x_t) - h_t \tag{3.14}$$

[5] In some fishery models, harvest costs increase as the resource stock diminishes, preventing extinction.

[6] Using equations (3.12) and (3.13), we have : $f''(h)dh = pd\theta$ and $f\prime(h)dh - f\prime(h)dh - hf''(h)dh = dw$ leading to $\frac{dw}{d\theta} = -ph < 0$.

[7] There is no uncertainty in this economy so that rational expectations are equivalent to perfect foresight.

$$f'(h_{t+1})\beta\theta_t[1+g'(x_{t+1})] = u'[f(h_t) - f'(h_t)h_t - \frac{1}{\theta_t}f'(h_t)x_{t+1}]f'(h_t) \tag{3.15}$$

where we have also used the periodic budget constraints (3.3) and (3.4). In this paper, we consider steady-state equilibria .

3.5 Competitive steady-states equilibria : existence, number and stability properties

Consistent with the durable nature of the quality of property rights, the study focuses on the steady-states of the dynamic system defined by equations (3.14) and (3.15). In addition, the quality of property rights is assumed constant over time, $\theta_t = \theta \; \forall t$, in what follows. Prior to addressing whether the steady states are optimal in sections 3.6 and 3.7, the conditions of existence and the number of steady-states are defined in this section using the approach of Koskela *et al.* (2002) adapted to a context involving partial property rights. The different phases of the dynamical system and the local stability properties of the steady-states are also determined.

3.5.1 Existence of steady-states

If steady-states exist, they are solution to the following system obtained from (3.14) and (3.15) with $\Delta x_t = 0$ and $\Delta h_t = 0$:

$$h = g(x) \tag{3.16}$$

$$u'[f(h) - f'(h)(h + \frac{x}{\theta})] = \beta\theta[1 + g'(x)] \tag{3.17}$$

In order to ensure that this system has at least one solution, we need to modify Koskela *et al.* (2002)'s conditions of existence to take into account the possibility of partial property rights as follows :

$$(1 + g'[x_c(\theta)])\theta\beta \geq u'[c_{1m}(\theta)] \tag{3.18}$$

with

$$x_c(\theta) = \arg\max[f(g(x)) - f'(g(x))(g(x) + \frac{x}{\theta})] \tag{3.19}$$

and

$$c_{1m}(\theta) = f[g(x_c(\theta))] - f'[g(x_c(\theta))][g(x_c[\theta]) + \frac{x_c(\theta)}{\theta}] \tag{3.20}$$

is the maximized first-period steady-state consumption. In other words, for a steady-state to exist, the marginal utility of the highest possible consumption in the first-period should be lower than the discounted benefits (taking into account the quality of the property rights) from the growth of the resource stock which maximizes the first-period consumption. If it is higher, it is not worth waiting to consume. With a very low discount factor or very weak property rights, consumers may not want to consume anything in any future period and, therefore, no decentralized steady-state equilibrium exists. In what follows, we call $\bar{\theta}$ the minimum quality of property rights for which steady-states exist.

A question arises : how restrictive is this condition of existence? An answer can be given through a numerical illustration. If we assume an annual pure rate of time preference of 2% per year (which is consistent with Arrow (1995)) and assume that a period lasts 30 years in our model, we have $\beta = 0.55$. With logarithmic preferences for the first period, with the Cobb-Douglas production function and the logistic growth function used in our numerical illustration (section 3.8), we find $\bar{\theta} \simeq 0.8$. Moreover, as we will be mainly interested in situations where there may be overaccumulation of resource at the steady-state, it is even more likely that this condition of existence will be verified as those require a high discount factor (i.e., a low rate of time preference) : in our numerical illustration, a discount factor higher than $\beta = 0.7158$ (corresponding to $\bar{\theta} \simeq 0.65$) leads to overaccumulation. In what follows, we consider situations where equation (3.18) is verified.

3.5.2 Number of steady-states

In order to determine the number of steady states, we need to first define the two isoclines corresponding to the system of equations (3.14) and (3.15) and then compare their slopes to see when, and how, they intersect. The first isocline is obtained from (3.14) when $\Delta x_t = 0$ but h_t can vary over time :

$$h_t = g\,(x) \tag{3.21}$$

For the second isocline, the isocline associated with the Euler equation, it is helpful to see that equation (3.15) defines h_t as an implicit function of x_{t+1} and then, using (3.14) consider that implicit function when $\Delta h_t = 0$ and x_t can vary over time[8] :

$$\Psi(h, x_t) = 0$$

with :

$$\Psi(h, x_t) = u'[f(h) - f'(h)h - \frac{1}{\theta} f'(h)(x_t + g\,(x_t) - h)] - \beta\theta[1 + g'(x_t + g\,(x_t) - h)] \tag{3.22}$$

The slope of (3.21) is :

$$\left.\frac{dh_t}{dx_t}\right|_{\Delta x_t = 0} = g'(x) \tag{3.23}$$

[8] Recalling that the quality of property rights is now constant.

The slope of (3.22) is $\left.\frac{dh_t}{dx_t}\right|_{\Delta h_t=0} = -\frac{\Psi_x(h,x_t)}{\Psi_h(h,x_t)}$ leading to :

$$\left.\frac{dh_t}{dx_t}\right|_{\Delta h_t=0} = \frac{(u''\frac{f'}{\theta} + \beta\theta g'')(1+g')}{u''[f' - f''(\frac{x}{\theta}+h)] + \beta\theta g''} > 0 \tag{3.24}$$

While the slope in (3.23) can be positive, null, or negative, the slope in (3.24) is always positive in the neighbourhood of an equilibrium given the assumptions on the utility function and because in the steady-state equilibrium $(1+g') = \frac{R}{\theta} > 0$. It can also be shown that $(h=0, x=0)$ is a point of (3.21) where $(h>0, x=0)$ is a point of (3.22)[9]. Therefore, by a similar rationale to Koskela *et al.* (2002)'s first proposition, we find that when there are steady-state equilibria (i.e., equation (3.18) is verified), there are at least two of them, except for the rare case, where the Euler equation and the growth curve are tangent to each other. Besides, when two steady-states exist, the isocline associated with the Euler equation necessarily cuts the growth curve first from above and then from below. On the portion of the growth curve where $g'(x) \leq 0$, there can only be one steady-state equilibrium because the slope of the Euler (equation (3.24)) is always positive. In what follows, we concentrate on the case of two steady-states; i.e., the isocline associated with the Euler equation cuts the growth curve from above in the case of the equilibrium with the smaller level of resource stock :

$$\left.\frac{dh_t}{dx_t}\right|_{\Delta h_t=0} < \left.\frac{dh_t}{dx_t}\right|_{\Delta x_t=0}.$$

[9]When the quality of property rights is explicitly considered, Koskela *et al.* (2002)'s proof must be amended as follows : when $x \to 0$, the second term on the Right Hand Side (RHS) of equation (3.22) approaches some finite number when $\theta \in [\bar{\theta}, 1]$. For $\Psi = 0$ to hold, the first term of the RHS of equation (3.22) must also approach some finite number. Koskela *et al.* (2002) show that it happens for some strictly positive finite value of h.

The isocline associated with the Euler equation cuts the growth curve from below in the equilibrium with the larger level of resource stock :

$$\left.\frac{dh_t}{dx_t}\right|_{\Delta h_t=0} > \left.\frac{dh_t}{dx_t}\right|_{\Delta x_t=0}$$

We call x_1^D and x_2^D those decentralized steady-state equilibria with $x_1^D < x_2^D$.

3.5.3 Stability properties of the steady-states

To study the stability properties of the steady-states, the different phases of the dynamical system are defined (phase-diagrams for specific sets of parameters are drawn in section 3.8 - Figure 3.1), then the local stability properties are determined.

Phases of the dynamical system

The paths, for which $x_{t+1} \geq x_t$ and $h_{t+1} \geq h_t$, are now considered. It follows from (3.14) that :

$$x_{t+1} \geq x_t \iff g(x_t) \geq h_t$$

Therefore, in the $\{x, h\}$ space, x increases inside the area delimited by $g(x_t)$ and x decreases outside that area. It follows from (3.15) and our assumptions on the production function that :

$$h_{t+1} \geq h_t \iff f'(h_{t+1}) \leq f'(h_t) \iff \frac{u'[f(h_t) - f'(h_t)h_t - \frac{1}{\theta}f'(h_t)x_{t+1}]}{\beta\theta[1 + g'(x_{t+1})]} \leq 1$$

This defines the area above the $\Delta h_t = 0$ isocline, which is made clear in the next paragraph. Therefore, h increases above the $\Delta h_t = 0$ isocline and decreases below.

Local stability properties

Equations (3.14) and (3.15) can be rewritten as :

$$x_{t+1} = x_t - h_t + g(x_t) = G(x_t, h_t) \tag{3.25}$$

$$f'(h_{t+1}) = [\frac{u'[f(h_t) - f'(h_t)h_t - \frac{1}{\theta}f'(h_t)x_{t+1}]}{\beta\theta[1 + g'(x_{t+1})]}]f'(h_t) \tag{3.26}$$

Substituting (3.25) into (3.26) leads to :

$$\Xi(x_t, h_t) = f'(h_{t+1}) - [\frac{u'[f(h_t) - f'(h_t)h_t - \frac{1}{\theta}f'(h_t)[x_t - h_t + g(x_t)]]}{\beta\theta[1 + g'(x_t - h_t + g(x_t))]}]f'(h_t) = 0 \tag{3.27}$$

which defines a two arguments implicit function for h_{t+1} :

$$h_{t+1} = F(x_t, h_t) \tag{3.28}$$

The planar system describing the dynamics of the resource stock and harvesting now consists of (3.25) and (3.28). The stability of the steady-states depends on the eigenvalues of the Jacobian matrix of the partial derivatives of the system :

$$J = \begin{bmatrix} G_x & G_y \\ F_x & F_y \end{bmatrix}$$

The eigenvalues of the Jacobian are studied in Appendix C and a proof of the following proposition, which is an extension from Koskela *et al.* (2002)'s proposition 2 to an economy where property rights can be partial, is provided.

Proposition 3.1 *When the quality of property rights is explicitly considered, in the case of concave resource growth with two steady-states, the steady-state equilibrium associated with a larger natural stock is saddle stable while the steady-state equilibrium associated with a smaller stock is unstable. To the extent that the steady-states* *exist, the stability properties of the steady-states do not depend on the quality of property rights.*

3.6 Efficient steady-state equilibria

De la Croix and Michel (2002) point out that the conditions for long run intergenerational efficiency depend on whether only the younger generation is considered in the steady-state or both the initial older generation and the younger generation are considered. We follow Diamond (1965)'s seminal article which defines "golden age" paths by excluding the initial older generation[10]. The social planner's problem is therefore to maximize the lifetime welfare of a representative individual subject to the constraint that the aggregate consumption is equal to production :

$$\max_{(c_1, c_2, x)} W = u(c_1) + \beta c_2$$

subject to :

$$h = g(x) \tag{3.29}$$

$$c_1 + c_2 = f(h) \tag{3.30}$$

As pointed out by Diamond (1965) in an economy where capital and labor were used as production inputs, such a maximization problem decomposes naturally into two separate problems : that of optimizing the height of the consumption constraint ; and

[10] In other words, it is assumed that the social planner gives the same weight to each generation, i.e. there is no social discounting. While this assumption is frequent in resource economics, a fruitful extension could consider the impact of social discounting on the findings of this paper. Based on our preliminary research, we expect those findings to hold for reasonable values of the social discount factors.

that of dividing this amount of consumption between the different periods of life. Here, resource and labor are used as production inputs, optimizing the height of the consumption constraints (equation (3.30)) means selecting the optimal *per capita* level of harvest. Note that the optimality of *per capita* harvest is independent of the exact division of consumption. Equations (3.30) and (3.29) define the maximum *per capita* harvest as the solution of :

$$g'(x^*) = 0 \tag{3.31}$$

$$h^* = g(x^*) \tag{3.32}$$

with x^* the optimal stock and h^* the optimal harvest levels at the steady-state. We note that equation (3.31) defines the maximum sustainable yield which is the Golden Rule level of resource stock and that equation (3.32) defines the Golden Rule level of harvest.

The second problem is to define the optimal intertemporal lifetime allocation of the maximized amount of total consumption obtained with h^* and x^*. The solution of the social planner's problem subject to the constraints (3.30), (3.31) and (3.32) is :

$$u'(c_1) = \beta \tag{3.33}$$

In the next section, we compare the efficiency conditions with the conditions defining our decentralized steady-state equilibria.

3.7 Optimal property rights

In our economy, the quality of property rights is represented by a single parameter. It is generally not possible to hit two birds with one stone. The problem of maximizing total consumption and the one of optimizing the allocation of that maximized consumption between the two lifetime periods are separate. In what follows, we focus on the first problem : we investigate whether a quality of property rights can be found to maximize total consumption. We discuss the second problem at the end of the section.

Let $x_i^D(\theta)$, $i = 1, 2$, represent the decentralized steady-state equilibria associated with property right quality θ, $\theta \in [\bar{\theta}, 1]$. At $x_i^D(\theta)$, $i = 1, 2$, $h = g[x_i^D(\theta)] \geq 0$, (3.29) and (3.30) are verified as they are constraints considered in the decentralized optimization problem. Efficient resource stock and harvest must verify equations (3.31) and (3.32). First, consider the situations where property rights are complete, $\theta = 1$, and focus on the steady-state with the larger stock. Koskela *et al.* (2002) have shown that $x_2^D(1)$ may or may not be optimal depending on the value of the parameters on technology, preferences and resource dynamics. A Pareto optimal competitive equilibria with complete property rights is such that :

$$g'(x^{*D}(1)) = 0 \tag{3.34}$$

The set of parameters implying a non efficient steady-state equilibrium in presence of complete rights is defined by :

$$g'[x^D(1)] < 0 \tag{3.35}$$

That is

$$x^D(1) > x^* \tag{3.36}$$

We must prove that, in situations where equation (3.35) holds, $\theta^* \in [\bar{\theta}, 1]$ exists such that, at the steady-state, resource stock and harvest are at their first-best levels. The first-best level of stock is defined by equation (3.31). $\theta^* \in [\bar{\theta}, 1]$ must verify :

$$x^D(\theta^*) = x^* \tag{3.37}$$

For a given quality of property rights, $x^D(\theta)$ is the solution of equation (3.17) :

$$u'[f(h) - f'(h)(h + \frac{x}{\theta})] = \beta\theta[1 + g'(x)]$$

which defines x as an implicit function of θ :

$$\Omega(x, \theta) = u'[f(h) - f'(h)(h + \frac{x}{\theta})] - \beta\theta(1 + g'(x)) = 0 \tag{3.38}$$

From the implicit function theorem, we know that :

$$\frac{dx}{d\theta} = -\frac{\frac{\partial\Omega}{\partial\theta}}{\frac{\partial\Omega}{\partial x}}$$

From equation (3.18), we know that a steady-state equilibirum exists only if $g'(x) > -1 \ \forall\theta \in [\bar{\theta}, 1]$ as the marginal utility of consumption is positive. When $-1 < g' < 0$, we have

$$\frac{\partial\Omega(x,\theta)}{\partial\theta} = \frac{x}{(\theta)^2} f'(h)u''(c_1) - \beta(1 + g'(x)) < 0$$

and, recalling that $h = g(x)$ at the steady state,

$$\frac{\partial\Omega(x,\theta)}{\partial x} = [-g'(x)f''(h)h - \frac{g'(x)f''(h)}{\theta}x - \frac{f'(h)}{\theta}]u''(c_1) - \beta\theta g''(x) > 0$$

Therefore,

$$\frac{dx}{d\theta} > 0 \tag{3.39}$$

The more partial the property rights, the lower the resource stock. From equations (3.36) and (3.39), we find $\theta^* < 1$. Let's prove that $\theta^* \geq \bar{\theta}$. When $\theta = \bar{\theta}$, we have

$$u'[f(h) - f'(h)(h + \frac{x}{\bar{\theta}})] - \beta\bar{\theta}(1 + g'(x)) = 0 \tag{3.40}$$

From equation (3.18), we know that $x_c(\bar{\theta})$ is solution of equation (3.40). $x_c(\bar{\theta})$ is the level of stock that maximizes the consumption in the first period. We know that any harvest corresponding to a level of stock beyond the maximum sustainable yield can also be reached with a level of stock below the maximum sustainable yield. Moreover, for any given level of harvest, a higher consumption will be achieved with a lower stock[11]. Therefore, in order to maximize consumption in the first period, $x_c(\bar{\theta})$ must be such that $x_c(\bar{\theta}) \leq x^*$. Hence, $\theta^* \geq \bar{\theta}$ meaning that the condition of existence of a steady state remains verified.

Using equations (3.17), (3.31) and (3.32), θ^* is the solution of[12]

$$u'[f(h^*) - f'(h^*)(h^* + \frac{x^*}{\theta^*})] = \beta\theta^* \tag{3.41}$$

Proposition 3.2 *When complete property rights are inefficient in a perfectly competitive OLG economy, there always exists a quality of property rights that leads to first-best steady-state levels of resource stock and harvest.*

From equation (3.41), it is also clear that the optimal quality of property rights depends on preferences, on technology and on resource stock. Finally, one can verify that θ^* does not solve the problem of the optimal intertemporal allocation of the maximized consumption (equation (3.33)). However, property rights on both labor and the production output are assumed complete in this paper. In the next chapter, we show that an efficient quality of property rights, not necessarily complete, on labor income can optimally reallocate the maximized consumption between the two lifetime periods.

[11] $\frac{dc_1}{dx}\Big|_{h \text{ constant}} = -\frac{f'}{\theta} < 0.$

[12] We have $u'[f(h^*) - f'(h^*)(h^* + \frac{x^*}{1-\varpi^*})] = \beta(1 - \varpi^*)$ where $\varpi^* = 1 - \theta^*$ is an alternative expression for the indicator of the quality of property rights, which has an interpretation consistent with the indicator for the quality of property rights in the previous chapter. In fact, $\varpi^* = 1$ corresponds to the absence of property rights and $\varpi^* = 0$ corresponds to complete property rights.

3.8 Numerical illustrations

To shed further light on the properties of the model and contrast the results with those with complete rights, the same parametric example as in Koskela *et al.* (2002) is used. The first-period utility function, the production function, and the resource growth function are assumed to be :

$$u(c_1) = \ln c_1 \tag{3.42}$$

$$f(h) = h^\alpha \text{ with } 0 < \alpha < 1 \tag{3.43}$$

$$g(x) = ax - \frac{1}{2}bx^2 \tag{3.44}$$

The economically interesting parameters are the output elasticity of the resource α which determines the price elasticity of resource demand, and the discount factor β. Equation (3.44) is the logistic growth function for renewable resources. With these specifications, equations (3.16) and (3.17) reduce to :

$$h = ax - \frac{1}{2}bx^2$$

$$\frac{1}{(1-\alpha)h^\alpha - \alpha h^{\alpha-1}\frac{x}{\theta}} = \beta\theta(1 + a - bx)$$

Koskela *et al.* (2002)'s situation where a steady state equilibrium can be inefficient under complete rights (when $\theta = 1$) is replicated by choosing $a = 1$, $b = 0.001$ which imply the Golden Rule level of stock and harvest $\hat{x} = 1000$ ($\hat{h} = 500$) and $\tilde{x} = 2000$ and by choosing $\alpha = 0.15$. Four scenarios summarized in table 3.1 are considered. Golden rule stock and harvest levels depend on the resource growth parameters and are the same for all scenarios. A perfectly competitive economy is considered in all scenarios, with the exception of partial property rights assumed in scenarios 3 and 4.

Scenario 1 considers a situation where the OLG economy has a decentralized Pareto optimal steady-state at the larger stock; resource stock and harvest are at their Golden Rule levels; intertemporal utility is optimized. In scenario 2, the discount factor is $\beta = 0.90$, property rights remain complete : the OLG economy now exhibits dynamic inefficiency : at the decentralized steady-state, the stock level is above its Golden Rule level, harvest is below its Golden Rule level. As $x_2^D > \hat{x}$, the optimality condition $g'(x_2^D) \geq 0$ is not verified : x_2^D is inefficient with complete rights. It is also saddle stable as it is the steady-state with the larger stock. Scenario 3 differs from scenario 2 : property rights are no longer complete. The optimal quality of property rights is computed, using equation (3.41), we find $\theta^* = 0.8675$. The decentralized steady-state at the larger stock with $\theta^* = 0.8675$ leads to first-best resource stock and harvest levels are at their Golden Rule levels. In other words, in order to reach the first-best levels of resource stock and harvest, the firm must harvest 13.25% of the old agent stock without paying for it. If the entire stock was protected, the steady-state equilibrium with the larger stock would not lead to first-best resource stock and harvest as was shown in scenario 2. In scenario 4, we consider property rights weaker than the optimal quality, $\theta = 0.8$, the OLG economy exhibits inefficiency due to too weak property rights : at the decentralized steady-state, both resource stock and harvest are below their golden rule levels. The resource is overextracted.

The graph on the left-hand side of Figure 3.1 shows that the steady-state with the larger stock of resource is saddle stable and inefficient as it is located to the right of the maximum sustainable yield ($x^D(1) = 1131.09 > \hat{x} = 1000$ and $h_2^D(1) = 491.408 < \hat{h} = 500$). The graph on the right-hand side of Figure 3.1 shows the steady-state with optimal incomplete property rights ($x(\theta^*) = \hat{x}$, $h(\theta^*) = \hat{h}$) and that it is saddle stable.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Golden rule stock level	1000	1000	1000	1000
Golden rule harvest level	500	500	500	500
Discount factor	0.7158	0.9	0.9	0.9
Property rights quality	1	1	0.8675	0.8
Resource stock	1000	1131.09	1000	914.386
Harvest level	500	491.408	500	496.374
Production	2.54007	2.53347	2.54007	2.5373
Resource price	0.000762	0.000773	0.000878	0.000958
Wage	2.15906	2.15345	2.15906	2.1567
Consumption first-period	1.39704	1.27875	1.28072	1.27989
Consumption second-period	1.14303	1.25473	1.25935	1.25741
Utility first-period	0.334354	0.245879	0.247421	0.246774
Utility second-period	1.14303	1.25473	1.25935	1.25741
Intertemporal utility	1.15254	1.37513	1.38084	1.37844

Tab. 3.1: Numerical Illustrations

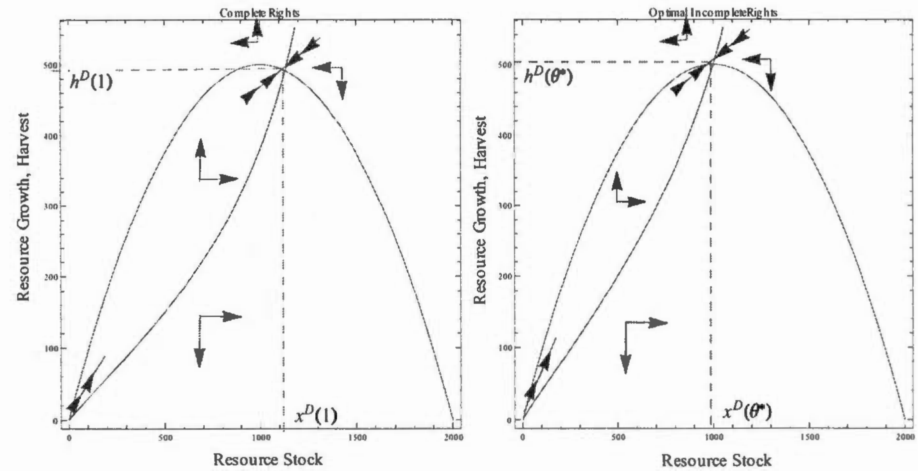

Fig. 3.1: Phase diagrams of the dynamical system with complete and partial property rights respectively.

3.9 Conclusion

Complete property rights can lead to resource overaccumulation at the steady-state. When property rights are complete, households appropriate themselves a share of the resource stock that should optimally be used in production. In other words, the paradigm according to which inefficiencies are a consequence of weak institutions that allow such ill behavior as theft is partly reversed. Inefficiencies can also be a consequence of too strong property rights. Efficient institutions may involve partial property rights. In this paper, we have shown that there always exists a quality of property rights, though not necessarily complete, leading to steady-state optimal resource extraction and resource stock. Optimal partial property rights increase the lifetime welfare of all individuals. We have also shown that steady-states with optimal partial property rights are saddle stable.

Overfishing, deforestation, endangered species often result from institutions that are too weak. Although property rights may need to be strengthened in those situations, we show that they do not need to be complete to achieve efficiency. Strong, efficient institutions often need to fall short of imposing complete property rights. Beyond a certain quality of property rights, strengthening them further is inefficient.

Chapitre 4

OVERLAPPING GENERATIONS, PHYSICAL CAPITAL AND THE OPTIMAL QUALITY OF PROPERTY RIGHTS

4.1 Introduction

The previous chapter considered an economy involving a renewable resource stock and we showed that partial property rights on a resource stock could lead to first-best steady-state resource harvest and stock. Conventional capital differs from a renewable resource. First, the services from the whole capital stock, not an extracted share of the stock, constitute the relevant production input. Important to this distinction is the macroeconomics tradition to normalize the rate of utilization of the capital factor to equal one, so that the flow dimension of the capital used in production corresponds to the stock dimension of the capital accumulated through savings. Second, capital depreciation is always a negative contribution to capital growth while resource growth is usually positive at relevant stock levels. Those differences matter for the optimal quality of property rights. In fact, if we were to adopt a rationale similar to the one of the previous chapter and to assume partial property rights on the stock of capital, they would lower its cost as an input in production, increase its demand and lead to further capital accumulation. Therefore, contrary to a resource stock, partial property rights on a capital stock do not prevent capital overaccumulation; they worsen the situation. In a perfectly competitive economy where agents live finite lives, property rights on capital stock must be complete. This observation justifies a separate study for the optimal quality of property rights when regular capital rather than a renewable natural resource is used as production input. This chapter therefore investigates the merits for an overlapping generations economy, using physical capital and labor as inputs in production, to have partial property rights. The quality of property rights on the young's income is defined as the proportion of her labour income that the young can retain.

As mentioned in the previous chapter, the steady-state equilibrium of a perfectly competitive OLG economy need not be Pareto efficient. The first theorem of welfare may fail to apply because there is an infinite number of finitely lived agents. However, not every equilibrium is inefficient. Efficiency is linked to the marginal productivity of capital; the Cass criterion (Cass, 1972) gives necessary and sufficient conditions for efficiency : the marginal productivity of capital must be high enough to compensate for the growth of the other productive factors in the economy. The possibility of inefficiency arises from the fact that the competitive growth equilibrium of an OLG economy may involve excessive savings. This paper formally investigates these Pareto inefficiencies in terms of the quality of property rights in an overlapping generations model with both capital and labor as inputs in production. We show that there always exists a quality of property rights on the young's income that leads to the first-best optimal steady-state. Under standard assumptions on preferences and technology, we establish the optimal steady-state quality of property rights. Partial property rights on income may wrongly be construed as a different name for an income tax on the young's income since both have the effect of transferring income from the young to the old. We therefore discuss in length how similarities in effects hide differences in nature and origins.

Few papers have studied the impact of partial property rights on equilibrium in OLG models. Schoonbroodt and Tertilt (2013) question the economic rationale of pronatalist policies. They consider an OLG model where capital and labor are inputs in production, with fertility choice and parental altruism. When the cost of bearing children is positive, they show that parents' appropriation of children's income is rendered necessary to have a non-zero equilibrium fertility. In this paper, the fertility is exogenous, there is no cost of bearing of children and, consistent with the Walrasian tradition, no altruism is assumed.

This paper investigates the optimality of partial property rights. Partial property rights can be the results of legal rights attributed to the old on a share of the young's income and/or the results of weakly enforced and/or defined property rights on the young's income. We consider effective or de facto property rights and not legal rights; the two coincide only when legal rights are perfectly defined and enforced. This paper also discusses how partial property rights on income differ from an income tax.

The paper is organized as follows. Section 4.2 presents the basic structure of the model. Section 4.3 characterizes the competitive equilibrium. In section 4.4, we characterize the decentralized steady-state equilibrium. Section 4.5 provides a characterization of the efficient steady-state. Section 4.6 studies the existence of an optimal quality of property rights and determines its expression as a function of technology and preferences. Section 4.7 discusses how partial property rights differ from an income tax. We conclude in the last section.

4.2 The model

We consider an overlapping generations economy where agents live for two periods : a working period and a retirement period. We assume that agents maximize the intertemporally additive lifetime utility function :

$$V(c_1^t, c_2^t) = u(c_1^t) + \beta u(c_2^t) \tag{4.1}$$

where c_i^t denotes the period $i = 1, 2$ consumption of a consumer-worker born at time t and $\beta = \frac{1}{1+\rho}$ with ρ being the exogenous rate of time preference. $u(c)$ is the period utility function. It is assumed to be the same in both periods of life. It is assumed continuous and twice continuously differentiable with $u' > 0$, $u'' < 0$, and $\lim_{c \to \infty} u'(c) = 0$ and $\lim_{c \to 0} u'(c) = \infty$. The population grows at a constant rate n :

$$L_{t+1} = (1 + n)L_t \tag{4.2}$$

The young are endowed with one unit of labor, which they supply inelastically to the firm. The labor earns a competitive wage. The representative consumer-worker uses the wage to buy the consumption good and save in the form of capital goods, which constitute the non-consumed part of aggregate output.

There is a representative firm which produces a good used for both consumption and investment. The firm has access to a constant returns to scale technology that produces output Y_t using two production factors : capital K and labor L. It is represented by a linearly homogeneous production function : $F(K_{t,}L_t)$. This technology can be expressed in factor-intensive form to give $f(k_t) = \frac{F(K_{t,}L_t)}{L_t}$ with the standard properties $f'_{k_t} > 0$ and $f''_{k_t} < 0$. Furthermore, we assume that the Inada conditions are verified : $\lim_{k \to 0} f'(k_t) = \infty$ and $\lim_{k \to \infty} f'(k_t) = 0$, where $k_t = \frac{K_t}{L_t}$ is the per-capita level of stock (also referred to as capital intensity or capital-labor ratio). The assumption of a representative firm is not restrictive because with constant returns to scale, the number of firms does not matter and production is independent on the number of firms which use the same technology. Moreover, since the firm has constant returns to scale technology, profits are zero in equilibrium and we do not have to specify ownership of the firm. The firm rents labor input and capital input from the representative household. Also, as noted by De la Croix and Michel (2002), we may assume that firms live forever. This would not change the results as the firm's problem in any case is a static one.

$\varphi \in [0, 1]$ is an indicator of the quality of property rights on the young's income. We assume that the old appropriate a share φ of her contemporaneous young's income at no cost. $\varphi = 0$ represents complete property rights on young's income and $\varphi = 1$ represents the absence of property rights. Partial property rights are not limited to legal rights attributed to the old on a share of the young's income[1], they can also be the results of weakly enforced and/or defined property rights on the young's

[1]Examples can be found in Schoonbordt and Tertilt (2010) : they include, but are not limited to, mandatory parental support or filial responsibility laws that affect parents' access to an offspring's labor income.

income. Effective or de facto property rights and legal rights coincide only when legal rights are perfectly defined and enforced. We note that indirect appropriation of the young's income could alternatively have been considered. It would require a slightly different settings : the representative young would be assumed to inelastically supply N labour hours, some of those working hours would be unpaid which would lead to a higher share of the firm's revenues paid to the old. To the extent that the rate of return on savings has second order impacts on savings decisions as would, for instance, be the case if preferences were, as is commonly assumed in OLG models, logarithmic, the resulting lower young's income would have the same effect on capital accumulation as the situation, considered in this paper, of direct appropriation of a share of the young's income by the old.

The capital in this model has two roles : it is a savings vehicle and an input in the production of a consumption good. The young's savings are denoted by s_t. The periodic budget constraints are thus :

$$c_1^t + s_t = (1-\varphi)w_t \tag{4.3}$$

$$c_2^t = R_{t+1}s_t + (1+n)\varphi w_{t+1} \tag{4.4}$$

where w_t is the wage rate and R_{t+1} is the return factor on savings from time t to time $t+1$. When old in period $t+1$, the young of period t appropriates $(1+n)\varphi w_{t+1}$ as there are $(1+n)$ young in period $t+1$. From equation (4.4), we have :

$$s_t = \frac{c_2^t}{R_{t+1}} - \frac{(1+n)\varphi w_{t+1}}{R_{t+1}} \tag{4.5}$$

The intertemporal budget constraint is :

$$c_1^t + \frac{c_2^t - (1+n)\varphi w_{t+1}}{R_{t+1}} = (1-\varphi)w_t \tag{4.6}$$

4.3 Competitive equilibrium

To study the competitive equilibrium, we follow De la Croix and Michel (2002)'s approach and distinguish the temporary equilibrium and the intertemporal equilibrium.

4.3.1 Temporary equilibrium

The temporary equilibrium of period t is a competitive equilibrium given price expectations. It is such that : (i) the representative agent optimizes her lifetime utility subject to both her budget constraint in each period and her price expectations, and, (ii) all markets clear at period t. The temporary equilibrium gives the equilibrium value of the current variables, including current prices as a function of the past and of the expectations about the future.

Consumptions at each period c_1^t and c_2^t by an individual of generation t are determined as a solution to the following utility's maximization problem :

$$\max_{c_1^t, c_2^t} u(c_1^t) + \beta u(c_2^t)$$

subject to the intertemporal budget constraint (4.6). It gives the following first-order conditions for c_1^t and c_2^t at the interior solution with λ a non-negative multiplier :

$$u'(c_1^t) = \lambda$$

$$\beta u'(c_2^t) = \frac{\lambda}{R_{t+1}}$$

which implies

$$u'(c_1^t) = \beta R_{t+1} u'(c_2^t) \tag{4.7}$$

Equation (4.7) is the Euler equation which provides that in an optimal plan the marginal utility cost of saving equals the marginal utility benefit obtained by doing that. More specifically, the opportunity cost (in terms of current utility) of saving one more unit in the current period must be equal to the benefit of having R_{t+1} more units in the next period. This benefit is the discounted additional utility that can be obtained next period through the increase in consumption by R_{t+1} units. An alternative interpretation follows from :

$$\frac{u'(c_1^t)}{\beta u'(c_2^t)} = R_{t+1}$$

That is, the utility marginal rate of intertemporal substitution $\frac{u'(c_1^t)}{\beta u'(c_2^t)}$ should be equal to the marginal rate of transformation R_{t+1} which is the rate at which savings allow an agent to shift consumption from period t to $t+1$. There are infinitely many pairs (c_1^t, c_2^t) satisfying equation (4.7). Only when requiring that the two period budget constraints be satisfied, do we get unique solution for c_1^t and c_2^t or equivalently for s_t for any given quality of property rights. With the budget constraint inserted in equation (4.7), it determines the saving of the young as an implicit function of w_t, R_{t+1} but also w_{t+1} and φ, i.e.,

$$s_t = s(w_t, R_{t+1}, w_{t+1}, \varphi) \tag{4.8}$$

which defines the savings function[2]. The partial derivatives of this function can be found by using the implicit function theorem on equation (4.7), which can be rewritten :

$$\Omega(w_t, R_{t+1}, w_{t+1}, \varphi) = u'((1-\varphi)w_t - s_t) - \beta R_{t+1} u'(R_{t+1}s_t + (1+n)\varphi w_{t+1}) = 0 \tag{4.9}$$

[2]For instance, it can easily be verified that if the functional form of the period utility is assumed CRRA, equation (4.8) becomes :

$$s_t = \frac{\beta^\sigma (R_{t+1})^{\sigma-1}}{1+\beta^\sigma (R_{t+1})^{\sigma-1}}(1-\varphi)w_t - \frac{1}{1+\beta^\sigma (R_{t+1})^{\sigma-1}} \frac{\varphi(1+n)w_{t+1}}{R_{t+1}}$$

The implicit function theorem leads to[3] :

$$\frac{\partial s_t}{\partial w_t} > 0 \tag{4.10}$$

$$\text{The sign of } \frac{\partial s_t}{\partial R_{t+1}} \text{ is indeterminate.} \tag{4.11}$$

$$\frac{\partial s_t}{\partial w_{t+1}} < 0 \tag{4.12}$$

$$\frac{\partial s_t}{\partial \varphi} < 0 \tag{4.13}$$

The interpretation of equations (4.10) and (4.11) is standard (De la Croix and Michel, 2002) : in particular, it is known that with logarithmic preferences $\frac{\partial s_t}{\partial R_{t+1}} = 0$ and with CRRA preferences $\frac{\partial s_t}{\partial R_{t+1}} > 0$ when the elasticity of marginal utility is lower than 1 : savings increases with an increase in the interest rate because the substitution effect (i.e., higher interest rate makes future consumption cheaper in terms of current consumption) dominates the income effects (i.e., a given budget can buy more consumption goods in both periods). We focus on the interpretation of equations (4.12) and (4.13). Equation (4.12) means that the anticipation of a greater appropriation in period t+1, for any given partial property rights, due to a greater wage income for the young of period t+1 leads to lower savings in period t. Equation (4.13) means that both a lower secure wage income in period t and the anticipation of a greater appropriation in period t+1, for any given young of period t+1's income, due to more partial property rights leads to lower savings in period

[3] Applying the implicit function theorem to equation (4.9) gives : $\frac{\partial s_t}{\partial w_t} = -\frac{\frac{\partial \Omega(.)}{\partial w_t}}{\frac{\partial \Omega(.)}{\partial s_t}}$; $\frac{\partial s_t}{\partial R_{t+1}} = -\frac{\frac{\partial \Omega(.)}{\partial R_{t+1}}}{\frac{\partial \Omega(.)}{\partial s_t}}$; $\frac{\partial s_t}{\partial w_{t+1}} = -\frac{\frac{\partial \Omega(.)}{\partial w_{t+1}}}{\frac{\partial \Omega(.)}{\partial s_t}}$; $\frac{\partial s_t}{\partial \varphi} = -\frac{\frac{\partial \Omega(.)}{\partial \varphi}}{\frac{\partial \Omega(.)}{\partial s_t}}$. We have $\frac{\partial \Omega(.)}{\partial s_t} = -u''(c_1^t) - \beta(R_{t+1})^2 u''(c_2^t) > 0$ and $\frac{\partial \Omega(.)}{\partial w_t} = (1-\varphi)u''(c_1^t) < 0$, $\frac{\partial \Omega(.)}{\partial R_{t+1}} = -\beta u'(c_2^t) - \beta(R_{t+1})^2 u''(c_2^t)$, $\frac{\partial \Omega(.)}{\partial w_{t+1}} = -\beta R_{t+1}(1+n)\varphi u''(c_2^t) > 0$, $\frac{\partial \Omega(.)}{\partial \varphi} = -w_t u''(c_1^t) - \beta R_{t+1}(1+n) w_{t+1} u''(c_2^t) > 0$.

t. We now consider the market clearing conditions.

$$L_t c_1^t + L_{t-1} c_2^{t-1} + L_t s_t = f(K_t, L_t) \tag{4.14}$$

is the consumption good market clearing condition.

$$L_t s_t + (1 - \delta) K_t = K_{t+1} \tag{4.15}$$

is the capital market's clearing condition with δ the rate of capital depreciation. In what follows, we assume for simplicity, as is common in OLG models, full depreciation in each period ($\delta = 1$). Equation (4.15) has a straightforward interpretation, the supply of funds by the representative young equals investment by the representative firm. It can be expressed in intensive terms using the expression of the savings function. Substituting (4.8) into (4.15) gives :

$$s(w_t, R_{t+1}, w_{t+1}, \varphi) L_t = K_{t+1}$$

dividing both sides by L_{t+1} gives :

$$(1 + n) k_{t+1} = s(w_t, R_{t+1}, w_{t+1}, \varphi) \tag{4.16}$$

Equation (4.16) states that savings of the young is transformed into productive capital for the next period.

The profit function is : $F(K_t, L_t) - R_t K_t - w_t L_t$. The firm maximizes profits under perfect competition. The first-order conditions are :

$$f_k(k_t) = R_t \tag{4.17}$$

$$f(k_t) - k_t f_k(k_t) = w_t \tag{4.18}$$

Equations (4.17) and (4.18) determine the demand for the factors of production K_t and L_t as a function of their marginal costs R_t and w_t[4]. Clearing of the factor markets determines the equilibrium factor prices : $R_t(k_t)$ and $w_t(k_t)$ and the levels of factor inputs consistent with the equilibrium. We define the intertemporal equilibrium in the next paragraph.

4.3.2 Intertemporal Equilibrium

In this economy, the link between two periods t and $t+1$ is given by the accumulation rule for capital (equation (4.16)) and by the formation of expectations. Using the first-order conditions for profit maximization (4.17) and (4.18) to eliminate input prices from equation (4.16), the intertemporal equilibrium is, for a given initial capital stock k_1, a sequence of temporary equilibria that satisfies for all $t \geq 0$ the following conditions[5] :

$$k_{t+1} = \frac{s(f(k_t) - k_t f_k(k_t), f_k(k_{t+1}), f(k_{t+1}) - k_{t+1} f_k(k_{t+1}), \varphi)}{1+n} \tag{4.19}$$

When property rights are complete, when the utility function is CRRA (with

[4]When the technology is Cobb-Douglas, we have :

$$\alpha k_t^{\alpha-1} = R_t$$
$$(1-\alpha)k_t^{\alpha} = w_t$$

[5]For CRRA utility and Cobb-Douglas technology, we have

$$(1+n)k_{t+1} = \frac{\beta^{\sigma}(\alpha k_{t+1}^{\alpha-1})^{\sigma-1}}{1+\beta^{\sigma}(\alpha k_{t+1}^{\alpha-1})^{\sigma-1}}(1-\varphi)(1-\alpha)k_t^{\alpha}$$
$$- \frac{1}{1+\beta^{\sigma}(\alpha k_{t+1}^{\alpha-1})^{\sigma-1}} \frac{\varphi(1+n)(1-\alpha)k_{t+1}^{\alpha}}{\alpha k_{t+1}^{\alpha-1}}$$

σ is positive), when the production function is Cobb-Douglas, the intertemporal equilibrium is unique (De la Croix and Michel, 2002). In this paper, we focus on situation where property rights can be partial and consider steady-state equilibria.

4.4 Decentralized steady-states

The steady-states must be solutions of[6] :

$$k^* = \frac{s(f(k^*) - k^* f_k(k^*), f_k(k^*), f(k^*) - k^* f_k(k^*), \varphi)}{1+n} \tag{4.20}$$

We explicitly determine the steady-state for a Cobb-Douglas technology and logarithmic preferences in Appendix D. Existence of the steady-states is ensured with CRRA preferences and a Cobb-Douglas technology. Discussion on the existence of steady states can be found in De La Croix and Michel (2002). Here, we assume that a non trivial steady-state exists. Its stability properties will be given by the value of $\left|\frac{dk_{t+1}}{dk_t}(k^*)\right|$ which can be calculated using the implicit function theorem on

[6] The steady-states are such that $k_t = k^*\ \forall t$. Therefore, with a CRRA utility and Cobb-Douglas technology, it must be solution of :

$$(1+n)k^* = \frac{\beta^\sigma(\alpha k^{*\alpha-1})^{\sigma-1}}{[1+\beta^\sigma(\alpha k^{*\alpha-1})^{\sigma-1}]\,(1+n)}(1-\varphi)(1-\alpha)k^{*\alpha} - \frac{1}{[1+\beta^\sigma(\alpha k^{*\alpha-1})^{\sigma-1}]\,(1+n)}\frac{\varphi(1+n)(1-\alpha)}{\alpha}k^*$$

There is a trivial steady-state $k_T^* = 0$ which is not a viable economic equilibrium, finding the other steady-states in presence of possibly incomplete property rights, $1 \geq \theta > 0$, requires to solve a polynomial in k^*, $k^{*(\alpha-1)\sigma+\alpha}$ and $k^{*(\alpha-1)\sigma}$ which can be done numerically. In Appendix D , we consider a more tractable problem by assuming logarithmic preferences (i.e., $\sigma = 1$).

equation (4.19). In particular, when

$$0 < \left| \frac{dk_{t+1}}{dk_t}(k^*) \right| < 1 \tag{4.21}$$

the dynamic path converges monotonically toward the locally stable steady-state k^*. We show in Appendix D that this condition is verified with a Cobb-Douglas technology and logarithmic preferences.

4.5 Efficient steady-state

The social planner's problem is to maximize the lifetime welfare of each generation subject to the constraint that the sum of aggregate consumption and saving is equal to production :

$$\max_{(c_1,c_2)} W = u(c_1) + \beta u(c_2)$$

subject to :

$$s = (1+n)k \tag{4.22}$$

$$c_1 + c_2 + s = f(k) \tag{4.23}$$

As pointed out by Diamond (1965) this maximization problem decomposes naturally into two separate problems, that of selecting the optimal capital-labor ratio and thus the height of the consumption constraint (equation (4.23)) ; and that of dividing this amount of consumption between the different periods of life. Note that the optimality of the capital-labor ratio is independent of the exact division of consumption. In this paper, we focus on the first problem. The optimal capital-labor ratio (which is also the Golden Rule capital-labor ratio) is given by :

$$f'(k^{GR}) = 1 + n \tag{4.24}$$

With a Cobb-Douglas technology, equation (4.24) becomes :

$$k^{GR} = \left[\frac{\alpha}{(1+n)}\right]^{\frac{1}{1-\alpha}}$$

4.6 Optimal quality of property rights

We call $k^*(\varphi)$ the capital-labor ratio corresponding to the quality of property rights φ. For logarithmic preferences and a Cobb-Douglas technology, we show in Appendix D that the expression of $k^*(\varphi)$ is :

$$k^*(\varphi) = \left[\frac{\alpha\beta(1-\varphi)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha + \varphi(1-\alpha)\right]}\right]^{\frac{1}{1-\alpha}}$$

In presence of complete rights, overaccumulation occurs when $\frac{(1-\alpha)}{\alpha} > \frac{(1+\beta)}{\beta}$ leading to :

$$k^*(0) > k^{GR}$$

We note that dynamic inefficiencies in presence of complete rights could arise for plausible values of the parameters. In fact, using Arrow (1995)'s parametrization for time preference, we find $\beta = 0.55$ and $\frac{1+\beta}{\beta} = 2.81$. In the empirical literature, the value of α is generally considered close to 0.3. Then, if $\alpha = 0.26$, the condition for dynamic inefficiency is verified as $\frac{1-\alpha}{\alpha} = 2.84 > \frac{1+\beta}{\beta} = 2.81$.

If a quality of property rights $\varphi^* \in [0, 1]$ can lead to the optimal capital-labor ratio, it must be such that

$$k^*(\varphi^*) = k^{GR} \tag{4.25}$$

Proposition 4.1 *When an economy is dynamically inefficient, optimal partial property rights on the young's income lead to the first-best optimal steady-state level of capital accumulation. Complete property rights are inefficient.*

Proof. We know that $k^*(0) > k^{GR}$. For $\varphi \in (0,1)$, as shown in equation (D.6) of Appendix D, we have :

$$\frac{dk^*}{d\varphi} < 0$$

Finally, we have $k^*(1) = 0 < k^{GR}$. Therefore, $\varphi^* \in (0,1)$. ■

We calculate the optimal quality of property rights when the technology is Cobb-Douglas and the preferences are logarithmic in Appendix E and find

$$\varphi^* = \frac{\frac{1-\alpha}{\alpha} - \frac{1+\beta}{\beta}}{(1+\beta)(1-\alpha)\frac{1}{\beta\alpha}}$$

where β is the utility discount factor and α is the elasticity of input productivity.

4.7 Partial property rights versus income tax

Optimal partial property rights in this paper result in a transfer of income from the young to the old. It is known that intergenerational transfers can solve dynamic inefficiencies : the optimal transfer can be achieved through public debt and its funding (Diamond, 1965), social security contributions (Samuelson, 1975) or taxes (Atkinson and Sandmo, 1980). We refer to those three solutions as income tax solutions. How do partial property rights differ from income tax ? The difference between tax and property rights have been extensively discussed in the Coase (1960) versus Pigou (1932) debate over the last fifty years. Do any of the arguments developed in Coase versus Pigou debate apply to the economy considered in this paper ? The first point to note is that dynamic inefficiencies arise in perfectly competitive economies without externality. Pigou and Coase approaches were aimed at correcting non-pecuniary externalities. A large part of the Coase versus Pigou debate is on how these respective approaches differ in doing so and which is the most efficient under what circumstances. A key difference between the two approaches is the role of government. Hence, Demsetz (1996) writes

> "Coase was guided toward privatization of the interaction between parties by his refusal to accept Pigou's [...] idealized State as a solver of the externality question."

Indeed, an implicit assumption made by Pigou is "an omniscient and omnipresent" government. Demsetz (1996) further writes

> "the tax policy of an all-knowing, well-motivated State results in corrective adjustments for externalities that accord with the economists prescriptions. The problem is analyzed as if the State is a perfect agent through which the blackboard plans of economists can be brought to fruition. Tax solutions ignores State's associated costs of errors, implementation and improper motivation."

Demsetz continues

> "if [Pigou] would have ruled out State action on grounds of impracticality or politics, or if he would have recognized that the common law offered potential corrective action even if the State did not act, he would more likely have been led, as Coase was, to consider the consequences of [assigning property rights]."

In other words, corrective taxes, social contributions, the funding of public debt are policy instruments : they must be designed, implemented, collected and managed by a government. Their efficiency relies on the existence of an efficient, knowledgeable government. They are what Weil (2008) refers to as "centralized remedies" when an economy is dynamically inefficient. The quality of property rights is not a handily available policy instrument. It is an institution and, as such, a more secular characteristic of an economy. It is not *per se* the solution of a problem but it happens that partial property rights can optimally offset the incentives in an economy to overaccumulate capital. The quality of property rights depends in part on laws and regulations but also on public investments over the long term : public investments in the judiciary system, police enforcement, etc. The quality of property rights also depends on social norms and culture. Moreover, efficient partial property rights do not require an efficient, knowledgeable government. They can be the results of history and social interactions. They can be the outcome from negotiated compromises between a multitude of economic and political forces pulling in different directions. When property rights are optimally partial, the adjustments towards optimality are decentralized. Competitive interactions of the "invisible hand" variety lead the economy towards the first-best steady-state equilibrium.

Another key difference between taxes, social contributions, funding of public debt and partial property rights lies on redistribution. Tax redistribution is another policy instrument for a government. The government collects, manages and redistributes tax proceeds. Not only does government's efficiency matter for implementing and collecting corrective taxes, it also matters for managing and efficiently redistributing the taxes collected. Again, taxes are a centralized instrument, the effects of partial property rights are the results of decentralized decisions. In fact, redistribution is inherent to the nature of partial property rights : appropriation is a redistribution. Efficient redistribution through partial property rights does not require an efficient government.

One may also consider that taxes generally affect values whereas partial property rights affect quantities. We argue that income tax and partial property rights do not differ in this dimension. Partial property rights result in a transfer of benefits : those benefits can be derived from value or from quantity. Partial property rights can affect either values or quantities : in this paper, partial property rights are considered on the young's income.

4.8 Conclusion

This paper shows that partial property rights on young's income can achieve an optimal transfer from the young to the old when an economy is dynamically inefficient. In circumstances different from those considered in the previous chapter where partial property rights were considered in a renewable resource economy, we find again that partial property rights can be optimal in a perfectly competitive economy where agents live finite lives and where physical capital and labor are used as production inputs. Complete property rights are then inefficient. Partial property rights are inefficient when the economy is dynamically efficient. Therefore, one may wonder how likely it is for an economy to be dynamically inefficient with complete property rights. Abel *et al.* (1989) develops a criterion for determining whether an economy is dynamically efficient. In application to the United States economy and the economies of other major OECD nations, their results suggest that those economies are dynamically efficient. However, the effective quality of property rights in those countries is not explicitly considered in that study. Moreover, the main message of this paper is that, *even* in a perfectly competitive economy with overlapping generations, partial property rights can be optimal.

Chapitre 5

CONCLUSION

We have seen that partial property rights are efficient under different circumstances that we formally specified. Complete property rights are then inefficient under these circumstances. In other words, the paradigm, according to which inefficiencies are a consequence of weak institutions that allow such ill behavior as theft, is partly reversed. Inefficiencies can also be a consequence of too strong property rights. In chapter 2, we considered a renewable resource economy where a limited number of firms exercised market power. Under standard assumptions, we showed that, even in the absence of completion and enforcement costs for the government, partial property rights could be efficient. Our results could provide an explanation for the existence of mixed regulatory/property rights regimes such as in some Nova Scotia fisheries, in some New Zealand ITQ regimes or in the South Pars/North Dome gas field. The determination of an analytic expression of that optimal quality of property rights has highlighted its main determinants. Greater buyer's responsiveness to price is consistent with more complete optimal property rights. Technology is an important determinant of the optimal quality of property rights. The dependence of the optimal quality of property rights to technology can also be regarded as a dependence to the relative price of output and input. The more valuable is output compared to input, the more complete property rights must be. Our results are consistent with Demsetz (1967)'s findings on the emergence of property rights : property rights develop to internalize externalities when the gains of internalization become larger than the cost of internalization. In fact, we build on Demsetz (1967)'s findings and explain how the outcome of the development of property rights, as a consequence of changes in economic values, is affected by the presence of market power : the more valuable is the output compared to the input, the greater the profits, the more intense is the commons problem and stronger partial property rights should be to offset market power. Biology impacts the optimal quality of property rights : when the stock of resource is more sensitive to harvesting efforts, optimal property rights can be more complete. Our results also confirmed Hotelling (1931)'s intuition of the existence of a tension between the number of firms and the optimal quality of property rights.

In chapter 3, we relaxed the assumption of the existence of market imperfections in the form of market power and considered a perfectly competitive renewable resource economy with overlapping generations. We have seen that complete property rights can lead to resource overaccumulation at the steady-state. When property rights are complete, households appropriate themselves a share of the resource stock that should optimally be used in production. We have shown that there always exists a quality of property rights on the resource stock, though not necessarily complete, leading to steady-state optimal resource extraction and resource stock. Optimal partial property rights increase the lifetime welfare of all individuals.

In chapter 4, we continued to investigate the optimal quality of property rights in a perfectly competitive economy. In an OLG economy where conventional capital rather than a renewable resource was used as the savings vehicle and input in production, we have shown that efficient capital accumulation could be reached when young agents cannot fully appropriate their income. We explained how conventional capital differs from a renewable resource and we have shown that partial property rights are efficient when the economy is dynamically inefficient.

Overfishing, deforestation, endangered species often result from institutions that are too weak. Although property rights may need to be strengthened in those situations, we show in this thesis that they do not need to be complete to achieve efficiency. Strong, efficient institutions often need to fall short of imposing complete property rights. Beyond a certain quality of property rights, strengthening them further is inefficient.

Several additional extensions remain. In our current research, the quality of property rights is essentially an exogenous parameter. There is a strand of the economic literature that considers endogenous property rights including Hotte (2005) and Copeland and Taylor (2009). A question remains as to whether a perfectly competitive economy, where agents have finite life, would endogenously acquire efficient property rights. Another extension could build on the findings : first, that weak property rights on production output generally reduce harvesting whereas weak property rights on production input increase harvesting (Hotte *et al.*, 2013) ; second, that market imperfections lead to either under harvesting such as incomplete information on the resource stock (Espinola-Arredondo and Munoz Garcia, 2011), etc. or over harvesting (risk, existence of a backstop resource, etc...) in order to investigate whether there exists partial property rights, on either production input, or output, that always optimally counterbalance those market imperfections. The second-best optimality of partial property rights in presence of multiple market imperfections would also be worth studying. Finally, a formal study of the dynamic trajectory of the quality of property rights leading to its optimal steady-state may be of interest.

Nous avons vu dans différentes circonstances que des droits de propriété partiels sont optimaux. Des droits de propriétés complets sont alors inefficaces. En d'autres termes, le paradigme selon lequel l'inefficacité est une conséquence de droits de propriété trop faibles est en partie contredite. Des inefficacités peuvent découler de droits de propriété trop complets. Dans le chapitre 2, nous avons considéré une économie avec une ressource naturelle renouvelable dans laquelle un nombre limité de firmes exerçaient leur pouvoir de marché. Sous des hypothèses standards, nous avons montré que même en l'absence de coût de définition et de protection des droits de propriété pour un gouvernement, des droits de propriété partiels peuvent être optimaux. Nos résultats peuvent fournir une explication à l'existence de régimes de droits de propriété mixtes tels que les régimes de quotas en Nouvelle-Ecosse ou en Nouvelle-Zélande ou tel que celui qui prévaut au gisement de gaz de South Pars/North Dome. Nous avons determiné une expression analytique de cette qualité optimale des droits de propriété afin de mettre en évidence les différents paramètres qui la determine. Une plus forte réponse des consommateurs à des variations de prix est ainsi cohérente avec des droits de propriété plus complets. La technologie est aussi un déterminant important de la qualité optimale des droits de propriété. La dépendance à la technologie peut aussi être comprise comme une dépendance de la qualité optimale des droits de propriété au prix relatif de la production et des intrants. Plus la production est précieuse par rapport aux intrants, plus les droits de propriété doivent être complets. Nos résultats sont cohérents avec ceux de Demsetz (1967) sur l'émergence de droits de propriété : les droits de popriété se développent pour internaliser les externalités quand les gains de l'internalisation excedent leurs couts. En fait, nous batissons sur les résultats de Demsetz et expliquons comment les effets de la mise en place de droits de propriété, en réponse à des changements dans les valeurs économiques, sont affectés par la présence de pouvoir de marché : plus la production a de la valeur par rapport aux intrants plus les profits sont importants, plus le problème des ressources communes est important et moins il est nécessaire que les droits de propriété soient partiels pour compenser l'exercice du pouvoir de marché par les firmes. La biologie a aussi des conséquence sur la qualité optimale des droits de propriété : quand un stock est plus sensible aux variations d'efforts, les droits de propriété optimaux peuvent être plus complets. Enfin, nos résultats confirment l'intuition d'Hotelling (1931) sur l'existence d'une tension entre le nombre de firmes et la qualité optimale des droits de propriété.

Dans le chapitre 3, nous relâchons l'hypothèse de l'existence d'une imperfection de marché sous la forme de pouvoir de marché et considérons une économie parfaitement compétitive avec générations imbriquées qui exploite une ressource naturelle. Nous avons vu que des droits de propriété complets peuvent conduire à une suraccumulation de la ressource à l'état stationnaire. Quand les droits de propriété sont complets, les ménages s'approprient sous forme d'épargne une proportion de la ressource qui devrait optimalement être utilisée dans la production. Nous montrons qu'il existe toujours une qualité des droits de propriété (les droits optimaux sont parfois partiels) qui permettent d'atteindre les niveaux de stock de ressource et d'extraction optimaux de premier rang à l'état stationnaire. Les droits de propriété partiels optimaux accroissent l'utilité de tous les agents sur l'ensemble de leur vie.

Dans le chapitre 4, nous continuons l'étude de la qualité optimale des droits de propriété dans une économie parfaitement compétitive. Dans un modèle à générations imbriquées où le capital plutôt qu'une ressource naturelle renouvelable est utilisé comme véhicule d'épargne et facteur de production, nous montrons que l'accumulation de capital optimale peut être atteinte quand les jeunes agents ne s'approprient pas la totalité de leurs revenus issus du travail. Nous expliquons comment le capital diffère d'une ressource naturelle renouvelable et nous montrons que des droits de propriété partiels sont optimaux en présence d'inefficacité dynamique.

La surpêche, la déforestation, la mise en danger d'espèces animales peuvent être la conséquence d'institutions trop faibles. Bien que les droits de propriété doivent certainement être renforcés dans ces situations, cette thèse montre formellement qu'ils n'ont souvent pas besoin d'être complets pour être optimaux. Des institutions fortes, optimales ne sont pas toujours celles qui imposent des droits complets. Au delà d'une certaine qualité des droits de propriété, les renforcer davantage est inefficace.

Plusieurs extensions à ce travail de recherche peuvent être considérées. Dans cette thèse, la qualité des droits de propriété est essentiellement une variable exogène. Il existe une litterature qui endogénéise la qualité des droits de propriété (par exemple Hotte (2005) ou Copeland and Taylor (2009)). Il serait intéressant d'étudier si une économie parfaitement compétitive où les agents ont une durée de vie finie se doterait de manière endogène d'une qualité des droits de propriété optimale. Un autre développement pourrait se baser d'une part sur le fait qu'il a été montré par Hotte *et al.* (2013) que des droits de propriété partiels sur la production réduisent en général l'exploitation tandis que des droits partiels sur les intrants accroissent l'exploitation et, d'autre part sur le fait que des imperfections de marchés peuvent conduire soit à une sous-exploitation de la ressource telle que de l'information incomplète sur le stock de ressource (Espinola-Arredondo and Munoz Garcia, 2011), soit au contraire à une surexploitation de la ressource (présence de risque, d'une ressource de substitution, etc..) afin d'étudier s'il existe toujours des droits de propriété partiels qui peuvent compenser optimalement les effets de ces imperfections de marché. L'optimalité de second-rang des droits de propriété partiels quand plusieures imperfections de marché existent simultanément constituerait également un sujet d'étude intéressant. Enfin, l'étude de la trajectoire dynamiquement optimale d'une qualité des droits de propriété peut aussi avoir un intérêt.

Annexe A Analytic expression of the optimal quality

We adopt the standard functional form :

$$\Psi(e_i, \sum_{j\neq i}^{n} e_j) = \frac{e_i}{\sum_{i=1}^{n} e_i}$$

Since $\beta = \frac{1-\theta}{n}$, equation (2.3) can be rewritten as :

$$h(e_i, S(E)) = \frac{1-\theta}{n} H + \frac{e_i}{\sum_{i=1}^{n} e_i}\theta H$$

We have :

$$\frac{\partial h(e_i, S(E))}{\partial e_i} = \frac{1-\theta}{n}\frac{\partial H}{\partial e_i} + \frac{\sum_{i=1}^{n} e_i - e_i}{(\sum_{i=1}^{n} e_i)^2}\theta H + \frac{e_i}{\sum_{i=1}^{n} e_i}\theta\frac{\partial H}{\partial e_i} \tag{A.1}$$

We can use (A.1) to rewrite (2.6) as :

$$\frac{\partial H}{\partial e_i}P'(H)h(e_i, S(E)) + P(H)\left[\frac{1-\theta}{n}\frac{\partial H}{\partial e_i} + \frac{\sum_{i=1}^{n} e_i - e_i}{(\sum_{i=1}^{n} e_i)^2}\theta H + \frac{e_i}{\sum_{i=1}^{n} e_i}\theta\frac{\partial H}{\partial e_i}\right] = w$$

At the symmetric Nash equilibrium, $e_i = \hat{e}\ \forall i$, then $\hat{E} = n\hat{e}$ and $\hat{S} = S(\hat{E})$, we have :

$$\begin{aligned}\Gamma(\widehat{e};\theta,n) &= \left.\frac{\partial H}{\partial e_i}\right|_{\hat{E},\hat{S}} P'(H)h(\hat{e},\hat{S}) \\ &\quad + P(\hat{H})\left[\frac{1-\theta}{n}\left.\frac{\partial H}{\partial e_i}\right|_{\hat{E},\hat{S}} + \frac{(n-1)}{n}\theta\frac{\hat{H}}{n\hat{e}} + \frac{1}{n}\theta\left.\frac{\partial H}{\partial e_i}\right|_{\hat{E},\hat{S}}\right]\end{aligned}$$

We want $\widehat{e}(\theta^*) = e^*$, so if θ^* exists, it must be solution of :

$$\begin{aligned}&\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*} P'(H^*)h(e^*(n),S^*) \\ &\quad + P(H^*)\left[\frac{1-\theta}{n}\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*} + \frac{(n-1)}{n}\theta\frac{H^*}{E^*} + \frac{1}{n}\theta\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*}\right] \\ &\qquad = P(H^*)\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*}\end{aligned}$$

Rearranging we have :

$$\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*} P'(H^*)h(e^*(n),S^*)$$

$$+(1-\theta)(\frac{P(H^*)}{n}\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*})+\theta(\frac{P(H^*)H^*}{E^*}+\frac{1}{n}(P(H^*)\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*}-\frac{P(H^*)H^*}{E^*})$$

$$=P(H^*)\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*} \tag{A.3}$$

If we divide both sides of (A.3) by $\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*} P(H^*)$, we obtain :

$$\frac{P'(H^*)h(e^*(n),S(E^*))}{P(H^*)}+\frac{1-\theta}{n}+\theta(\frac{H^*}{E^*}\frac{1}{\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*}}+\frac{1}{n}(1-\frac{H^*}{E^*}\frac{1}{\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*}})=1 \tag{A.4}$$

The term $\frac{P'(H^*)h(e^*(n),S^*)}{P(H^*)}$ can be rewritten as :

$$\frac{P'(H^*)h(e^*(n),S(E^*))}{P(H^*)}=\frac{P'(H^*)H^*}{nP(H^*)}=\frac{1}{n\epsilon_D}$$

with ϵ_D the market elasticity of demand at point (E^*,H^*).

We call ϵ_c the effort elasticity of harvest at (E^*,H^*) :

$$\epsilon_c=\frac{E^*}{H^*}\left.\frac{\partial H}{\partial e_i}\right|_{E^*,S^*}$$

We can rewrite (A.4) as :

$$\frac{1}{n\epsilon_D}+\frac{1-\theta}{n}+\theta[\frac{1}{\epsilon_c}-\frac{1}{n\epsilon_c}]=1$$

and finally :

$$\theta^*=\epsilon_c+\frac{1}{1-n\,\epsilon_D}\frac{\epsilon_c}{} \tag{A.5}$$

Equation (A.5) is an analytic expression of the optimal quality of property rights. Before discussing the conditions of existence of θ^*, it can be verified that when the number of firms is infinite (i.e., $n\to\infty$) then $\theta^*\to 0$ as $\epsilon_c\to 0$ when $n\to\infty$; the well-known result according to which property rights must be complete to reach the first-best optimum is verified.

Annexe B Derivation of the condition of existence

In order for θ^* to exist, it must verify $\theta^* \in [0, 1]$.

For given technologies and market demand, the conditions of existence of θ^* are conditions on the number of firms n.

For $\theta^* \leq 1$, we must have :

$$\epsilon_c + \frac{1}{1-n}\frac{\epsilon_c}{\epsilon_D} \leq 1$$

which, remembering that as $n > 1$ and $\epsilon_D < 0$, $(1-n)\epsilon_D$ is positive, leads to :

$$\frac{1}{1-\epsilon_c}\frac{\epsilon_c}{\epsilon_D} - 1 \leq -n$$

and

$$n \geq \bar{n} = 1 + \frac{1}{\epsilon_c - 1}\frac{\epsilon_c}{\epsilon_D}$$

$\overline{n}$ is the Pareto optimal number of firms in pure common-access as defined in equation (4) of Cornes *et al.* (1986)'s article.

Annexe C Proof of proposition 3.1

We rewrite (3.14) and (3.15) as :

$$x_{t+1} = x_t - h_t + g\left(x_t\right) = G(x_t, h_t) \tag{C.1}$$

$$f'(h_{t+1}) = [\frac{u'[f(h_t) - f'(h_t)h_t - \frac{1}{\theta}f'(h_t)x_{t+1}]}{\beta\theta[1 + g'(x_{t+1})]}]f'(h_t) \tag{C.2}$$

Substituting (C.1) into (C.2) leads to :

$$\Xi(x_t, h_t) = f'(h_{t+1}) - [\frac{u'[f(h_t) - f'(h_t)h_t - \frac{1}{\theta}f'(h_t)[x_t - h_t + g\left(x_t\right)]]}{\beta\theta[1 + g'(x_t - h_t + g\left(x_t\right))]}]f'(h_t) = 0 \tag{C.3}$$

which defines a two arguments implicit function for h_{t+1} :

$$h_{t+1} = F(x_t, h_t) \tag{C.4}$$

The planar system describing the dynamics of the resource stock and harvesting now consists of (C.1) and (C.4) and the stability of the steady-states depends on the eigenvalues of the Jacobian matrix of the partial derivatives of the system :

$$J = \begin{bmatrix} G_x & G_y \\ F_x & F_y \end{bmatrix}$$

The determinant of the Jacobian is $D = G_x F_h - G_h F_x$ and the trace is $T = G_x + F_h$. The characteristics polynomial is :

$$p(\zeta) = \zeta^2 - T\zeta + D = 0$$

From the stability theory of difference equations (Azariadis, 1993), we know that, for a saddle point, the roots of $p(\lambda)$ need to be on both sides of unity. Thus, we need that $D - T + 1 < 0$ and $D + T + 1 > 0$ or $D - T + 1 > 0$ and $D + T + 1 < 0$. We find :

$$\begin{aligned} G_x(x_t, h_t) &= 1 + g'(x_t) \\ G_h(x_t, h_t) &= -1 \end{aligned}$$

and the implicit function theorem gives :

$$F_{x_t} = -\frac{\Xi_{x_t}(x_t, h_t)}{\Xi_{h_{t+1}}(x_t, h_t)} \text{ and } F_{h_t} = -\frac{\Xi_{h_t}(x_t, h_t)}{\Xi_{h_{t+1}}(x_t, h_t)}$$

That is,

$$\begin{aligned} F_x(x_t, h_t) &= \frac{1}{\beta\theta f''(h_{t+1})}\left[\frac{-\frac{1}{\theta}(f'(h_t))^2 u''(c_t)[1 + g'(x_t)]}{(1 + g'(x_{t+1}))}\right] \\ &\quad - \frac{1}{\beta\theta f''(h_{t+1})}\left[\frac{f'(h_t)u'(c_t)g''(x_{t+1})(1 + g'(x_t))}{[(1 + g'(x_{t+1}))]^2}\right] \end{aligned}$$

$$
\begin{aligned}
F_h(x_t,h_t) &= \frac{1}{\beta\theta f''(h_{t+1})}\left[\frac{f''(h_t)u'(c_t)}{(1+g'(x_{t+1}))}\right] \\
&+\frac{1}{\beta\theta f''(h_{t+1})}\left[\frac{f'(h_t)u''(c_t)[\frac{f'(h_t)}{\theta}-f''(h_t)(\frac{x_t+g(x_t)-h_t}{\theta}+h_t)]}{(1+g'(x_{t+1}))}\right] \\
&+\frac{1}{\beta\theta f''(h_{t+1})}\left[\frac{f'(h_t)u'(c_t)g''(x_{t+1})}{(1+g'(x_{t+1}))^2}\right]
\end{aligned}
$$

Evaluating the elements of the Jacobian at the steady state and utilizing the facts that $u'=\beta\theta(1+g')$ and $h=g$:

$$
\begin{aligned}
G_x(x_t,h_t) &= 1+g' \\
G_h(x_t,h_t) &= -1
\end{aligned}
$$

$$
F_x(x_t,h_t)=\frac{-\frac{1}{\theta}(f')^2u''-f'\beta\theta g''}{\beta\theta f''}<0
$$

$$
F_h(x_t,h_t)=1+\frac{\frac{(f')^2}{\theta}u''}{\beta\theta f''(1+g')}-\frac{f'u''[\frac{x}{\theta}+h]}{\beta\theta(1+g')}+\frac{f'g''}{(1+g')f''}>0
$$

Based on these partial derivatives, the trace T and the determinant D of the characteristic polynomial can be calculated to be :

$$
\begin{aligned}
D &= G_xF_h-G_hF_x \\
&= (1+g')+\frac{\frac{(f')^2}{\theta}u''}{\beta\theta f''}-\frac{f'u''[\frac{x}{\theta}+h]}{\beta\theta}+\frac{f'g''}{f''}+\frac{-\frac{1}{\theta}(f')^2u''-f'\beta\theta g''}{\beta\theta f''}
\end{aligned}
$$

which simplifies to :

$$
D=(1+g')-\frac{f'u''[\frac{x}{\theta}+h]}{\beta\theta}>0
$$

and

$$
\begin{aligned}
T &= G_x+F_h \\
&= 2+g'+\frac{\frac{(f')^2}{\theta}u''}{\beta\theta f''(1+g')}-\frac{f'u''[\frac{x}{\theta}+h]}{\beta\theta(1+g')}+\frac{f'g''}{(1+g')f''}>1
\end{aligned}
$$

It is easy to see that $D+T+1>0$ holds. The nature of the stability of the steady-states then depends crucially on the sign of $D-T+1$. Calculating $D-T+1$ gives :

$$\frac{1}{\beta\theta}\left[-f'u''[\frac{x}{\theta}+h][\frac{g'}{1+g'}]-\frac{f'}{f''(1+g')}(\frac{f'}{\theta}u''+\beta\theta g'')\right] \tag{C.5}$$

To determine the sign of $D-T+1$, we compare the slopes of the growth curve and the consumer optimization condition at the steady state. At the steady-state, the slope of the Euler equation is :

$$\left.\frac{dh_t}{dx_t}\right|_{\Delta h_t=0,\Delta x_t=0}=\frac{(u''\frac{f'}{\theta}+\beta\theta g'')}{-f''u''(\frac{x}{\theta}+h)}>0$$

At the larger steady-state, the consumer first-order condition cuts the growth curve from below and we have :

$$\frac{(u''\frac{f'}{\theta}+\beta\theta g'')}{-f''u''(\frac{x}{\theta}+h)}>g'$$

which can be rewritten as, keeping in mind that $-f''u''[\frac{x}{\theta}+h]<0$,

$$0<g'(-f''u''(\frac{x}{\theta}+h))-(\frac{f'}{\theta}u''+\beta\theta g'')$$

Finally, multiplying both sides by f' and dividing both sides by $f''<0$ and $1+g'$, we obtain :

$$0>-f'u''(\frac{x}{\theta}+h))[\frac{g'}{1+g'}]-\frac{f'}{f''(1+g')}(\frac{f'}{\theta}u''+\beta\theta g'') \tag{C.6}$$

Multiplying both sides of equation (C.6) by $\frac{1}{\beta\theta}$ implies :

$$\frac{1}{\beta\theta}\left[-f'u''[\frac{x}{\theta}+h][\frac{g'}{1+g'}]-\frac{f'}{f''(1+g')}(\frac{f'}{\theta}u''+\beta\theta g'')\right]<0 \tag{C.7}$$

The left hand-side of equation (C.7) is $D-T+1$ (equation (C.5)) which proves that

$D-T+1<0\ \forall\theta\in[\bar{\theta},1]$.

Annexe D Illustration using a logarithmic period utility and a Cobb-Douglas technology

With logarithmic preferences and a Cobb-Douglas technology, equation (4.19) can be rewritten as :

$$(1+n)k_{t+1} = \frac{\beta}{1+\beta}(1-\varphi)(1-\alpha)k_t^{\alpha} - \frac{1}{1+\beta}\frac{\varphi(1-\alpha)(1+n)}{\alpha}k_{t+1} \tag{D.1}$$

which implies :

$$k_{t+1} = \left[\frac{\alpha\beta(1-\varphi)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}\right]k_t^{\alpha} \tag{D.2}$$

At the steady-state, equation (D.1) becomes :

$$(1+n)k^* = \frac{\beta}{(1+\beta)}(1-\varphi)(1-\alpha)k^{*\alpha} - \frac{1}{1+\beta}\frac{\varphi(1-\alpha)(1+n)}{\alpha}k^*)$$

which can be rewritten as :

$$k^*\left[\frac{(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}{(1+\beta)\alpha} - \frac{\beta(1-\varphi)(1-\alpha)}{(1+\beta)}k^{*\alpha-1}\right] = 0 \tag{D.3}$$

We find two steady-states : a trivial one $k_T^* = 0$ which is not a viable economic equilibrium and

$$k^* = \left[\frac{\alpha\beta(1-\varphi)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}\right]^{\frac{1}{1-\alpha}} \tag{D.4}$$

For $\alpha \in (0,1)$, $\beta \in (0,1)$ and $\varphi \in (0,1)$, we have $k^* > 0$. We focus on the stability properties of k^*. In order to determine, the local stability property of k^*, we must study the value of $\frac{dk_{t+1}}{dk_t}$ at k^*. First, if property rights are complete $\varphi = 0$, it is well-known (De la Croix and Michel, 2002) that with logarithmic preferences and a Cobb-Douglas production function, the strictly positive steady-state is globally stable : for all $k_0 > 0$ the trajectory converges to k^*. When $\varphi \in (0,1)$, using equation

(D.2), we find :

$$\left.\frac{dk_{t+1}}{dk_t}\right|_{k^*} = \alpha\left[\frac{\alpha\beta(1-\varphi)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}\right]k^{*\alpha-1}$$

$$\left.\frac{dk_{t+1}}{dk_t}\right|_{k^*} = \alpha\left[\frac{\alpha\beta(1-\varphi)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}\right]\left[\frac{\alpha\beta(1-\varphi)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}\right]^{-1}$$

$$\left.\frac{dk_{t+1}}{dk_t}\right|_{k^*} = \alpha \qquad \text{(D.5)}$$

For $\alpha \in (0,1)$ and $\varphi \in (0,1)$, equation (D.5) implies :

$$0 < \left.\frac{dk_{t+1}}{dk_t}\right|_{k^*} = \alpha < 1$$

Therefore, the steady-state defined by equation (D.4) with $\varphi \in (0,1)$ is locally stable and the convergence is monotonous.

Using equation (D.4), we find :

$$\frac{\partial k^*}{\partial \varphi} = \left[-\frac{\alpha\beta(1-\varphi)(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}{\left[(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]\right]^2} - \frac{\left[(1+n)(1-\alpha)\alpha\beta(1-\varphi)(1-\alpha)\right]}{\left[(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]\right]^2}\right] \left[\frac{\alpha\beta(1-\varphi)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha+\varphi(1-\alpha)\right]}\right]^{\frac{\alpha}{1-\alpha}} < 0$$

The weaker the property rights (i.e., the higher φ), the lower the capital-labor ratio at the decentralized steady-state.

Annexe E Analytic expression of the optimal quality of property rights when the technology is Cobb-Douglas and preferences are logarithmic

Using equations (4.24) and (D.4), equation (4.25) implies :

$$\left[\frac{\alpha\beta(1-\varphi^*)(1-\alpha)}{(1+n)\left[(1+\beta)\alpha+\varphi^*(1-\alpha)\right]}\right]^{\frac{1}{1-\alpha}} = \left[\frac{\alpha}{(1+n)}\right]^{\frac{1}{1-\alpha}}$$

which leads to :

$$\frac{\beta(1-\varphi^*)(1-\alpha)}{(1+\beta)\alpha+\varphi^*(1-\alpha)} = 1 \tag{E.7}$$

It can be verified that when property rights are complete, $\varphi = 0$, the competitive equilibrium is Pareto optimal when :

$$\frac{(1-\alpha)}{\alpha} = \frac{(1+\beta)}{\beta}$$

which is a well-known result. Here we consider situations where $\frac{(1-\alpha)}{\alpha} > \frac{(1+\beta)}{\beta}$. We can rewrite (E.7) as :

$$\varphi^* = \frac{\frac{1-\alpha}{\alpha} - \frac{1+\beta}{\beta}}{(1+\beta)\,(1-\alpha)\,\frac{1}{\beta\alpha}} \tag{E.8}$$

The optimal quality of property rights depends on the utility discount factor β and the elasticity of capital input productivity α.

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